For High-Voltage Interconnects, One Size Does Not Fit All

The long-awaited inflection point for electric vehicles has arrived. Consumers are demanding EVs, regulations are tightening, battery prices are falling and OEMs are ramping up manufacturing capabilities. According to Boston Consulting Group, the global market share of battery electric vehicles is expected to skyrocket from 3 percent in 2020 to 45 percent by 2035.

This shift to EV architectures brings with it a series of new challenges. How can the infrastructure support increasing voltage levels? How can OEMs cost-optimize designs for scaling up mass production? How can designers solve the issue of electromagnetic interference from high-voltage components?

Many of the answers to those questions can be found in high-voltage interconnects. This early in the adoption curve, however, there are many approaches and few industry standards. What is needed is a flexibility that gives OEMs the freedom to innovate based on their individual design requirements and intelligently optimize for weight, mass and cost — because one size does not fit all.

TYING IT ALL TOGETHER

High-voltage interconnect technology plays a key role in EVs. HV wiring and interconnects deliver power from the AC/DC charge inlet to the vehicle's battery, and then distribute that electrical power throughout the vehicle's architecture. This includes high-power devices, such as electric motors and inverters, auxiliary devices such as the air conditioner and electric heater, and electrical center devices, such as power distribution boxes and battery disconnect units.

Without industry standard designs or commonly accepted templates for creating the complex architecture required to provide power to the many devices that need it, individual OEMs are making their own architectural decisions. Each OEM defines its own requirements for electrification technology. Those specifications can differ across brands and models, and within brands based on factors such as size, weight and whether the vehicle has luxury features that require additional electrical power.

The key for OEMs is to work with an electrification partner that can help design the most efficient, safest, most reliable and most cost-effective system that is customized to the vehicle's specific requirements, and that has the technical expertise and comprehensive product line to deliver a complete, integrated solution.

THE CHALLENGE

Hybrid vehicles were once thought to be the next logical step in the evolution toward full EVs. Today, consumers thinking about going electric are more likely to buy an all-electric vehicle than a hybrid model, and sales of all-electric vehicles have been running twice those of plug-in hybrids, according to Boston Consulting Group.

That shift has major architectural implications for OEMs, because all-electric vehicles have to deliver power not only to drive the wheels of the vehicle, but also to run all of the other devices that in a gas-powered or hybrid vehicle would be powered by the engine. Instead of taking a gas-powered vehicle and bolting on an electrification component, an all-electric vehicle means redesigning from the ground up.

The move from internal-combustion engines or hybrids to all-electric models requires the cables and connectors to be larger and heavier to handle higher power levels. There is limited space in a

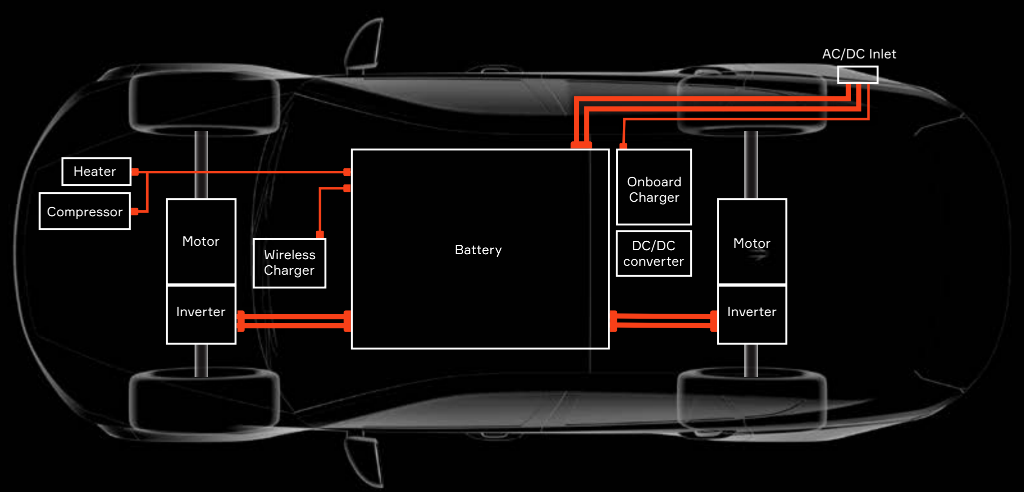


Figure 1. Examples of high-voltage interconnects in a battery electric vehicle.

vehicle chassis to begin with, and the increased size and weight associated with the high-power electrical distribution system creates even bigger challenges for vehicle packaging design.

