

WHITE PAPER / WP2609

Superior Power Efficiency in Silicon Carbide Inverter Technology

Measured performance of SiC inverter systems

SCOPE

A technical examination of conversion efficiency, torque capability, and power density, based on measurements obtained at customer testing sites.

SiC and IGBT comparison / Efficiency across the operating range
Thermal management and drivetrain implications

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Introduction

Power electronics continue to evolve as electrification expands across the mobility, industrial, and energy sectors. Traditional Insulated Gate Bipolar Transistor (IGBT) inverters have served reliably in many applications, but new performance demands—higher efficiency, higher power density, and improved thermal characteristics—are pushing the industry toward Silicon Carbide (SiC) semiconductor technology.

This transition reflects a basic principle in improving vehicle performance: **reducing weight in one area will trigger a beneficial cascade throughout the entire vehicle**, enabling smaller and lighter surrounding systems. In an electrified vehicle, a more efficient and compact SiC inverter can similarly reduce cooling circuits, passive components, packaging, and potentially battery requirements, creating a cascade that improves overall mass, efficiency, and power density.

SiC technology also enables the move towards higher-voltage architectures by combining high voltage capability with low switching losses. For a given power transfer, increasing the DC bus voltage reduces the required DC current, allowing reductions in motor dimensioning, smaller cable and busbar cross-sections and overall lower copper usage. Lower current also offers scope to reduce resistive losses and cooling requirements, depending on conductor sizing. Together, these improvements initiate a further cascade of cumulative weight and cost reductions: lighter electrical interconnections and smaller thermal management systems reduce vehicle mass, lowering energy demand and potentially allowing a smaller battery for the same range.

Both sets of measurement data presented in this white paper were obtained at customer testing sites, providing practical evidence of the performance achieved by CISSOID's SiC inverter technology. Together, they illustrate the benefits in power output, torque capability, and conversion efficiency across a broad operating range, demonstrating how these advantages translate into measurable results in customer test environments.

Performance Comparison: CISSOID SiC vs IGBT Inverter

This first case compares a SiC inverter reference design developed by CISSOID with a comparable state-of-the-art IGBT inverter, both operating at 650 V DC, driving the same motor. It highlights the benefits of SiC technology in improving power conversion efficiency and performance in demanding applications such as electric vehicles and heavy-duty electrified drivetrains.

The following table presents a direct comparison between the CISSOID SiC Inverter Reference Design and a typical IGBT-based inverter at the same DC bus voltage:

Parameter	IGBT Inverter <i>(figure 1)</i>	CISSOID SiC Inverter <i>(figure 2)</i>
DC Bus Voltage	650V	650V
Max Speed	14,500 rpm	14,500 rpm
Max Torque	120 Nm	190 Nm
PWM Frequency	12 kHz	12 kHz
Peak Output Power	120 kW @ 11,500 rpm	260 kW @ 13,500 rpm
Peak Efficiency	96.6%	98.9%

Table 1 – SiC vs IGBT Inverter Performance

Typically, the power losses decrease by a factor of three when transitioning from IGBT to silicon carbide: reaching the maximum power losses rating was found to be the limiting factor for the IGBT inverter, despite more than doubling volume and weight with respect to the SiC inverter. As a result, in this case here, the CISSOID SiC inverter more than doubles the maximum output power compared to the IGBT system, **increasing the output power by a factor of 2.16**. While as an additional consequence, increasing maximum torque from **120 Nm to 190 Nm, a 58.3% improvement**. At the same time, peak efficiency rises from **96.6% to 98.9%**, a gain of **2.3 percentage points**, delivering significant benefits in energy consumption, vehicle range, and thermal management reduction.

The major improvements come to light however, when comparing the level of efficiency over the complete operating range (cfr. Fig 1 and Fig 2).

Efficiency Across the Power Range

Analysis of the efficiency curves reveals a compelling advantage for the CISSOID SiC inverter across the full torque and speed spectrum. At the low end, where partial load operation is commonly found, the SiC inverter already starts operating with an impressive **93–94% efficiency**. In contrast, the IGBT inverter begins **below 80% efficiency** and only reaches its peak within a narrow high-load window, generally operating between **80–94% efficiency** across its usable range. This means the SiC inverter maintains consistently high efficiency—even in urban, stop-and-go, or light-load conditions—making it ideally suited for real-world electrified mobility scenarios.

