7th-Generation "X Series" IGBT-IPMs

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ABSTRACT

Fuji Electric has developed the 7th-generation "X Series" IGBT-IPMs that allow inverters to achieve further miniaturization, loss reduction and performance improvement. By using the latest 7th-generation "X Series" chips and new control ICs, the product enables continuous operation at 150 °C, while achieving a loss reduction of about 10% compared with previous products. This makes it possible to increase the output current of equipment by approximately 31%. Furthermore, in addition to conventional protection functions, built-in temperature warning function makes it possible to avoid inverters stoppages. Moreover, the brake IGBT can be independently operated when lower-arm protection is activated, preventing overvoltage breakdown of semiconductor devices.

1. Introduction

In recent years, there have been increasing expectations for power electronics technology capable of contributing to energy conservation through efficient use of energy in order to mitigate global warming and help achieve a responsible and sustainable society. Therefore, demand has been expanding for power semiconductors, which are key devices in the power conversion equipment used in a wide range of fields such as the industrial, consumer, automotive and renewable energy sectors.

Since first releasing a power semiconductor insulated gate bipolar transistor (IGBT) module in 1988, Fuji Electric has utilized many technological innovations to achieve size reductions, less power dissipation and higher reliability. An intelligent power module (IPM) is an IGBT module that comes with driving and protection functions. Our IPM is characterized by having the industry's first built-in IGBT chip overheat protection function and alarm-cause identification function. It enhances the miniaturization, efficiency and reliability of power conversion equipment in order to meet the industry's high-performance and high-reliability needs.

Now we have developed the 7th-generation "X Series" IGBT-IPM (X Series IPM) to achieve further miniaturization, less power dissipation and reliability demands of inverters.

2. Product Overview

Figure 1 shows the external appearance of the X Series IPM, and Table 1 shows the product line-up and outline dimensions. In order to meet the market's demand for miniaturization, the X Series IPM will include three new packages, including the "P639," "P644" and "P638," as well as five packages corresponding to rated currents. By utilizing a reverse conducting-IGBT (RC-IGBT)[1], the new P639 package has achieved a smaller size than the previous smallest package size "P629," further miniaturizing the footprint of the cooling unit by 27%. The P644 package has the same external dimensions as the previous package "P626," enabling it to achieve a 7 in 1 configuration. The P638 package is in the same current capacity band as the "P630" package, but has miniaturized the footprint of the cooling unit by 54%. Products with a high rated current required for high exothermicity utilize high heat-dissipating insulating substrates. The X Series IPM has also enhanced its line-up of products with current ratings that meet market demands for higher current. In the conventional "V Series" IGBT-IPMs (V Series IPMs[2]), the line-up consisted 600-V products with a rating up to 400-A and 1,200-V products with a rating up to 200 A. The X

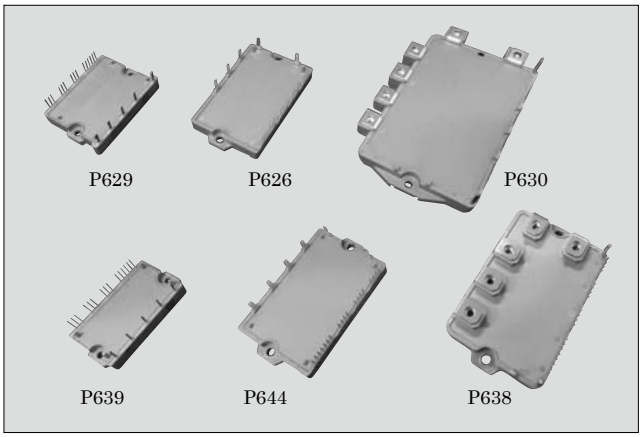

Fig.1 7th-generation "X Series" IGBT-IPM (typical packages)

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Table 1 “X Series” IPM product line-up and product outline dimensions

(a) Product line-up

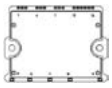
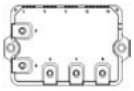
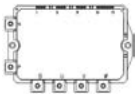
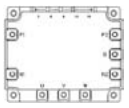
New package Conventional package Rated current expansion

