High Speed Hybrid Modules Combining High Speed IGBTs with SiC-SBDs

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ABSTRACT

In recent years, there have been an increasing number of power converter applications that require power conversion in the high frequency region to achieve further compactness, weight savings and high efficiency for their power converters. Switching devices are thus greatly demanded for high speed and low loss. Fuji Electric has developed a high speed hybrid module combining IGBTs with SiC-SBDs, both of which operate with low loss and high speed in the high frequency region, significantly reducing switching loss. As a result, power dissipation during high-frequency inverter operation can be reduced by approximately 50% compared with existing products, thereby increasing expectations that it can be utilized with applications that require compactness, weight savings and high efficiency.

1. Introduction

In recent years, there has been increasing demand to reduce emissions of the greenhouse gas CO_2 as a measure to suppress global warming. Against this background, renewable energies, such as photovoltaic power generation and wind power generation, not only require proliferation, but also need to be efficiently converted to power at sites that face various limitations. Moreover, in order to realize further miniaturization and better efficiency in power conversion equipment typified by inverters, an increasing number of applications are performing power conversion at high frequencies of 20 kHz or higher.

Therefore, Fuji Electric has developed high-speed hybrid modules that incorporate low-loss high-speed insulated gate bipolar transistors (IGBT) that can operate in a high switching frequency region of 20 kHz or higher and silicon carbide Schottky barrier diodes (SiC-SBD) into a conventional package.

In this paper, the product's features, application effects and benefits to power conversion equipment are described.

2. Overview of the High-Speed Hybrid Modules

Figure 1 shows applications targeting power device switching frequency and power capacity. Some of the main applications of high-speed hybrid modules include power conversion equipment, such as those used for renewable energies, automotive applications and uninterruptible power systems (UPS), which need to convert power at high frequencies.

Table 1 shows the external appearance of the high-speed hybrid modules, and Table 2, product line-up.

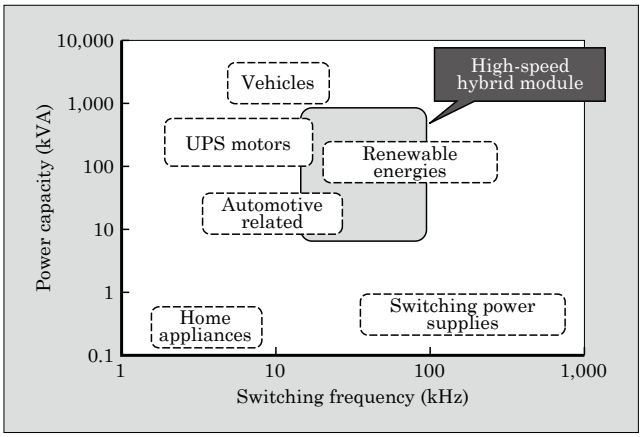
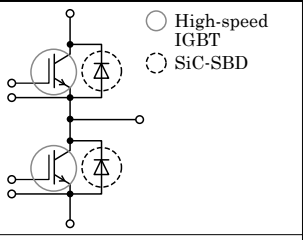
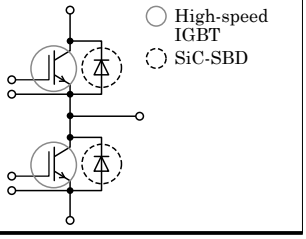


Fig.1 Main applications of high-speed hybrid modules

Table 1 High-speed hybrid module

Package	Equivalent circuit
 Standard 2-in-1 M276	
 Dual XT M254	

The high-speed hybrid modules make use of the same package as conventional Si modules in order to main-

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Table 2 High-speed hybrid module product line-up

Package	Circuit configuration	Dimensions W × D × H (mm)	Rated voltage (V)	Rated current (A)
Standard 2 in 1	2 in 1	62.0 × 108.0 × 30.9	1,200	200
				300
Dual XT	2 in 1	62.0 × 150.0 × 20.5	1,200	300

tain compatibility and consist of a 2-in-1 circuit configuration that combines high-speed IGBTs and SiC-SBDs. The IGBT utilizes a chip optimized for high-speed switching on the basis of the conventional IGBTs while using a SiC-SBD chip as the free wheeling diode (FWD).

3. Features of the High-Speed Hybrid Modules

It is important to improve the generated loss of IGBT modules in order to achieve miniaturization and better efficiency for devices that perform high-speed switching. The generated loss depends largely on the characteristics of IGBT and FWD semiconductor chips. In this chapter, the characteristics of the high-speed IGBT and SiC-SBD chip used for high-speed switching are described.

