“P633C Series” 3rd-Generation Small IPMs

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ABSTRACT

Worldwide energy consumption has been increasing year by year, resulting in many countries advancing policies and regulations related to energy savings. In addition to these energy-saving policies and regulations, there is also demand for low-noise and noise-immunity features in compliance with EMC-related standards for communication and control equipment. To meet these demands, Fuji Electric has developed the “P633C Series” 3rd-generation small IPMs with improved energy-saving and EMC performance. Applying the 7th-generation FWD chip technology improves the trade-off between generated loss and generated noise. In addition, they come with newly developed 3ch-HVIC and LVIC chips to improve malfunction and breakdown capability against external surges.

1. Introduction

Recent energy consumption throughout the world has been increasing year by year due to economic development in China and other emerging economies. As energy consumption increases, CO_2 emissions also increase, and since it is considered the main cause of global warning, it has become imperative to reduce energy consumption.

Against this background, countries are promoting policies and regulations that promote energy savings.

Residential air conditioners are one of the most energy-consuming equipment. In China, which accounts for about half of global demand, most of the air conditioners produced have been changed to inverter types that comply with the stricter energy-saving regulations enacted in 2020. Furthermore, inverter air conditioners are expected to become popular in emerging markets such as Southeast Asia, the Middle East, and South America as a way of balancing the growing demand for air conditioners among people who enjoy a higher standard of living with the need to reduce energy consumption.

In addition to meet stricter energy saving regulations, it is also necessary to prevent emission noise generated by the switching operation of inverter circuits from adversely affecting communication and control equipment. Specifically, low noise and noise tolerance also need to be achieved at the same time in compliance with electromagnetic compatibility (EMC) standards set by the Comité international spécial des perturbations radioélectriques (CISPR), the IEC’s special committee on radio interference. Moreover, since air conditioners are installed in close proximity to the same power system as other electrical equipment, they must be able to continue to operate without malfunctioning or breaking down even when there are external surges due to lightning and static electricity or electrical surges generated by other equipment.

To meet these requirements, Fuji Electric has been commercializing small intelligent power modules (IPMs) for use in three-phase inverter bridge circuits for air conditioners since 2012. We have recently developed the “P633C Series” as a line-up of 3rd-generation small IPMs that exhibit reduced loss and generated noise and improved noise tolerance compared to our conventional 2nd-generation small IPMs.[(1),(2)]

2. Product Overview

Figure 1 shows the external appearance of the product, and Table 1 shows the product’s outline specifications.

The product line-up consists of three types rated at 650 V/15, 20, and 30 A. In terms of protection functions, they have a built-in overcurrent protection, low

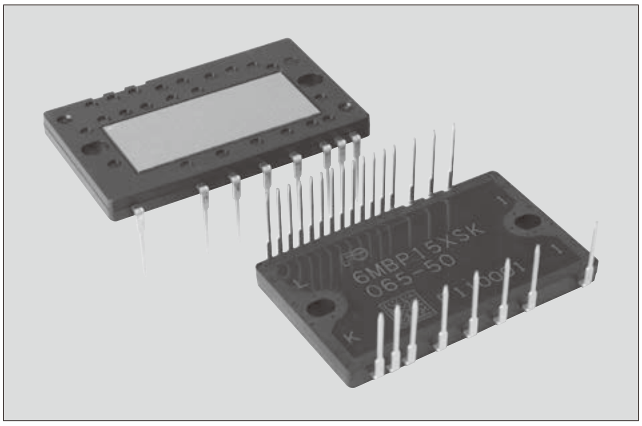

Fig.1 “P633C Series”

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Table 1 Outline specifications for the “P633C Series” 3rd-generation small IPMs

Item	Specification		
Parts number	6MBP15XSK065-50	6MBP20XSK065-50	6MBP30XSK065-50
Collector-emitter voltage V_{CES}	650 V (max.)		
Collector current I_C	15 A (max.)	20 A (max.)	30 A (max.)
Collector-emitter saturation voltage $V_{CE(sat)}$	1.6 V (typ.)		
Diode forward voltage V_F	2.0 V (typ.)		
Isolation voltage V_{isol}	1,500 V $AC_{(rms)}$		
Chip junction temperature during continuous operation T_{vjop}	−40°C to +150°C		
Protective function	Overcurrent protection, undervoltage protection, overheating protection, error alarm output, temperature output protection		

input voltage protection, temperature output, overheat protection and alarm output.

