



# Leveraging Silicon Carbide Power Semiconductor Devices for Renewable Energy Applications

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## Abstract

The distinct characteristics of silicon carbide (SiC) power semiconductor devices allow for significant advancements over conventional power conversion methods. SiC power semiconductor devices provide reduced switching and conduction losses, increasing the efficiency of the converter. By using this material, it is anticipated to lower the weight and cost of the conversion system due to its fast-switching speed. These developments will allow solar energy to become more affordable than conventional sources of power. This wide-band-gap transistor developments are expected to drive the rapid development of renewable energy generation systems. Hence, this article discusses the benefits of SiC power semiconductor devices, their application, challenges, and future prospects in diverse fields, including renewable energy.

**Keywords:** Silicon Carbide; Renewable Energy Systems; Sic Technology; Voltage Spikes; Electric Vehicles

## Introduction

Silicon carbide (SiC) power semiconductor devices are getting much attention in the field of power electronics, with the potential to completely change electricity production and distribution [1]. The excellent electrical properties of SiC power semiconductors and their ability to meet important energy concerns have made them more well-known in recent years. Higher efficiency and less expensive systems have been the targets of designers of renewable energy systems [1,2]. Increased use of renewable energy sources will result directly from these advantages.

SiC power semiconductor devices provide higher voltage, lower on-state resistance, and faster switching speeds than silicon devices [3]. As a result, switching and conduction

losses are decreased, increasing converter efficiency [2,4]. For instance, SiC technology enables the design of photovoltaic inverters to be more compact, lightweight, and reasonably priced [5]. These advancements will enable the cost of solar energy to approach that of conventional energy sources. Other uses for the highly efficient and reasonably priced SiC-based system include hybrid cars and wind power [6,7].

Over the last decade, there has been significant interest in SiC research. The wide band-gap transistor advancements are anticipated to rule the rapidly expanding renewable energy production systems [8,9]. Hence, taking into account the importance of SiC in the renewable energy field, this article reviews the advantages of SiC, its applications, challenges, and future prospects in various fields.

## SiC as Wide Bandgap Material

Silicon carbide is a compound semiconductor that has a crystalline lattice structure made up of silicon and carbon atoms [10]. Due to its special configuration, SiC has a number of advantages over conventional silicon-based semiconductors [11]. SiC's wide bandgap characteristic serves as one of the major roles for these advantages. The bandgap is the energy difference between an electron's initial position in the valence band (nonconductive state) and the level it must reach for electricity to conduct [12]. SiC's wide bandgap enables it to withstand high voltage, making it more resistant to voltage spikes. Additionally, its smaller devices result in faster performance [13]

## Advantages of SiC

Despite its wideband gap features, SiC offers many other advantages, which make it favourable for high-voltage-based applications. SiC semiconductors are the preferred material for the next generation of power devices due to their excellent features. SiC devices are significantly more resilient

to high temperatures than their silicon counterparts [14]. This feature is critical for applications where temperature variations are frequent, such as renewable energy systems, electric vehicles (EVs), and aerospace [6,7].

In high-power applications, SiC devices' ability to withstand higher voltage levels means fewer switching and conduction losses [2-4]. More energy efficiency results from this. In addition, SiC has exceptional switching properties that enable faster switching times and lower energy losses when operating. As a result, there is less heat generated and increased efficiency. The higher frequencies at which SiC power semiconductors operate allow for the construction of power electronic systems that are both smaller and lighter. This is especially useful for small and portable applications.

## SiC Power Semiconductor Applications

SiC power semiconductors are used in many different industries and are revolutionizing the management and use of energy.

Application	Descriptions
Electric vehicles (EV)	SiC technology plays a crucial role in enhancing the efficiency of electric vehicles (EVs). Power inverters and onboard chargers based on SiC technology lead to increased driving ranges, decreased charging times, and reduced heat production [15].
Industrial Motor Drives	SiC power semiconductors enable accurate motor control in industrial applications, resulting in reduced energy consumption and enhanced automated processes [16,17].
Renewable Energy	SiC devices play a vital role in solar and wind power converters by facilitating the effective conversion of direct current (DC) electricity to alternating current (AC) power. This enhances the overall energy output from renewable sources [18].
Aerospace	The aircraft sector is increasingly adopting SiC technology because of its lightweight nature, strong endurance for high temperatures, and efficiency. It has a crucial function in providing energy to electric propulsion systems [16,19].
Power Grids	SiC power electronics are employed to enhance the efficiency and dependability of power transmission and distribution systems. They aid in minimizing energy losses during the transmission of power [20].
High-Frequency Converters	SiC power semiconductors play a crucial role in the advancement of high-frequency converters utilized in telecommunications and data centers, where achieving optimal energy efficiency is of greatest significance [16,21].

