WHITEPAPER

Separating Charging and Load Requirements for Advanced Drivetrain and HV-DCDC Applications

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For modern electric vehicles, voltage conversion is essential, as is an always-available power supply – especially in safety-critical applications such as x-by-wire applications and ADAS. By separating charging and load requirements, advanced powertrain configurations and HV-DCDC applications can be implemented. Semiconductors play a crucial role in this.

By Dirk Geiger, Infineon Technologies

As environmental awareness grows and regulatory frameworks adapt for a more sustainable future, demand for electric vehicles (EVs) is on the rise: almost every second vehicle is expected to be electrified by 2030 (Fig. 1). This trend increases the demand for faster automotive charging options as well as higher charging capacities, which in turn has a direct impact on the requirements for HV-DCDC applications and electric drivetrain configurations. As a result, the global HV-LV DCDC converter market is expected to grow at a compound annual growth rate (CAGR) of over 15 to 20 percent between 2023 and 2028. In addition, the demand for x-by-wire applications and ADAS is contributing to the increasing emphasis on safety and reliability in electric vehicles, which is directly related to the requirements of high-voltage DC applications and electric drivetrain configurations. And there are other factors, too: for example, power conversion systems must be both efficient and economical. High-voltage DCDC converter applications that convert high voltage to low voltage or vice versa are particularly significant for the overall efficiency and performance of vehicles.

