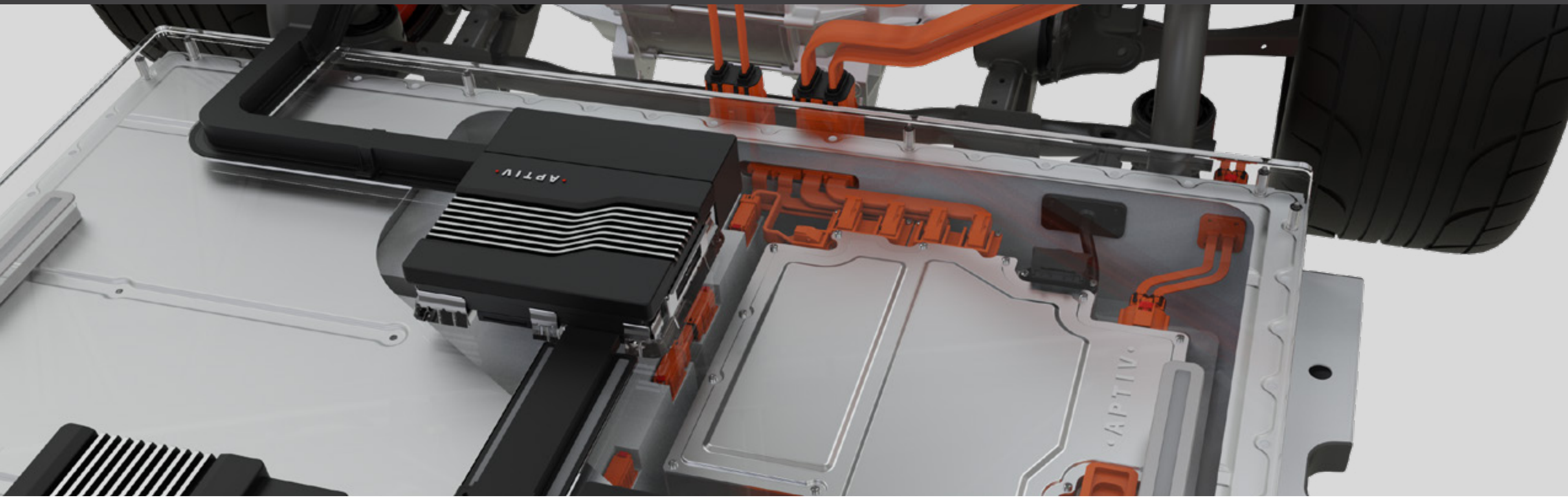


Integrated Power Electronics: The Road Merges

As electric vehicles have rapidly matured, certain features that were never necessary for internal combustion engines have become critical to EVs' operation: a power distribution unit; a battery disconnect unit; an electric vehicle supply equipment (EVSE) controller; a battery management system; an onboard charger; a DC-to-DC converter.

The trend is reminiscent of the growth in internal combustion engines' electrical/electronic architectures, where each feature required an electronic control unit — a separate box that took up precious space within a vehicle chassis. Every box needed its own software, its own connectors and its own housings, all of which resulted in added complexity and cost.

But just as traditional electrical/electronic architectures are up-integrating to reduce complexity and enable new functionality, so too must power electronics. The challenge is to consolidate those functions while supporting redundancy, increasing power density and maintaining the highest levels of safety.

EVOLVING EVS

In 2021, the median range of gasoline-powered vehicles was 403 miles, compared with a median range for battery electric vehicles (BEVs) of 234 miles. But consumers are looking for a lot more from their BEVs: Not only do they want greater range than current BEVs are able to provide, but they also are looking to leverage BEVs to supply power at remote sites, to power their homes, or even to sell energy back to the grid.

Automakers know that not meeting expectations about range and other capabilities could slow BEV growth, so they continue to expand vehicle battery packs and conduct research to identify materials with higher power density. With limited space in a vehicle chassis, a larger battery pack means less room for the high-voltage components that perform critical functions to support the battery pack and ensure the smooth operation of a BEV. These functions include:

- An **EVSE controller** to communicate with the grid and the vehicle-level controller, and to help regulate charging current.
- A bidirectional **onboard charger** to convert AC power from the grid to DC power to charge the battery, and then to invert DC from the battery to AC to provide power to off-vehicle devices or to the grid.
- A **battery management system** that coordinates high-voltage relays, monitors and balances the battery cells during charging, regulates charging and traction current to keep it within acceptable levels, and calculates the state of charge and health.
- A **battery disconnect unit** to disconnect and reconnect the battery under both normal and emergency (or urgent) conditions.
- A **power distribution unit** to deliver power with fusing protection to various high-voltage devices, such as heaters or compressors.
- A **DC-to-DC converter** to safely convert power from the 400V or even 800V primary high-voltage battery to lower voltages needed for auxiliary devices or electronic components, which often operate at 12V or 48V.