**Table 1:** Applications of SiC Power Semiconductor Devices.

## Advantages of SiC Properties in Renewable Energy Applications

SiC is utilized to develop power devices that exhibit conduction and switching characteristics comparable to those of ideal switches. The advancement of SiC power devices has an effect on numerous facets of converter design and performance, particularly for renewable energy sources.

SiC-based power devices offer lower resistance, which reduces conduction loss and raises converter efficiency [2,4]. The ability of SiC switches to switch at higher frequencies while minimizing switching energy loss results in improved converter efficiency. Additionally, it permits the use of greater switching frequencies. As a result, the inductor and capacitors, which are passive components, decrease in size and weight, hence enhancing the power density of the converter unit [22].

Furthermore, SiC-based power devices offer high blocking voltage capability, which offers advantages for high-power renewables like wind energy [7]. Megawatt wind turbines can be paired with generators that have a high output voltage, specifically below 20 kV. These devices' high blocking voltage makes converter design simpler and more dependable. For instance, an individual high-voltage equipment has the capability to substitute a multi-level converter or the need for a three-phase inverter.

SiC devices have the ability to operate at junction temperatures of up to 700 °C until their pn junction fails. Nevertheless, such a high operating temperature is not possible with current packing technologies. It's crucial to consider that the high temperature capacity reduces the need for system heat control, which is another benefit. For instance, this may enable the utilization of an already-existing high-temperature coolant cycle or result in the need for a smaller heat sink, such as when combining the engine and converter cooling cycles in a hybrid car system [6].

Solar panel electricity produced as direct current is transformed into alternating current that is compatible with the grid by inverters. A portion of the energy is wasted as heat throughout the conversion process. Modern silicon inverters have an efficiency of 98%, whereas SiC inverters have an efficiency of roughly 99% over a broad power range and can provide ideal quality frequencies. Even though the 1% efficiency gain might not seem like much, it actually amounts to a 50% decrease in energy loss. An improvement of 1% in efficiency would result in 600 megawatts of extra solar output annually and cost reduction during the lifespan of the device with 60 gigawatts of solar deployed in the United States [23].

### The Effect of SiC Power Semiconductors on the Energy Performance

The use of SiC power semiconductors has a significant impact on energy efficiency in numerous industries. During power conversion, SiC's improved electrical characteristics lead to fewer energy losses. As a result, there is a decrease in the impact on the environment and electricity costs due to better energy efficiency. Furthermore, SiC devices have a higher operating temperature without experiencing degradation, which means that electronic systems have a longer lifespan [24]. This saves energy and resources by lowering the need for regular replacements. Finally, SiC power semiconductors are a crucial technology in the fight against climate change because they increase energy efficiency, which lowers greenhouse gas emissions [25].

### Challenges and Future Prospects of SiC Power Devices

SiC power semiconductors provide many benefits; however, there are still obstacles to be solved. Many of the technological issues that SiC devices face today stem from defects in the material in SiC [26]. These include the cost of manufacturing, the need for additional standardization, and scalability. Nevertheless, ongoing research and development initiatives are addressing these issues, and SiC technology is steadily becoming more accessible. SiC power semiconductors are anticipated to become more and more significant in our shift towards a sustainable and energy-efficient future in the years to come. SiC technology will become a mainstay of contemporary power electronics as demand rises and production costs fall, making a substantial contribution to the worldwide effort to create a more sustainable and energy efficient environment.

### Conclusion

Silicon carbide power semiconductors are anticipated to lead the charge in a technological revolution that might fundamentally alter electrical energy utilization. SiC devices' remarkable qualities and adaptability are propelling advancements in energy efficiency in a range of sectors. Furthermore, the device's capacity to function at elevated temperatures allows for designs with smaller heat sinks, resulting in a greater gain in power density. These characteristics are anticipated to decrease the expenses associated with renewable energy systems, ultimately resulting in greater demand of renewable energy sources. SiC power semiconductors will remain essential in lowering energy consumption, minimizing environmental effects, and reshaping the power electronics sector as the world progresses toward a more sustainable future.

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