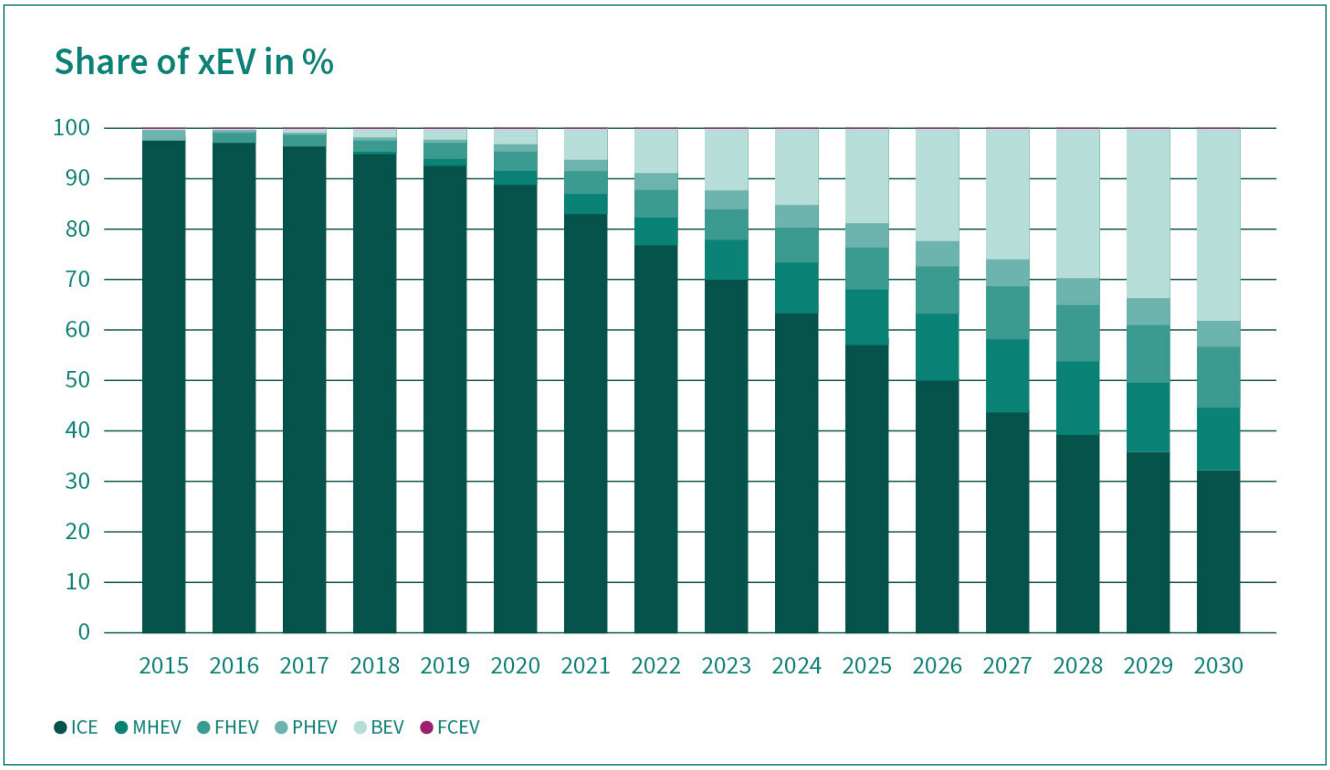


Figure 1 **By 2030, almost every second vehicle will be electrified.**

1 Improving the overall system

Efficiency requirements at vehicle and application level play an important role in drivetrain development. Developing the most efficient applications, systems and vehicles requires a holistic approach and must not be limited to individual components: The interrelationships between applications in a system must be understood and considered, as well as external influences. For traditionally structured companies, this is quite challenging, especially when individual departments achieve partial optimizations that are clearly defined and measurable, but do not necessarily improve the overall system.

Modern structures overcome these narrow boundaries and make it possible to identify necessary measures for individual applications that ultimately benefit the overall system. For example, if an inverter and motor system has been optimized for propulsion, but performs poorly in recuperation mode, it has a negative impact on vehicle efficiency in the WLTP (Worldwide harmonized Light vehicles Test Procedure) driving cycle. Instead, if the entire system is considered when making optimizations, the improvement in efficiency has several implications. For example, a truly more efficient application is likely to require less space and material to manufacture, cooling requirements are also likely to decrease, and integration into the vehicle will be more flexible.

The methods of improving the overall efficiency of an electric vehicle can vary depending on the OEM’s goals: One option is to downsize the battery while maintaining the desired range. This makes the vehicle more affordable, and lighter and more efficient. Alternatively, if customer benefits are to be increased for specific use cases, the range can be increased instead while the battery size remains the same. Another possibility is to reduce the required raw materials. Here, the efficiency of applications and systems in particular plays a major role, as these generally require fewer raw materials and rare materials in production. With this, dependence in supply is reduced or more vehicles can be produced with the same number of raw materials.

2 Power conversion in electric vehicles

The high-voltage energy stored in the EV battery is converted by HV-LV DCDC conversion systems into a low voltage that can be used by the vehicle’s electrical and electronic systems. This conversion is critical to the intended operation of the vehicle as it contributes to maintaining the power supply to vital systems such as electric motors, lighting, and navigation systems. As such, it is essential that the system is built to meet the functional safety standards set by the automotive industry to protect both the vehicle occupants and the vehicle itself.

Power networks in vehicles are an important factor, and implementation varies greatly. Typical grids and power conversions in an electric vehicle include both HV (high voltage) and LV (low voltage) requirements. Any application directly connected to the high-voltage battery converts electrical energy, and you can distinguish between charging and load requirements. Today’s vehicles with a main HV battery and a separate 12 V battery usually include these functions:

- DC fast charging – the conversion from alternating current to direct current takes place outside the vehicle. After that, the direct current is transferred directly to the battery.
- Potentially, a DCDC boost from 400 V to 800 V is required in the vehicle to charge an 800 V battery at a 400V charging station.
- The on-board charger is located within the vehicle and converts the typical 110/220 V AC to HV DC to charge the battery.
- To both charge the 12 V battery and operate the 12 V loads while driving, a DC-DC converter is required.
- A DC-to-AC 110/220 V inverter is used to run external loads (V2x) or even to use the vehicle to connect to the grid (V2G).

3 Separating charging and load

With increasing electrification and the rapidly growing availability of ADAS, the complexity of the network will increase significantly in the coming vehicle generations (Fig. 2). To keep up with the increasing requirements on the overall system, such as redundancy, independent or diversified energy sources, the main battery could be divided in two, so that the charging and the load sides can be separated. For example, a setup with two 400 V batteries would allow charging at 400 V or 800 V, depending on whether the batteries are connected in series or in parallel. Similarly, a traction inverter can operate at 400 V or 800 V on the load side, giving the designer more options while focusing on cost or efficiency.