Of note, the IGBT inverter is limited to delivering a maximum torque output of **120 Nm**, while the SiC inverter reached **190 Nm**, a clear indicator of the performance headroom that SiC technology offers.

These advantages are particularly relevant to heavy-duty machines in construction, agriculture, and material handling, where demanding tasks often require **high torque at low speed**. Such operating points place substantial current demands on the inverter, even when mechanical power output remains relatively low, making efficient current delivery essential. By reducing inverter losses under these conditions, SiC technology can help sustain demanding work cycles while limiting heat generation, cooling requirements, and battery energy consumption. This strengthens

the case for electrifying machines such as excavators, loaders, and tractors, where sustained pulling, lifting, and digging capability matters as much as peak power.

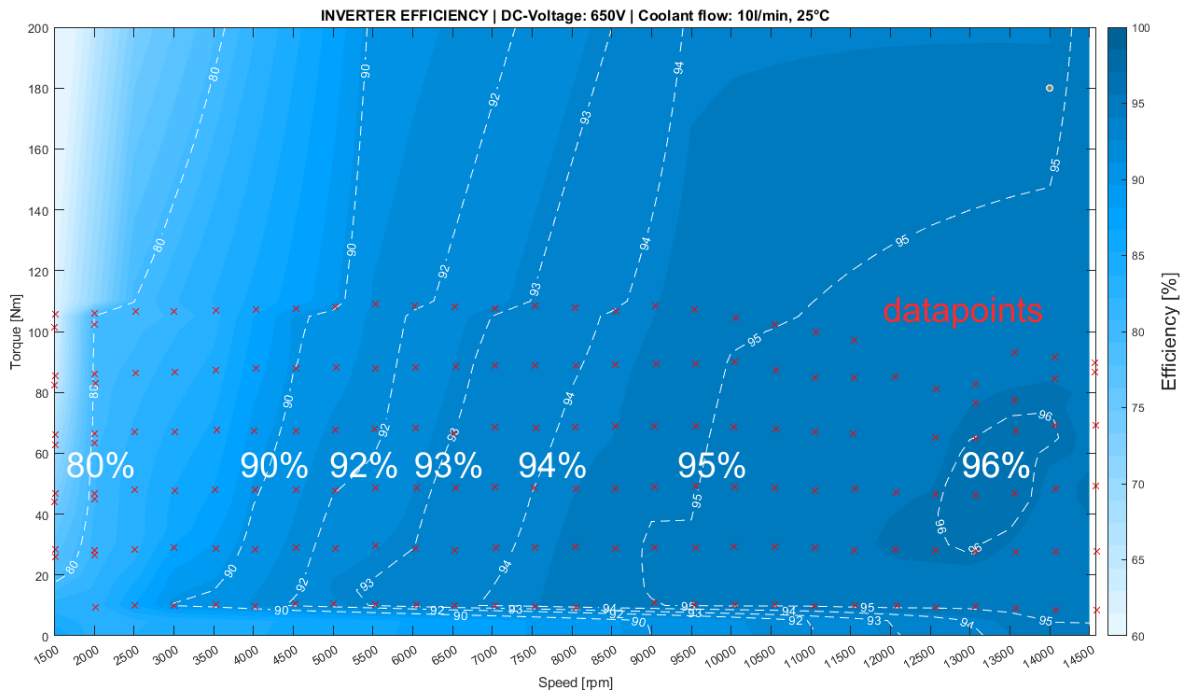


Fig. 1 – Standard IGBT Inverter Efficiency Map

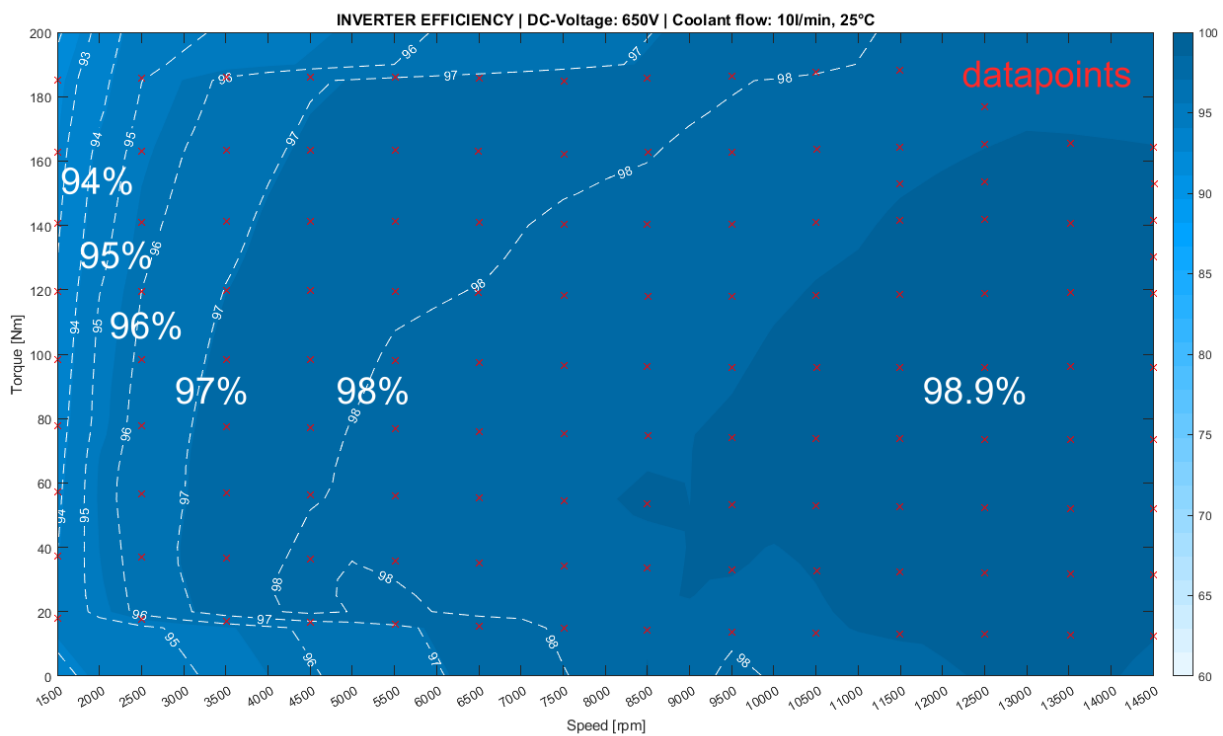


Fig. 2 – CISSOID SiC Inverter Reference Design Efficiency Map

Efficiency Under Real Operating Conditions

In real-world operating scenarios, efficiency matters not just at the peak, but across a wide load range. The CISSOID SiC inverter achieves **>99% power efficiency**, measured in this second case under the following operating conditions:

- **DC bus voltage (V_{DC}):** 700 V
- **Output power (P_{OUT}):** 210 kW
- **Output current (I_{OUT}):** 275 A_{RMS}
- **Torque:** 480 Nm
- **Speed:** 4000 rpm
- **PWM Frequency (F_{PWM}):** 10 kHz

