Hybrid SiC Modules for High-Frequency Applications

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1. Introduction
A high-frequency hybrid SiC power module reduces losses during operation in high-frequency regions. It increases the switching frequency of the equipment and thus enables the size, weight, and cost of the equipment to be reduced.

2. Increase in Switching Frequency
Power supply systems often employ AC reactors and/or filter circuits for suppressing harmonics, output transformers for power conversion, and DC reactors for voltage boosting circuits. These reactor components are generally bulky and thus occupy considerable space, particularly in a large-capacity system, making it difficult to reduce the size, weight and cost of power electronics devices and peripheral systems.

From the designer’s standpoint, it is advantageous to increase the switching frequency of the power device, because higher frequency allows the use of smaller reactor components, thus reducing the size and cost of equipment as well as potentially creating new added value such as the integration of external reactors and improved filter performance. Since 2004, Mitsubishi Electric has provided the fifth generation insulated-gate bipolar transistor (IGBT) optimized for high-frequency switching, namely the carrier-stored trench-gate bipolar transistor (CSTBT). These have been commercialized as the “NFH Series” high-frequency IGBT modules, which are widely used for uninterruptible power supply (UPS), power conditioners for solar power generation, medical power units and other equipment that runs at a high switching frequency.

3. Development of Hybrid SiC Module

3.1 Features
As the successor of the “NFH Series”, our newly developed high-frequency hybrid SiC module employs a silicon carbide Schottky barrier diode (SiC-SBD) to meet the requirements for increasing the power system frequency. The SiC-SBD is expected to exhibit much higher performance than the silicon diode (Si-Di). Figure 1 compares the turn-on current waveforms of the Si-Di and SiC-SBD. Inside the Si-Di, which is a bipolar device with a PN junction, minority carriers (holes) are accumulated during the conduction period, and then are discharged by the electric field applied during the switching period. Consequently, a spike-like transient current (recovery current) appears and acts as a factor to increase the switching power loss. In contrast, the SiC-SBD operates as a unipolar device and thus generates no recovery current. There is only a small charge current due to the parasitic capacitance of the device, resulting in an extremely small switching loss.

Fig. 1 Comparison of turn-on waveforms

In contrast, it is less meaningful for the transistor switch to employ a SiC – metal oxide semiconductor field effect transistor (MOSFET) to reduce conduction loss, because the conduction loss accounts for a relatively small percentage of the applied equipment’s total loss. Considering cost effectiveness too, we adopted a well-proven Si-IGBT device for the NFH Series. In response to the market demand, we have developed a product lineup with a rated voltage and current of 1,200 V and 100 to 600 A (Table 1). The packages are fully compatible with those of the conventional NFH Series and so the existing devices can be easily replaced. In addition, since the IGBT

<table>
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characteristics remain the same as those of the conventional products, the driving circuit requires no modification for the replacement.

![Image of external view of modules](image1)

**Fig. 2 External view of modules**

### 3.2 Reduction in power loss and increase in Switching Frequency

Figure 3 shows the breakdown of the power loss per half module of the 1,200 V/100 A rated conventional and new power modules. Assuming application to a general-purpose power supply, the operating conditions are set to provide an output of 30-A sinusoidal current (effective value) at a switching frequency of 30 kHz. Under these operating conditions, the hybrid SiC module reduces the power loss by almost 40% compared with the conventional NFH Series. This is mainly attributable to the reduction in the diode switching loss. This reduction level is sufficient to improve the total power conversion efficiency of the power electronics system. As an alternative, the reduction in power loss can be used for increasing the switching frequency. Figure 4 compares the power loss – switching frequency relationship at varying switching frequencies, otherwise under the same operating conditions as those of Fig. 3. According to the results, if the power loss is kept equal, the switching frequency of the hybrid SiC module can be doubled from that of the conventional NFH Series.

### 4. Conclusion

The combined technologies of the existing Si device and advanced SiC device have achieved a much higher performance than that of the conventional high-frequency NFH Series module. By increasing the equipment operating frequency, it is possible to reduce the size of reactor components, and hence reduce the size, weight, and cost of the equipment. In response to diversified user needs, we will continue to develop high value-added products.

### References