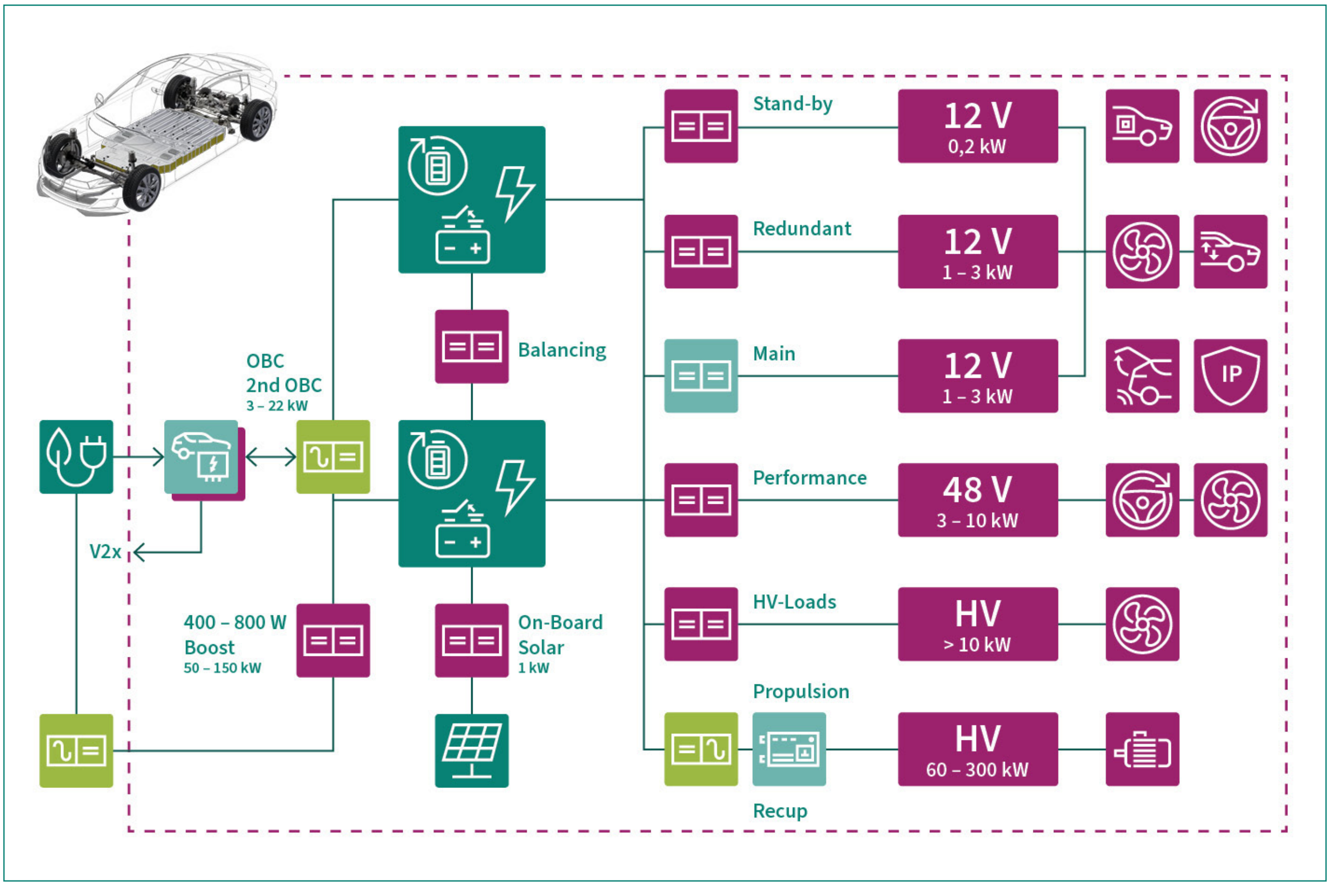


Figure 2 The increasingly complex and demanding energy conversion in future drivetrains can be realized with chipsets from Infineon.

Although it sounds simple, such a setup also brings additional challenges, like the need for a more complex battery management system and the management of switches for a dynamic battery string configuration. But there are other issues to consider when optimizing the power conversion system, too:

- Multiple HV-to-12-V DCDC converters are needed to supply additional loads, such as heat pumps or self-regulating heaters.
- A standby HV-to-12-V DCDC converter, typically 100 W to 300 W, is necessary to charge the 12 V battery during parking or to provide power capacity for large SOTA updates.
- An HV-to-48-V DCDC may be required for even more powerful loads, such as a heater for plug-in hybrid electric vehicle exhaust air cleaning that meets new Euro VII emissions standard.
- To balance both batteries, a special DC-to-DC system could be implemented.
- Some vehicles offer a solar upgrade, where solar cells are added to the roof to boost range.

