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The Switch from IGBTs: How SiC MOSFETs Represent the Next Level of Performance for Large-Scale Power Conversion Systems

The high-powered catalyst for the clean energy transformation

SiC MOSFET technology is transforming large-scale energy systems by supporting power plant operators in:

- **Delivering exceptional efficiency and reliability**
- **Reducing operational costs**
- **Accelerating the integration of renewable energy into the grid**

With these benefits, SiC MOSFET technology is shaping the future of clean energy.

The shift from silicon-based IGBTs to advanced SiC MOSFETs brings unprecedented efficiency, reliability, and performance to central inverters. These innovations drive a new era of robust, large-scale power conversion systems, meeting the rising demands of renewable energy integration and grid stability.

Today's central inverters rely on silicon-based IGBTs for power switching and conversion, with semiconductor design dictating performance. Replacing IGBTs with next-gen SiC MOSFETs significantly enhances efficiency and robustness in utility-scale systems, playing a key role in a stable, sustainable energy transition.

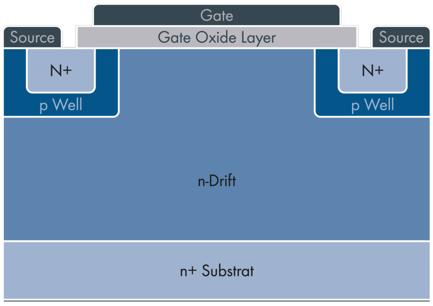
Silicon Carbide: A Game Changer in Evolving Stack Technology

Silicon-based IGBTs have been widely used for power conversion for decades. They are most effective for high-voltage (>1.0 kV) and high-power applications and deliver high efficiency at medium switching speeds (typically under 20 kHz). However, their disadvantages include slow turn-off times, especially at high temperatures, which can lead to greater switching losses. Additionally, their heat tolerance is limited to approximately 50 °C. Due to silicon's electrical resistance and thermal conductivity properties, IGBTs are regularly operated at close to their temperature limits, which can increase the risk of device failures.

First released on the market in 2011, silicon carbide MOSFETs have demonstrated several advantages over silicon-based semiconductor stacks. Silicon carbide has higher thermal conductivity than silicon, so it can tolerate higher temperatures with a lower risk of thermal failure. It also features a wider band gap than silicon, provides high electric field breakdown strength, delivers faster switching times, and can support high-density electrical currents and nearly 10 times as much voltage.

Recent innovations have made the transformative benefits of silicon carbide (SiC) technology accessible for large-scale central power conversion systems (PCS), something that was previously unattainable due to the lack of appropriately sized SiC MOSFETs for such applications.

SMA has been using SiC MOSFETs in string inverters for many years, gaining extensive experience with the new technology and fostering strong and reliable partnerships with suppliers along the way. These proactive collaborations have enabled SMA to monitor advancements in technology closely. Therefore, SMA worked closely with a supplier to define the specifications for a custom ≥ 2 kV SiC MOSFET chip, which was developed specifically to meet SMA and our customer needs.



