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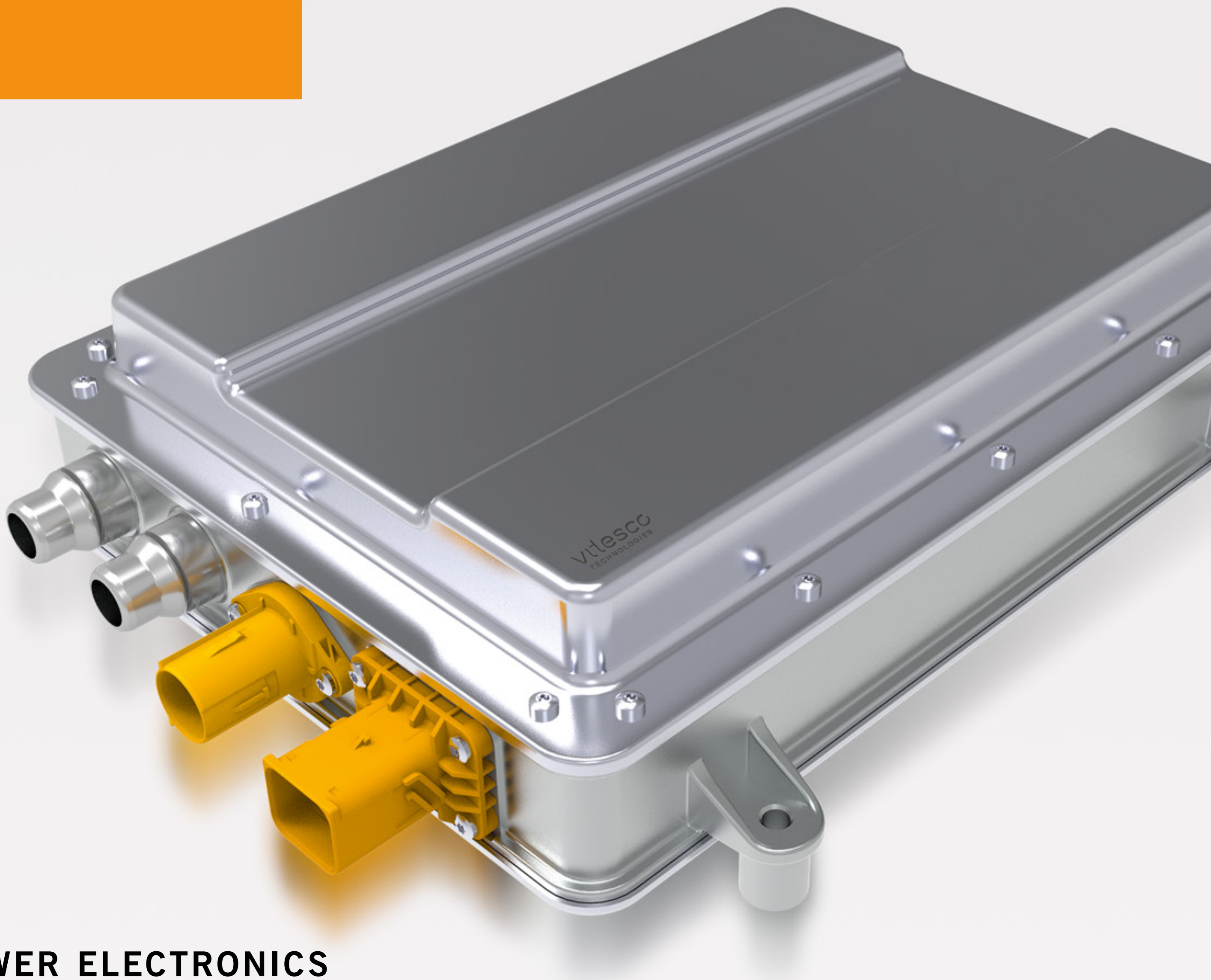