3.1 High-speed IGBT based turn-off loss improvement

Figure 2 shows the trade-off characteristic between the 1,200-V high-speed IGBT collector-emitter saturation voltage $V_{CE(sat)}$ and turn-off loss E_{off}. The high-speed IGBT, developed on the basis of the existing IGBT, uses the active structure that significantly reduces parasitic capacitance and reduces the concentration of impurities in the collector layer responsible for suppressing hole injection. Compared with the 7th-generation "X Series IGBT," it further reduce turn-off loss and has the $V_{CE(sat)}$-E_{off} trade-off characteristic that is suitable for high-speed switching[1]. Figure 3 shows a comparison between the turn-off waveforms of a 1,200-V/200-A high-speed hybrid module and

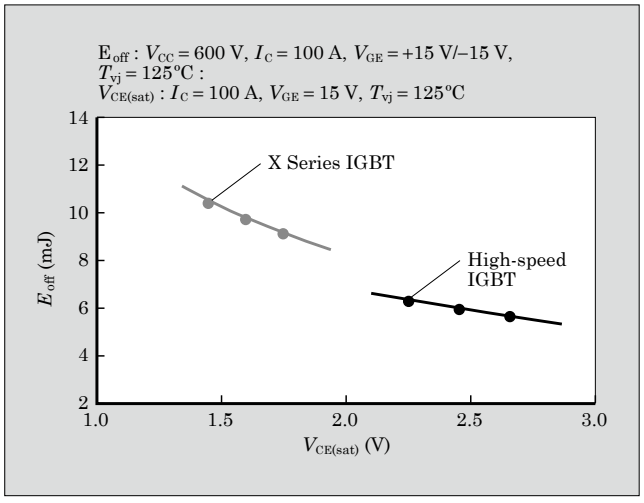

Fig.2 1,200 V high-seed IGBT $V_{CE(sat)}$-E_{off} characteristic

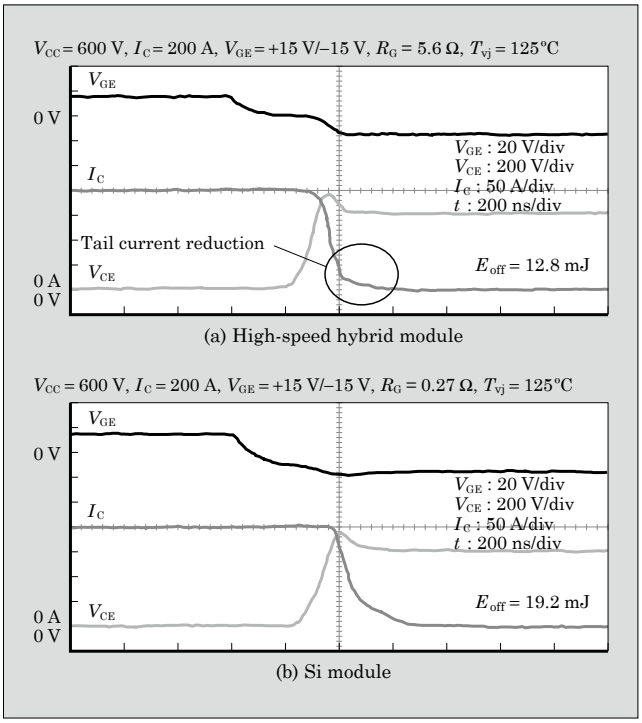

Fig.3 Turn-off waveforms

X Series Si module. Compared with the X Series Si module, the high-speed hybrid module achieves a 33% reduction in turn-off loss E_{off} by greatly improving tail current during turn-off.

