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Uninterruptible Power Supply (UPS) Design Challenges and Considerations

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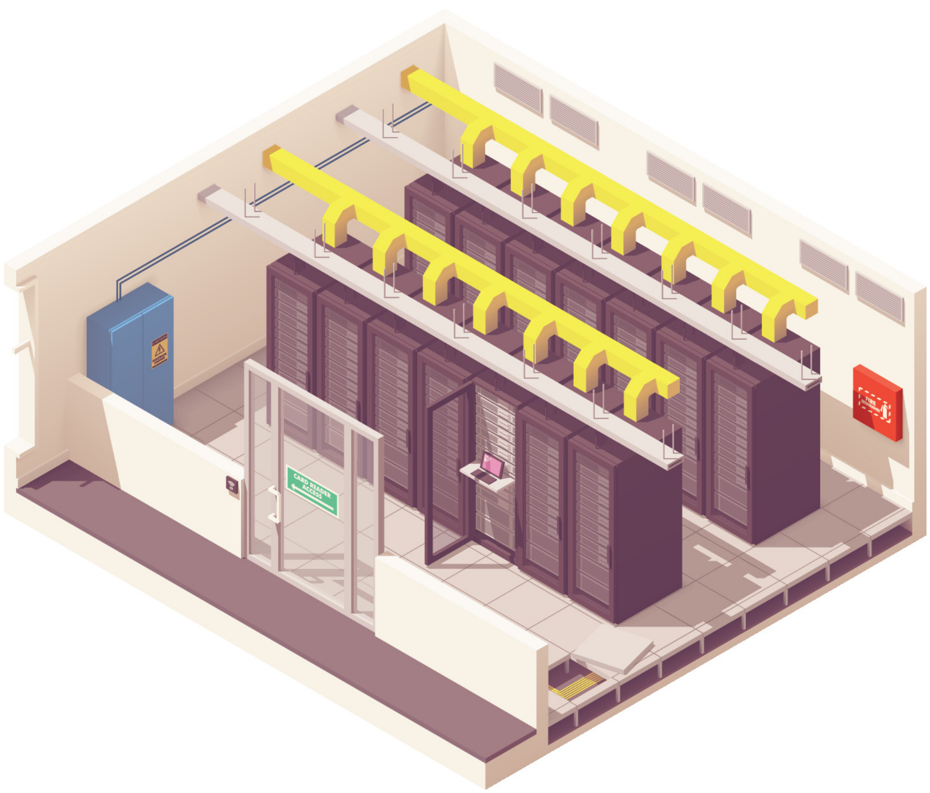
Uninterruptible power supply (UPS) and other energy−storage systems incorporating batteries can ensure continuous power availability for residential, telecommunications, data centers, industrial, medical, and other critical equipment. With state−of−the−art semiconductor technology, these systems ensure a reliable power supply, provide a filtering function, and compensate for short−term grid outages. For longer−term outages, they can give sufficient time for critical equipment to shut down safely.

The following Top Tips can help you design a UPS or other battery energy storage system for the growing number of use cases emerging to take advantage of continuing advances in battery and semiconductor technology.



Understanding the Use Cases

We usually categorize a UPS system by the output power because it's the most efficient way to size it. A UPS system with an output power under 10 kVA is always small and inexpensive − most commonly in small/home offices and personal workstations with low requirements for power supply – best value for PC, printers, and lighting. Cabinets can always be seen in the data center of a medium–sized corporation with several modular UPSs that can provide 10 kVA – 50 kVA output power individually. Modular UPS is becoming typical in data centers because it's designed to be compact and expandable. Integrating multiple modules can provide higher power output, equivalent to a huge UPS, and the failure of one module will not stop the system. You might spend more space to place a UPS system that can support over 50 kVA. Such a system is larger in size and stricter in space limitation because of the bigger passive components, battery packs and cooling fans that can solve the heat issue.

We can see a trend from leading UPS manufacturers to design modular UPS with output capacities over 100 kVA. It's better to get more power without changing your space arrangement, but it will also create more challenges for the modern UPS design.

