V-Series Intelligent Power Modules

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ABSTRACT

Fuji Electric has developed a series of intelligent power modules for industrial applications, known as V-Series IPMs. This product combines high-performance 6th-generation V-chip technology for the IPMs with a new control IC to realize lower loss and a smaller package size. The short-circuit protection function was made to operate at faster speeds and the trade-off relation between conduction loss and short-circuit withstand capability was improved to reduce switching loss. Additionally, the new control IC and the package were optimized to reduce turn-on loss and improve radiation noise characteristics. In addition to the conventional protection functions, a new function that outputs different alarm pulse widths for each alarm factor is also provided. Ground-fault protection can also be provided even in a small package.

1. Introduction

An IPM (Intelligent Power Module) is an intelligent power device that combines a standard IGBT module containing an IGBT (Insulated Gate Bipolar Transistor) chip and a FWD (Free Wheeling Diode) with a drive IC equipped with drive and protective functions. IPMs are used in machines in a wide range of fields, but mostly in motor-driven equipment (such as NC (Numerical Control) machine tools, general-purpose inverters, servos, air conditioners and elevators) and power supply devices (such as UPS (Uninterruptible Power Supplies), and PCS (Power Conditioning Systems) for solar energy generation), and are required to have compact size, high efficiency, low noise, long life and high reliability.

Fuji Electric, in 1997, devised the industry's first internal IGBT chip over-temperature protection function, and developed the "R-IPM Series" that aimed to achieve higher reliability with an all-silicon design that reduced the number of parts. In 2002, Fuji Electric developed the "R-IPM3 Series" in which the chip structure was changed from PT (punch through) to NPT (non-punch through). In 2004, Fuji Electric integrated a newly developed NPT-type trench-gate structure IGBT and a new structure FWD into the "U-IPM Series" which improves the tradeoff relation between lower switching loss and radiation noise.

Recently, Fuji Electric has developed an FS (field stop) type "V-Series" IGBT chip (V-IGBT) having a trench gate structure that achieves even lower loss and lower input capacitance. Fuji Electric has also developed a drive IC that uses finer line widths to realize a more compact size, and features improved temperature characteristics with less variation among chips. These technologies and packages have been optimized to develop the "V-Series IPM" (V-IPM) that is housed in a new compact package and that features an improved tradeoff relation between total dissipation loss and radiation noise. This paper describes Fuji Electric's new V-IPMs.

2. Product Concept and Product Lineup

Development concepts for the V-IPM are listed below.

- (1) Reduction of total dissipation loss
- (2) Improvement of tradeoff relation between switching loss and radiation noise
- (3) Shorter dead time
- (4) Individual outputs for each cause of alarm
- (5) More compact and thinner packages
- (6) Provision of ground fault protection for small capacity packages
- (7) Compliance with RoHS^{*1} directive

Details of these concepts are explained in chapters 3 to 6 below.

Table 1 shows the V-IPM product lineup. For V-IPM devices, the current capacity has been increased compared to the previous devices, and 600 V-rated devices have rated currents of 20 to 400 A, and 1,200 V-rated devices have rated currents of 10 to 200 A. The four types of newly developed packages are all RoHS compliant.

Table 2 lists characteristics and internal functions of the V-IPM devices. A small capacity package (P629) newly realizes short-circuit protection (ground fault protection) function in its upper arm. Also, throughout

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^{*1:} RoHS: EU Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment

Table 1 V-IPM product lineup

(a) Product lineup

Rated voltage	Number of elements	20 A	30 A	$50\mathrm{A}$	75 A	100 A	150 A	200 A	300 A	400 A
200 H	6 in 1	$P629^*$								
				P626						
600 V	6 in 1 7 in 1			P630*						
						P631*			•	
Rated voltage	Number of elements	10 A	15 A	$25\mathrm{A}$	35 A	50 A	75 A	100 A	150 A	200 A
1,200 V	6 in 1	P629*								
				P626						
	6 in 1 7 in 1			P630*						
								-	P631*	*

* : Upgrade of capacity compared to existing products
(b) Package types

	P629 package	P626 package	P630 package	P631 package	
	Image: Apple of the second s		0 N 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	P P P P	
	L×W×H (mm)	L×W×H (mm)	L×W×H (mm)	L×W×H (mm)	
ſ	$49.5 \times 70 \times 12$	$50 \times 87 \times 12$	$84 \times 128.5 \times 14$	$110 \times 142 \times 27$	

Table 2 V-IPM characteristics and internal functions

Package	Arm	Drive circuit	Over current protec- tion	Short- circuit protec- tion	Chip over temper- ature protec- tion	Low voltage protec- tion	Alarm output
D620	Upper	0	0	0	0	0	-
1029	Lower	0	0	0	0	0	O
Deac	Upper	0	0	0	0	0	O
F 620	Lower	0	0	0	0	0	O
Depo	Upper	0	0	0	0	0	O
F 050	Lower	0	0	0	0	0	O
P631	Upper	0	0	0	0	0	O
	Lower	0	0	0	0	0	O

 \bigcirc : Improvement from existing product

the lineup, a pulse output width that changes according to the alarm cause makes it possible to specify the cause of the alarm.