3.2 SiC-SBD based improvement in reverse recovery loss and turn-on loss

Figure 4 shows a comparison between the reverse

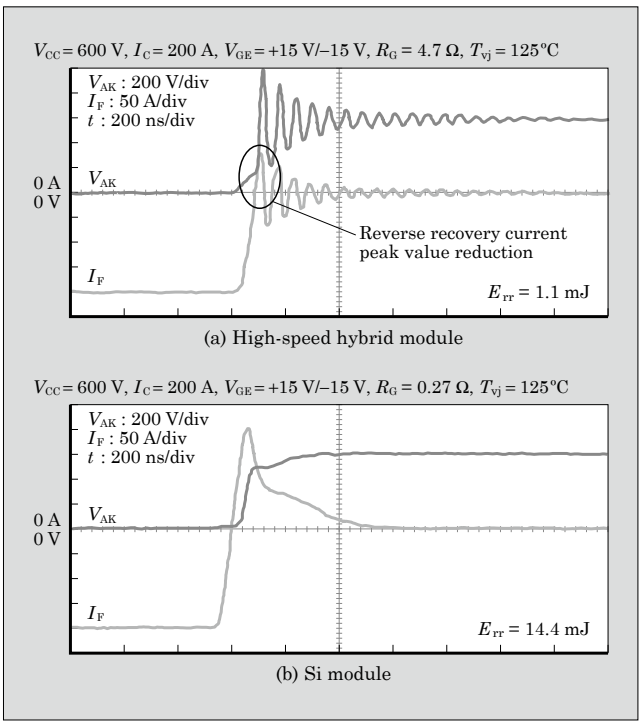

Fig.4 Reverse recovery waveforms

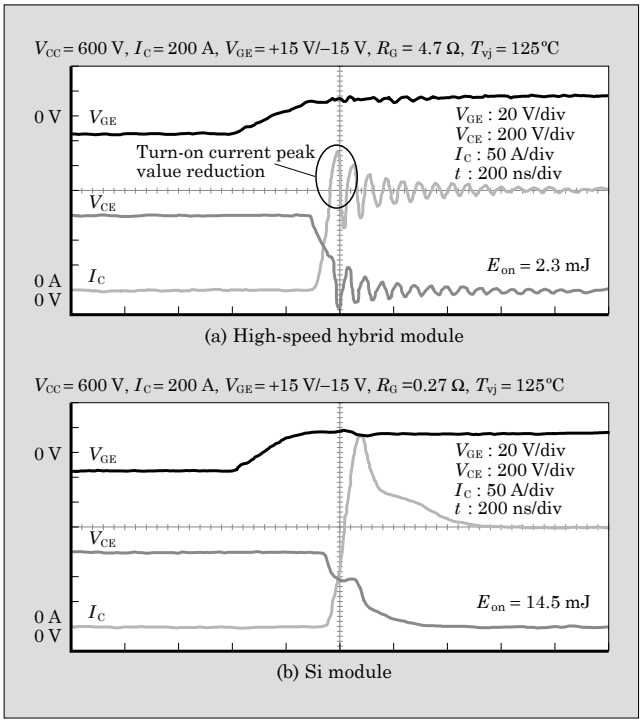

Fig.5 Turn-on waveforms

recovery waveforms of a 1,200-V/200-A high-speed hybrid module and the X Series Si module. The high-speed hybrid module can reduce reverse recovery current peak value by about 60%. This is explained by the fact that SiC-SBD is unipolar device, and so it causes no minority carrier injection. Compared with the X Series Si modules, the high-speed hybrid modules are reduced in reverse recovery loss E_{rr} by 92%.

Furthermore, the peak value of the reverse recovery current in the FWD is reflected in the peak value of the turn-on current in the IGBT of the opposing arm. Since the peak value of the turn-on current reduces as the peak value of the reverse recovery current gets smaller, it has become possible to reduce turn-on loss[2]. Figure 5 shows a comparison between the turn-on waveforms of a 1,200-V/200-A high-speed hybrid module and X Series Si module. Similar to the reverse recovery waveforms, the peak value of the turn-on current can be reduced by about 60%, thereby demonstrating the superiority of the SiC-SBD. Compared with X Series Si modules, the high-speed hybrid modules are reduced in turn-on loss E_{on} by 84%.

3.3 Switching loss reduction effect

Table 3 shows a comparison of loss between a high-speed hybrid module and X Series Si module. Compared with the X Series Si module, the high-speed hybrid module, which combines a high-speed IGBT and SiC-SBD, achieves a significant reduction in total loss of 66%.

Table 3 Switching loss comparison

	E_{on} (mJ)	E_{off} (mJ)	E_{rr} (mJ)	Total loss (mJ)
X Series Si module	14.5	19.2	14.4	48.1
High-speed hybrid module	2.3	12.8	1.1	16.2
Reduction rate	84%	33%	92%	66%

4. High-Speed Hybrid Module Effect

In this section, as an example, the inverter generated loss and chip junction temperature of a distributed small capacity power conditioning system (PCS) equipped with a 1,200-V/200-A hybrid module that utilizes an M276 package are described.

Figure 6 shows The result of simulating generated loss in the inverter. Compared with the inverter equipped with the X Series Si module at switching frequencies of 20 kHz or higher, the one equipped with the high-speed hybrid module was greatly reduced in switching loss, despite the slight increase in IGBT steady-state loss P_{sat} due to a high $V_{CE(sat)}$.

