Optimizing Power Efficiency and Performance for Hybrid and Electric Vehicles

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With rising interest − and market support − for electric vehicles (EV) and hybrid electric vehicles (HEV), there is increased competition among automotive manufacturers to deliver superior offerings to an expanding customer base. As the electric motor of an EV needs a high kW source to drive it, the traditional 12 V battery has given way to battery packs on the order of 400−450 V DC as the mainstream battery voltage of choice for EVs and HEVs.

The market is already pushing a shift to even higher voltage batteries. 800 V DC and larger batteries will become more dominant because utilizing a higher voltage means the system can operate at a lower current while achieving the same power output. The advantage of lower current is lower losses and less heat dissipation to manage. Lower current also makes it possible to use smaller cabling to pass power throughout the vehicle.

Evolving EV technology will be critical in enabling more sustainable transportation globally. By the end of 2024, more than 7 million vehicles on the road will be built with **onsemi** VE−Trac™ power modules. Just counting these vehicles will reduce CO_2 emissions by more than 29 million metric tons every single year (see Figure 1).

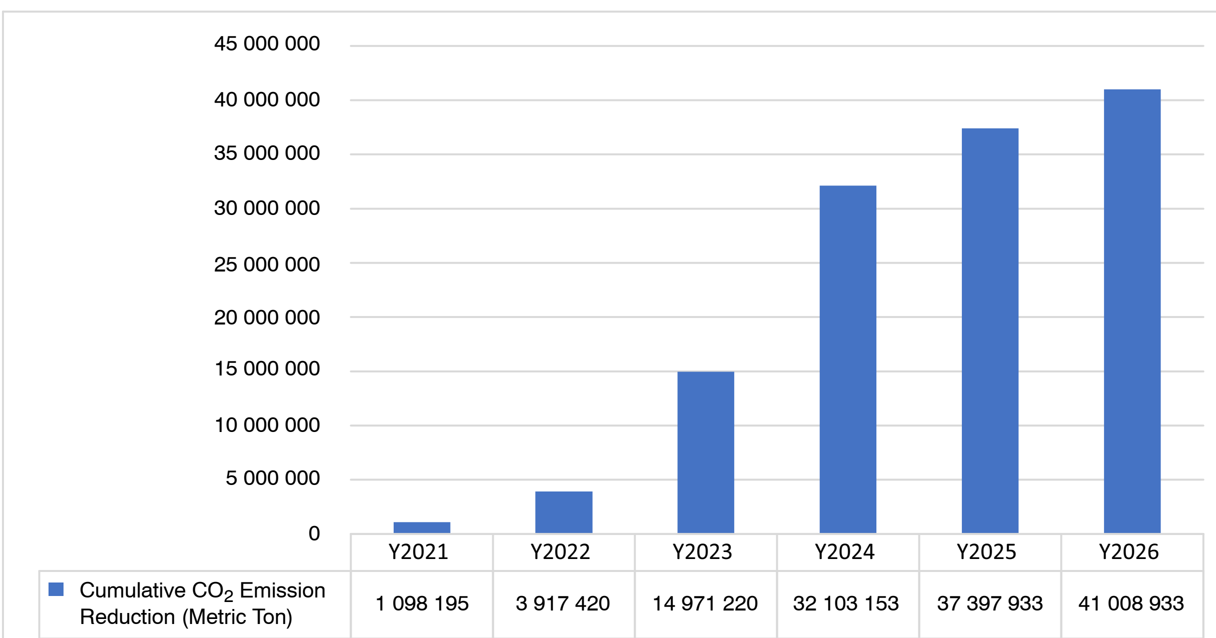

Figure 1. Reduction in CO_2 Emissions Based on Vehicles Built with onsemi VE−Trac Power Modules

The Traction Inverter

The principal load on the battery is the vehicle's motor. EV and HEV that utilize an AC electric motor rely on a traction inverter to convert the DC battery source to AC (see Figure 2). The traction inverter is the heart of an electric vehicle, providing the torque and acceleration needed to drive the car forward. Two primary design considerations for traction inverters include conversion efficiency and peak power.