Rating	Device qty.	20 A	30 A	50 A	75 A	100 A	150 A	200 A	250 A	300 A	450 A
600 V	6 in 1	P639									
				P629							
				P626*2							
				P638*2		P638*1*2					
	7 in 1			P644							
	6 in 1 7 in 1			P636*1*2							
				P630*2							
						P630*1*2					
								P631*1*2		P631*1*2	

Rating	Device qty.	10 A	15 A	25 A	35 A	50 A	75 A	100 A	150 A	200 A	300 A
1,200 V	6 in 1	P639									
				P629							
				P626*2							
				P638*2		P638*1*2					
	7 in 1			P644							
	6 in 1 7 in 1			P636*1*2							
				P630*2							
						P630*1*2					
								P631*1*2			

*1: Products using high heat dissipating insulating substrate *2: Products with built-in temperature warning function (6 in 1 only)

(b) Product outline dimensions

Package	P639	P629	P626	P644	P636	P638	P630	P631
Outline dimensions								
D × W × H (mm)	36.0 × 70.0 × 12.0	49.5 × 70.0 × 12.0	50.2 × 87.0 × 12.0	50.2 × 87.0 × 12.0	55.0 × 90.0 × 18.5 or 17.0	55.0 × 90.0 × 22.0	84.0 × 128.5 × 14.0	110.0 × 142.0 × 27.0

Series IPM expands this line-up, including 650-V products with a rating up to 450-A and 1,200-V products with a rating up to 300 A. This series of new packages and expansion of rated current for existing packages contributes to the miniaturization of the mounted equipment.

In addition, the X Series IPM has reduced power dissipation by more than 7% compared with the V Series IPM by utilizing 7th-generation IGBT technology and drive control circuit technology. Furthermore, by improving the 7th-generation package technology and control circuit, the X Series increases the range of chip junction temperature T_{vjop} during continuous operation from 125 °C to 150 °C compared with the V Series IPM to allow high temperature operation. These improvements can increase output current by approximately 31%.

At the same time, it also has the industry’s first temperature warning function as a protective feature. This function makes it possible to alert users that the IGBT chip is overheating. This contributes to improving the performance of power conversion equipment by shortening emergency stop times.

3. Main Functions and Features

3.1 Initiatives to reduce power dissipation

In order to improve the efficiency of power conversion equipment, it is important to reduce power loss of IPM. This power loss is determined by the characteristics of semiconductor chips, such as those that use IGBTs and free wheeling diodes (FWDs), as well as the performance of the control circuit that drives it.

Figure 2 shows a comparison of the cross-sectional structure of IGBT chips. The 7th-generation IGBT[3] comes equipped with a miniaturized trench-gate structure on the surface, similar to 6th-generation IGBTs, while also utilizing a thin-wafer IGBT with a field-stop (FS) layer on the back side. Compared with 6th-generation IGBTs, it improves on-voltage (collector-emitter saturation voltage) and turn-off loss by reducing the chip thickness. Furthermore, by optimizing the trench-gate structure of the surface, it increases the injection enhanced (IE) effect for increasing the carrier concentration on the surface and improves the trade-off relationship between on-voltage and turn-off loss. The IGBT-IPM optimizes the surface structure more than the IGBT mounted on standard IGBT modules. This is an IPM-specific improvement achieved by built-in short-circuit protection function. Therefore,

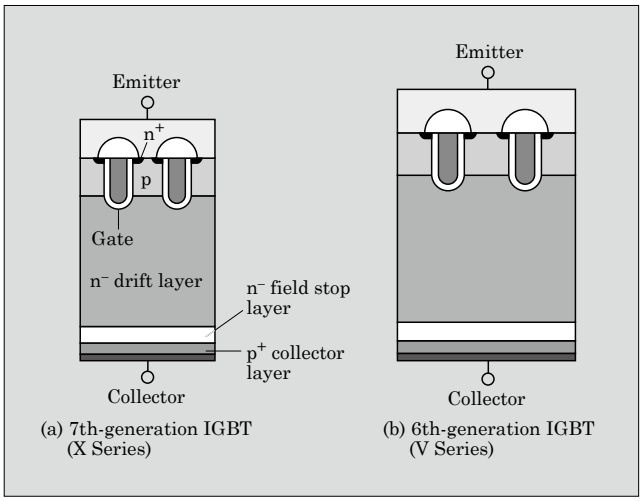


Fig.2 IGBT chip cross-sectional structure

the trade-off is further improved. Figure 3 shows the trade-off between the collector-emitter saturation voltage $V_{CE(sat)}$ and the turn-off loss E_{off}. At the same turn-off loss, the 7th-generation IGBT-IPM has 0.25 V lower on-voltage than the 6th-generation IGBT-IPM and 0.15 V lower on-voltage than the 7th-generation IGBT for modules. However, the reduced on-voltage achieved through miniaturizing the surface structure facilitates current flow, and this, in turn, increases current of short circuit. Therefore, the trade-off has been improved by speeding up short-circuit protection.

