2.3 kV SiC MOSFET with New High-Power Package HPnC for 1500 VDC Applications

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Abstract

An optimum combination of the newly developed 2.3 kV rated SiC MOSFET and the high power package: High Power next Core (HPnC) is introduced in this paper. The 2.3 kV SiC MOSFET module is designed for 1500 VDC applications and its excellent characteristics enables 2-level topology instead of 3-level NPC topology for the systems. In addition, the newly developed HPnC package, featured low-inductive inside structure, is suitable for fast switching devices represented by SiC MOSFET, and maximizes its performance. The simulation result of power losses in a 1500 VDC inverter with the 2.3 kV SiC MOSFET HPnC modules was 38% smaller than that of a conventional 3-level NPC with 1.2 kV Si IGBT modules, and the total footprint of the power modules was reduced by 68%. This result indicates that the developed module can realize a cost-effective power converter for 1500 VDC applications.

1 Introduction

In recent years, the global shift towards higher voltage levels, particularly in the realm of renewable energy and industrial applications, necessitates the continuous evolution of power electronic components and systems. New DC-voltage class of 1500 V has become the standard for several applications such as wind and photovoltaic energy converters, energy storage systems, UPSs and hydrogen electrolyzers, to enhance output power and improve transmission efficiency. For 1500 VDC applications, 3-level I-type NPC or ANPC topologies with series-connected 1.2 kV rated devices are a common solution. However, the 3-level I-type NPC requires at least three of half-bridge modules to implement the circuit, resulting in a large footprint, large commutation inductance and high on-state voltage due to the series connection of modules. We have developed a new voltage class 2.3kV SiC MOSFET module with a High Power next Core (HPnC) package, which is a new high power package to breakthrough these limitation. This module realizes a 2-level configuration in 1500 VDC applications, and it will contribute higher efficiency and simplification of the systems. This paper describes the characteristics of the 2.3 kV SiC MOSFET device and the features of the HPnC package, and demonstrates the advantages of the 2.3 kV SiC MOSFET HPnC for 1500 VDC applications.

2 2.3 kV All-SiC Module with HPnC Package

2.1 Newly developed 2.3kV/1200A All-SiC Module for 1500V DC applications

Figure 1 shows an outline appearance the newly developed All-SiC module.

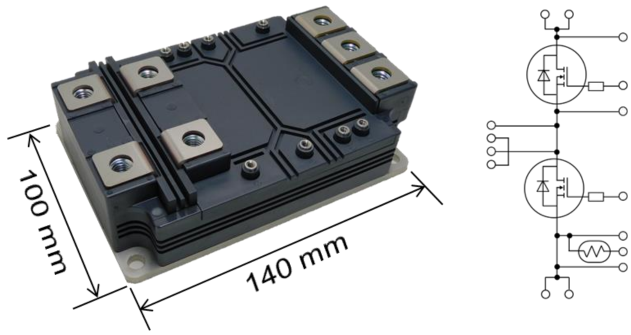


Fig. 1 Developed 2-in-1 2.3 kV / 1200 A All-SiC module

The voltage and current ratings are 2.3kV and 1200 A. The circuit configuration is a 2-in-1 module for a half-bridge circuit. The HPnC package, a new standard package for high power modules, is adapted to the 2.3 kV All-SiC module. The HPnC is suitable for easy paralleling and further output power expansion of inverters thanks to the compact and symmetrical outline.

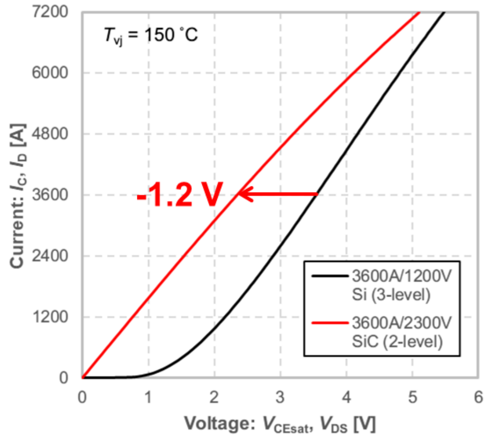
2.2 2.3 kV rated SiC MOSFET device

The 2.3kV All-SiC module is adopted a new voltage class 2.3 kV SiC MOSFET device with a trench gate structure [1-5]. The SiC MOSFET has trench gate structures, and several technologies are applied to realize low $R_{DS(on)}$, such as thinning the drift layer, finer cell pitch, improving channel mobility. By an innovative design optimization and quality improvement, the body diode of the MOSFET can be used as a free-wheeling diode without an anti-parallel SiC SBD. Higher output current and power density are achieved by expanding die area of SiC MOSFET chips instead of SiC-SBD chips.