Figure 3 shows the measured efficiency maps obtained from the EVK-PLA1050 SiC Inverter Reference Design, demonstrating that efficiencies above **95–96% are readily achieved even at the low end of the operating range and under partial-load conditions**. Across a broad operating area, the inverter maintains very high efficiency, reaching a **peak efficiency of 99.6%**.

This exceptional performance results from combining the material properties of Silicon Carbide—including high breakdown field strength and superior thermal conductivity—with device characteristics that support fast switching and low conduction losses. Realizing these benefits at inverter level requires coordinated design of the power semiconductor assembly, gate drivers, thermal management, and state-of-the-art motor control software. Low-inductance power layouts and carefully tuned gate drivers help minimize switching losses while controlling voltage overshoot, ringing, and electromagnetic interference. Effective thermal paths limit junction temperatures and support sustained current delivery, all contributing to high efficiency and power density across the complete operating range.

Key Efficiency Drivers of SiC Inverter Technology

1. **Reduced Switching Losses**
SiC MOSFETs switch faster than IGBTs, enabling operation at higher frequencies with significantly less energy loss per cycle.
2. **Lower Conduction Losses**
At comparable current levels and blocking voltage, SiC devices offer lower on-resistance, leading to reduced conduction losses, especially under high-load conditions.
3. **Higher Thermal Limits**
SiC devices can operate at higher junction temperatures, which reduces the need for extensive cooling systems and increases overall inverter robustness.
4. **Compact, High Power Density Design**
With less need for thermal management overhead and lower passive component requirements (e.g., capacitors), SiC inverters enable more compact, lighter-weight systems, ideal for electric mobility.