Three Types of UPS

There are two versions of UPS: **offline** and **online**. With an offline UPS, the load is usually connected directly to the AC source and switches to the UPS only in the event of a power outage or disturbance. It needs about 10 ms to complete the switch, so it's not safe to have an offline UPS to protect the industrial facilities. Line–interactive UPS, another type of offline UPS, can actively regulate voltage by either boosting or decreasing utility voltage as needed before allowing it to pass to the protected load. In such a way, a line–interactive UPS can act as a voltage optimizer and have a longer life because the battery mode is not activated so often.

The load always connects to the UPS's DC/AC inverter with an online UPS, eliminating switching delays. Similarly, a battery energy storage system with a bidirectional charger can provide continuous, seamless power when the AC input is interrupted. An online UPS has the highest price among these three types, but it can solve the most power issues and provide the output with the highest quality; this makes it best suited for high–sensitive devices, data centers, and other critical equipment.

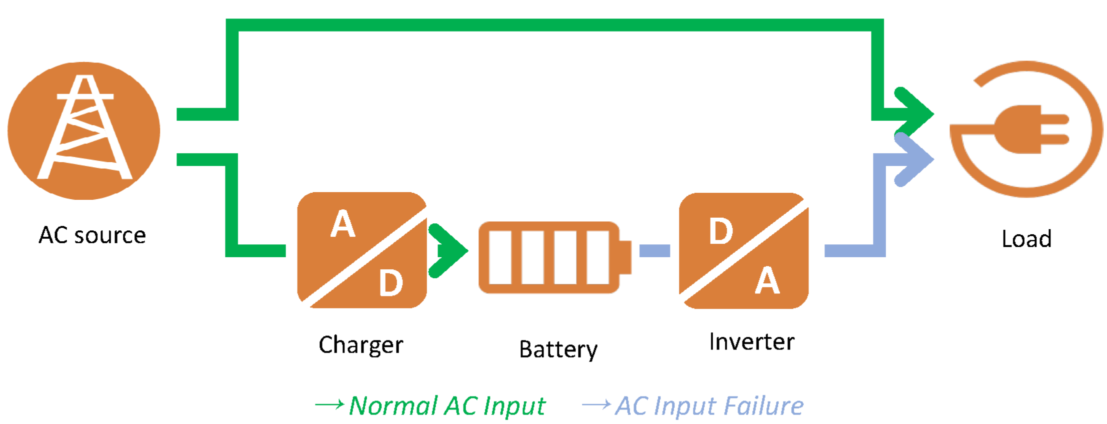


Figure 1. Offline UPS

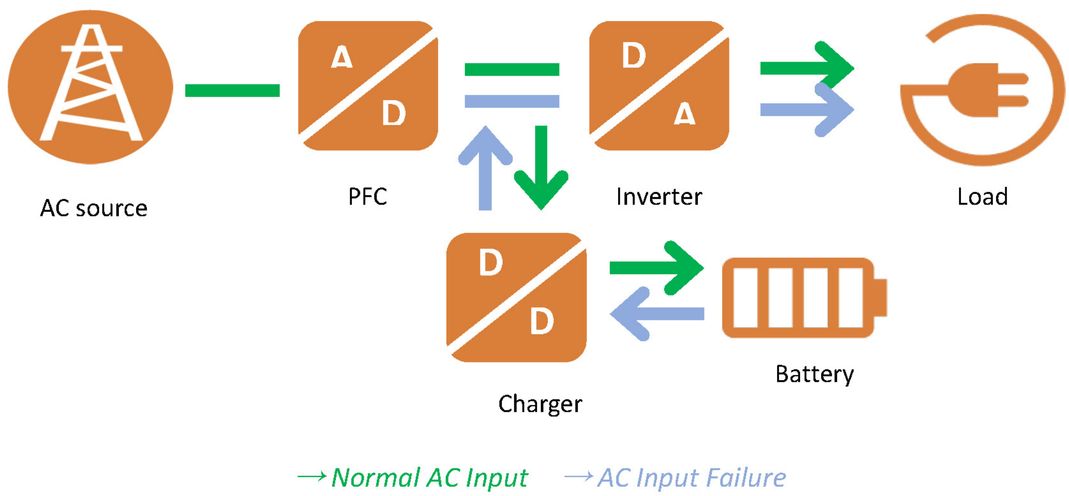


Figure 2. Online UPS

Into the Specifikations

Size

Considering the total cost of UPS ownership, we should never ignore the money and time spent on installation, transportation, and maintenance. Inside a UPS, battery, transformers, cooling fans, and heatsinks take up the most space. But thanks to the semiconductor technology, we can now see transformer−less UPS modules, each producing 200 kVA output power, mounted in parallel in a 200×60×60 cm cabinet to protect your data and equipment. **onsemi** can provide you with state−of−the−art products with a high switching frequency, low losses, and high operating voltage, which effectively reduce the heat generation and size of passive components.

