3.3-kV SiC Hybrid High Power Modules for Railcars

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In recent years, demand has been increasing for more powerful and smaller power electronics equipment in various fields, including infrastructure fields such as railroads, solar power generation, and wind power generation. Therefore, the power semiconductor modules installed in power conversion systems need to have even lower loss and higher power density.

In order to achieve lower loss, Fuji Electric has developed 3.3-kV SiC hybrid high power modules (HPMs) for railcars that incorporate an insulated gate bipolar transistors (IGBTs) that use the latest 7th-generation “X Series” Si-IGBT chips and silicon carbide Schottky barrier diode (SiC-SBD) chips as free wheeling diodes (FWDs) (see Table 1).

1. Features

The 3.3-kV SiC hybrid HPMs for railcars combine X Series Si-IGBT chips and SiC-SBD chips and use the same package as conventional Si-IGBT HPMs to provide package compatibility (see Table 1). Furthermore, by using the latest IGBT chip and SiC-SBD chip technologies, we have reduced inverter generated loss by more than 40% compared with conventional Si-IGBT HPMs.

Table 1 SiC hybrid HPMs and SiC-SBD HPM for railcars

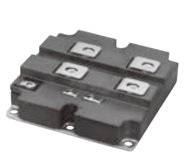
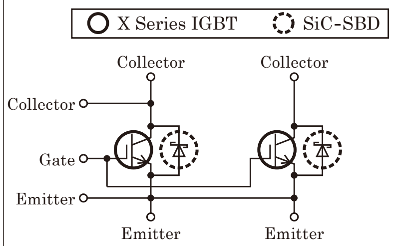
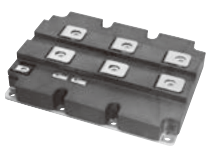
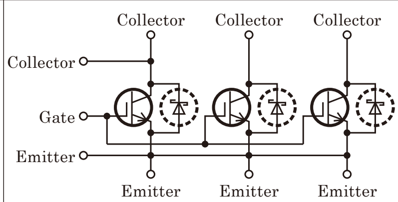
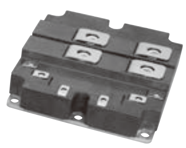
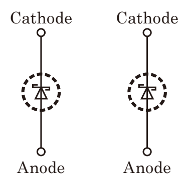
Package	Equivalent circuit
 M155	
 M156	
 M278	

Table 2 SiC hybrid HPM product line-up

Package	Circuit configuration	Dimensions W × D × H (mm)	Rated voltage (V)	Rated current (A)
M155	1-in-1	140 × 130 × 38	3,300	1,200
M156		140 × 190 × 38		1,800
M278	Diode (2-in-1)	140 × 130 × 38		900 (2-in-1)

1.1 Product line-up

Table 2 shows the product line-up of SiC hybrid HPMs. We have developed two versions of the 3,300-V/1,200-A and 3,300-V/1,800-A SiC hybrid HPMs with a 1-in-1 circuit configuration and a 3,300-V/900-A SiC-SBD HPM for 3-level circuits.

1.2 Inverter generated loss comparison

We compared the generated loss in the inverter when using a conventional Si-IGBT HPM with the same package as the M155 package 3,300-V/1,200-A rated product. We calculated the operating conditions by referring to the operating conditions of conventional lines in Japan, using a carrier frequency of 1.0 kHz, current of 314 $A_{(rms)}$ (powering), current of 508 $A_{(rms)}$ (regenerating), V_{CC} of 1,500 V, and power factor of ±0.9. Figure 1 shows the results of calculating the inverter generated loss under conventional line operating conditions. Compared to the conventional Si-IGBT HPM, the SiC hybrid HPM reduced the inverter’s generated loss by 52% under driving conditions and by 39% under regenerative conditions. The introduction of the X Series IGBT chip to the HPM design reduced the generated loss P_{sat} during IGBT conduction by 33%, and using the SiC-SBD, we reduced the generated loss P_{on} during turn-on by 65% and the generated loss P_{rr} during reverse recovery by 95%. This enabled us to significantly reduce the generated loss of the inverter.