Early BEV architectures separated each aforementioned function into an individual box and attempted to package each component near the battery pack to minimize the cable harness length needed to reach the battery they served. But every inch of harness and connector between the component and the battery introduces more potential points of failure, higher costs and added weight. Plus, many of those components require shielding to protect other electronics from the electromagnetic interference that can be generated by the high voltage.

The logical next step is to integrate the six unique functions described above into a single system-level solution. An integrated system could reduce packaging space by more than 30 percent by sharing electronics and active-cooling mechanisms, simplifying power distribution and optimizing connections with busbars and flexible connectors. Such a solution could be integrated directly atop the battery pack or embedded into the battery pack itself to take advantage of the existing pack enclosure and cooling system.

Software is key

This combined system, an integrated power electronics controller (IPEC), will be one of the most important systems in a BEV; without it, the vehicle simply will not function. For that reason, some of the software that will run the system has to be designed for the highest level of risk management: Automotive Safety Integrity Level D (ASIL-D). It has to be capable of receiving over-the-air updates to ensure that it is fully optimized at all times. And it must be guarded with the most robust cybersecurity controls.

For Level 3 automated driving and above, system redundancy is crucial to protecting against potential failures, and that means software communication, coordination and control are key. The IPEC will play a critical role. For example, the software must ensure that if a DC-to-DC converter fails, a second 12V energy source can continue to provide power to safety-critical advanced driver-assistance systems, such as power steering and brake-by-wire.

The IPEC should also be sophisticated enough to support software enhancements that improve optimization and power conversion efficiencies. This includes managing three controllers that must work in concert — a microcontroller unit (MCU) and two digital signal processors (DSPs). The MCU is the EVSE controller, communicating with the grid to optimize the flow of current into the battery. The DSPs perform the real-time digital control of the power conversion stages on a very granular basis to ensure that they can effectively manage the charging. As they control the AC side, converting power to DC to feed the battery, they send commands every nanosecond to individual switches. Aptiv's advanced real-time control algorithms enable conversion efficiency to reach up to an industry-leading 97 percent.

The IPEC will also be responsible for communicating to the outside world, executing handshake communications with a charging station to properly coordinate charging activities and understand the nuances in the grid across all regions. The software in the IPEC will seamlessly provide payments to the charging station or even trigger LED notification lighting at the charging inlet to make people aware of the charging progress.

All in the process

To achieve this precision in such a safety-critical area, it is imperative that the software development teams work under the most rigorous quality standards. The best way to evaluate software development processes is through the industry-standard guideline ASPICE (Automotive Software Process Improvement Capability dEtermination).

ASPICE is a domain-specific adaptation of SPICE, the ISO 15504 standard, which has been used by a variety of industries for decades to sharpen their software development. ASPICE addresses specific needs of the automotive industry that its predecessor was not designed to meet, including a greater focus on cybersecurity.

ASPICE assessments look at how well engineers conduct a requirement analysis to distill customer requests into software requirements, and then trace their work back to those requirements. Assessors assign a rating for multiple expected outcomes and use the aggregate rating to determine the overall capability level of the entire project. Achieving ASPICE Capability Level 2 and Level 3 has become more critical for completing an ISO 26262 functional safety audit.

The importance of quality extends to the design and manufacturing of the hardware. Designers must conduct thorough thermal and mechanical analyses via software-based simulations, looking at the trade-offs between different design choices. And manufacturers must meet rigorous quality and cleanliness standards, using electronics redundancy and isolation techniques to ensure that the printed circuit boards can function well under extreme conditions.

Emerging technologies

As batteries move to higher voltages, new technologies and new materials are needed to ensure their safety and efficiency.

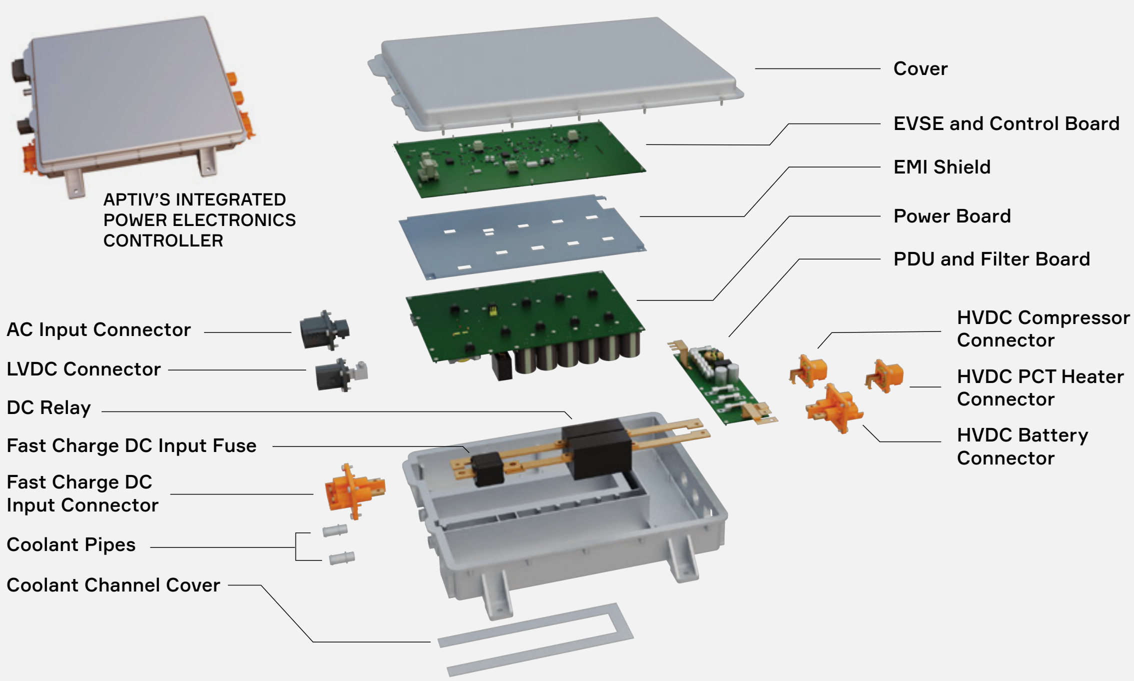
For example, electronics are built on silicon — but as voltages move to 800V, a more attractive alternative is silicon carbide, which combines silicon with carbon to create a semiconductor material that is more efficient and dissipates heat more easily than silicon at those voltages. While silicon carbide is more expensive than silicon at a component level, its advantages at a system level allow it to become cost-effective while also providing opportunities to significantly increase power density for smaller packaging volumes and downsize the thermal management systems that are responsible for cooling the electronics.