The 3rd-generation small IPMs apply a 7th-generation free wheeling diode (FWD) chip technology[3] that has been optimized to improve the trade-off between generated loss and generated noise. In addition, they are equipped with a newly developed 3-channel high voltage integrated circuit (3ch-HVIC) chip and a low voltage integrated circuit (LVIC) chip to improve the malfunction and breakdown capability due to external surges.

The 3rd-generation small IPMs use the P633 Series package, which has the same external dimensions of W43 × D26 × H3.7 (mm) as the 2nd-generation small IPMs. They comply with the UL1557 standard of electrically isolated semiconductor devices.

Figure 2 shows the circuit configuration of the 3rd-generation small IPMs, and Fig. 3 shows their cross-sectional structure. The 3rd-generation small IPM comprises 7th-generation insulated gate bipolar transistor (IGBT) chips and FWD chips on the insulating substrate to configure a three-phase inverter bridge circuit. The LVIC for driving the low-side IGBTs and the HVIC for driving the high-side IGBTs of the three-phase inverter bridge circuit are mounted on a lead frame. A 3ch-HVIC is used, in which three phase circuits are integrated into a single chip.

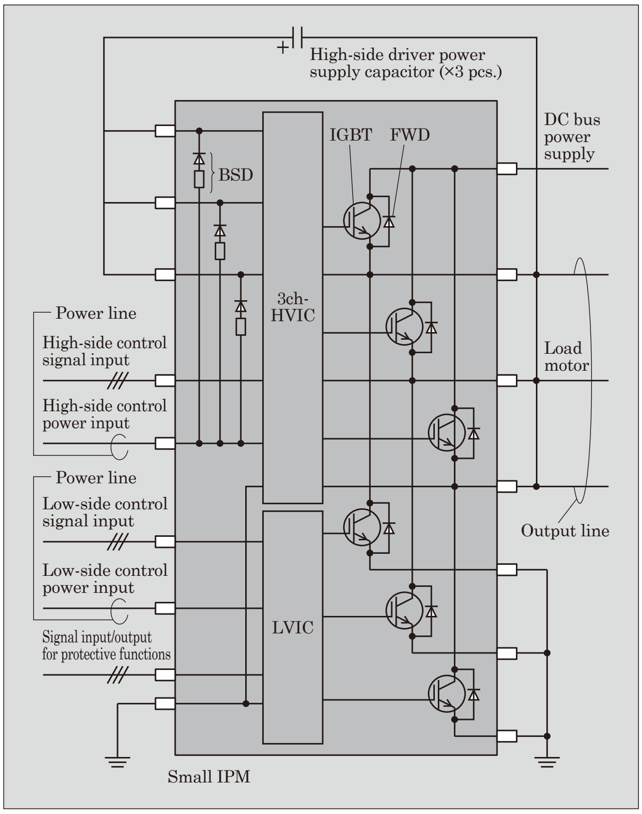

Fig.2 Circuit configuration of the 3rd-generation small IPMs

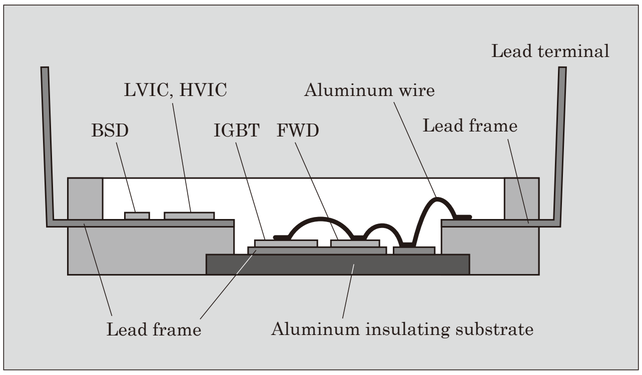

Fig.3 Cross-sectional structural diagram of the small IPM

The high-side circuit includes three boot strap diodes (BSDs) with built-in current-limiting resistors that have linear resistance characteristics. Therefore, only three external capacitors are required to the small IPM to realize a power supply circuit for high-side driving. This eliminates the need for a separately configured insulated power supply circuit, thereby simplifying the circuit and reducing the size of the print circuit board.