Input Regulation

The double conversion in the online UPS solves 90% of input power issues while line−interactive UPS deals with fewer and offline UPS have to switch to the battery mode when the input is abnormal. Both online and line−interactive UPSs can regulate the input voltage with ±20% tolerance, which reduces the frequency of battery mode startup, but the principles are different. The line−interactive type uses transformer taps, while the online type optimizes the voltage through high−frequency PWM (20 kHz−40 kHz). That's the reason why the online UPS produces the best output.

Output

The inverter defines the output performance of a UPS system. A sine wave output like a utility power source is always the best option to avoid damage to sensitive equipment (output tolerance comparison: Online UPS ±1.5% versus offline UPS ±10%). To produce a pure sine wave, we need the IGBT/MOSFETs, which compose the inverter operating at a high frequency, and an optimized topology to reduce the noise/loss/EMI created from the high−frequency switching. Two− or three−level topology greatly influences efficiency, dependent mainly on switching losses in switches and diodes and high−frequency losses in the inductors and EMI. It will also strongly influence the topology, as not all provide three−level capabilities.

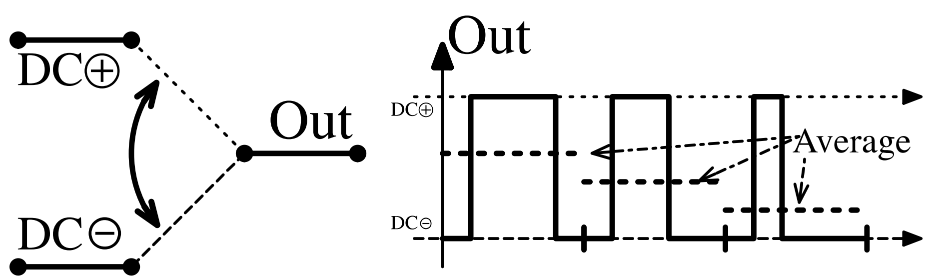


Figure 3. Unipolar or 2−Level Switching Principle

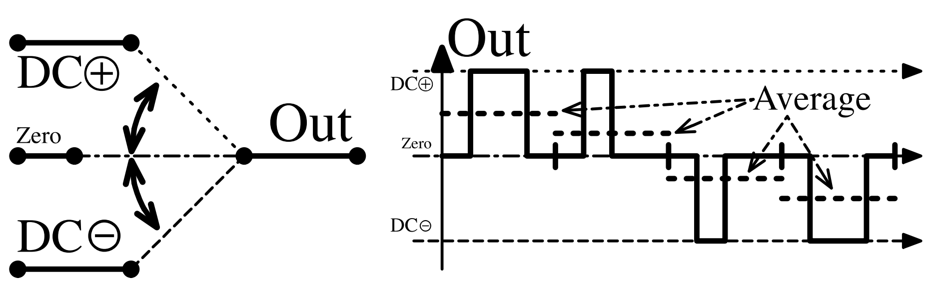


Figure 4. Bipolar or Three−Level Switching Principle

Battery Management

Battery packs for high−voltage systems are stacked to create a string with a battery−management module − several strings of battery packs in a shipping container, including a master battery−management module. Battery−management functions include load balancing, voltage and current protection, string connection and disconnection, charge and discharge control, thermal management, fan control, monitoring, and communications. Devices used in battery management include low−voltage MOSFETS, current sensors, op−amps, isolators, eFuses, protection diodes, high−voltage switches and intelligent power modules (IPMs).

Topology Determines Performance

As mentioned in the last section, topology is essential to performance. There are three advantages to using three−level topologies. First, they offer smaller switching losses. Generally, switching losses are proportional to the voltage applied to switches and diodes to the power of two (switching losses $\alpha\ V^2_{\text{switch or diode}}$).Only half of the total output voltage is applied to (some) switches or (some) diodes in three−level topologies.

