IGBT Module Series for Advanced-NPC Circuits

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ABSTRACT

A series of insulated gate bipolar transistor (IGBT) modules has been developed to enable advanced neutral-point-clamped (A-NPC) inverters. Modules in this series integrate A-NPC circuits for three phases with thermistors in a single package. Loss is minimized by the adoption of 6th-generation IGBT, free wheeling diode (FWD) and reverse blocking IGBT (RB-IGBT) devices. Power dissipation is reduced by 51% compared to conventional two-level inverters and by 33% compared to conventional NPC three-level inverters. Two types of pin configuration are available, and selectable according to customer requirements.

1. Introduction

In recent years, initiatives to reduce CO_2 emissions in order to protect the environment have been implemented in countries throughout the world. The shift to clean energy, such as to wind power and solar power, which does not rely on conventional fossil fuels, is becoming increasingly prominent.

The use of power electronics devices to conserve energy can be found in a wide variety of applications, from consumer electronics to electric railways, FA systems and the like. Moreover, power electronics are used not only in power-consuming applications, but their use has also spread to the fields of power generation, transmission and supply such as in uninterruptible power supplies (UPS), wind power generators and solar power generators. In particular, multi-level inverters have been proposed as an efficient way to increase the power conversion efficiency of a UPS or power generation system(1), and neutral-point-clamped (NPC) inverters have been put into practical use. A 3-level inverter*1 having a simpler circuit configuration than this NPC inverter has also been proposed, but when configured with typical insulated gate bipolar transistor (IGBT) and diode, an increase in conduction loss and a high surge voltage due to the wiring inductance were problems.

Fuji Electric has developed circuit systems for inverters and converters, which are power electronics devices, and has contributed to energy conservation mainly in devices in the industrial field. Additionally, by adopting a custom low inductance package using a reverse-blocking IGBT(2) (RB-IGBT), a proprietarily developed power semiconductor, Fuji Electric has developed an IGBT module for use in advanced NPC (A-NPC) circuits that solves the aforementioned problems(3). A UPS that utilizes this module has been introduced to the market.

Presently, Fuji Electric is aiming to expand its series of IGBT module for A-NPC circuits, and is developing an IGBT module for A-NPC circuits that integrates a three-phase A-NPC 3-level inverter circuit and a thermistor into a single package. This paper presents an overview of these efforts.

*1: 3-level inverter technology; See supplemental explanation 1 on page 87.

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2. Characteristics of IGBT Modules for Advanced NPC Circuits

2.1 Overview

An overview of the ratings, dimensions and the like of Fuji Electric's IGBT module series for A-NPC circuits is shown in Table 1. The rated voltage of the main switches is 1,200 V, the rated voltage of the intermediate bidirectional switches is 600 V, and the rated current is 100 A. The modules have the following characteristics.

(a) Integration of a 3-phase A-NPC circuit and a thermistor into a single package

(b) Selectable pin shape according to the inverter production line

Figure 1(a) shows the appearance and Fig. 1(b) shows the equivalent circuit of the IGBT modules.

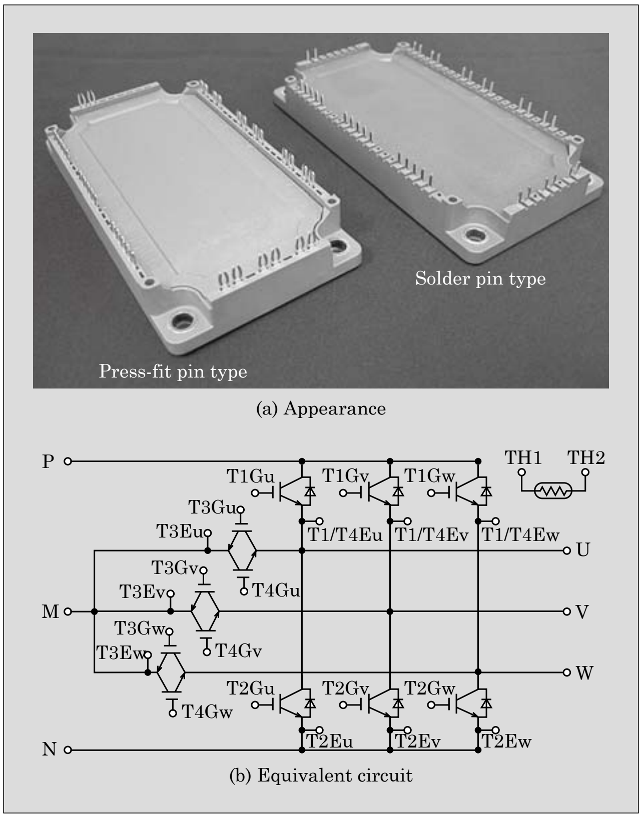
2.2 Electrical characteristics of the device