Overall, the additional flexibility in the design of the electric drivetrain enables scalable platform solutions and easier adaptation to the existing charging infrastructure.

To take advantage of such a drivetrain, separating the on-board charger (OBC) from the DCDC converter is becoming more attractive. OEMs are starting to introduce dedicated DCDC units that integrate the different application requirements while separating the OBC. This allows the industry to focus on standardized and optimized OBC solutions with integrated communication at the application level that meet the ISO15118 standard. The separate DCDC unit would thus be optimized for specific vehicle requirements.

But ultimately, this is not just about additional flexibility in the drivetrain, but also about additional functions and values. For example, a limp-home function can easily be implemented with two 400V batteries. If one battery pack fails, it is switched off. With the other, however, the vehicle can continue to be operated reliably and thus safely reach the desired destination.

4 A typical DCDC conversion system

A typical SiC-based HV-LV-DCDC conversion system (Fig. 3) for electric vehicles consists of many different components: SiC Power MOSFETs, Si-Superjunction MOSFETs or IGBTs for switching, Si Power MOSFETs for synchronous rectifying, magnetic components and capacitors for energy transfer and filtering, control circuits for voltage regulation and protection, heat sinks for cooling and thermal management, PCB and packaging for integration and protection of components, as well as safety and protection circuits for under-voltage, over-voltage, over-temperature, and over-current conditions.