POWER ELECTRONICS

High Voltage Box for Electrified Vehicles

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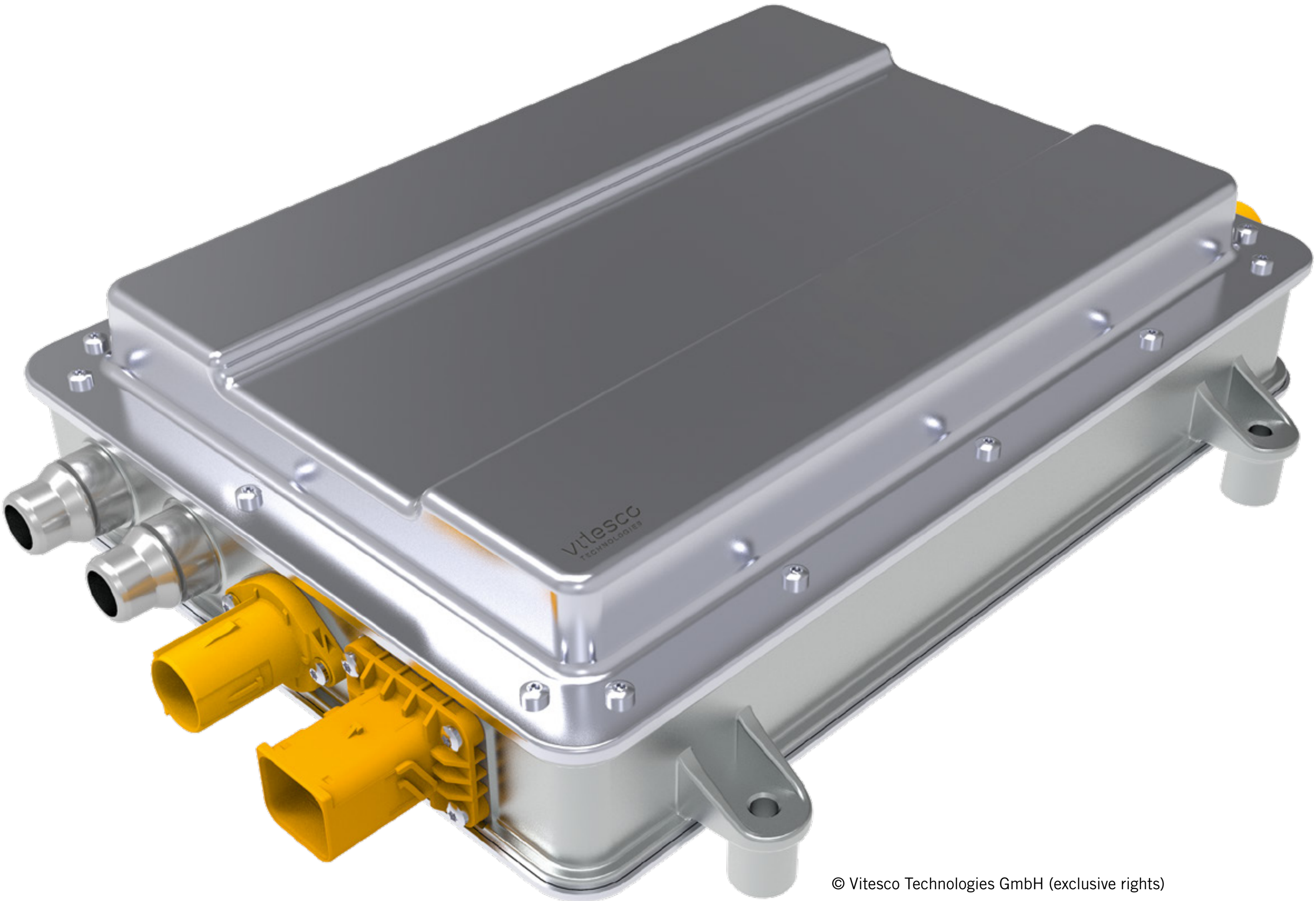
TECHNOLOGIES



High Voltage Box for Electrified Vehicles

Through a higher mechatronic integration of energy conversion and distribution in the vehicle one can reduce weight and cost, while at the same time functional reliability can be improved. Vitesco Technologies is presenting a new approach to the system architecture of charging and conversion electronics with its high voltage box prepared for series model application. Wide bandgap transistors are increasingly relevant for this approach.

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Electromobility brings with it both hope and challenges. It brings hope, because the political and regulatory framework conditions are focusing worldwide on electrified vehicles. It brings challenges, because this global trend translates into an enormous growth in units. Two areas need to be optimized systematically in particular: For one thing, the efficiency of the electric drive needs to be increased in order to make the best use of the electric energy during charging and driving. This aspect impacts sustainability and the general appraisal of electromobility. For another thing, it is about cost-cutting potentials as high production volumes require lean technologies with a strong focus on avoiding any waste, for instance, through multi-purpose or avoidable infrastructure in the vehicle, to achieve competitiveness. The system architecture of electric cars or plug-in hybrids offers especially rewarding opportunities for optimization [1].