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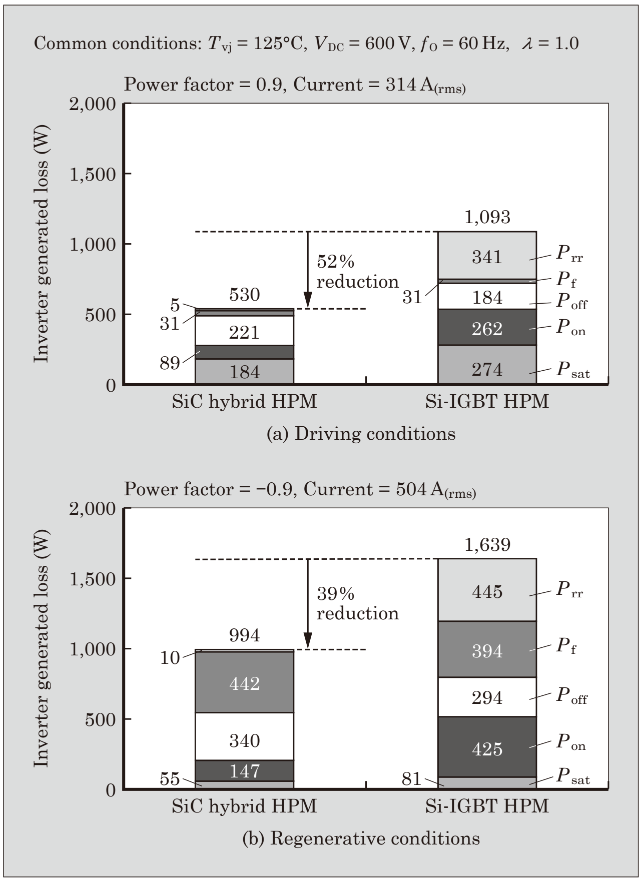

Fig.1 Results of calculating the inverter generated loss under conventional line operating conditions

2. Background Technologies

2.1 Reduction of X Series IGBT turn-off loss and $V_{CE(sat)}$

Figure 2 shows the turn-off loss and collector-emitter voltage $V_{CE(sat)}$ trade-off characteristics of the 3.3-kV X Series IGBT. The thinning of the drift layer of the chip and the miniaturization of the trench gate structure are features of X Series IGBTs, which resulted in a $V_{CE(sat)}$ of 1.0 V lower than that of the conventional Si-IGBT HPM under the same conditions of turn-off loss.

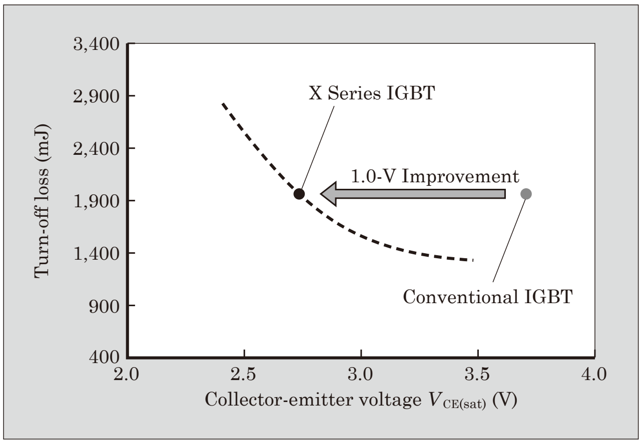

Fig.2 3.3-kV IGBT turn-off loss and $V_{CE(sat)}$ trade-off characteristics

2.2 Reduction of switching loss through use of SiC-SBD

Figure 3 shows a comparison of the switching waveforms of the SiC hybrid HPM and conventional Si-IGBT HPM during reverse recovery. SBDs, which are unipolar devices, have a low peak current during reverse recovery because there is no minority carrier injection. As shown in Table 3, the reverse recovery loss of the new SiC hybrid HPM has been reduced by 98% compared with the conventional Si-IGBT HPM.