3. Characteristics of V-IPM Power Chips

V-Series IPMs are utilizing 6 th generation V-IGBT chips. The V-IGBT is an FS-type IGBT having a trench gate structure formed by using thin wafer process technology with a FZ (floating zone) wafer. Figure 1 compares the cross-sectional structure of various chips, and Table 3 shows the history of IGBT technology.

The surface structure has been optimized to make

Fig.1 Comparison of IGBT chip cross-sectional structures (660 V-IPM)



Table 3 History of IGBT technology (600 V-IPM)

IGBT	Generation	3rd generation	4rd generation	5rd generation	6rd generation
technology	IPM	R-IPM	R-IPM3	U-IPM	V-IPM
	IGBT	N-IGBT	T-IGBT	U-IGBT	V-IGBT
Wafer		Epitaxial	\mathbf{FZ}		
Structure		PT	NPT		\mathbf{FS}
Gate structure		Pla	nar Trench		nch
Lifetime control		Yes	No		
Carrier injection		High injection	Low injection		
Transport	efficiency	Low efficiency	High efficiency		

a drift layer have lower resistance and be thinner. As the result, the V-IGBT has the advantage of lower on-voltage $V_{CE(sat)}$ and improved switching loss. Additionally, the optimization of the surface structure and the lower resistance of the drift layer also improve the controllability of the turn-on di/dt. The radiation noise is less than compared to a conventional device.

The IGBT chip for the V-IPM, compared to a chip for an IGBT module, realizes an improved tradeoff relation between $V_{\text{CE(sat)}}$ and turn-off loss E_{off} as a result of a finer surface structure. When $V_{\text{CE(sat)}}$ is reduced, the short-circuit current increases and the short-circuit withstand capability decreases, and short-circuit protection must engage rapidly in practical applications.

The FWD with improved lifetime control realizes lower recovery current and soft recovery.

4. Characteristics

4.1 Total dissipation loss

The marketplace requests IPMs to have lower loss. There are two objectives for reducing the loss, one is to increase the carrier frequency in order to improve equipment controllability, and the other is to increase the output current at the same carrier frequency. Also, the reduction in loss will lead to reduced cost of the equipment since less cooling capability will be required than before.

Figure 2 compares examples of dissipation loss during PWM inverter operation. The loss in the V-IPM is approximately 27% lower than that of the R-IPM, approximately 17% lower than that of the R-IPM3, and approximately 10% lower than that of the U-IPM.

This reduction in loss is due to an improved tradeoff relation between $V_{\text{CE(sat)}}$ and E_{off} , and a lower turn-on loss E_{on} . These techniques for reducing loss are described below.

4.2 Improvement of V_{CE(sat)} and E_{off} tradeoff relation

Static loss and $E_{\rm off}$ account for more than 50% of the total loss in an IGBT chip. However, as shown in Fig. 3, tradeoff relations exist among $V_{\rm CE(sat)}$, which determines the static loss of the IGBT chip, $E_{\rm off}$ and the short-circuit withstand capability, This tradeoff must be optimized. Since the IPM has a short-circuit protection function, by increasing the speed of the short-circuit protection, the IGBT chip short-circuit withstand capability can be diverted to reduce loss. With the V-IPM, the achievement of higher speed short-circuit protection resulted in an improved tradeoff relation between $V_{\rm CE(sat)}$ and $E_{\rm off}$, and lower loss.

Fig.2 Comparison of total dissipation loss (simulation results)



Fig.3 IGBT tradeoff relationships



Also, optimization to improve the $V_{\text{CE(sat)}}$ tradeoff is being implemented with the goal of maintaining the same level of surge voltage as before, but with lower loss.

4.3 Lower turn-on loss

As a result of lower IGBT input capacitance, a new drive method for the control IC and improved temperature characteristics, as shown in Fig. 4, the tail of the collector-emitter voltage VCE becomes shorter and $E_{\rm on}$ is reduced by approximately 35%.