In addition, the X-Series IPM comes with a turn-on drive-current switching function on the IGBT drive circuit in order to reduce turn-on loss during switching. This function increases the current driving the IGBT at high temperatures and reduces turn-on losses at high temperatures. Moreover, IGBT chip temperature is detected in real time to enable switching at optimum timings. The drive current value has also been optimized so that there is no impact on the emission noise related to the trade-off with switching loss. Figure 4 shows the effect of reducing turn-on loss using the drive-current switching function of the IGBT gate

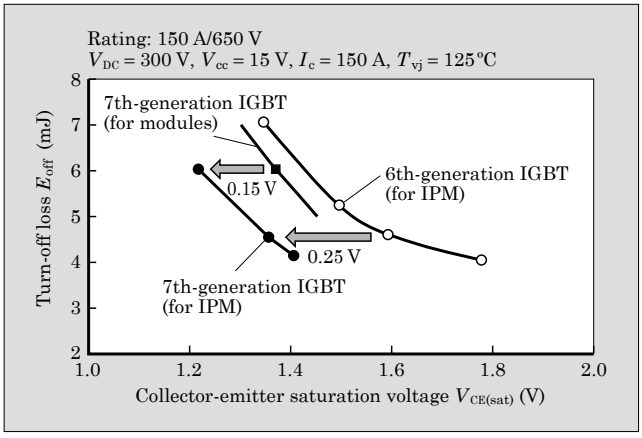


Fig.3 Collector-emitter saturation voltage and turn-off loss trade-off

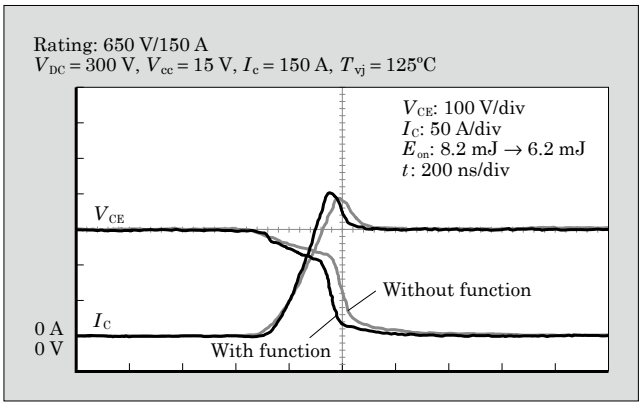


Fig.4 Effect of turn-on loss reduction via drive-current switching function

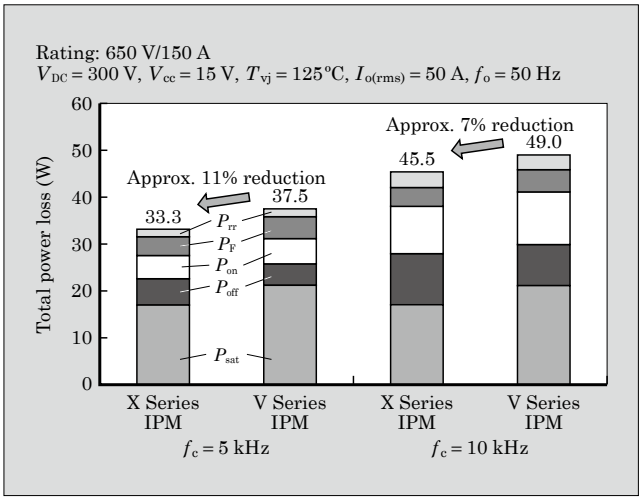


Fig.5 Comparison of power loss simulations

drive circuit. The function has reduced turn-on loss by approximately 24%.

Figure 5 shows the result of simulating the power loss during PWM inverter operation at the product rating of 650 V/150 A. The improvement in the characteristics described above has improved the total power dissipation of the X Series IPM by approximately 11% at a carrier frequency of 5 kHz and by approximately 7% at a carrier frequency of 10 kHz, compared with the V Series IPM.