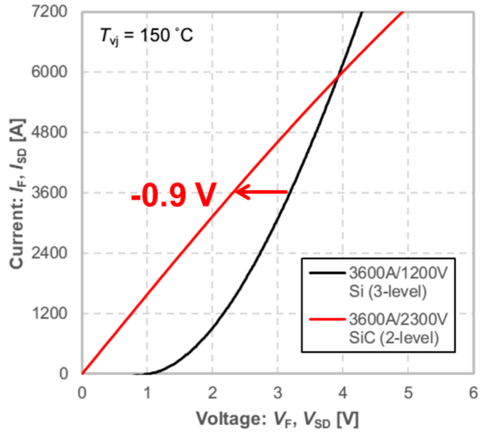
Figure 2 shows output characteristics comparison between the 2.3 kV rated SiC MOSFET (2-level) and the latest generation 1.2 kV Si IGBTs (3-level I-type NPC). Due to series connection of devices in the 3-level I-type NPC topology, the on-state voltage of Si IGBTs become very high. In contrast, the SiC MOSFET reduced on-state voltage by 0.9 - 1.2 V.

Figure 3 shows turn-on and turn-off switching waveforms of the 2.3kV rated SiC MOSFET HPnC at the condition of DC 1500 V and rated module current 1200 A. Fast and stable switching are achieved, and the turn-off spike voltage is around 2.0 kV even at the full DC link voltage without any snubber capacitors.

Figure 4 shows a switching waveform comparison of the 2.3kV SiC-MOSFET at T_{vj} = 25°C and 150°C. The vertical axis is the ratio of their rated current shown on the right side and the V_{DS} voltage is shown on the left side. The results indicate that the turn-on switching speed become faster at higher T_{vj} and E_{on} is reduced by 20%. During turn-off, no tail current is observed, and the spike voltage is very small even at high temperature. The spike voltage reduced by 10% at T_{vj} = 150°C compared to T_{vj} = 25°C [5].

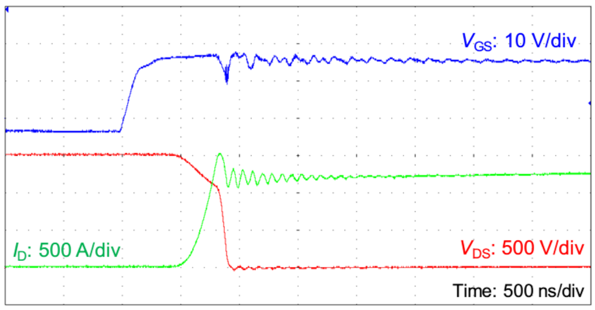


(a) Si IGBT and SiC MOSFET

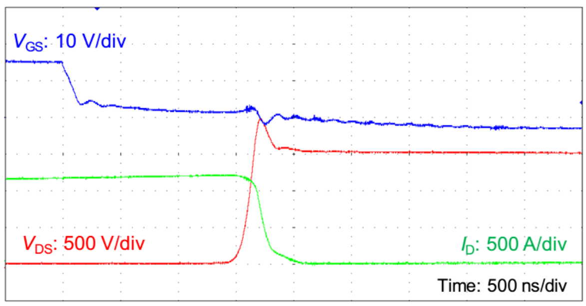


(b) Si FWD and SiC MOSFET (body diode)