The other major trend is the increase in size and weight of the battery to combat what is known as "range anxiety." The single biggest factor holding back EV sales is concern over the lack of range of EVs, leading to the nightmare scenario of the battery going dead while the vehicle is nowhere near the closest charging station.

Because OEMs are installing larger and heavier batteries, freeing up space to accommodate the rest of the electrification system becomes a priority, as does offsetting the increased weight with lighter, smaller components.

The good news is that there are innovative ways to reduce weight, cut the number of cables and splices, reduce the size of the electrification components and deliver high-voltage interconnect power in a way that makes vehicle assembly safer and less complex.

SHIELDING, CABLING AND CONNECTORS

Architectural decisions facing OEMs include how best to shield cables from electromagnetic interference, the design and safety specifications of connectors and other electrical variants, whether cabling will be copper or aluminum, and how to reduce the total amount of cabling through splice connectors and other techniques.

Shielding

High-voltage electric components are more complex than traditional wiring, particularly when it comes to shielding components for electrical interference. Higher power generates stronger electromagnetic noise, and OEMs must prevent that interference by wrapping each cable with shielding.

There are four basic approaches to shielding, each with its own pros and cons, depending on the specific use case.

Single-core shielding is the most popular approach today for both auxiliary connectors and power conversion. Each cable is wrapped in a metal braiding that forms the shield while maintaining flexibility. Single-core shielding makes routing and bending the cables easier, and it also makes for easier assembly by the harness maker.

Multicore shielding wraps multiple cables within one shield, making it thicker and less flexible than single core, but it can simplify routing and connections. Multicore shielding is most commonly deployed for auxiliary connectors.

Bundled shielding uses an external braid for the shielding. Similar to multicore, bundled shielding is less popular than single core because of its size, weight and lack of flexibility, but it can provide high shielding performance at low cost, depending on the cable length and the application.

Unshielded cables are also an option for some harnesses to optimize cost. This option can work well in applications like charging harnesses that interface with unshielded grid infrastructure and are primarily used when the car is not driving. Other harnesses can also use this option, but the cost advantage would have to be balanced with additional device interference mitigations.

Clearly, there are a variety of shielding options, and OEMs can choose stronger shielding with higher performance if the application requires it. In other words, the type and strength of shielding will depend on the specific use case.

Cabling

Every gram matters when it comes to electrification systems, which is why it is important to optimize the cabling for the whole system — not just for high voltage, but also for the literally hundreds of low-voltage electrical components in a vehicle. Through the use of sophisticated optimization techniques, Aptiv was able to show one OEM how it could reduce low-voltage wiring mass by 10 percent and remove 150 meters of cabling. In another case, an SUV manufacturer was able to reduce the mass of its electrical distribution system by 15 percent by eliminating 300 meters of cabling.

One option to reduce weight is to transition from copper to aluminum cables. Corrosion between aluminum wiring and copper connectors had previously been a hurdle, but OEMs can now use a lightweight coating applied to aluminum wires or plating at the terminal to prevent corrosion. Swapping out copper wiring can reduce cabling mass — and cost — by as much as 50 percent.

Another technique that can reduce the need for cables, and therefore reduce cost, is the deployment of splice connectors. In this scenario, one connector on the battery can feed multiple auxiliary devices, which eliminates the need for a downstream splice center, reduces the total number of connectors and lessens the amount of wiring.

By deploying splice connectors and high-voltage auxiliary connectors in tandem, OEMs can gain an architectural advantage by reducing the total number of overall connections required to power the vehicle.