(1) Main switches

For the main switches T1 and T2 (see Table 2), the new "V Series" IGBT and free wheeling diode (FWD) having a rated voltage of 1,200 V were used. The V Series has the following characteristics.

Table 1　Overview of IGBT modules for A-NPC circuits

Model	Package dimensions	Rated voltage	Rated current
12MBI100VN-120-50 (Solder pin type) 12MBI100VX-120-50 (Press-fit pin type)	L122.5×W62.5×H17 (mm)	1,200 V (M10Aain switch part) 600 V (Bidirectional switch part)	100 A (Main switch part) 100 A (Bidirectional switch part)



(a) Appearance

(b) Equivalent circuit

Fig.1　Appearance and equivalent circuit of IGBT module for A-NPC circuits

(a) Lower on-state voltage $V_{CE\ (sat)}$ and less switching loss due to optimized field stop (FS) and trench gate structures

(b) Improved controllability of turn-on di/dt with gate resistance R_g

(2)　Bidirectional switches

For the bidirectional switches T3 and T4 (see Table 2), RB-IGBTs having a rated voltage of 600 V were used. The RB-IGBT characteristics are as follows.

(a) RB-IGBT has reverse blocking voltage capability, and can therefore be connected in a anti parallel configuration to enable bidirectional switching.

(b) When a forward gate bias voltage is applied to cause the chip to exhibit reverse recovery switching as a FWD, the reverse recovery characteristics are the same as that of a conventional FWD.

(3)　Conduction loss

An A-NPC inverter circuit, as compared to a conventional NPC inverter circuit, has half the number of conducting elements throughout its entire current path. As a result, conduction loss can be reduced by approximately 30% compared to a conventional NPC inverter. Table 2 compares the current paths and on-state voltages of the conventional NPC inverter and the A-NPC inverter.

(4)　Switching loss

An IGBT module for use in A-NPC circuit differs from a conventional IGBT module in that it has the following three switching paths as shown in Fig. 2.

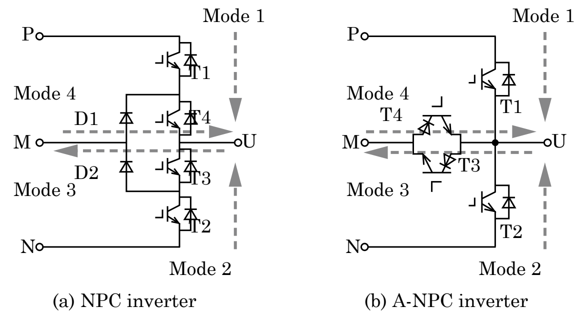
(a) Path in which the main IGBTs operate as switches and the main FWDs operate in reverse recovery (Mode A)

(b) Path in which the RB-IGBTs switch and the main FWDs operate in reverse recovery (Mode B)

Table 2　NPC inverter and A-NPC inverter on-state voltage comparison

I_C=100 A, V_{GE}=+15 V, T_j=25 °C

	Current path			
	Mode 1	Mode 2	Mode 3	Mode 4
NPC inverter	3.20 V	3.20 V	3.20 V	3.20 V
A-NPC inverter	1.85 V	1.85 V	2.45 V	2.45 V