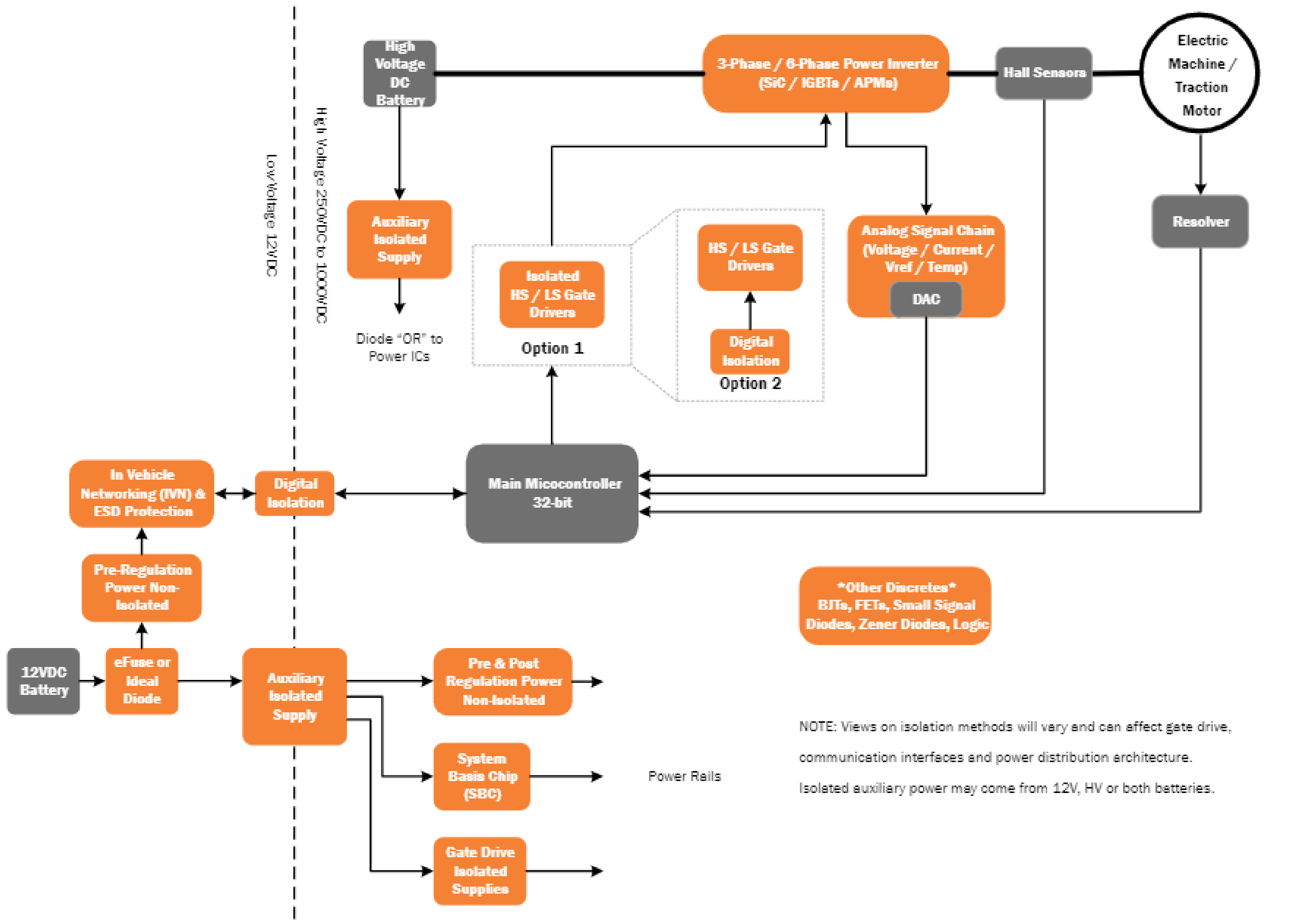

Figure 2. Traction Inverter Converts DC Battery Source to AC, Providing Torque and Acceleration

The more efficient power conversion from DC to AC is, the more the vehicle can do with a smaller battery. Higher efficiency also means the system can provide more power with less heat dissipation to manage.