Moreover, the peak current during reverse recovery in the FWD also affects the peak current during turn-on in the IGBT of the opposite arm. Therefore, switching loss during turn-on can also be reduced. Figure 4 shows a comparison of the switching waveforms of the SiC hybrid HPM and conventional Si-IGBT HPM during turn-on. Similar to the switching waveform during reverse recovery, the peak current during turn-on was reduced and the turn-on loss was reduced by 51% compared with the conventional Si-IGBT HPM (see Table 3).

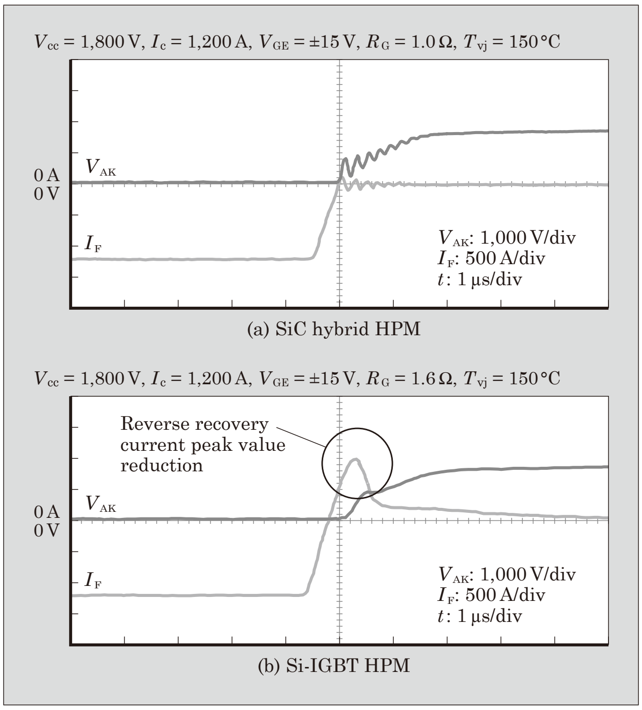

Fig.3 Comparison of switching waveforms during reverse recovery

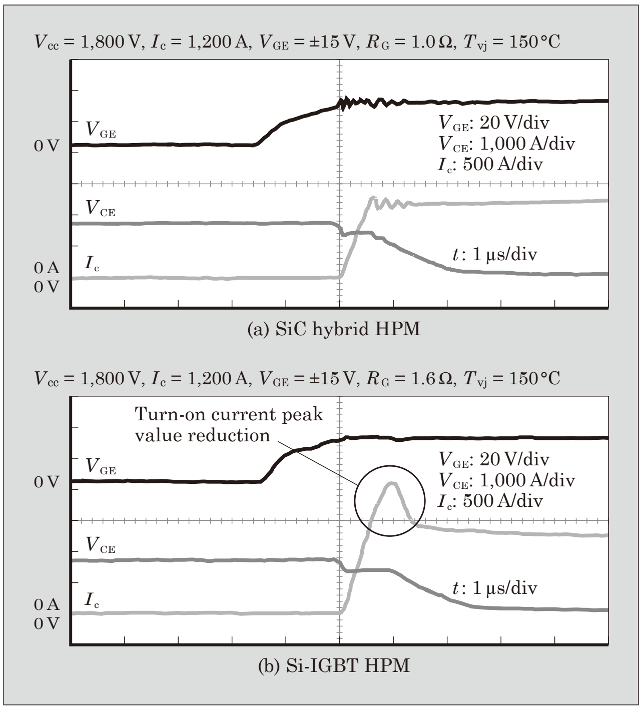

Fig.4 Comparison of switching waveforms during turn-on

Table 3 Comparison of switching loss

Item	New product SiC-IGBT HPM	Conventional product Si-IGBT HPM	Improvement rate*
Turn-on loss (mJ)	1,425	2,933	51%
Turn-off loss (mJ)	1,900	1,957	3%
Reverse recovery loss (mJ)	30	1,548	98%

*Improvement rate (%) = (Conventional product − new product)) / Conventional product

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Product Inquiries

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