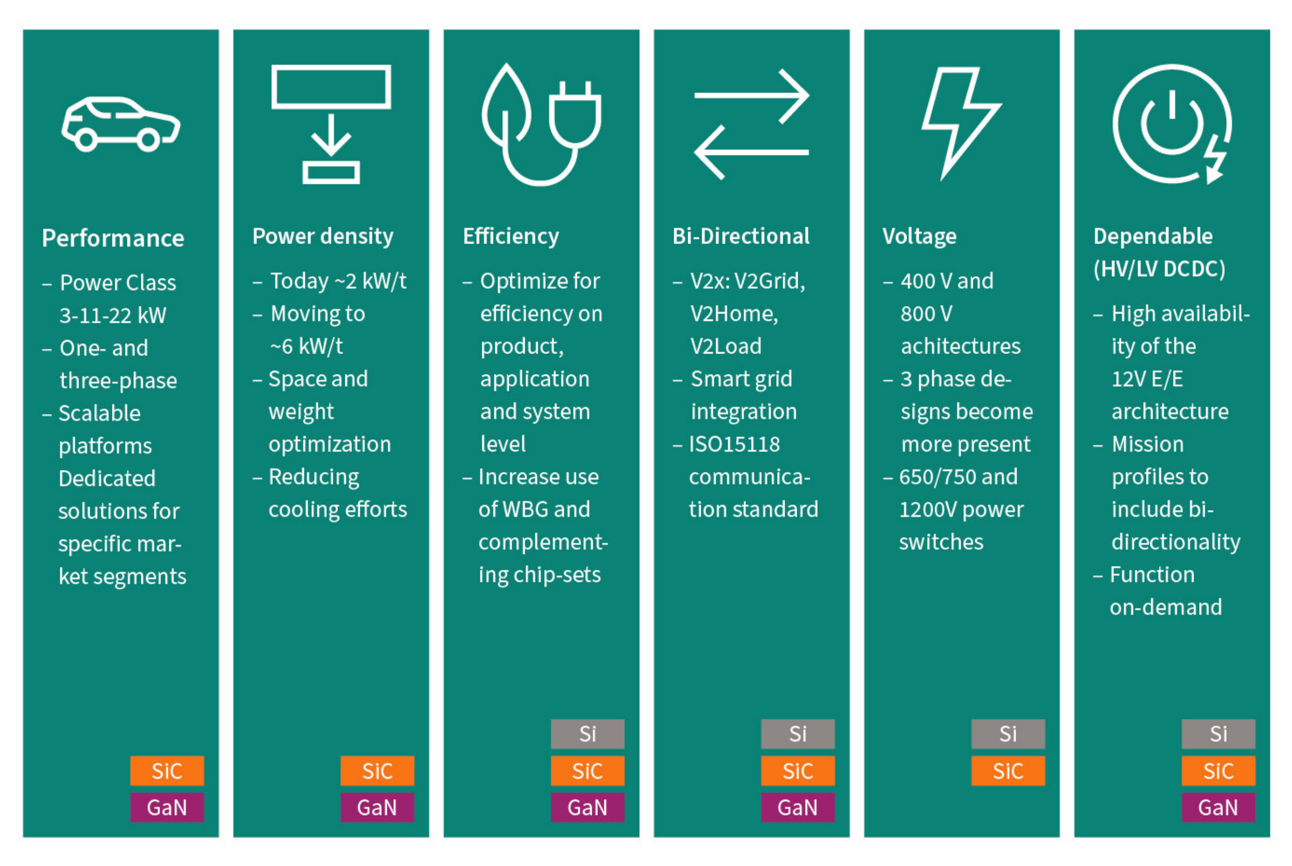


Figure 3 Leading trends for HV-DCDC power conversion applications.

For a high-voltage to low-voltage DCDC converter (Fig. 4) for electric vehicles, it can be difficult to determine the exact relationship between semiconductor cost and total application cost. This is because it depends on several factors, such as the complexity of the converter, the size of the system, the quality and quantity of components used, and other design considerations. It is believed that the cost of semiconductors, such as SiC- or GaN-based devices, accounts for between 20 and 50 percent of the total cost of an HV-LV DCDC converter.