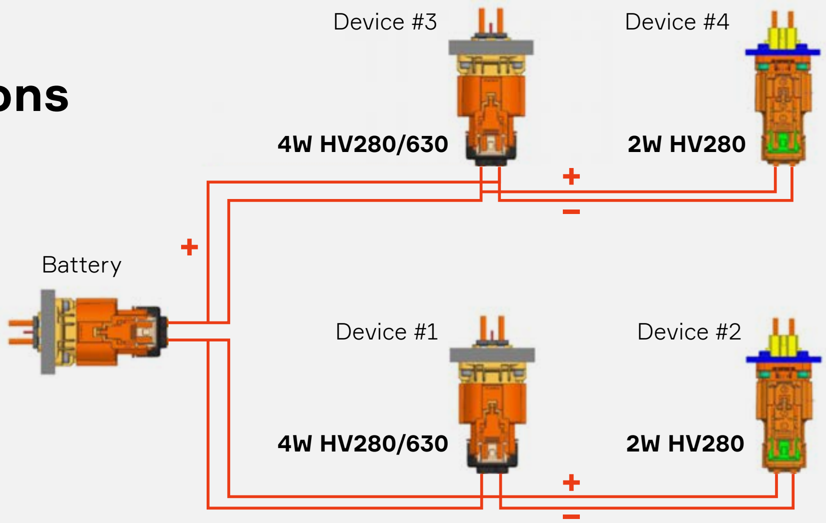
Busbars

While weight reduction is a primary design consideration in cabling, space constraints are also a factor. Formed busbars are an alternative to round cabling and can provide packaging advantages. They can also facilitate automated assembly, improving quality and consistency. Aptiv has developed unique interconnect design solutions to address busbars' thermal expansion and shielding challenges.

Four-way and Splice Connections

Four-way/splice connectors offer OEMs an architectural advantage to reduce the overall number of connections.

- One connector on the battery can feed multiple devices
- No need for downstream splice center



Terminals

There are two types of terminals, and the choice between them really depends on the specific design constraints for the vehicle architecture. A pin-and-sleeve design is heavier but also more compact. A box-and-blade design is thinner, easier to produce and easier to connect to a busbar.

Safe Mating Options

When high-voltage electricity is powering a vehicle that is subject to constant vibrations, bumps, potholes, fender-benders, and so forth, safety is paramount for everyone, including the people assembling the vehicle, fixing it or driving it.

On the assembly side of the equation, high-voltage interlock loop technology (HVIL) ensures that a connection has been safely secured. HVIL is a circuit breaker system that cuts power if a worker accidentally unmates a connector, and a device can automatically and safely cut power when the interlock has been disconnected. Some OEMs are moving toward detecting such issues at a system level.

The large connectors used in high voltage require innovations in mating and unmating options that smaller connectors do not, such as using a lever or a slider mechanism. Each OEM has its own preferences, which are based on a variety of considerations. For example, screwing in a connection requires a separate tool, but it allows for the torque to be measured and for traceability. Using a lever is simpler, but it means that there needs to be enough room to turn the lever. Using a slider requires space as well, but only in one direction, and it offers maximum pressure surface in areas where there is limited space. So, the decision all depends on the design of the vehicle and which option provides a mechanical advantage to the OEM.

The goal is to make absolutely certain that the connection has been locked in, and that there is technology in place to prevent the connection from coming loose under adverse driving conditions.

HV Auxiliary Connectors

As vehicle platforms switch from internal combustion engines, the vehicle devices typically powered by the engine shift to the high-voltage network. Some of the 12V devices can also shift to high voltage to operate more efficiently. These are devices like heaters, electric air conditioners, onboard chargers, or some DC/DC converters

that typically require less than 100 amps. When it comes to high-voltage auxiliary connectors, OEMs want compact packaging so they can provide the necessary power while taking up the least amount of space and/or reducing the most amount of mass.

There are many types of connector solutions for auxiliary devices, including individually shielded, multicore shielded, bundle shielded and unshielded systems. Four-way and splice connectors represent innovative ways to cut costs and reduce cabling by enabling one connector to feed multiple devices. Different OEMs might take different approaches to these design decisions based on the unique characteristics of their architecture.

Another important consideration for OEMs is making sure that the connectors can handle high levels of vibration. The concern is that vibrations could cause the integrity of the terminal connection to degrade over time, with microabrasions creating increased resistance. And today's EVs are expected to last longer than cars with internal combustion engines, with fewer moving parts that can wear out — so the connectors need to be built to last as well.

Power Conversion Connectors

Other devices in the vehicle require even higher power to operate. Power conversion devices such as the e-motors, batteries, inverters or some DC/DC converters can require up to 400A. Interconnects for power conversion devices come in a wide variety of shapes and configurations, including plastic or metal pass-throughs, straight or right-angle connectors, one-way, two-way or three-way configurations, individual, bundle, unshielded and so forth. At higher current levels, it becomes even more important to have properly designed connection systems that are safe and have robust performance relative to temperature, vibration, sealing and shielding. Again, the design decisions are not one-size-fits-all; everything depends on what makes the most sense for the specific architecture of the vehicle.