Peak power determines the overall performance of the vehicle, in particular, the vehicle's instantaneous torque and acceleration capability. Together, efficiency (range) and peak power (performance) ultimately define the vehicle's applications and use cases.

Today, many EVs and HEVs are built upon IGBT technology. With the introduction of silicon carbide (SiC) technology, new levels of efficiency and performance become possible.

The SiC Advantage

IGBT technology generally provides a more cost−efficient solution for low− to mid−range vehicles. SiC offers superior efficiency and peak power, especially at higher voltages, for vehicles where range and performance are vital, and system cost is more flexible. State−of−art impedance per die enables best−in−class efficiency and thermal optimization. Together, these capabilities lower battery consumption per mile. And while SiC comes at a higher component cost than IGBT, in many applications, this is more than offset by other cost savings throughout the vehicle made possible by SiC's increased power efficiency.

Figures 3 to 6 compare IGBT efficiency with SiC efficiency. In Figures 3 and 4, the NVH820S75L4SPB is an IGBT module (square plot), and the NVXR17S90M2SPB is a SiC module (circle plot). These two graphs show how IGBT has substantially higher power losses based on switching frequency and RMS load current.

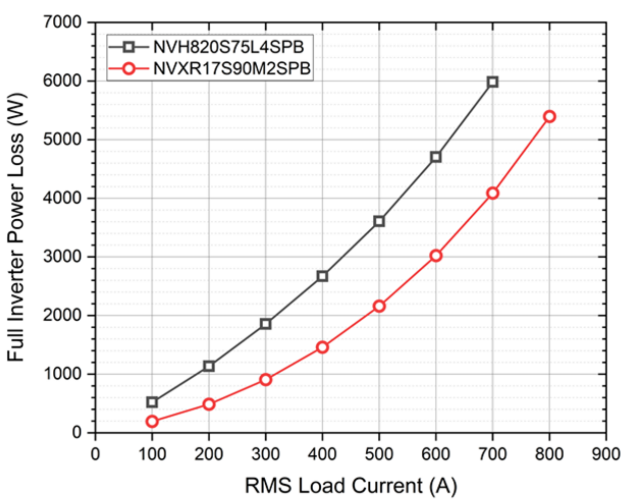

Figure 3. Power Losses at 8 kHz Switching Frequency

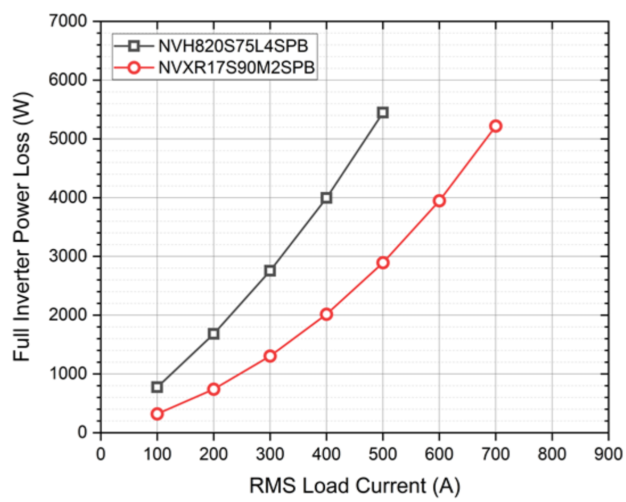

Figure 4. Power Losses at 15 kHz Switching Frequency

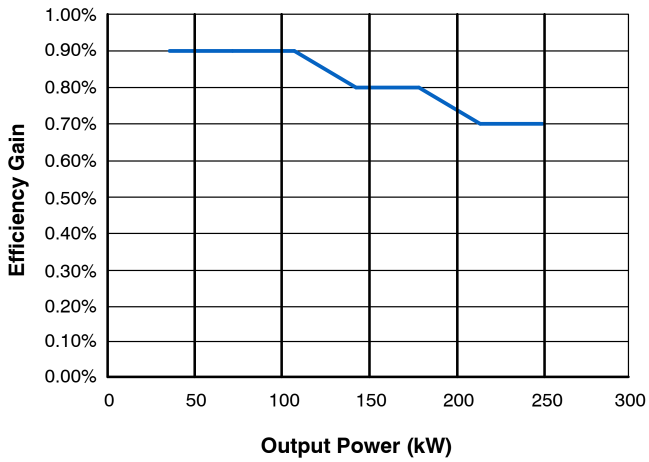

Figure 5. Efficiency Gain at 8 kHz

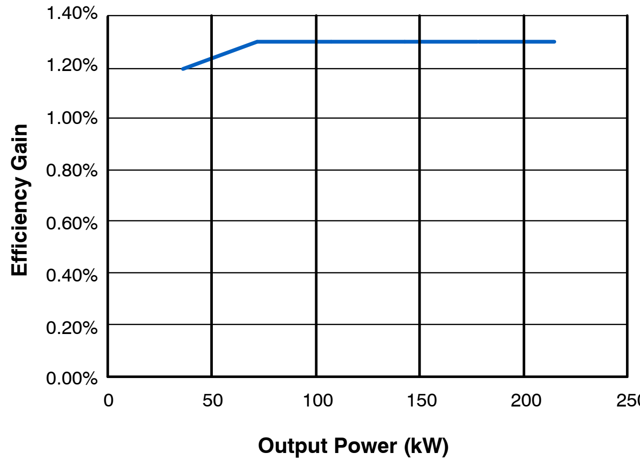

Figure 6. Efficiency Gain at 15 kHz

Figures 5 and 6 show that SiC operating at a higher frequency achieves superior efficiency gain.

Conversion Efficiency:

By its nature, current IGBT technology becomes thicker and less efficient as voltage increases, resulting in the need for a higher blocking voltage. It is possible to build higher voltage inverters based on IGBT, but as EVs move to 800 V and above, SiC becomes substantially more efficient than IGBT. SiC doesn’t have to be as thick as IGBT at higher voltages to achieve the blocking voltage. At standard loads, IGBT performs on the order of 94% efficiency. However, efficiency drops to 92% at lower loads, such as when the vehicle operates at cruising speed. In contrast, SiC achieves up to 98% at standard loads, for a gain of 4%. SiC has 95% efficiency at lower loads, for a gain of 3%.

Extended Operating Range:

Consider a 100−kWh battery with IGBT−based inverter solutions that can yield a maximum driving range of 300 miles. With SiC, a 3%+ increase in efficiency would increase vehicle range by 9 or more in extra distance. The range extension would be even farther for vehicles with larger batteries, such as long−distance shipping trucks.

Smaller Cabling:

The motor can be driven with a lower current because a SiC−based traction inverter operates more efficiently at a higher voltage. In turn, cabling with a smaller diameter can be used. Smaller cabling throughout the vehicle reduces overall weight, requiring less power to move the vehicle and increasing overall vehicle range. Furthermore, smaller cabling comes at a lower cost, offsetting the cost of using a high voltage SiC−based traction inverter.

System Size:

The higher efficiency of SiC technology enables a high voltage traction inverter to be physically more compact without compromising efficiency or peak power. A smaller inverter gives designers more flexibility regarding its placement and maximizes passenger and usable space within the vehicle.