As a result, total generated loss can be reduced by about 50%. Furthermore, the rate of reduction increased in correlation with increases in switching frequency, and therefore, it can contribute to high-efficiency operation and miniaturization via the high-frequency operation of the inverter.

Figure 7 shows the junction temperature of the chip when mounted to the inverter. The junction temperature of the chip for the high-speed hybrid module at a switching frequency of 20 kHz was lower than that of the X Series Si module with temperature of about 18 °C for the IGBT and 19 °C for the FWD, enabling the inverter to increase the output current during high-frequency.

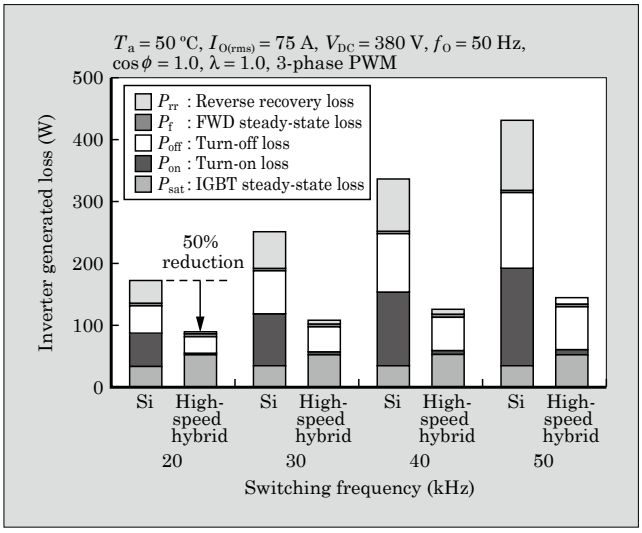

Fig.6 Simulation based comparison of inverter generated loss

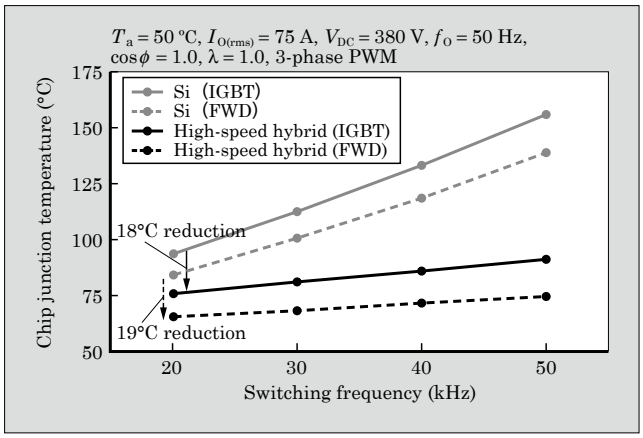

Fig.7 Chip junction temperature when mounted to inverter

5. Contribution to Power Conversion Equipment

Figure 8 shows the dependence of reactor volume on switching frequency. When switching frequency is increased from 10 kHz to 30 kHz, reactor volume can be reduced by about 50%. By miniaturizing passive components, such as reactors, via high-speed switching, the size of the entire unit can be reduced, and this can most likely lead to cost reduction.

Figure 9 and Fig. 10 show examples of using the high-speed hybrid module in a PCS and UPS respectively. The demand for small, lightweight PCS has been increasing due to the proliferation of distributed photovoltaic power generation. Parallel redundant UPS configurations are necessary to ensure high reliability for servers and data centers. There is a growing need for miniaturized UPS since parallel redundant configurations require the use of multiple systems. By using the high-speed hybrid modules, equipment can be compact and lightweight because increased operating frequency help miniaturize capacitors and reactors for filter circuits, which have been large in volume and mass. Furthermore, low loss in the high frequency region is expected to help improve power conversion efficiency.