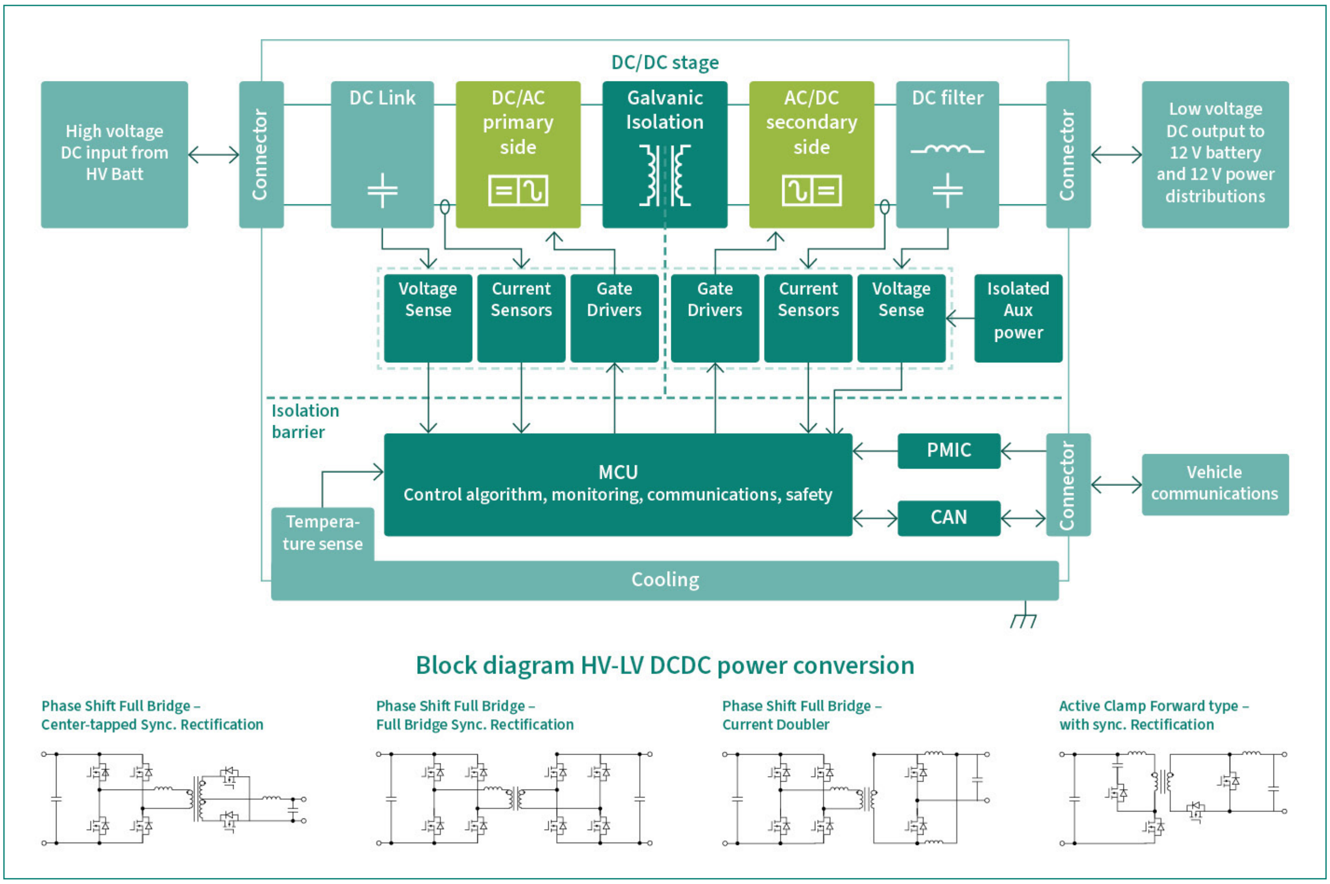
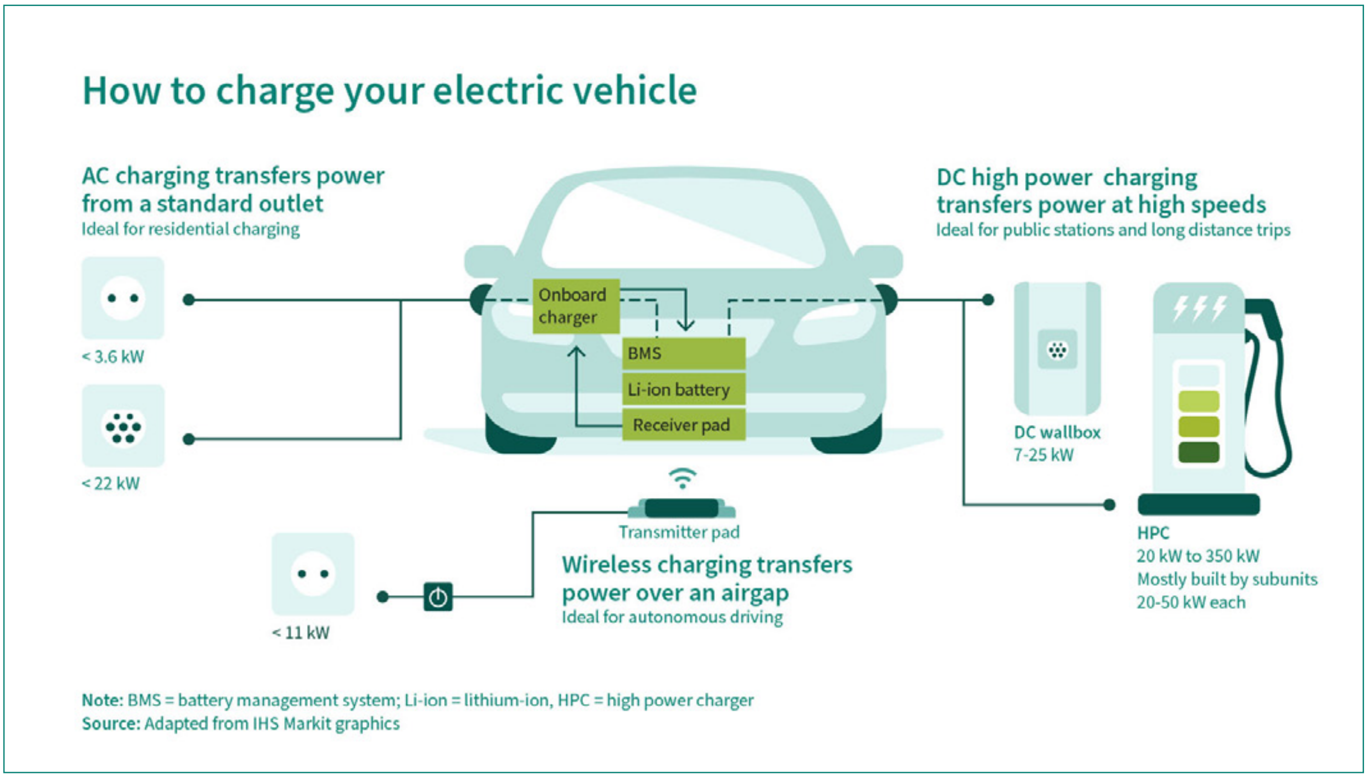


Figure 4 Function block and topologies of a HV DCDC/OBC.