Thermal Management:

Managing heat within a vehicle is critical for maintaining overall system efficiency. The higher thermal efficiency of a SiC−based traction inverter produces lower losses and less heat dissipation. This means the inverter runs at a cooler temperature, proving a dual benefit: the traction system can achieve a higher peak power while lowering overall cooling system costs.

VE−Trac Highly Integrated Power Modules

IGBT and SiC are both viable options for traction inverter systems. However, many factors contribute to the efficiency and performance of a traction inverter in the overall traction system. There isn't a simple equation to determine the best approach for a given application.

By working with **onsemi**, engineers can explore the various options open to them. **onsemi** has a complete portfolio of traction inverter solutions, including both IGBT and SiC technologies, so OEMs and Tier 1 companies can select the optimal inverter semiconductor solutions for their applications.

With its VE−Trac family of highly integrated power modules for vehicle electrification, **onsemi** provides a wide range of traction inverter solutions for EV and HEV applications. These modules offer innovative packaging, advanced cooling technology, and high reliability.

onsemi has tooled its entire line of IGBT and SiC traction inverters to standard case module packaging and outlines. With standard packaging, OEMs can migrate existing IGBT−based systems to SiC using an equivalent module form factor. This enables OEMs to gain the full benefits of SiC in existing applications with only minor modifications to the inverter system design.

However, as the industry moves towards increased reliability, **onsemi** provides transfer molded packaging (TMP) for more excellent reliability. As OEMs introduce new designs to the market. TMP encases components in a very rigid molded plastic package that increases the reliability of electrical connections in the harsh operational environment of an EV. **onsemi** offers solutions in half−bridge configurations.

Among its packaging options, **onsemi** offers advanced direct cooling technologies to maximize thermal conductivity, which increases system performance and reliability. The module has a direct cooling path between the coolant and the IGBT / SiC chips without needing additional thermal components, e.g., Thermal Interface Material (TIM) or heatsinks.

For applications requiring more heat dissipation, dual−side cooling allows coolant to flow on both the top and bottom sides of the module to remove heat even faster.

Reliability is an essential factor in EV and HEV. With advancing cooling that improves heat dissipation and rigid packaging that protects electrical connections, OEMs can design EVs that can operate over longer distances without traction system failures. To further increase reliability, **onsemi** uses Press−Fit pin technology to connect signal pins between the power module and the gate driver board. Press−Fit pins are proven technology in other automotive applications − such as TPMS and Motor Control. Press−Fit pins assure robust connections that are strong, reliable, solder−free, repeatable, and optimized for automation and high−volume manufacturing.

Various VE−Trac modules also integrate smart IGBT chips, enabling the module to self−monitor its own operating conditions for protection events such as over temperature and overcurrent. Performing self−monitoring on−the−chip level rather than through an external NTC thermistor allows the module to respond more quickly and minimize the impact of such events if they occur.