(a) NPC inverter　(b) A-NPC inverter

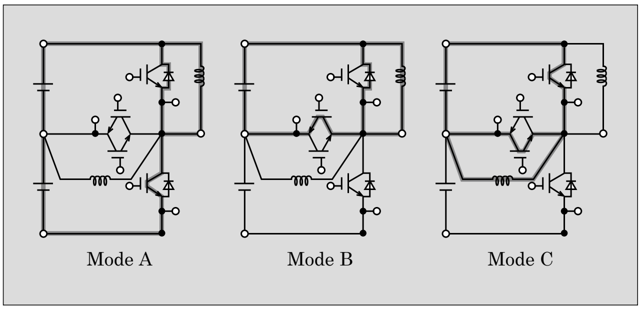


Fig.2　Example of current paths in each switching mode

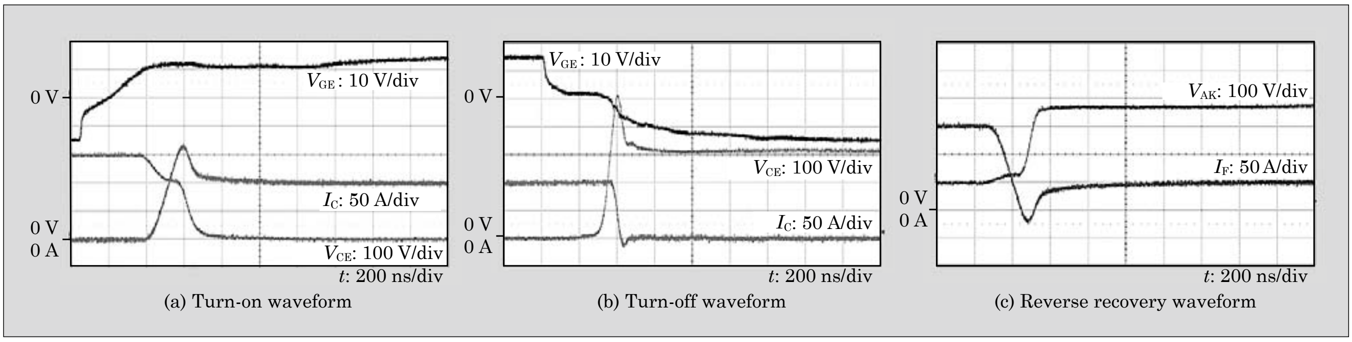


Fig.3 Switching waveform (mode B)