3.2 Protective function characteristics

Table 2 shows a comparison of the protective functions of X Series IPMs and conventional V Series IPMs. The features of X Series IPMs include a high-speed short-circuit protection function, improved alarm output function, built-in temperature warning output function and standalone brake operation during alarms.

As mentioned in Section 3.1, the miniaturized surface structure of IGBT chips can improve IGBT trade-off and maximize chip performance. However, since the short-circuit current of the IGBT chip increases, it is necessary to speed up short-circuit protection with-

Table 2 Comparison of protective functions

Protective function	X Series IPM	V Series IPM
Overcurrent protection	○	○
Short-circuit protection	◎ Shorter shutdown time (1 µs)	○ (3 µs)
Chip overheat protection (Minimum protective temperature)	◎ (175°C)	○ (150°C)
Power supply voltage drop protection	○	○
Alarm output	◎ 2 ms, 4 ms, 8 ms Identification width = 1.1 ms or more	○ 2 ms, 4 ms, 8 ms Identification width = 0.1 ms
Temperature warning output	◎ (Specific type)	×
During alarm Brake IGBT standalone operation	◎	×

○: With function ×: Without function
◎: Improvements over conventional V Series IPM

out producing false positives. Therefore, in addition to speeding up the suppression of peak current in short-circuit currents, the shutdown delay time has also been optimized to prevent malfunctions due to false positives.

Furthermore, the X Series IPM utilizes the industry's first alarm-cause identification function that expands the identification range of each alarm cause from 0.1 ms to 1.1 ms or more, thereby increasing identifiability for the alarm-cause identification function. This facilitates and accelerates factor analysis at the time of alarm output and the investigation of causes.

In addition, the X Series IPM comes with a new alarm output function that is capable of standalone operation for the brake IGBT during lower-arm protection. In conventional IPMs, when an alarm is output after detecting an abnormality with the lower arm, circuit logic would be activated to stop all lower-arm operation. In such a case, the brake IGBT would also stop, and this would prevent the brake circuit from regenerating energy created in the rotating motor and cause P-N voltage to increase. In X Series IPMs, the brake IGBT remains operable even when the inverter of the lower arm detects an abnormality and outputs an alarm. As a result, the X Series resolves the above mentioned problem. Furthermore, this suppresses the increase in P-N voltage in the main power supply caused by power regeneration from the motor and prevents overvoltage breakdown of semiconductor devices. Moreover, it is designed so that the brake IGBT and inverter of other lower arm are protected as usual when an abnormality occurs in the brake IGBT.

3.3 Temperature warning output function (applicable to some models)

The X Series IPMs are the industry's first IPMs to come with a temperature warning output function. This output function monitors the temperature of the IGBT chip and alerts IPM users of the chip's overheating state when the temperature exceeds the specified temperature. Figure 6 shows the operating waveforms of the temperature warning output function. The chip over-temperature protection function operates when the chip temperature of the IGBT exceeds 175 °C in order to output an alarm and stop the switching operation. In contrast to this, the temperature warning output function enables the switching operation of the IGBT to continue while outputting the temperature warning. In particular, if an equipment such as a machine tool or elevator has a cooling failure (fin clogging, fan failure, compound depletion, etc.), a temperature warning signal will be output to the equipment side if the IGBT chip temperature inside the X Series IPM exceeds 150 °C. The equipment receiving the signal avoids stoppage by preventing the chip temperature of the IGBT from exceeding 175 °C by reducing the load current applied to the IPM. By doing this, operation can continue and equipment maintenance can be performed at an appropriate time.