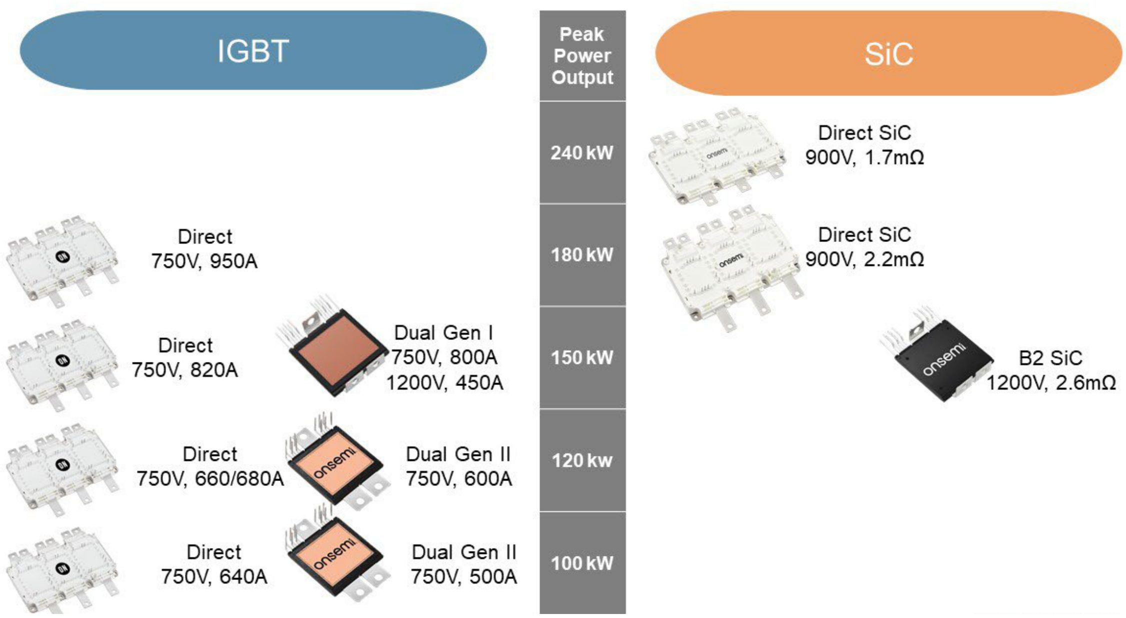

Figure 7. The VE−Trac Family Is a Comprehensive Portfolio of Highly Integrated Power Modules that Crosses a Range of Voltage, Power, and Manufacturing Technologies to Provide an Optimal Solution for Every Hybrid and Electric Vehicle Application.

Figure 7 shows the many options available to OEMs within the VE−Trac family. VE−Trac Direct modules with direct liquid cooling offer ease of integration with Press−Fit standard case module packaging for flexibility and reliability (see Figure 8). With IGBT and SiC options, VE−Trac Direct modules offer power class scalability from 100 kW up.

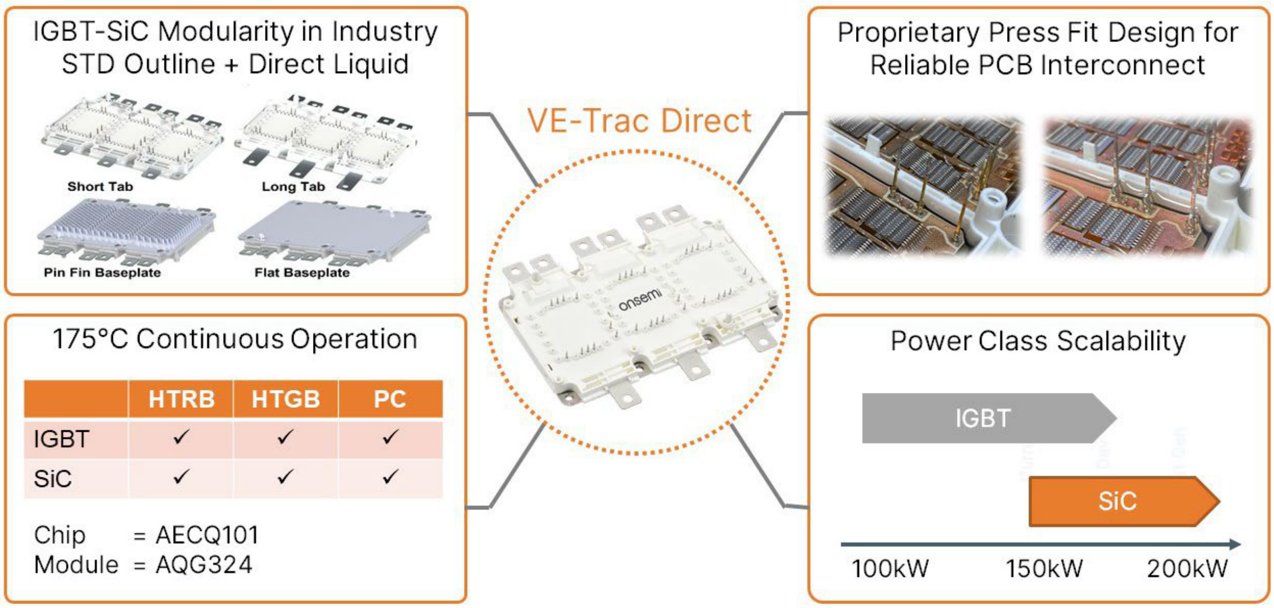

Figure 8. VE−Trac Direct Modules Offer Power Class Scalability from 100 kW up with Ease of Integration.