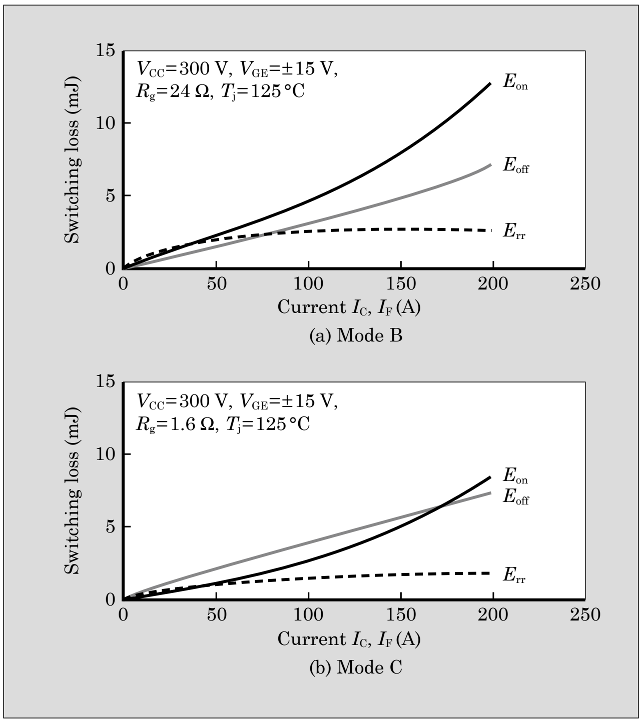


Fig.4 Current dependence of switching loss

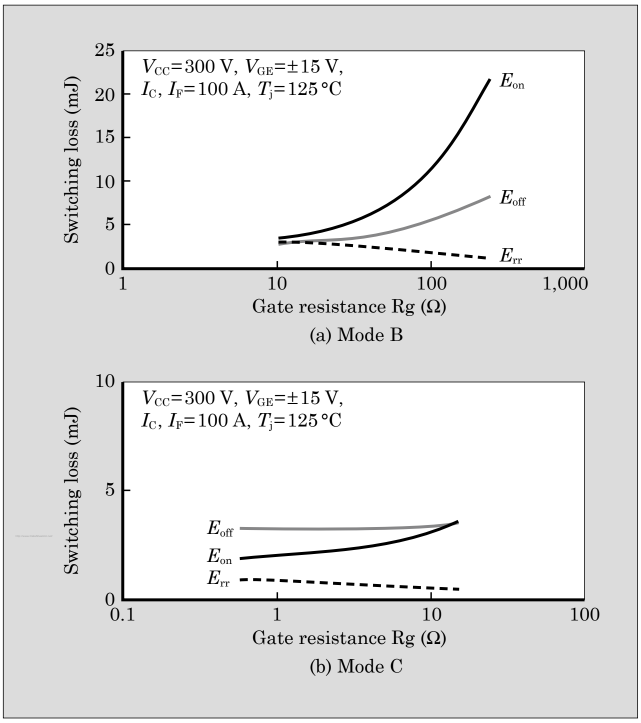


Fig.5 Gate resistance dependence of switching loss

(c) Path in which the main IGBTs switch and the RB-IGBTs operate in reverse recovery (Mode C)

For the 3-level inverter operation, basic operation is in mode B and mode C. Figure 3 shows the turn-on, turn-off and reverse recovery waveforms in mode B for a module at V_{CC}=300 V, I_C=100 A, R_g=24 Ω and T_j=125 °C.

The switching loss is 3.0 mJ at turn-on, 4.1 mJ at turn-off, and 1.67 mJ at reverse recovery, and no turn-off surge that exceeded the rated voltage was found.

Figure 4 shows the current dependence of the switching loss, and Fig. 5 shows the gate resistance dependence of the switching loss. As described above, the reverse-recovery loss characteristics when the RB-IGBT is in reverse-recovery mode C are no different from when a conventional FWD is in reverse-recovery mode B.

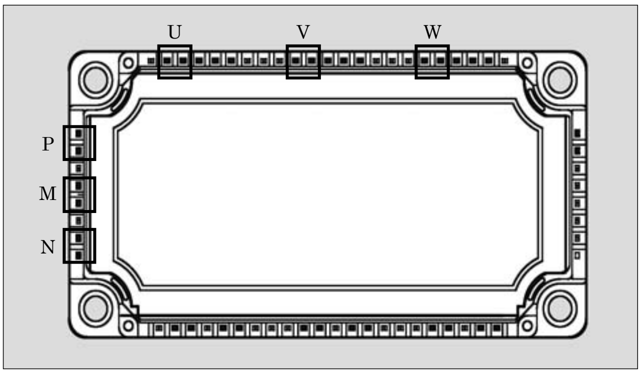


Fig.6 Main terminal arrangement

2.3 Package

A conventional compact package (EconoPIM™*2 3/

*2: EconoPIM™ is a trademark or registered trademark of Infineon Technologies AG.

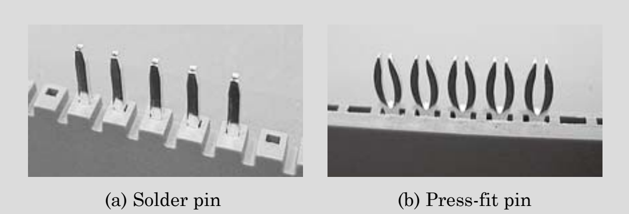


Fig.7 Terminal shape

PC-Pack3) was selected for the newly developed IGBT module for A-NPC circuits. As a result, the package has the following characteristics.

(a) Main terminals P, M, N
Layout allows for easy placement of snubber capacitors (between P-M, between M-N) to reduce surge voltage (see Fig. 6)

(b) Terminal shape
2 types of terminal shapes (solder pin, press-fit pin) can be selected according to customer needs (see Fig. 7)

(c) Environmentally friendly
Lead-free and compliant with RoHS directive*3

3. Power Dissipation

Figure 8 compares the power dissipation per phase of a conventional 2-level inverter, an NPC 3-level inverter and an A-NPC 3-level inverter when operating under the same conditions.