Managing the electric energy flows is a core task in all electrified vehicles. This ranges from different charging options (AC charging and DC fast charging) on to supplying energy to the 12-V DC net from the high voltage net and up to the energy distribution within the DC high voltage net. Up to now, separate high-power electronics were integrated for the individual tasks of charging and conversion/inversion: An onboard charger (OBC) handles the AC charging of the high voltage battery, a DC/DC converter supplies the 12-V net, and another electronics box enables super-fast charging (within an 800-V architecture), **FIGURE 1**.

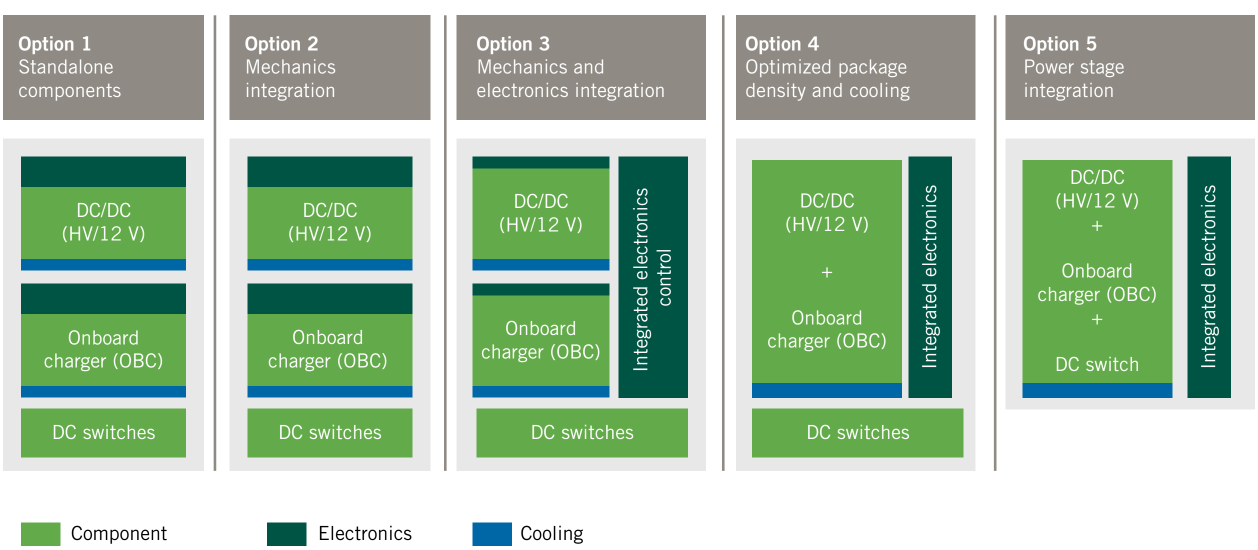
This kind of discrete architecture is typical for an intermediate stage of a technology on its evolutionary slope. However, a discrete design is not efficient, as it leads to additional mass, size and costs. In addition to housings and equally heavy and costly cabling, which includes connectors that are expensive in this performance range, the control electronics, filter functions and cooling pipes are core issues.

Vitesco Technologies has utilized the previously published architecture analysis to address high voltage electronics with the goal to take weight, size and cost out of the vehicle through higher mechatronic integration. At the same time the functional reliability of the charging electronics benefits from this. This new approach to architectures up to 800 V is called high voltage box. The system will go into production for the first time at a premium OEM.

DESIGN AND FUNCTION OF THE HIGH VOLTAGE BOX

The high voltage box was developed within a distributed, international pro-

FIGURE 1 Integration options of charging and conversion/inversion technology in the vehicle, ranging from discrete to fully integrated (© Vitesco Technologies GmbH (exclusive rights))