VE−Trac Dual modules come in a compact TMP form factor that is 30% smaller while delivering comparable output power for space−constrained applications that need to scale up to 300 kW (see Figure 9). Providing more than 3x longer lifetime than standard modules, VE−Trac also offers best−in−class electrical and thermal performance, with the lowest package inductance (<7 nH) and superior $/kW value. Integrated smart IGBT on−chip temperature and current sensors achieve tighter tolerances ($\pm$ 7° vs. $\pm$ 14° for NTC−based sensing) and faster fault detection (200 ns compared to DESAT of 2 μs+).

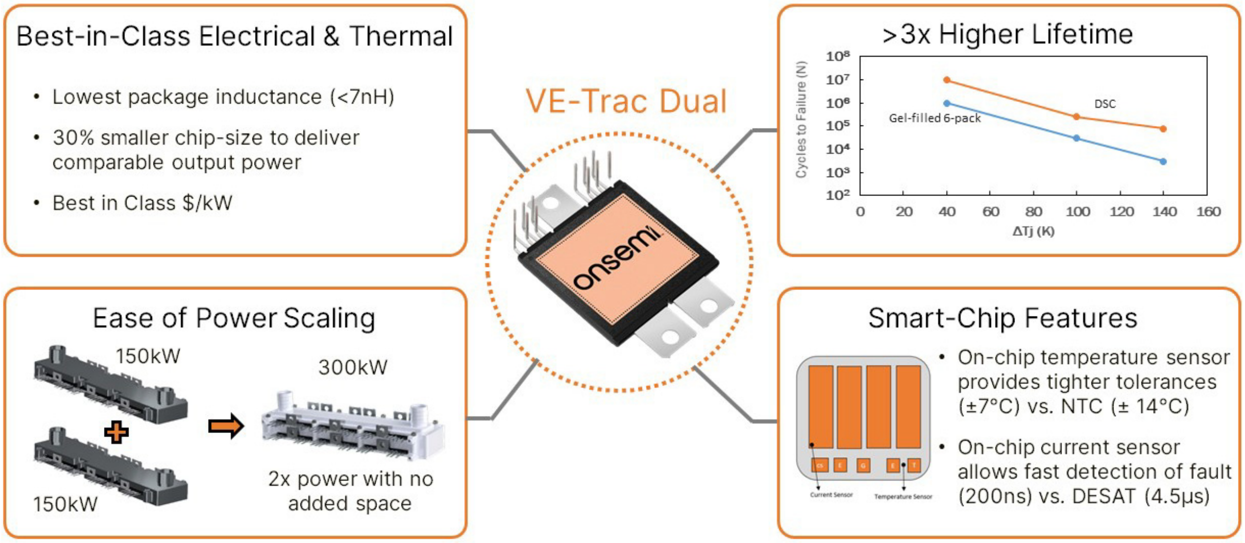

Figure 9. VE−Trac Dual Modules Come in a Compact TMP Form Factor, Offering Best−in−Class Electrical and Thermal Performance with Superior $/kW Value.

VE−Trac B2−Direct SiC modules, offering the latest technology, deliver the efficiency and high peak power of SiC with next−generation packaging, direct cooling, and thermal performance to extend overall lifetime performance (see Figure 10). Other key features include die−attach to DBC by silver sintering, source clip interconnect, footprint compatibility with AHPM DSC, and scalable power output from medium to high power.