Fig. 2 Static characteristics



(a) Turn-on waveform



(b) Turn-off waveform

Fig. 3 Dynamic characteristics

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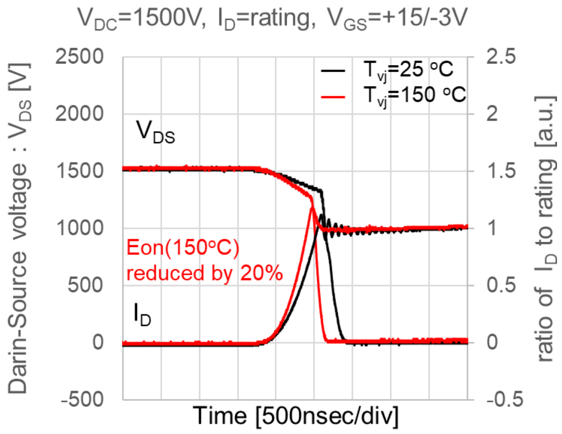
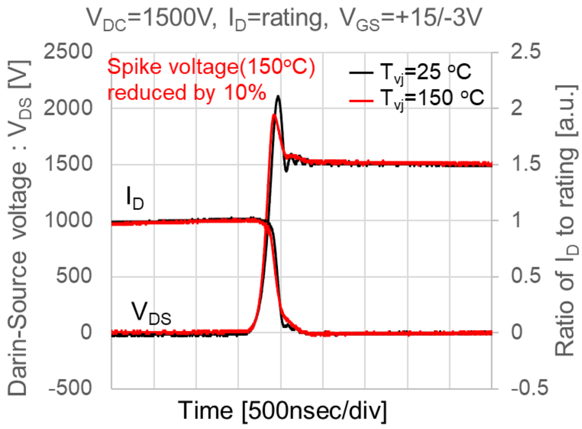
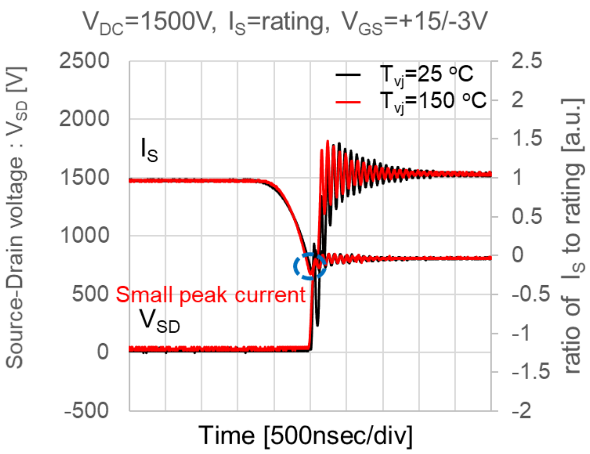


(a)Turn-on waveform



(b) Turn-off waveform



(c) Reverse recovery waveform

Fig. 4 Switching waveforms of 2.3kV SiC-MOSFET at T_{vj}=25°C and 150°C

2.3 New HPnC Package

In general, fast switching devices require low-inductance packages to suppress spike voltages and oscillations. Conventional packages have higher stray inductance, which causes snappy behaviors of fast switching devices. Newly developed HPnC package solve these problems of the conventional high-power device packages [6]. Figure 5 shows cross section diagram of the internal terminal structure of the HPnC. The laminated structure of P and N terminals inside the module reduces the stray inductance and this package achieves 10 nH. In addition, a high thermal conductive substrate is applied to realize effective heat dissipation.

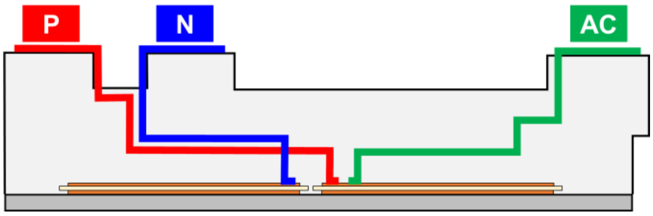


Fig. 5 HPnC internal terminal structures

The newly developed 2.3 kV All-SiC module enables a 2-level topology with a single half-bridge module for a 1500 VDC inverter instead of a 3-level topology. Figure 6 shows a configuration comparison of a 3-level I-type NPC circuit with conventional 1.2 kV rated modules and a 2-level circuit with a 2.3 kV HPnC module. The number of power modules is reduced, and the total footprint size of the power modules is shrunk by 68%. Therefore, the newly developed 2.3 kV HPnC contributes minimizing commutation inductance and increasing power density of the system.

A 3-level NPC inverter requires three half-bridge modules to be connected per phase leg. In addition, each arm requires an individual gate driver channel, for a total of 12 gate driver channels. In case of A-NPC topology, additional two IGBT switches are required, for a total of 18 gate driver channels. On the other hand, a 2-level inverter can be configured with one half-bridge for each phase leg, which reduces the footprint by 67% compared to the 3-level NPC inverter. The smaller footprint size leads to miniaturization and cost-effectiveness of the inverter.

