

Silicon-Carbide Based Uninterruptible Power Supplies:

A technological leap in efficiency and reliability

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The Challenge

When it comes to energy requirements for today's data centers, we find that there are ever increasing needs to be able to operate at higher efficiencies, maximize floor space, and reduce operating costs across the facility. These goals need to be achieved while still providing clean, reliable power to data center critical loads. It is our objective to show that through the use of emerging technologies in UPS double conversion systems, these goals are becoming easier to achieve.

As you would expect, the data center challenges described above parallel the challenge in semiconductor manufacturing to maximize efficiency, reduce size, increase power quality and reduce costs. Over the course of the last 25 years, researchers have learned that the use of Wide Bandgap (WBG) materials, such as Silicon Carbide (SiC), allows semiconductor components to be smaller, faster, more reliable and more efficient than the existing Silicon (Si) technology [1].

Wide Bandgap semiconductors are semiconductor materials, like SiC, that permit devices to operate at much higher voltages, frequencies and temperature than conventional semiconductor materials. This allows more powerful electrical mechanisms to be built that are cheaper and more energy efficient. Bandgaps determine how a material's electrons behave.

In solid-state-physics a bandgap, also called an energy gap, is an energy range in a solid where no electron states can exist. The bandgap generally refers to the energy difference (in electron volts) between the top of the valence band and the bottom of the conduction band in insulators and semiconductors. See Table 1.

TABLE 1: Bandgap Energy Levels [2]

MATERIAL	BANDGAP ENERGY (eV)	APPLICATION
Germanium (Ge)	0.67	First generation electronics, Fiber optics, Transistors
Gallium Arsenide (GaAs)	1.4	Microwave circuits, Thin-film solar cells
Silicon (Si)	1.11	Lasers, LEDs, Integrated circuits, Photo-voltaic cells, Power electronics
Silicon Carbide (SiC)	3.25	LEDs, Power electronics, new emerging technology

The term "Wide Bandgap" refers to **higher**-energy electronic band gaps, usually significantly larger than one electronvolt (eV). "Wide" Bandgap typically refers to material with a bandgap of at least two or three eV, significantly greater than that of the commonly used semiconductor silicon (1.1 eV). The result is SiC has a specific forward conduction resistance 400 times lower than Si, thus reducing power losses [2]. WBG semiconductors are considered by the US Department of Energy to be a foundational technology that will transform multiple markets and industries, resulting in billions of dollars of savings for businesses and consumers when use becomes widespread.

WBG semiconductors permit devices to operate at much higher temperatures, voltages, and frequencies making the power electronic modules using these materials significantly more powerful and energy efficient than those made from conventional semiconductor materials [3]. In the 21st century, the integration of WBG technology will set a new course for all industries. The Institute of Electrical Engineers (IEEE) states silicon carbide may be to the 21st century what silicon was to the 20th century [4].

The State of the Union Today

With the use of conventional Si based components, double-conversion Uninterruptable Power Supplies (UPS) have characteristically been trapped in the range of 93% to 96% for operating efficiencies. In an attempt to increase efficiencies, UPS manufacturers have introduced what is called a “high efficiency” mode or ECO-Mode. In order to achieve this “high efficiency” mode of operation, the use of the UPS internal bypass to supply power to the critical load under normal operating conditions is utilized. By running on bypass and eliminating power conversion losses you have raised the efficiency but subjected the critical operation to running on utility power. A study conducted by the Electrical Power Research Institute (EPRI) concluded that a potential drawback existed. Enabling the high efficiency ECO-mode in double-conversion UPS leaves mission critical loads exposed to power abnormalities like voltage sags and line noise [5].