Another advantage is a lower current ripple in the boost inductors. The peak−to−peak voltage applied to the inductor is also half of the total output voltage in three−level topologies for the same inductor value. This leads to less current ripple, making it easier to filter with a smaller inductor, allowing for more compact inductor designs and reduced cost. Also, part of the inductor losses is directly proportional to the current ripple. So, a lower ripple will help cut down the losses in the inductor. Finally, EMI is reduced and conducted EMI is mainly linked to the current ripple. Three−level topologies reduce the current ripple, making filtering easier and producing lower conducted EMI. Meanwhile, there is also a benefit concerning radiated emissions.

Radiated EMI is linked to dV/dt and dI/dt. First, three−level topologies reduce peak−to−peak switching voltage, leading to smaller electric fields radiated by switching node pc−board traces. Secondly, three−level topologies reduce peak−to−peak switching currents. This leads to smaller magnetic fields radiated in switching power stage loops.

(For more in−depth details about three−level topologies, refer to Demystifying Three Phase PFC Topologies)

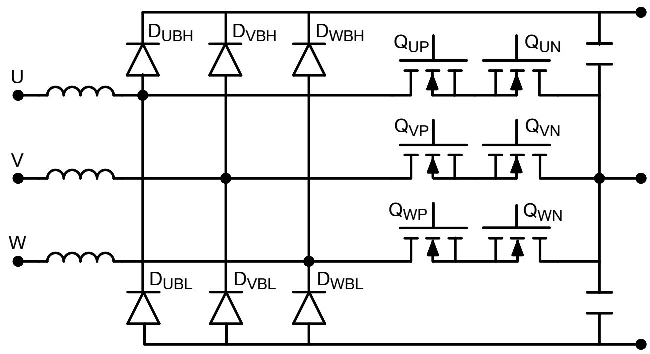


Figure 5. T−NPC Boost PFC Schematic

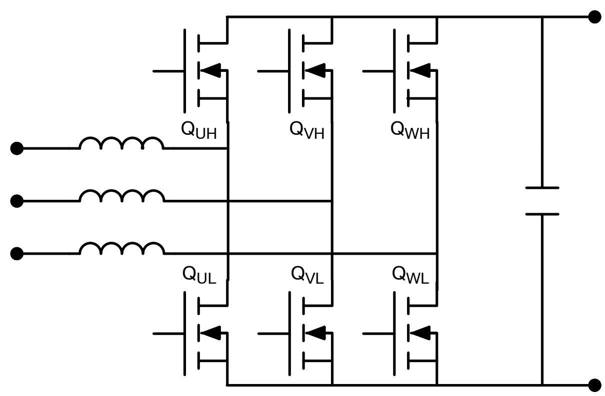


Figure 6. Six Switch Bi−Directional 2−Level Boost PFC

SiC is Driving the Revolution

Silicon carbide (SiC) products, the so−called wide bandgap products, can positively impact the key UPS parameters mentioned above. The high switching frequency can reduce the size of passive components and reduce the product's overall weight, facilitating transportation and reducing the cost of ownership to allow users to have more space to store larger capacity UPSs to embrace the continuous growth of the big data era.

All **onsemi** SiC MOSFETs are avalanche rated and qualified to 100% operating voltage, resulting in industry−leading levels of robustness and reliability. Like many other planar SiC MOSFETs, there is no problem operating with negative gate drive voltages. All families of **onsemi** SiC MOSFETs have no drift in $R_{DS(ON)}$, V_{TH}, or diode−forward voltage over a lifetime due to the specialized planar design. The recommended gate voltage is 18 V for optimum performance and works down to 15 V for compatibility with older generation SiC MOSFETs.

onsemi is one of the world's only "end−to−end" vendor of SiC – from the substrate to module. With the integrated end−to−end supply chain and market−leading efficiency of our SiC products, we provide our customers with the assurance of supply required to support tomorrow's rapidly growing market.