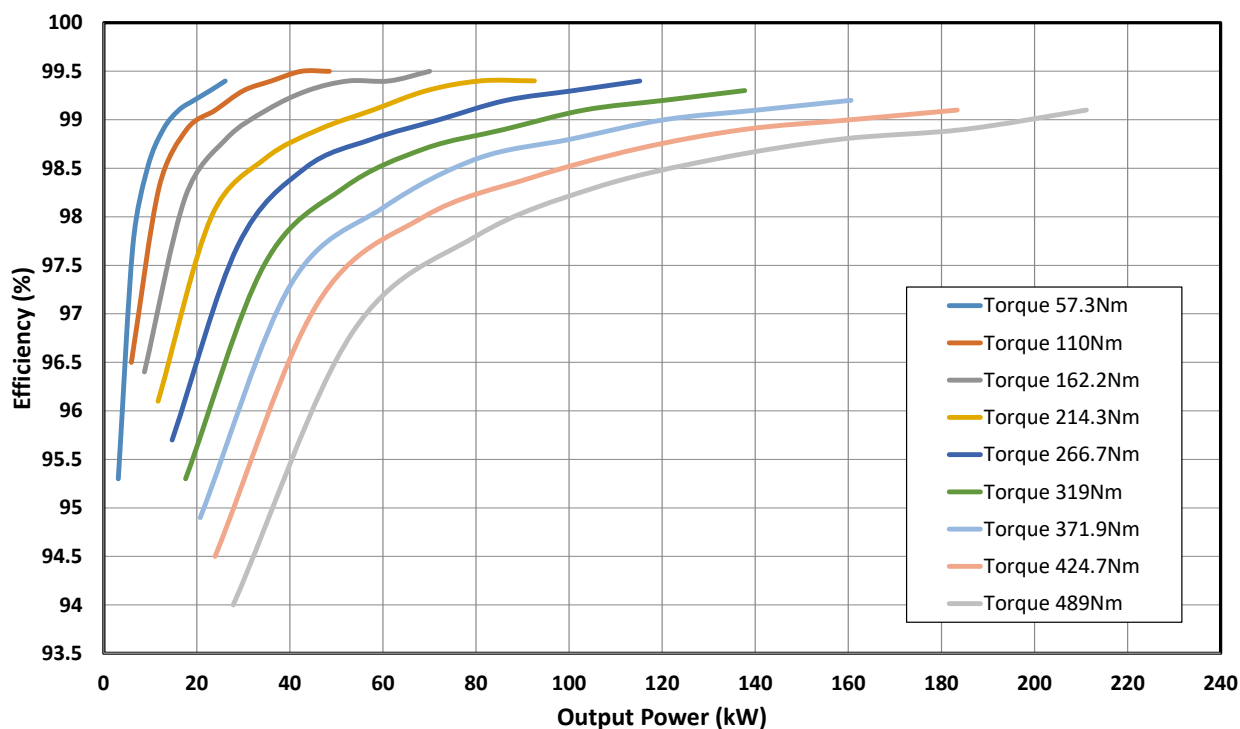


Fig. 3 – EVK-PLA1050 SiC Inverter Reference Design Efficiency

Implications for Electric Drivetrain Applications

The increased power output and efficiency of SiC inverters directly translate to better drivetrain performance:

- **Extended Vehicle Range:** Higher efficiency reduces energy losses, boosting range without increasing battery size.
- **Improved Acceleration and Load Capability:** With higher torque and power, electric vehicles can meet or exceed performance expectations of internal combustion counterparts.
- **Simplified Thermal Management:** Less heat generation leads to smaller, simpler cooling systems, improving reliability while reducing cost, size and weight.

Conclusion

The data clearly shows that SiC inverter technology, as exemplified by CISSOID's inverter solutions, significantly outperforms conventional IGBT-based systems in both peak and operational efficiency, while delivering superior power and torque capabilities.

This makes Silicon Carbide technology a critical enabler for next-generation electric drivetrains and high-performance industrial drives—where every watt, every newton-meter, and every kilogram counts.

For design engineers and system integrators, adopting a SiC-based inverter platform is no longer a futuristic option but a current-day competitive advantage. CISSOID's scalable, modular, and application-ready SiC solutions ensure a faster, more efficient path to market.