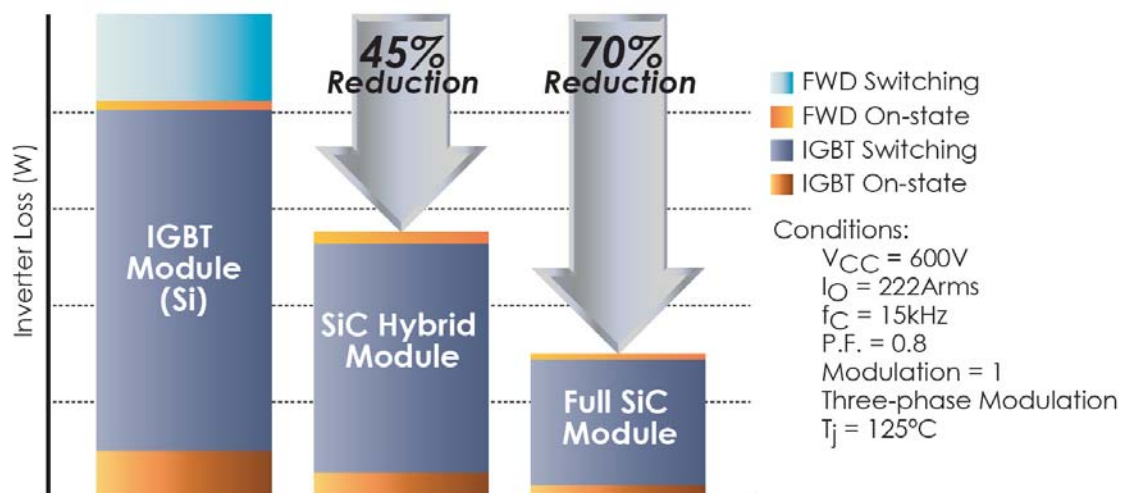
The EPRI study examined the reaction of a UPS operating in high efficiency mode to a 30% voltage sag for 1-cycle. The result was a 16.7ms event created 20.9ms of unconditioned UPS output power where 15.6ms was a complete power outage [5]. Analyzing the impact of this voltage sag using the Institute Of Electrical and Electronic Engineers (IEEE) orange book indicates that an outage longer than 8.35ms exceeds most computer equipment manufacturer’s stored energy capacity causing the equipment to shutdown [6]. Moreover, the IEEE orange book indicates a utility voltage swell of 115% for 16.7ms (1 cycle) will cause an equipment voltage breakdown potentially leading to premature equipment failure [6].

The EPRI findings demonstrate that while operating a UPS in high efficiency mode provides a 5% efficiency savings it comes at the expense of reliability [6].

Out with Silicon – In with Silicon Carbide

Let us introduce the *Game Changer*. The use of SiC components in double conversion UPS technology allows the user to operate in the double-conversion mode and maintain higher efficiencies. A hybrid configuration of power-switching SiC-IGBTs produces a 45% reduction of power losses. A 100% SiC set of power-switching modules produces a 70% reduction of power losses. (See Figure 1.)

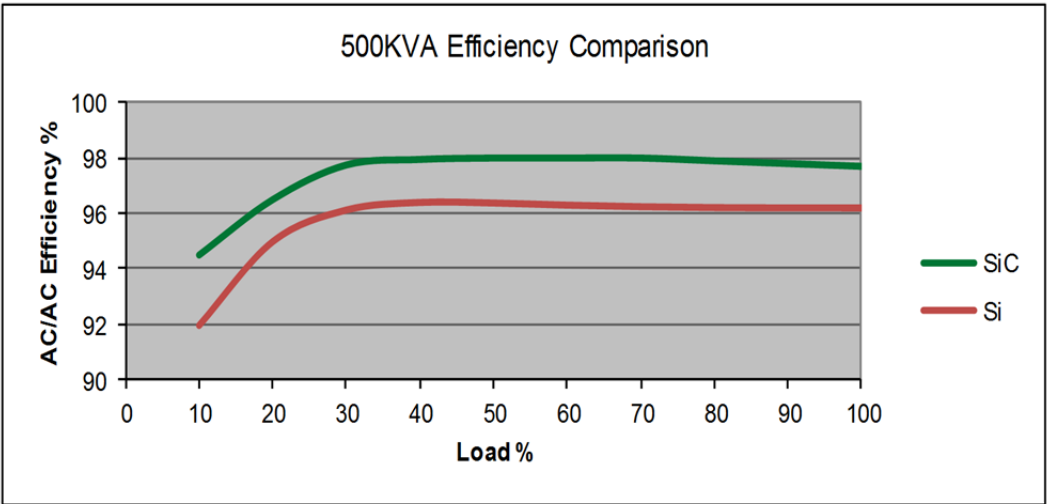
FIGURE 1.