However, developing an HV DCDC is not just about semiconductors. With growing production volumes, new platform concepts, and flexible vehicle configurations, engineers must also consider manufacturability, repairability, sustainability and recyclability. Infineon’s complete and complementary chipsets for HV-DCDC applications come in handy here, as they have been designed with such applications in mind. Developers thus have a semiconductor one-stop store at their disposal, offering them all the components they need and allowing them to focus entirely on application capabilities. This enables them to bring their differentiated, powerful, and efficient application solution to market as quickly as possible.

But developers must also consider the integration of the electric vehicle into the overall charging infrastructure and the power grid. And other questions must not be ignored either: Is enough green electricity being produced and is it available? Will the electric vehicle be charged with alternating current or with fast direct current? How can the electric vehicle be part of the power grid in a V2X scenario? Might the vehicle even be a mobile energy bank, storing valuable energy that can be fed into the grid when needed? All these considerations can change the usage profiles of vehicles and applications. However, they also enable new use cases and business models. Depending on the application, different components are needed for implementation: A vehicle that is charged via a DC wall box requires different components than a vehicle designed for AC charging stations (Fig. 5). This makes it even more important for a developer to have a supplier with a broad portfolio that considers many different industries and application scenarios.



Note: BMS = battery management system; Li-ion = lithium-ion, HPC = high power charger
Source: Adapted from IHS Markit graphics

Figure 5 There are different approaches for the implementation for EV charging solutions. Infineon offers solutions for all of them from a single source.

5 Future challenges

Looking ahead, these developments open the door for the next generation of vehicles and applications (Fig 6.). Soon, for example, efficiency optimized OBCs could be air-cooled which allows for more flexibility in vehicle integration and reduces the cost for liquid cooling. The use of 400 V batteries could even eliminate some DCDC applications entirely, including a DCDC boost from 400 V to 800 V.