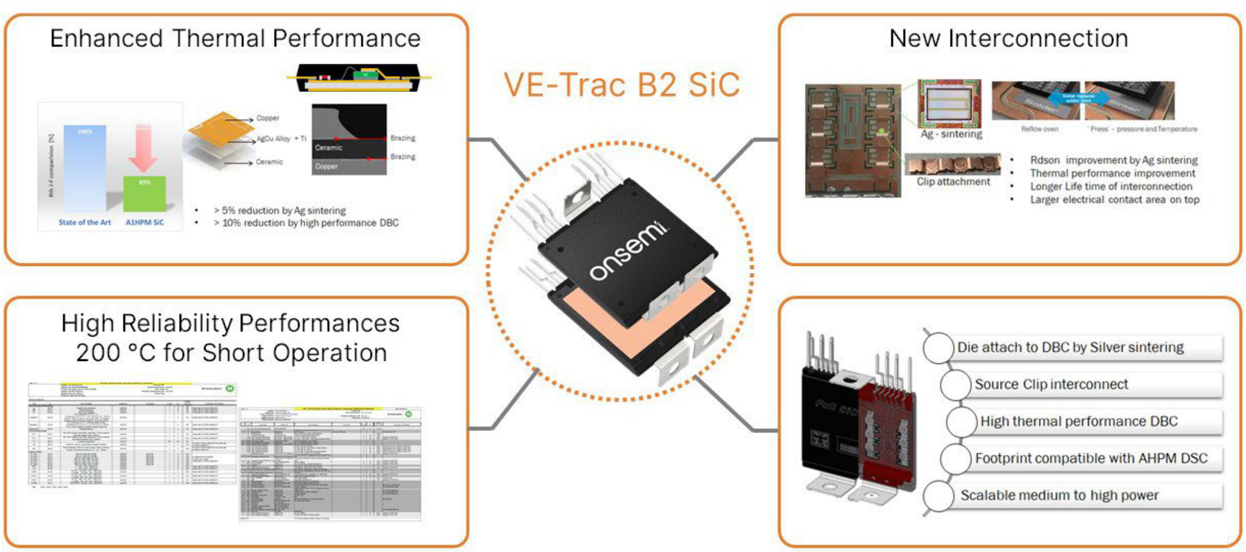

Figure 10. VE−Trac B2−Direct SiC Modules Deliver Efficiency, High Peak Power with Next−Generation Packaging, Direct Cooling, and Thermal Performance.

Scalable Integration

Versatile and scalable packaging options allow **onsemi** to provide an optimal module for every application. VE−Trac Direct power modules offer a scalable solution from 100 to 180 kW with the same mechanical footprint for three−phase motor applications. VE−Trac dual solutions provide maximum flexibility with power modules that can be arranged vertically lateral, adjusting the inverter system to be longer and thinner or shorter and thicker, depending upon the application. Additionally, inverter systems can place two multiple power modules in parallel on the same phase to increase the peak power to deliver up to 2x in a similar compact form factor.

As a power semiconductor market leader, **onsemi** knows the importance of designing efficient, reliable, and sustainable power solutions. Availability of an extensive and flexible portfolio of integrated modules such as the VE−Trac family enables OEMs to select the optimal solution for their application, from low voltage, cost−effective IGBT modules to high voltage SiC modules delivering the highest efficiency and peak power (performance). **onsemi** is also a leading SiC supplier offering full vertical integration at volume.

With its longevity in the automotive industry (40+ years), **onsemi** also provides complete design support with comprehensive application notes and simulation models, as well as access to **onsemi** functional safety experts and global development support teams. In addition to significant investment in technologies like SiC manufacturing, **onsemi** continuously drives improvement across the industry with innovations such as reliable packaging, full vertical power integration, and advanced cooling options. **onsemi** understands where the automotive industry is going and is committed to providing the technology OEMs need to deliver reliable, high−quality power to hybrid and electric vehicles.

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