The 70% reduction in power losses of SiC based UPS directly leads to an increase in the double-conversion efficiency to 98.2%. This high efficiency not only occurs at high load situations but also continues on into lower load situations. (See figure 2.)

It is a fact of life that most energized UPS modules are less than 50% loaded. With a UPS operating in ECO-Mode, EPRI reported efficiencies of up to 98%. Looking at the curves in figure 2, we see that the efficiency benefits of SiC technology can be realized during lightly loaded situations. The SiC based UPS is able to achieve the same high efficiencies while operating in double-conversion mode! The UPS can now provide the same energy savings while also providing the critical load with conditioned, *reliable*, high-quality power.

FIGURE 2: 500kVA UPS Efficiency Comparison (SiC vs. Si)



Another significant advantage of SiC based UPS is the reduction in heat loss. At 100% load a conventional Si based UPS has a heat rejection of 69.2 kBTU/HR, whereas a SiC based UPS has a heat rejection of 42.0 kBTU/HR. This results in a heat loss energy savings of 39.4% over the Si based UPS.

TABLE 2: SiC UPS Heat Loss Energy Savings (500KVA)

UPS LOAD (%)	SiC UPS ENERGY SAVINGS (%)
100	39.4%
75	49.9%
50	46.9%

The intrinsic characteristics of SiC based semiconductors also allow them to operate at higher temperatures than conventional Si semiconductors. This reduction in UPS heat loss and the ability to operate at higher temperatures help the customer to decrease their cooling costs which accounts for approximately 35% of a data centers electrical energy consumption.

Size and Weight

When it comes to maximizing the available floor space in a data center, SiC based UPS offer a reduction in weight and size when compared to the conventional Si based UPS. The weight of a 500kVA SiC based UPS is 2770lbs, whereas the weight of a conventional UPS is 3330lbs reducing the floor load by 17%. Moreover, a 500kVA SiC based UPS occupies 14ft² compared to the conventional UPS that occupies 20ft². This is a 30% reduction in the required floor space required increasing the available power capacity in a given area. The SiC based 500kVA UPS has a power capacity of 36kVA/ft² compared 25kVA/ft² for the conventional UPS. Comparing the power capacity on a 1MVA system, a SiC based UPS system will require a floor space of 28ft², and the conventional UPS will require a floor space of 40ft². Consequently, the SiC based UPS can deliver more power within a limited floor space.

Summary

In summary, SiC technology is an innovation that will establish a new trajectory for small devices and power electronics. Benefits include: increased system efficiency, lower cooling system requirements, operation at higher temperatures, and higher power density. With the integration of SiC based technology into UPS, the goals of data center operators to operate at higher efficiencies, maximize floor space, and reduce operating costs across the facility are being achieved.

REFERENCES

1. Ren, F., Zolper, J.C. Wide Energy Band Electronic Devices. World Scientific Publishing, 2003
2. Li, Haixing; Su, Timothy; Zhang, Vivian *Electric Field Breakdown in Single Molecule Junctions*. Journal of the American Chemical Society, 2015, pp 5028-5033.
3. *Wide Bandgap Semiconductors: Pursuing the Promise*. US Department of Energy, Advanced Manufacturing Office.
4. *IEEE Spectrum*, Vol 52, no.5 (INT) May 2015, Front Cover.
5. Ton, My & Fortenbury, Brian. *High Performance Buildings: Data Centers Uninterruptible Power Supplies (UPS)*. Electric Power Research Institute, December, 2005
6. IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications. IEEE Std 446-1995