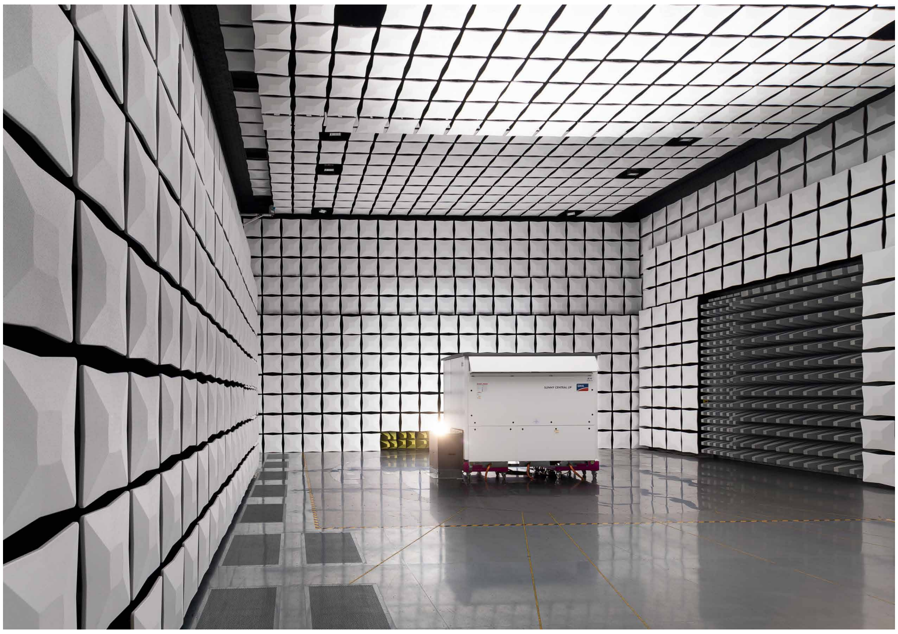
Structure of the SiC MOSFET chip

SiC MOSFETs: Redefining Efficiency and the Future of Large-Scale Power Conversion Systems

Utilizing SiC MOSFETs for large-scale power conversion systems provides a range of significant advantages over traditional IGBTs, such as:

- Enhanced efficiency
- Higher power density
- Improved thermal management
- Better harmonics
- Lower noise emmissions

All of these features make SiC MOSFETs particularly suitable for applications that require high efficiency and performance, such as in renewable energy technologies. As a result, SiC MOSFETs are reshaping the landscape of energy conversion, making large-scale energy systems more reliable, efficient and cost-effective.



Higher voltage ranges
The wide band gap of silicon carbide enables SiC MOSFETs to support higher voltages compared to 1.2 kV and 1.7 kV IGBTs. This is because silicon carbide has a dielectric breakdown strength approximately 10 times greater than that of silicon. Silicon carbide can also withstand temperatures of up to 300 °C.

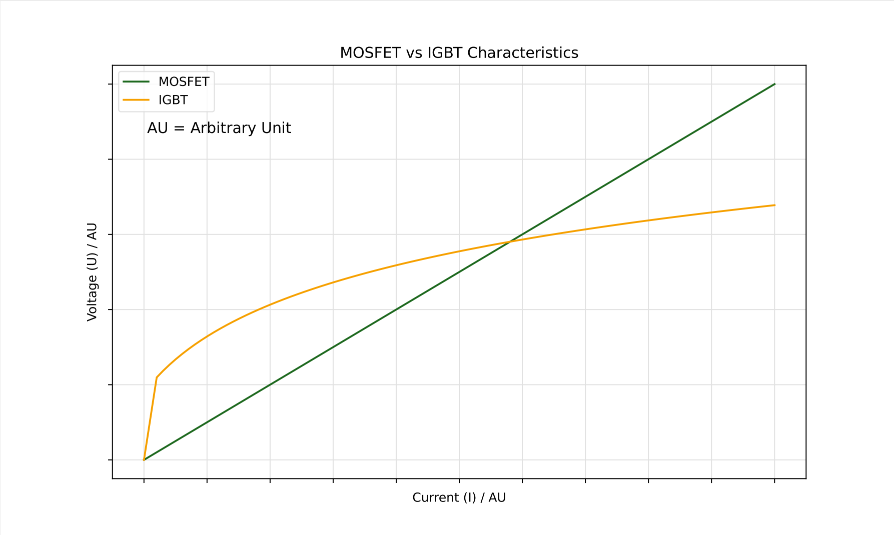
Lower switching losses
Due to their monopolar structure, SiC MOSFETs have inherently lower switching losses than IGBTs, and can support faster switching of up to 200 kHz with less turn-off loss. This is generally the case across all areas of work, ensuring that SiC MOSFETs deliver higher efficiency than IGBTs.