Another practice that is becoming useful at high voltages is the consolidation of multiple power transformer magnetics into a single magnetic housing. The reduction in current enabled by higher voltage supports a design technique that allows the manufacturer to use components that are lighter in weight and smaller in volume.

As we create these high-voltage components, we can use our experience with low voltages to build in the right safety capabilities. For example, low-voltage architectures are migrating from thermal fuses to controllable and resettable silicon solid-state circuit protection, often called e-fuses. Similarly, on the high-voltage side, e-fuses and e-disconnects can leverage advances in high-voltage silicon and silicon carbide to replace high-voltage thermal fuses, contactors or relays, and pyro fuses and ensure that the battery is safely and quickly disconnected if an emergency condition arises.

ALL-IN-ONE

The integrated power electronics controller that consolidates so much functionality is taking shape.



THE ARCHITECTURAL FUTURE

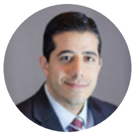
Hardware and software technologies like these will help make possible the consolidation of multiple functions into a single, integrated power electronics system — which opens the door for truly transformative architectural changes.

The power electronics can integrate with the rest of the vehicle architecture through zone controllers, giving the vehicle new levels of charging control and communication with the grid, and a better understanding of the state of the vehicle as a whole.

OEMs can also eliminate components, reduce weight, and save space and cost. For example, a well-designed system can eliminate the need for four unique controllers, three active-cooling circuits and many unique enclosures. And by achieving a higher power density, Aptiv has shown that we can reduce electronic components by 30 percent. In fact, Aptiv has achieved a best-in-class power density for onboard chargers and DC-to-DC converters, utilizing next-generation silicon carbide MOSFET (metal-oxide-semiconductor field-effect transistor) solutions for 800V architectures.

Aptiv is able to draw upon many strengths because we provide both the brain and nervous system of the vehicle. We are a leader in grid-to-battery system solutions. We are a leader in high-voltage and low-voltage circuit protection, including smart fuses and disconnects. We have industry-leading capabilities in automotive software development and functional safety. We offer a broad range of feature integration capabilities and packaging solutions, as well as global manufacturing capabilities to bring those solutions to life. Integrated power electronics will increasingly become a key component of Aptiv's Smart Vehicle Architecture™ approach to the full electrical/electronic architecture as we build the next generation of electric vehicles.

ABOUT THE AUTHORS



Brian McKay, Ph.D.
Global Product Segment Director, Integrated Power Electronics & Battery Management Systems

Dr. Brian McKay's team is responsible for the design and industrialization of integrated grid-to-battery system solutions combining power distribution, circuit protection, onboard charging, DC-to-DC conversion, and battery management system hardware and controls. During his automotive career, Brian has leveraged his technical expertise in motors, power electronics, batteries, transmissions, combustion, aftertreatment systems and thermal management systems to develop optimized system-functional architectures for electrified and hybrid propulsion systems. The technologies he and his team developed have led to numerous business awards and patents and garnered recognition by customers globally.

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Dr. Lewei Qian has been developing vehicle electrification technologies throughout his career, from off-highway electric vehicles to automotive EVs. His experience spans R&D, technology development, product launch and execution, strategy, program management, customer pursuits and supply chain management. Lewei has held multiple leadership positions related to EVs and successfully brought 3 MW traction inverters and other power electronics products from concept to mass production. At Aptiv, Lewei has played a key role in establishing the company's power electronics organization from the ground up. He holds bachelor's and master's degrees in electrical engineering, and a doctorate in mechanical engineering and power electronics from Florida State University.

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