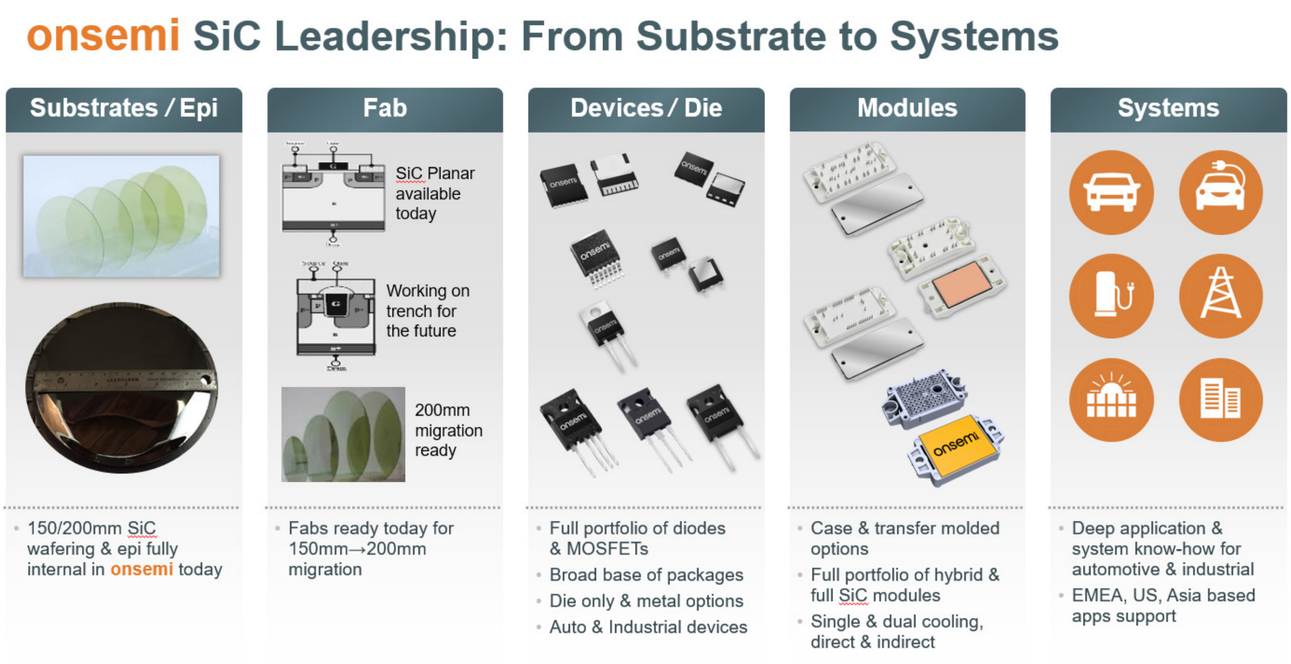


Figure 7. onsemi SiC Leadership: From Subsstrate to Systems

The Driver of SiC MOSFET

A SiC–based UPS system is beneficial for high frequencies, which place greater demands on the SiC gate driver than a silicon gate driver. Several points below need to be highlighted when choosing a SiC MOSFET for a new generation UPS system to increase the robustness of a SiC MOSFET power implementation:

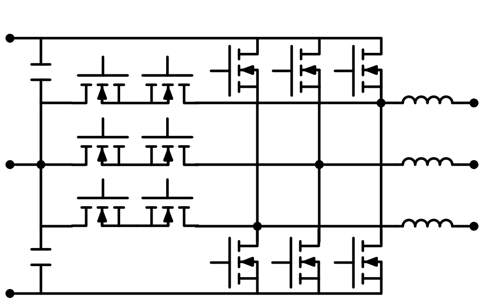
- High current capability: High peak current at turn–on and turn–off can quickly charge/discharge the CGS and CGD capacitances.
- Strong immunity: SiC gate drivers in systems with fast switching of SiC MOSFETs must consider immunity related to fast dV/dt and induced noise. In particular, the maximum and minimum voltages allowed represent immunity to positive and negative surge events.
- Matched propagation delay: Propagation delay is the time delay from 50% of the input to 50% of the output, which is crucial in high–frequency applications; a delay mismatch will cause switching losses and heat generation.

(Please refere to the Guideline on the Usage of an Isolated Gate Driver to Efficiently Drive SiC MOSFETs.)