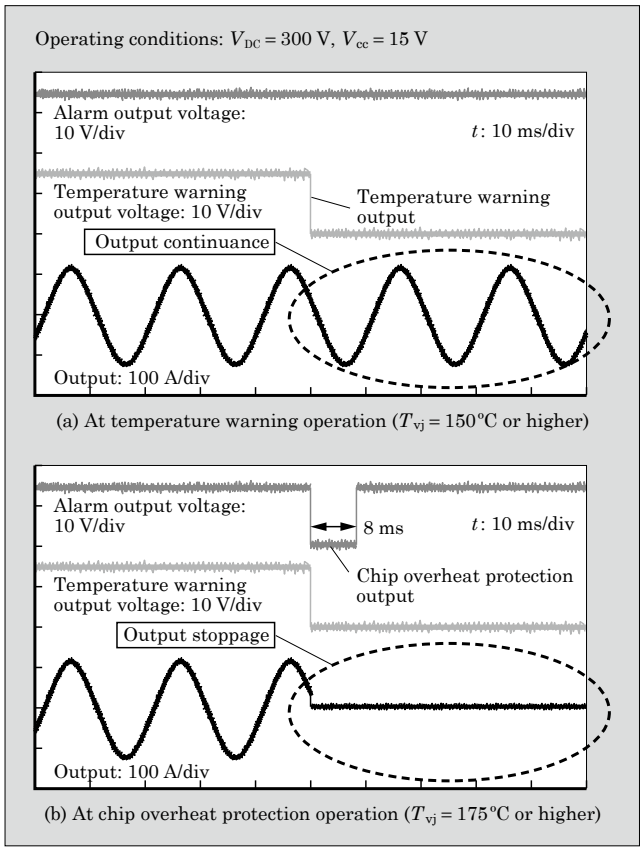


Fig.6 Operating waveforms of the temperature warning output function

4. Effect of High Temperature Operation and Loss Reduction

Table 3 shows a comparison of the operating temperature of the X Series IPMs and V Series IPMs. The X Series IPM expands T_{vjop} during continuous operation from 125 °C to 150 °C compared with the V Series IPM, while improving the maximum chip junction temperature T_{vjmax} from 150 °C to 175 °C compared with the V Series. In order to achieve high temperature operation, the X Series IPM utilizes 7th-generation packaging technologies such as high heat resistant gel and high reliability solder. Furthermore, the IPM's built-in control IC also enables operation at high temperatures by implementing a layout design that takes into account a circuit design not susceptible to temperature and electromigration at high temperatures. As a result, it can be applied in power conversion equipment under more severe load conditions and lower heat dissipation designs.

Table 3 Comparison of operating temperatures

Item	X Series IPM	V Series IPM
Maximum case temperature T_{cmax}	125°C	110°C
Chip junction temperature during continuous operation T_{vjop}	150°C	125°C
Maximum chip junction temperature T_{vjmax}	175°C	150°C

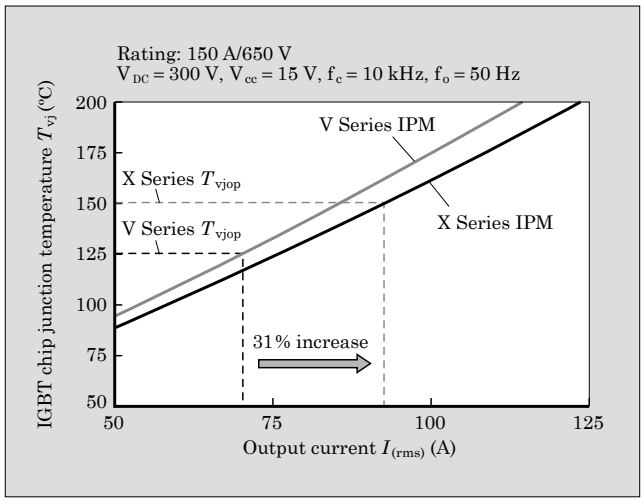


Fig.7 Inverter output current and IGBT chip junction temperature

Figure 7 shows a comparison of the inverter output current and chip junction temperature when the IPM is mounted to an inverter acting as a typical power conversion equipment. The X Series IPM can increase output current by approximately 31% compared with the V Series IPM by expanding the IGBT chip junction temperature during continuous operation and reducing the power loss.

5. Postscript

In this paper, we introduced our 7th-generation "X Series" IGBT-IPMs. In addition to the utilizing the most recent X Series IGBT, FWD and control IC, this IPM simultaneously achieves miniaturization, less heat dissipation and high performance by using a package characterized by its high heat dissipation and high reliability. By replacing conventional products with the 7th-generation "X Series" IGBT-IPMs, it is possible to achieve higher efficiency, miniaturization and cost savings for power conversion equipment, and thereby contribute to the further spread of power conversion equipment and significantly help resolve worldwide energy problems.

Fuji Electric plans to continue to develop products that meet market requirements.

References

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