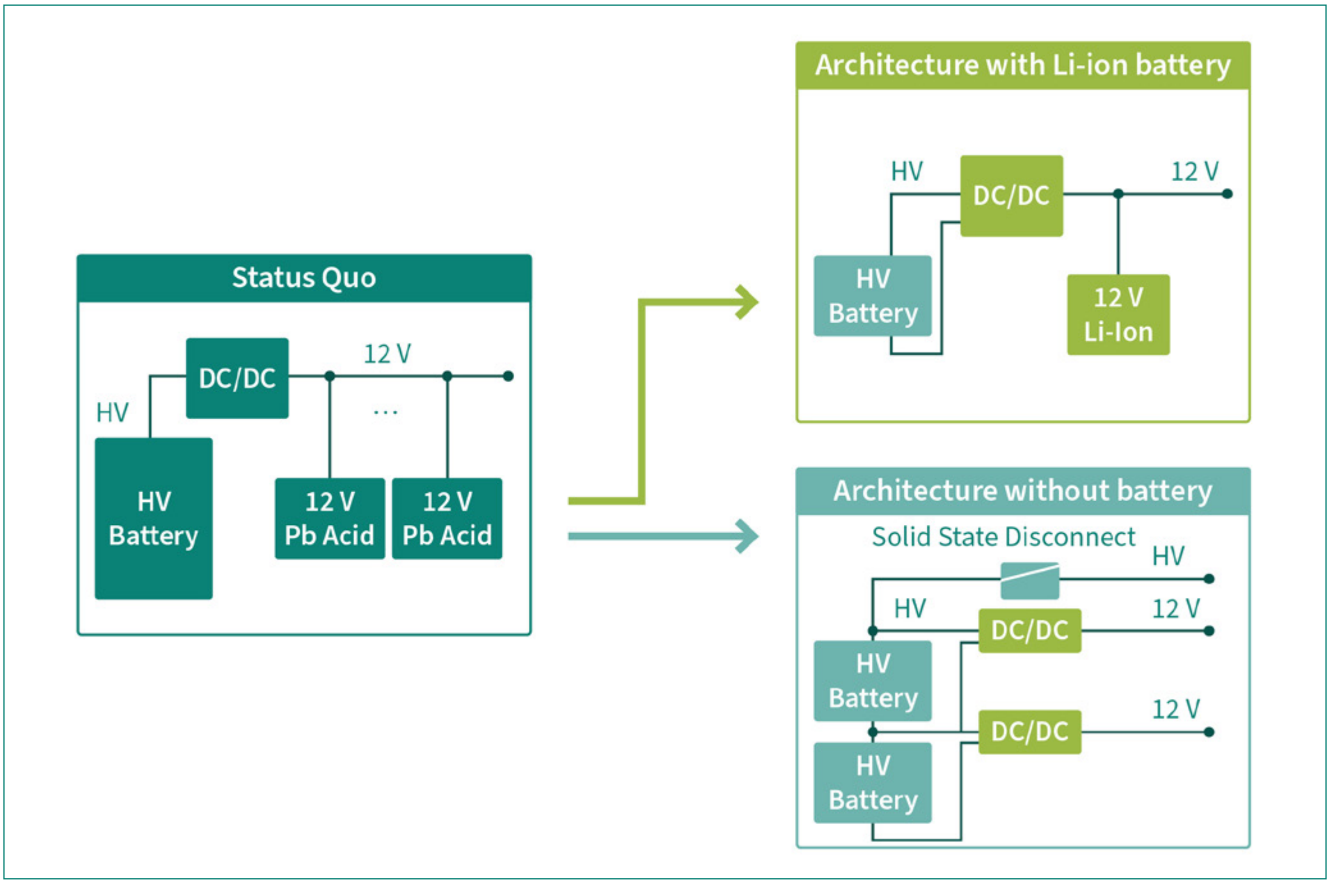


Figure 6 Further development of drivetrain architectures.

With HV-to-12-V DCDC, even a 12-V supply is possible. This raises the question of whether a special 12 V battery will be necessary at all in the future. An important point, because the 12 V battery used today is generally a lead-acid battery. Although the use of lead is currently still covered by an exemption in the RoHS and ELV (End of Life Policy) guidelines for vehicles, these must be reviewed every few years. So, the exemption might expire sooner or later. By then at the latest, the lead-acid battery would have to be replaced with a Li-ion battery, which would lead to additional costs. For this reason, there are considerations to simply remove the 12 V battery altogether. However, this requires a completely new drivetrain and network concept. Think, for example, of critical functions such as the brake-by-wire or steer-by-wire application. Their operation must not be compromised under any circumstances. Redundancy is therefore urgently required, from the power source to the load, including the two main batteries, redundant HV-12V DCDC, HV load path. This allows the drivetrain to operate reliably without a 12V battery and continue to enable ADAS and by-wire functions. At the same time, weight and space requirements are reduced, which in turn improves vehicle efficiency. In addition, scalable vehicle platforms can be realized that address both affordable market segments and high-performance vehicles.

6 New battery concepts

Now that we have looked at vehicles with two batteries and potential added value, why not think a little further? How about dividing the main battery into even smaller segments, such as multiple 12 V modules? On the load side, the high voltage would be generated by connecting the battery modules in series in 12 V increments upward. This approach would eliminate the need for special DCDC converters since the desired voltage would be provided directly by the battery itself. However, this would require intelligent battery management to ensure that all modules are charged and discharged evenly.

In addition, the battery could generate not only direct current but also alternating current via fast semiconductor switches, for example to operate the traction motor directly. With this setup, a dedicated inverter can be eliminated. With a charge that can be easily adapted to the existing charging voltage, an ACDC converter would also be unnecessary. In such a multi-string battery, redundancy is already included, and scalability is readily available. In addition, it is easier to support a sustainable life cycle as well as maintenance and repairability. While we cannot yet say where the development will take us, we may see exactly this drivetrain evolution: from a single main battery to two main batteries to a multi-string battery.

Infineon offers many different products for HV-LV-DCDC conversion in electric vehicles, including high-voltage MOSFETs, IGBTs and SiC MOSFETs. They provide high efficiency, fast switching speeds, and improved thermal performance, as well as effective and reliable power conversion. Compared to silicon MOSFETs, SiC MOSFETs can achieve even better thermal performance, higher switching frequency and lower power dissipation, leading to increased system efficiency, reduced device size, and longer component lifetime. In addition, Infineon offers microcontrollers, gate drivers, current sensors, and power management ICs (PMICs) for HV-LV DCDC converter systems in electric vehicles. Together, these products form complete, integrated solutions for high-performing and reliable HV-LV DCDC converter applications.

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