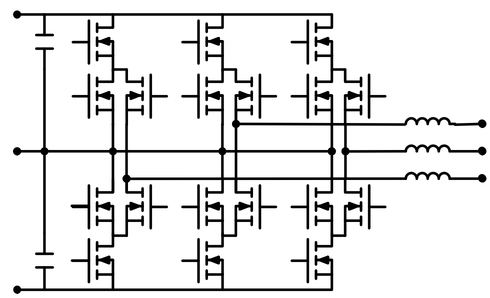
All these points are included in the NCP51561 SiC MOSFET, an isolated dual–channel SiC MOSFET gate driver with a 4.5–A/9–A source and sink peak current. The NCP51561 offers short and matched propagation delays. Two independent and 5 kV RMS (UL1577 rating) galvanically isolated gate driver channels can be used in any possible configurations of two low–side, two high–side switches, or a half–bridge driver with programmable dead time.

Evaluating Design Tradeoffs

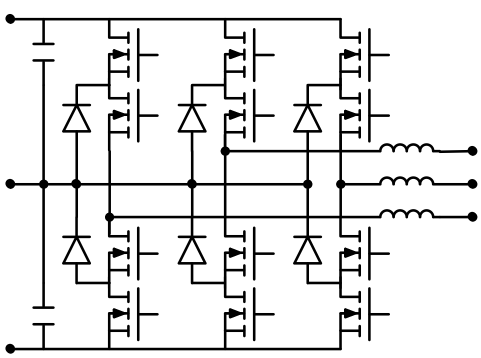
Efficiency is a crucial consideration in energy−storage systems, and keys to efficiency are high−speed switching and efficient topologies, such as the NPC inverter topology. High−switching−speed semiconductors incorporated into comparatively complex yet efficient topologies will cost more than their lower speed counterparts configured in simpler topologies. However, the increased cost of the semiconductors will be more than offset by savings elsewhere. High−speed switching translates to lower module losses and longer battery life. It enables the use of smaller, lower−cost capacitors and inductors, providing for a more compact end product. There is always a compromise between performance and cost/size/control difficulty.



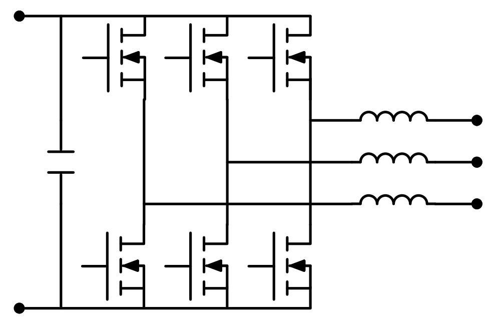
(a) **T−NPC**



(b) **A−NPC**



(c) **I−NPC**



(d) **6−switch**

	T−NPC	**A−NPC**	**I−NPC**	**6−switch**
Switching levels	3	3	3	2
Number of switches	12	18	12	6
Number of diodes	0	0	6	0
Number of drivers	9	18	12	6
Reduced EMI	Medium	Good	Good	Bad
Efficiency	Good/medium	Good	Good/medium	Medium
Semiconductor Requirements	Low	Low	Low	High
Control difficulty	Easy	Hard	medium	Easy

Figure 8. Inverter Topology Comparison

Look for Product Lifecycle Support

When beginning a design, ensure you have access to SPICE models and STEP files for the power products you choose. PSpice models enable the investigation of reverse−recovery behavior and parasitic effects at the circuit, module, and die levels. The models also support thermal simulation and the exploration of self−heating effects.

Also, look for support for third−party simulation tools. In addition, your vendor should support you through the entire product lifecycle, including simulation, product selection, layout, optimization, prototyping, and production of the end customer system. **onsemi** is a full−service vendor of a wide variety of power semiconductor devices and related components, offering the benefits of a complete internal end−to−end supply chain and worldwide customer support.

Conclusion

In this paper, we have discussed a UPS and other battery energy storage system, use cases, topology, and choosing right power semiconductors. The long−term expertise of **onsemi** and our leading role in power management and conversion help customers across the globe develop UPS systems at the cutting edge of technology that maximizes power quality and reliability to the loads while reducing the cost of ownership.

Adopting Silicon carbide (SiC) based power stages plays a critical role in reducing power losses, increasing power density, and reducing cooling costs when it comes to designing robust UPS systems. Selecting highly robust SiC power devices built with infrastructure−class reliability in mind is a key part of designing best−of−breed long lasting, rugged UPS systems. **onsemi**'s end−to−end SiC manufacturing starting from silica and graphite and finishing with complete module solutions ensures high supply quality and dependability.

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