4.4 Comparison of radiation noise

A tradeoff relation exists between radiation noise and Eon, whereby loss can be reduced when di/dt is increased and radiation noise can be reduced when di/dtis decreased. Figure 5 shows an example of relative comparison test results as measured by Fuji Electric. Using a dummy load testing device, measurement was made during acceleration and deceleration operations. By employing the method for reducing turn-on loss described in section 4.3 and by optimizing the internal circuit wiring pattern in the package to reduce the radiating area, the peak value of radiation noise was approximately 3db lower than that of a conventional product. With this V-IPM, both lower E_{on} and lower radiation noise were realized.

4.5 Shorter dead time interval

In an inverter circuit, a dead time interval is



Fig.4 Turn-on waveform

Fig.5 Comparison of radiation noise (results of relative comparison test at Fuji Electric)



provided in order to prevent overlapping of the onintervals of the upper and lower arms of the IPM. Shortening of the dead time interval is important for reducing waveform distortion and rotational unevenness. With the V-IPM, the switching time interval has been optimized by improving the temperature characteristics and reducing fluctuation during switching by the control IC. As a result of these techniques, the V-IPM realizes a minimum dead time interval of 1 μ s at its IPM input section.

5. Protection Functions

5.1 Short-circuit protection

As described in section 4.2, the tradeoff relation between $V_{\rm CE(sat)}$ and $E_{\rm off}$ in the IPM can be improved by diverting the short-circuit withstand capability of the IGBT chip to loss reduction. To realize this improvement, the speed at which the short-circuit protection operates must be increased. To speed up the protection circuit, the design of the V-IPM must ensure that the short-circuit protection function operates correctly

Table 4 Alarm pulse width for each alarm cause

Alarm cause	Alarm pulse width
Over current protection (including short-circuit protection)	2 ms (standard value)
Low voltage protection	4 ms (standard value)
IGBT Chip over temperature protection	8 ms (standard value)

Fig.7 V-IPM block diagram



with a shorter filter time. For this purpose, the sense voltage for the collector current monitor, which performs recognition sensing for the protection circuit, must be optimized.

With the IGBT, the sense ratio is adjusted to reduce the sense current and to stabilize the sense voltage during switching. Also, with the control IC, by changing to a new drive method from a gate resistance method based on the highly temperature dependent on-resistance of a MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor), the sense voltage is limited especially at high temperature conditions. As a result of these improvements, we successfully improved the tradeoff relation between loss and

Fig.6 External appearance of package





short-circuit withstand capability.

5.2 Separate output for each alarm cause

A conventional IPM only has a single alarm pulse width of 2 ms, from which the cause of an alarm cannot be identified, but with the V-IPM, the alarm pulse width changes for each alarm cause, enabling the cause analysis to be performed more quickly when troubleshooting.

The alarm pulse widths for each V-IPM alarm cause are listed in Table 4.

6. Package

Figure 6 shows the external appearance of several packages. P629 is a small capacity package, P626 is a medium capacity and small size package, P630 is a medium capacity, thin package, and P631 (not shown) is a large capacity package.

The newly developed IPM has an external package shape designed in response to requests for thinner modules. A conventional package uses overhead crossing type bar wiring, and the wiring distance was shortened. With the new package, the internal circuit wiring is fabricated only from aluminum wire and the copper pattern on the insulating substrate to realize a thin package. Additionally, the internal inductance was reduced due to the mutual inductance effect from parallel PN lines. The resultant effect is that radiation noise is decreased, and turn-off surge does not become excessively large.

An additional advantage is that since a 50 A/600 V capacity is realized with the thin package of the P629, the height on the device is uniform, and the P629 can be used together with the P626. Moreover, the package design ensures sufficient insulation distance to ground and inter-phase insulating distance, and therefore, the insulating distance can be ensured without any special insulation design on the device side. All

packages have RoHS compliant structures.

7. Block Diagram of IPM

Figure 7 shows block diagrams of IPMs. With a conventional small capacity type, current is detected with a shunt resistance that has been inserted into the N line, and therefore short-circuit protection could be implemented in the lower arm only. With the V-IPM, since all IGBTs use the sense current for detection, short-circuit protection of the upper arm device can be implemented. The P626, P630 and P631 packages are also provided with an alarm terminal on the upper arm, and alarm signals can be transmitted to the device side. Because P629 is designed to be compatible with the installation of previous models, an alarm signal terminal is not provided for the upper arm.

8. Postscript

Fuji Electric's FS-type "V-Series" IGBT chips (V-IGBT) having a trench gate structure and the "V-Series IPM" (V-IPM) that incorporates a new control IC into a new package have been introduced. The V-IPM realizes a compact size and high efficiency, and is able to meet market expectations. In the future, Fuji Electric intends to continue to concentrate on product development to satisfy market needs.

References

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