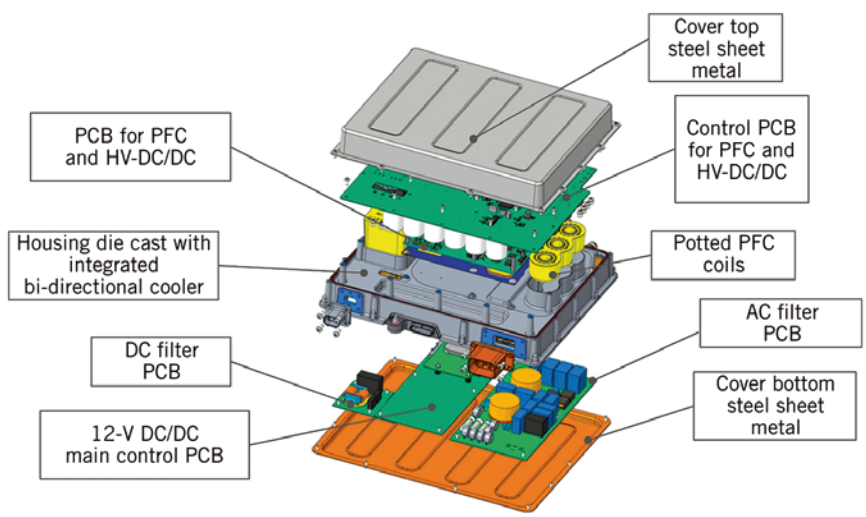


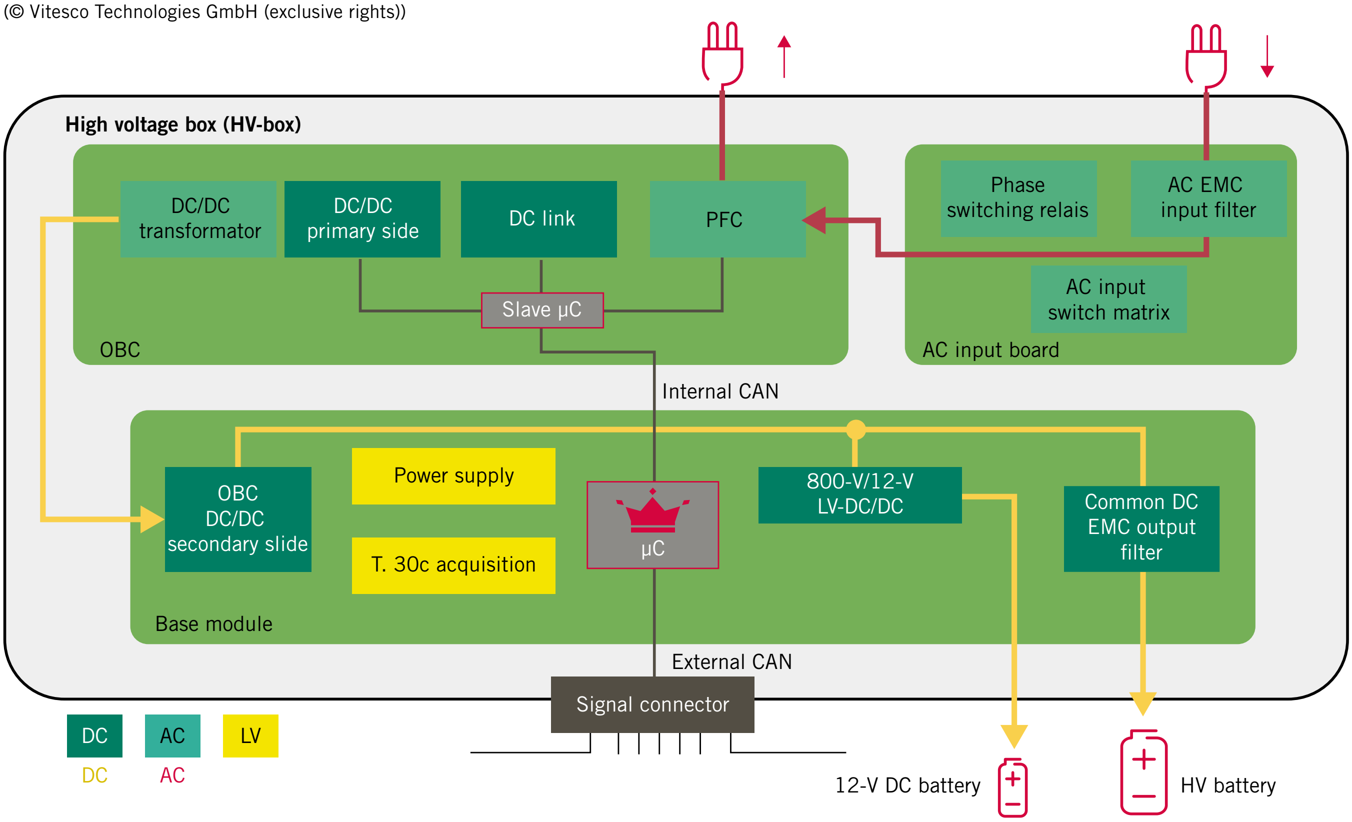
FIGURE 2 3-D intermeshed design of the modular function units in the high voltage box (© Vitesco Technologies GmbH (exclusive rights))