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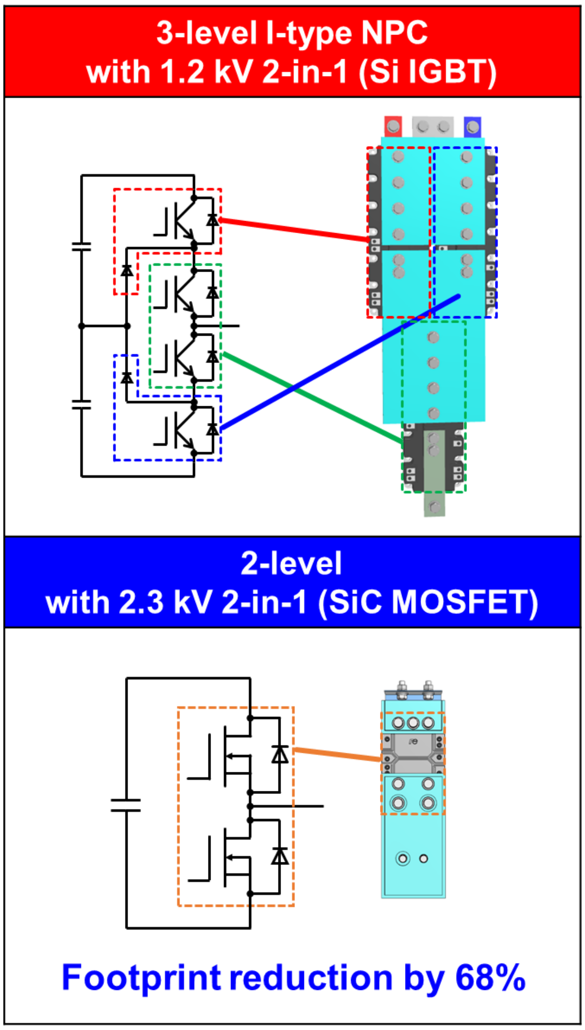

Fig. 6 Comparison of 3-level I-type NPC (top) and 2 level (bottom) configurations

2.4 Low Power Losses

To confirm advantages of the newly developed 2.3 kV SiC MOSFET HPnC, power losses of 2.3 MW class 1500 VDC inverter was calculated and compared. For conventional 3-level configuration, six of 1800 A / 1.2 kV rated 2-in-1 modules per phase and total 18 modules are necessary. On the other hand, for 2.3 kV rated SiC MOSFET HPnC, three of 1200 A / 2.3 kV rated 2-in-1 modules per phase and total nine modules were enough. Figure 7 shows a comparison of inverter power losses between a 3-level I-type NPC and 2-level inverters. Power losses of 2.3 kV SiC MOSFET HPnC is reduced by 13%. By SiC MOSFET, conduction losses are reduced by 58%, therefore even though the switching losses are increased due to higher carrier frequency, total power losses are lower.

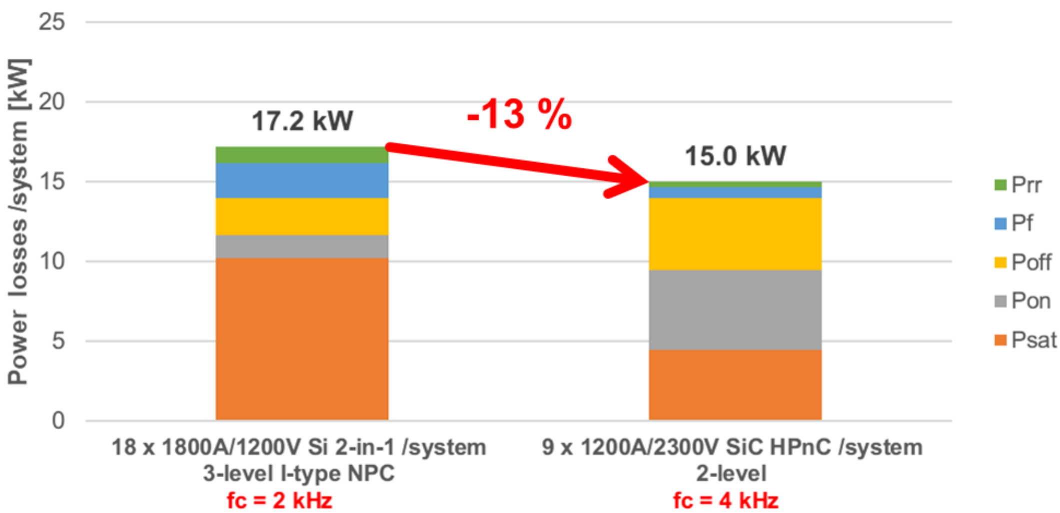

Fig. 7 Comparisons of power losses (left: Si 3-level, right: SiC 2 level)
I_o = 1800 Arms, V_{DC} = 1500 V, pf = 0.9, λ = 0.9, f_o = 50 Hz, f_c = 2 kHz (3-level), 4 kHz (2-level)

3 Conclusion

A new voltage class 2.3 kV SiC MOSFET with low-inductance new high-power package HPnC has developed. The 2.3kV SiC MOSFET HPnC is suitable for 1500 VDC applications and enables a simplified 2-level topology instead of a conventional 3-level I-type NPC topology with 1.2 kV devices. It has been demonstrated that a 2-level topology composed of this module achieves 13% reduction in power losses and 68% smaller footprint and lower commutation inductance compared to a 3-level NPC topology. It will contribute size and cost reduction and enhance reliability of systems.

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