Higher efficiency
MOSFETs are characterized by an linear ohmic relationship between current and voltage, in contrast to the logarithmic ohmic curve of IGBTs. Particularly at low currents, the voltage drop across SiC components is lower than that of Si semiconductors, as shown in the graph below.

As a result, conduction losses ($P = I^2R$) decrease, enabling SiC MOSFETs to achieve greater efficiency than IGBTs, especially in the partial load range.

Higher switching frequency
SiC MOSFETs with their higher switching frequency, effectively reduce harmonics and smooth the sine wave, leading to reduced filter size.

Lower thermal stress
As they can withstand higher temperatures than IGBTs, SiC MOSFETs experience lower thermal stress and improved cycling times. This means that SiC MOSFETs can provide a longer service life for critical energy infrastructure.



Pioneering the Future of Power Conversion: SMA's SiC MOSFET Technology

SiC MOSFET-based central inverters provide power plant operators with a highly efficient, reliable foundation for their systems. By reducing energy losses and enabling higher switching frequencies, they lower operational cost and increase energy output. The result: maximized performance, greater stability and higher profitability.

SMA's Proven and Fully Tested Stack Design

With more than 60 GW of capacity installed to date, SMA has demonstrated the effectiveness of reliable and efficient stack design for inverters. SMA uses a 2-level B6 design rather than the 3-level NPC design used in many other inverters. Each stack design offers different advantages and disadvantages.

The 3-level NPC design features switches at plus, middle point and minus, while the 2-level B6 design has a simpler structure with switches at plus and minus.

Although the 3-level NPC design delivers better harmonics and slightly higher efficiency compared to the 2-level B6 design, it is also more complex and difficult to control, increasing the likelihood of failures. By comparison, the simplified design of the 2-level B6 stack is easier to manage, offering greater robustness and better reliability.

SMA's inverters have demonstrated this stability and reliability in real-world applications.

North American Electric Reliability Corporation (NERC)[1]

SMA's inverters have consistently proven their unmatched stability and reliability in real-world applications. This is supported by disturbance reports from the North American Electric Reliability Corporation (NERC) on fault ride-through events across the country. These reports show that all the inverters that failed share a 3-level NPC stack design - commonly found in many IGBT-based inverters. In stark contrast, SMA's central inverters, with 2-level B6 design, were not mentioned in these reports which shows no such vulnerabilities, reinforcing their industry-leading performance and dependability.

Maximizing Benefits for Plant Owners with a Powerful Combination: SiC MOSFET with B6 Topology

Although the stack topology used in inverters is independent of the semiconductor material used, advances in silicon carbide technology make it possible to improve the efficiency and effectiveness of inverters designed with a 2-level B6 stack. This eliminates almost all of the disadvantages of the 2-level B6 architecture while adding the advantages of a silicon carbide semiconductor material.

It's clear that introducing SiC MOSFETs into central inverters for large-scale applications creates significant benefits for plant operators and now by incorporating a simplified stack design like the 2-level B6 topology, the advantages become even greater.

Incorporating SiC MOSFETs into a new generation of SMA central inverters helps to overcome the 2-level B6 design relative to the 3-level NPC technologies, and even to surpass the 3-level NPC design in terms of efficiency. Using SiC MOSFETs, the 2-level B6 topology also retains its advantages over the 3-level NPC stack MOSFETs in the case of transient network events.

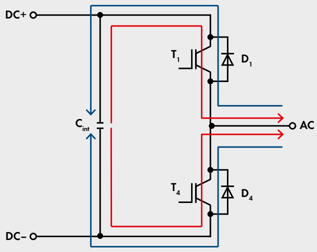
Testing to date shows that SiC MOSFET-based technology from SMA doubles the switching frequency of silicon-based IGBT devices and achieves a maximum efficiency of 99.2%* compared to 98.9% for SMA central inverters with silicon IGBTs.