cess spanning Regensburg (Germany), Timisoara (Romania), Toulouse (France), and Auburn Hills (USA). The result is a unit that is highly intermeshed on a three-dimensional level and which meets high standards through its modular and scalable design. One option is just to integrate the onboard charger (AC charging with 7.2 to 22 kW either for a specific grid or for global use) and the bi-directional 12-V DC/DC conversion (up to 3.7 kW), or to include the power distribution (DC switch/power distribution unit) in the vehicle, which is also suitable for high DC charging powers, **FIGURE 2**.

The main feature of mechatronic integration is visible, for instance, in the fact that the power electronics of the OBC and the 12-V DC/DC converter have a common control and drive unit. The EMC filter for the high voltage DC side is also effective for both. The mechanic design with a sandwich cooler contributes to a modular, yet individual build. Modular extensions are conceivable, such as a high voltage DC booster, the charging communication, a high voltage heater, and the battery management system.

The modular high voltage box saves space, weight and cost, for instance on the housing and cabling levels. On top of installation space improvements and the resulting ease of vehicle integration, this approach also enables a more robust design with greater reliability when compared to individual components, because typically it is the electrical connections that can cause issues over time as experience tells. To achieve modularity, a lot of know-how went into defining the interfaces of the high voltage box's sub-modules to ensure scalability without repetitive trial-and-error testing. Consistent design for manufac-

FIGURE 3 Topography of the system architecture (© Vitesco Technologies GmbH (exclusive rights))



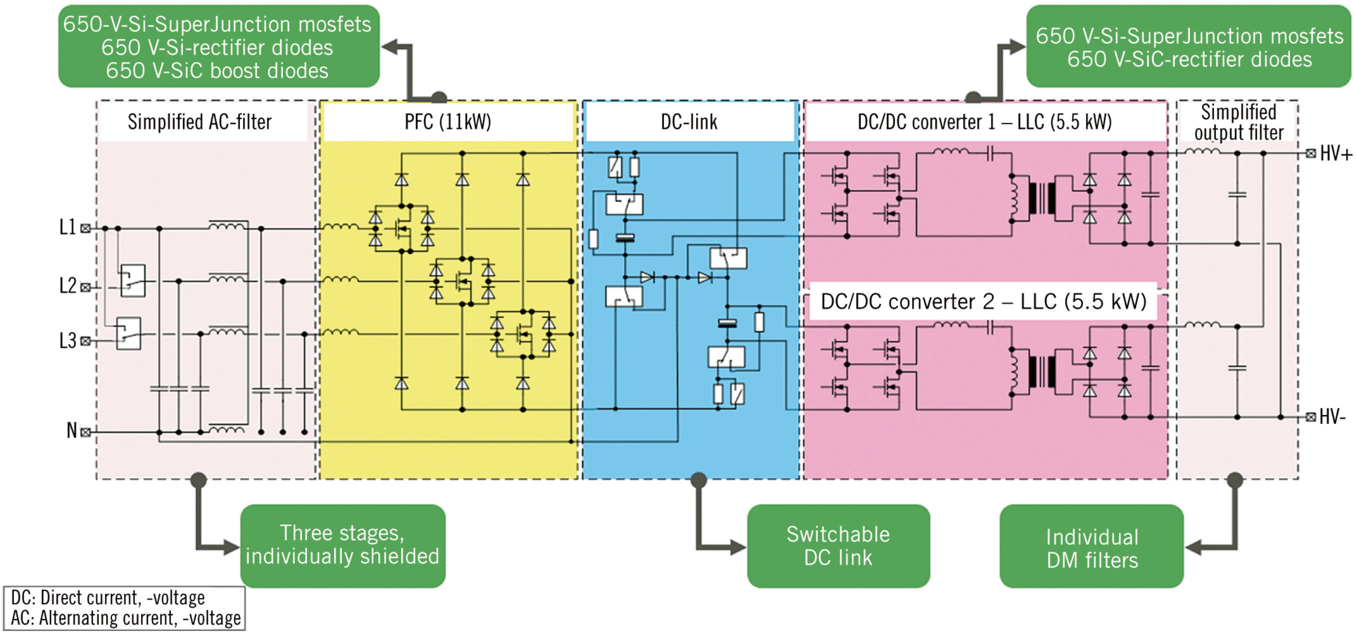


FIGURE 4 Schematic design of the OBC in the 11 kW AC charging power version (© Vitesco Technologies GmbH (exclusive rights))