The power dissipation was computed with the V Series ratings of 100 A/1,200 V (EconoPIM™ 3) for the conventional 2-level inverter and using the V Series ratings of 100 A/600 V (EconoPIM™ 3) for the NPC 3-level inverter. Operating conditions for the 20 kVA inverter were f_C=7 kHz, DC voltage=700 V, and output current=30 A (rms). As a result, the A-NPC 3-level inverter exhibited the least power dissipation, 51% less than the conventional 2-level inverter and 33% less than the NPC 3-level inverter. Viewed individually, these inverters have the following characteristics.

The 2-level inverter has the smallest conduction loss since it has only one device that conducts current. However, because the DC voltage is twice that of a 3-level inverter, switching loss accounts for 76.6% of the total power dissipation.

The NPC 3-level inverter has the largest conduction loss since there are two conducting devices in each current flow path. With three levels, however, the DC voltage is halved and the switching loss is less than half that of a 2-level inverter. Consequently, the conduction loss accounts for 54.8% of the power dissipation per phase. As the carrier frequency decreases,

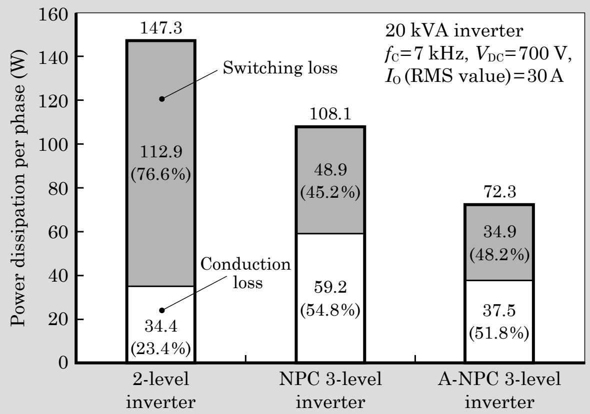


Fig.8 Comparison of power dissipation for various inverters

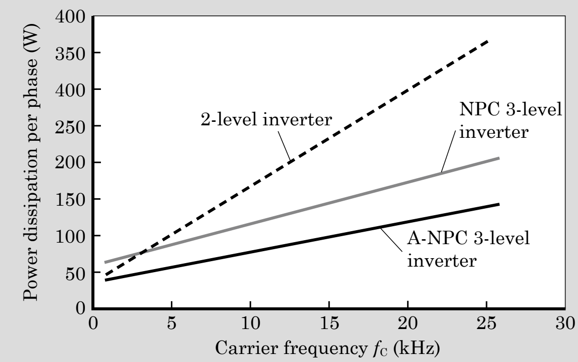


Fig.9 Carrier frequency dependence of power dissipation

conduction loss accounts for a higher percentage of total power dissipation.

With an A-NPC 3-level inverter, because an RB-IGBT has larger conduction loss than an ordinary IGBT, the conduction loss is 8.7% larger than that of a 2-level inverter, but can be reduced to about 37% less than an NPC 3-level inverter. On the other hand, the switching loss is smaller as in the case of the NPC 3-level inverter. As a result, in contrast to the loss in the NPC 3-level inverter, the percentages of conduction loss and switching loss become equal, and even if the carrier frequency changes, the power dissipation never exceeds that of the NPC 3-level inverter.

Figure 9 shows the carrier frequency dependence of power dissipation. In the region of carrier frequencies of 5 kHz or higher, the power dissipation is less for a 3-level inverter than a 2-level inverter. In the region of carrier frequencies lower than 5 kHz, the 2-level inverter appears to have less power dissipation, but the noise filter attached to the inverter apparatus is larger for the 2-level inverter than a 3-level inverter, and as a result, the total loss (power dissipation including fixed loss and filter loss) generated by the entire inverter apparatus, the 3-level inverter has less power dissipation.

*3: RoHS directive: European Union (EU) directive on restriction of the use of certain hazardous substances in electrical and electronic equipment

4. Postscript

This paper has presented an overview and described characteristics of Fuji Electric's IGBT module series for advanced-NPC circuits. This product supports applications of several tens of kVA, and will surely satisfy customer requests for high efficiency, small size and ease of use.

In the future, Fuji Electric will expand the product lineup of this IGBT module series for advanced-NPC circuits, and intends to develop modules in response to requests for higher efficiency in UPSs and the like.

References

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