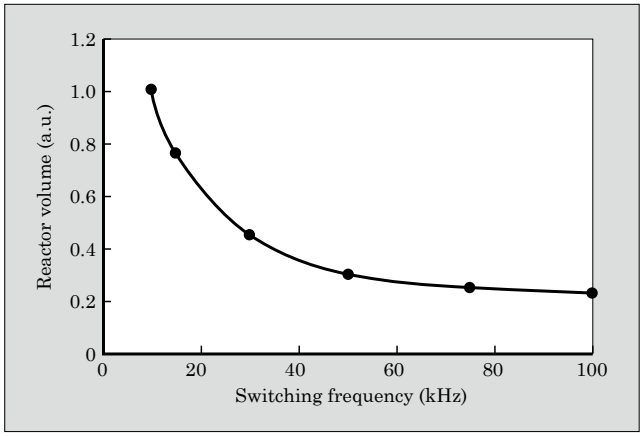

Fig.8 Dependence of reactor volume on switching frequency

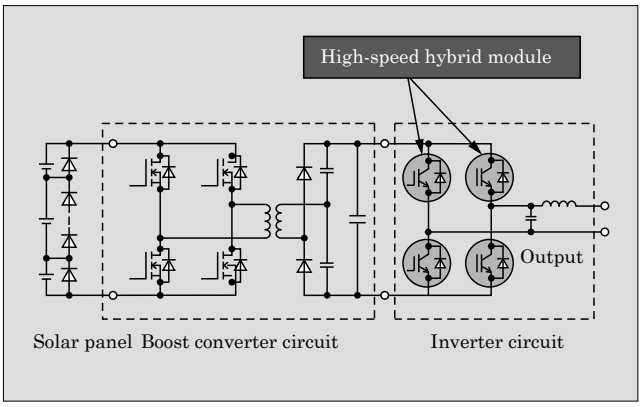

Fig.9 Configuration of PCS power supply using high-speed hybrid modules

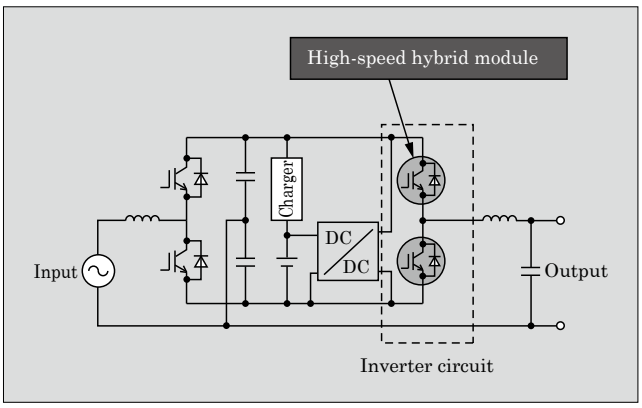

Fig.10 Configuration of UPS power supply using high-speed hybrid modules

Figure 11 shows an example of using the high-speed hybrid module to a power conversion unit used with a welding machine. High-speed switching is required to miniaturize a transformer in power conversion equipment with a high-frequency isolation system, such as welding machines, plasma cutters, and induction heaters (IH). In these types of applications, a resonant circuit system is used to reduce high-speed switching loss and noise. By using a high-speed hybrid module, this circuit system can contribute to the min-

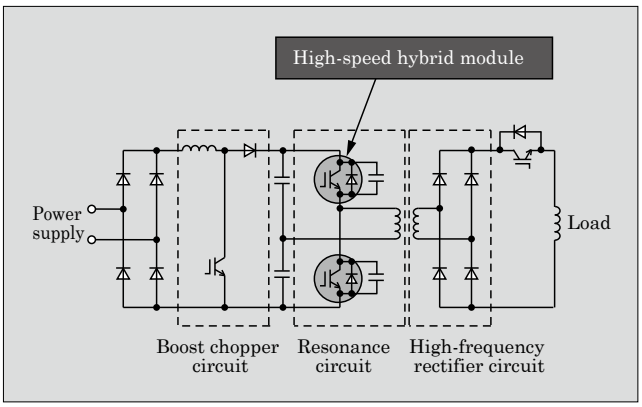

Fig.11 Configuration of welding machine power supply using high-speed hybrid modules

iaturization and efficiency of power conversion equipment because high-speed switching of 20 kHz or higher is used in the circuit.

In addition, the module is expected to be applied to medical device power supplies such as those for X-rays, as well as EV quick chargers and gas turbines, all of which are requiring further miniaturization, weight savings and enhanced efficiency.

6. Postscript

In this paper, Fuji Electric introduced our high-speed hybrid modules that combine a high-speed IGBTs and SiC-SBDs. The high-speed IGBT reduces turn-off loss, and the SiC-SBD reduces turn-on loss, thereby enabling the module to achieve low loss characteristics during high-frequency operation.

As the demand for applications that perform power conversion at high frequencies increases, Fuji Electric plans to continue pursuing ways to reduce loss so that Fuji Electric can contribute to energy savings through the development of products that meet market demands.

References

(1) Hara, Y. et al. High-Speed Discrete IGBT “High-Speed W-Series”. FUJI ELECTRIC REVIEW. 2015, vol.61, no.4, p.280-284.

(2) Onezawa, T. et al. 1,700-V Withstand Voltage SiC Hybrid Module. FUJI ELECTRIC REVIEW. 2015, vol.61, no.4, p.228-231.

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