turing was another success factor for modularity and scalability because there is no other way to manufacture products combined from various module variants effectively and in high quality on a single production line.

SYSTEM ARCHITECTURE AND FUNCTION PRINCIPLE

The design as seen in **FIGURE 2** shows the allocation of the core functions to four individual PCBs. **FIGURE 3** depicts the system architecture. The AC input area is highlighted. The four main function areas as shown in the figure are again identical with the four PCBs of the high voltage box. The schematic diagram in **FIGURE 4** shows the stages of the AC charging electronics in a flow from left to right using the example of a version scaled for 11 kW charging power. The AC filter is designed to allow either one-phase or three-phase charging. The Power Factor Correction (PFC) stage that protects against harmonics contains standard ICs (650-V mosfets and rectifier diodes) as well as silicon carbide (SiC) components. This applies to the high voltage box in general: Si and SiC technology already balance each other out. Placing the potted PFC filter coils was done with the aim to improve the cooling efficiency. In the actual high voltage DC/DC conversion stage the charging power is split into two paths with 5.5 kW charging power each in order to increase conversion efficiency. In the version for 22 kW charging power, the same principle is applied with two paths of up to 11 kW each.

POTENTIAL OF WIDE BANDGAP MATERIALS

Soon it will become even more important to increase an electric vehicle's charging electronics efficiency, because the efficiency of charging the traction battery is yet another influence on the total energy consumption. A second development goal is to reduce the spatial envelope of the high voltage box to achieve greater freedom of integration. Wide bandgap (WBG) semiconductor materials offer a lot of potential for both

SiC

SiC structure

- Vertical component
  - Mosfet construction
  - Better semiconductor material than **Si**
  - **SiC** substrate
  - High current density

Main characteristics

- Low ON resistance (> greater stability than GaN across temp.)
- High breaking voltage (> higher than GaN)
- Fast switching
- Bi-directional component (body diode)

GaN

GaN structure

- Lateral component
  - 2 layers on **Si**
    - GaN (few µm)
    - AlGaN (few nm)
    - Very high electron mobility
    - Planar device

Main characteristics

- Low switch-on resistance $R_{DS(ON)}$
- Very high switching frequencies possible (> higher than SiC)
- Voltage maximum ~650 V; GaN epitaxy
- Bi-directional component

FIGURE 5 Structure and characteristics of WBG transistors (© Vitesco Technologies GmbH (exclusive rights))