SMA Stack Design (B6) with SiC Mosfets

Robustness of B6 2 Level Topology vs 3 Level NPC

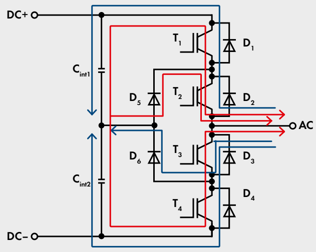
SMA Stack Design: 2 Level – B6

- Proven technology for PV and Battery Energy Storage Systems (BESS) (>60GW installed based)
- **Disadvantages:** More filter capacity.
- **Advantages:** Less complex, robust and reliable
- **Future Proof:** Advanced Grid Support features (Grid Forming with Inertia, Fast Frequency Control)



Competition Stack Design:*3 Level NPC

- Established in AC drive industry
- More semiconductors
- **Disadvantages:** Higher fault liability, unstable FRT events and Grid Forming behaviour, less reliable
- **Advantages:** Less mandatory filter capacity



[1] *Various FRT events show inverters that failed share a 3-level NPC stack design. SMA's Sunny Central units had no complaints in the NERC Report.*

Features of the New Generation of Central Inverters

High-Efficiency Energy Conversion

SiC MOSFETs in central inverters boost efficiency in PV power plants by reducing losses and improving thermal management, maximizing energy yield.

In storage power plants, their impact is even greater. Since round-trip efficiency matters, every loss occurs twice – during charging and discharging. SiC MOSFETs minimize these losses, increasing usable energy and reducing needed battery capacity, and therefore accelerating the return on investment.

Higher Switching Frequency Results in Cost Savings

Beyond the technical switching frequency limits of SiC semiconductors, the optimal frequency depends on the stack topology and involves a trade-off between efficiency, filter capacity and power density. SMA has set the switching frequency for its new generation central platform at 6.3 kHz, considering it the optimal switching frequency for MOSFETs based on the previously explained trade-offs and the implemented 2 Level B6 topology.

Compared to traditional IGBT-based designs, this more than twofold increase in switching frequency enables SMA's next-generation central inverters to deliver smoother harmonics with a smaller choke – resulting in lower CAPEX and enhanced overall performance.

* *Preliminary test results*

A Tested and Proven Design That's Ready for Production

To develop its new stack design for higher voltage and higher power class central inverters, SMA has spent several years working with its trusted chip suppliers and conducting internal tests to assess performance. Those tests performed at different levels of power, efficiency and reliability have demonstrated that these updated devices are now ready for production, and further testing is expected to show that the performance gains are even higher than current estimates. Additionally, EMI and dielectric strength test have shown the same or even better performance than previous generations.

After thoroughly assessing this new inverter technology, SMA has now secured reliable market availability with high-quality semiconductor manufacturers and resilient independent supply chains.

Now, this cutting-edge solution is available from SMA, ready to meet the demands of modern large-scale energy applications.

Powering the Future: Paving the Way for a Renewables Based Grid

Central inverters with advanced grid support functionalities will play a key role in the ongoing transformation to a 100% renewable energy grid. Such devices are needed to provide safety and reliability, especially in transient grid events. With its decades of experience and demonstrated success with the robust and simple 2 level B6 topology and its experience with SiC MOSFETs – SMA believes the future lies in the combination of both.

By combining this holistic approach with our next level advancements in semiconductor technology, SMA's new generation of central inverters delivers a future-proof solution that not only meets today's energy demands but tomorrow's power plant requirements. Together, we can power a cleaner, smarter, and more efficient energy future.

SMA's award-winning Sunny Central FLEX, powered by advanced SiC MOSFET semiconductors, offers a future-proof solution for evolving energy demands.

Discover how SiC MOSFET technology can transform your energy project

Transform your large-scale energy projects with SMA's advanced SiC MOSFET technology. Contact us today to learn how our cutting-edge stack designs and high-power, high-voltage central inverters can drive innovation in utility-scale PV power conversion!

Contact SMA today!

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