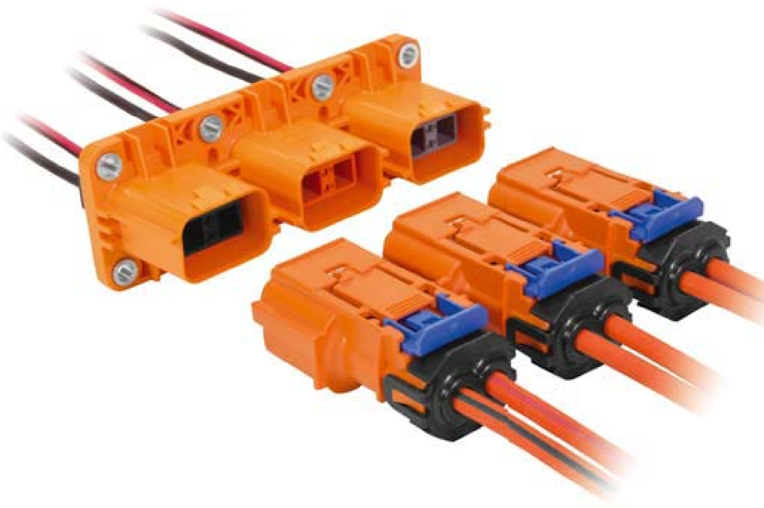
Of course, none of these architectural decisions can be made in a vacuum; they are all part of a comprehensive design strategy aimed at optimizing integration among components, reducing cost, saving space and cutting weight. And OEMs must consider how these design decisions simplify the assembly of the vehicle, particularly in light of their desire to automate as much of the assembly as possible.

FUTURE-PROOFED 1,000-VOLT INTERCONNECTS

Battery technology is improving very quickly, so OEMs are installing new batteries in their vehicles that can hold more charge for greater range. While a typical vehicle battery previously would have supplied about 50 kilowatt-hours of power, future battery capacities are rising toward 200 kWh as energy density increases and battery costs rapidly decrease.

While the increased capacity is a boon to the consumer to eliminate range anxiety and provide increased acceleration, charging the battery in a reasonable time frame becomes a challenge. OEMs can reduce these charging times by increasing the current, increasing the voltage, or both.

Higher currents require larger cables in the vehicle, adding cost, space and weight. Therefore, manufacturers are also looking at increasing voltage as an option.



For example, in a simplified comparison, a typical EV with a 100 kWh battery pack charging at 250A and 400V would take approximately 48 minutes to charge to 80 percent. With an 800V system, this time could be cut in half.

Higher-voltage systems enable faster charging, less heat, and thinner wiring or busbars.

Increasing voltage means ensuring that the components are built with safe distances between the terminals and with safe distances between the terminals and ground/shield. Designs must take into account both clearance distance over the air and creepage distance over the surface — to prevent arcing and to prevent small currents going from one terminal to the other.

Aptiv's broad portfolio of high-voltage interconnect technology is designed to handle 1,000 volts, so OEMs can install the latest battery technology today with the assurance that it will meet their needs for years to come.

WHAT OEMS SHOULD LOOK FOR

The OEMs that succeed in making the transition from gas-powered vehicles to all-electric models will be those that do the best job developing safe, efficient and cost-effective electrification that can scale for high-volume production.

There is no one-size-fits-all approach to addressing the challenges associated with offsetting the push for larger, heavier batteries with the need to reduce the size and weight of high-voltage interconnects and other parts of the electrification infrastructure.

OEMs should look to partner with an electrification technology provider that offers the experience, innovation and customization needed to develop a whole-vehicle or system-level approach, rather than addressing these challenges in a piecemeal manner.

Aptiv understands that electrification is about more than just batteries and high-voltage interconnects; it is also about overall system optimization across the low-voltage and high-voltage architectures. Aptiv is a global leader in vehicle electrification and can partner to provide everything from charging cables to inlets, wiring, busbars, connectors, power distribution boxes, and battery disconnect units, with a high degree of vertical integration at manufacturing facilities across the globe. Aptiv can deliver unique value, such as integrated connector splice technology. We are leaders in the transition from copper to aluminum cabling, and we offer both connectors and cables to provide important integration and connectivity advantages. Most importantly, Aptiv has a unique view into how high-voltage interconnects fit into the full electrical and electronic architecture of the next generation of vehicles, embodied in our Smart Vehicle Architecture™ approach.

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