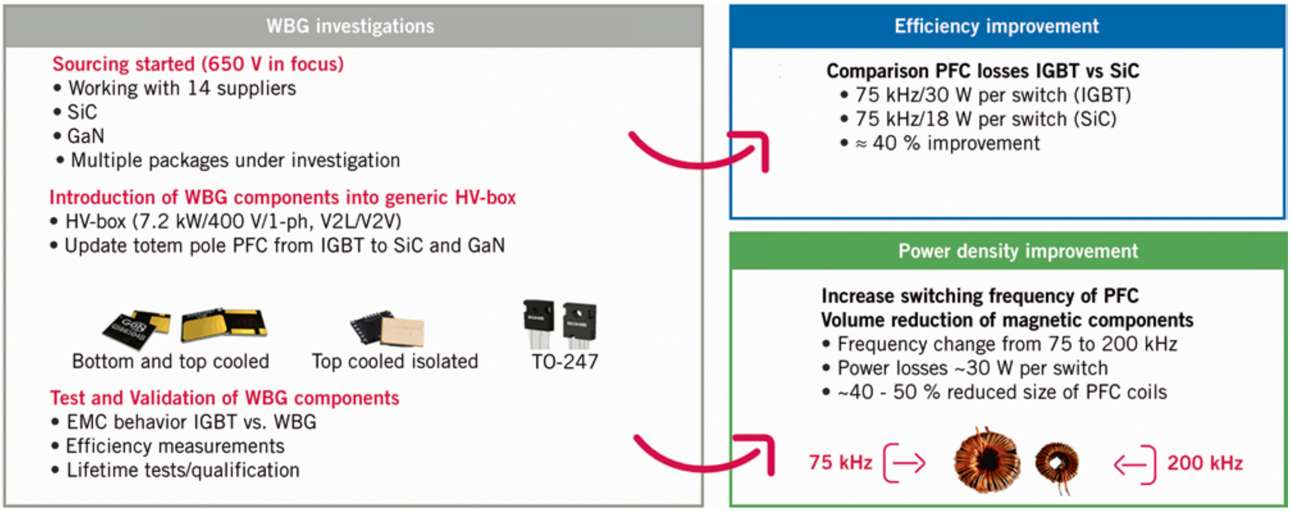


FIGURE 6 SiC and GaN ICs offer potential to optimize the efficiency or the power density or, respectively, a partial improvement of both target parameters (© Vitesco Technologies GmbH (exclusive rights))

purposes. Currently, SiC components are already part of the box design. For the future, the use of gallium nitride (GaN) components is being analyzed and prepared as well. Both WBG materials share common advantages, however, they also have differing characteristics which can be specifically exploited in charging electronics applications.

Both materials enable much higher switching frequencies at considerably lower switching respectively conduction losses ($R_{DS(ON)}$), **FIGURE 5**. On a detail level, SiC components offer advantages at high power and high temperature. GaN ICs on the other hand, enable higher switching frequencies than SiC and lower switching losses. This makes WBG materials a pivotal technology for the transition to 800-V systems. Since the switch to 800-V systems is happening faster than was originally announced, it is essential to further develop automotive WBG solutions.

The two materials do not just offer considerably lower power dissipation, but also tolerate higher operating temperatures. This enables higher power density levels at lower cooling requirements. So, optionally, WBG semiconductors either facilitate a higher efficiency at the same switching frequency, or they facilitate a greater power density owed to higher switching frequencies (via smaller magnet coils). Also, it is possible to exploit a balanced combination of both potentials, **FIGURE 6**. Considering the above mentioned challenges of electromobility when it comes to efficiency, cost, and sustainability, WBG materials will continue to gain importance in the future. They will make a substantial contribution to thermal management and optimized package sizes.

SUMMARY AND OUTLOOK

A high voltage architecture analysis has revealed that it is beneficial to integrate the closely related tasks of energy distribution, energy conversion and storage. The actual goal was not to simply place the individual components into a single housing, but to develop a fully integrated solution that is closely interlocked to fulfill several tasks in one unit using a common infrastructure, for example, for cooling. The onboard charger served as integration platform for the high voltage box which mechatronically integrates the OBC and the 12-V DC/DC conversion in its minimum function content version.

In principle, the innovative unit acts as a transformer station in the vehicle and unites three functions for operating voltages up to 800 V: Firstly, it controls the AC charging process from the AC grid by inverting this to DC and feeding it forward to the high voltage battery. Secondly, the high voltage box carries out the high voltage management in the vehicle, and especially the energy distribution from the high voltage battery to the consumers plus providing the DC charging function at high power charging points with a three-digit kW level of charging power. Thirdly, it powers the traditional 12-V net.

The interfaces in the box are designed to allow the integration of additional functions. This concept of high integration in combination with modularization and scalability facilitates shorter development lead times at an attractive cost level. Owed to fewer high voltage cables and high voltage connectors and a simplification of cooling lines and connectors, weight and package size go down, while ruggedness and reliability of the solution increase. Wide bandgap materials such as SiC and GaN offer future potential, on the one hand to further reduce the spatial envelope, on the other hand to further increase efficiency which is why the application of more WBG ICs in the high voltage box electronics is already being prepared.

REFERENCE

[1] Adler, C.; Deinhard, S.; Hackelsperger, M.; Mühlbauer, K.: High-Voltage Architecture Analysis – Key to Affordable Electric Mobility. In: ATZworldwide 12/2018, pp. 52-56

IMPRINT:
Special Edition 2022 in cooperation with Vitesco Technologies GmbH, Postfach 200230, 93061 Regensburg;
Springer Fachmedien Wiesbaden GmbH, Postfach 1546, 65173 Wiesbaden,
Amtsgericht Wiesbaden, HRB 9754, USt-IdNr. DE811484199

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