3. Low Loss and Low Noise

Figure 4 shows the results of switching loss analysis for a standard inverter air conditioner when operating under typical conditions. The loss generated by the turn-on operation of the IGBT, consisting of the turn-on loss P_{on} of the IGBT itself and the recovery loss P_{rr} of its opposite FWD, is the dominant factor accounting for 68% of total switching loss.

A common technique to reduce turn-on and recovery losses is to increase the switching speed. However,

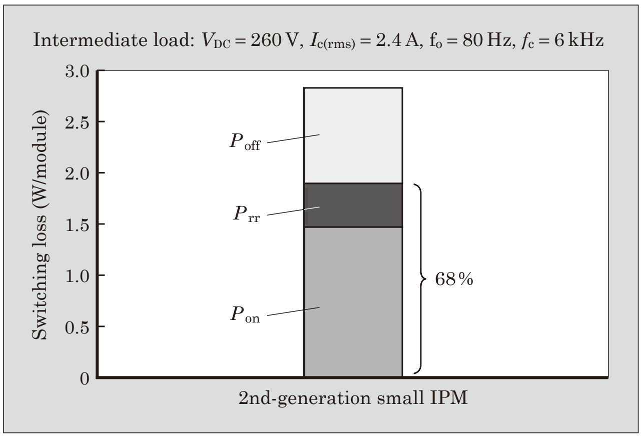

Fig.4 Switching loss of a standard inverter air conditioner

this technique results in the sharp rise of the voltage change rate d*v*/d*t* during switching, which increases emission noise. Therefore, it is important to reduce switching loss without increasing d*v*/d*t*. We optimized the lifetime killer and drift layer thickness of the 3rd-generation small IPMs using a 7th-generation FWD chip technology, resulting in both lower switching loss and d*v*/d*t*.

Figure 5 shows the FWD recovery operation waveforms of 2nd- and 3rd-generation small IPMs. The d*v*/d*t* during recovery operation of the FWD in 3rd-generation small IPMs is 58% lower than that of 2nd-generation small IPMs. As a result, oscillations of V_R after voltage rise-up are no longer observable. The

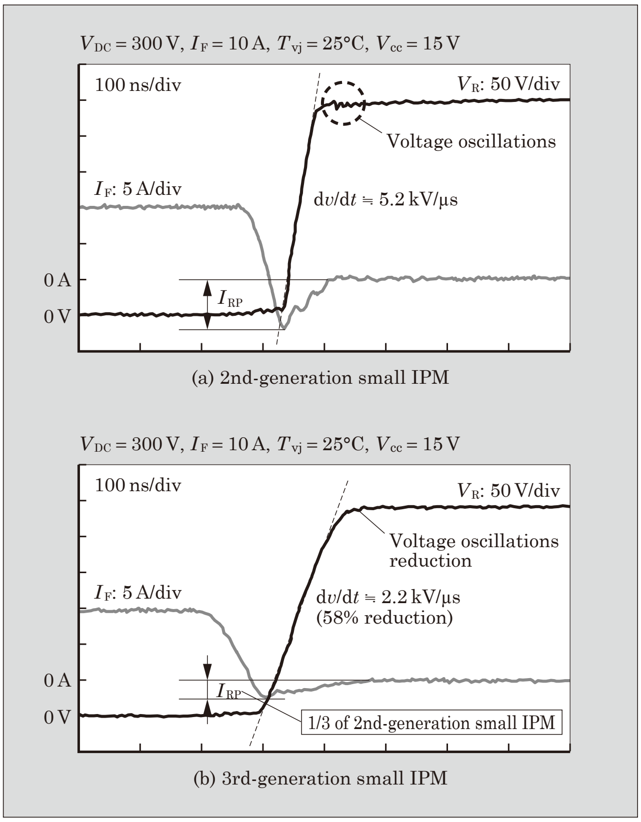

Fig.5 Comparison of FWD recovery operation waveforms

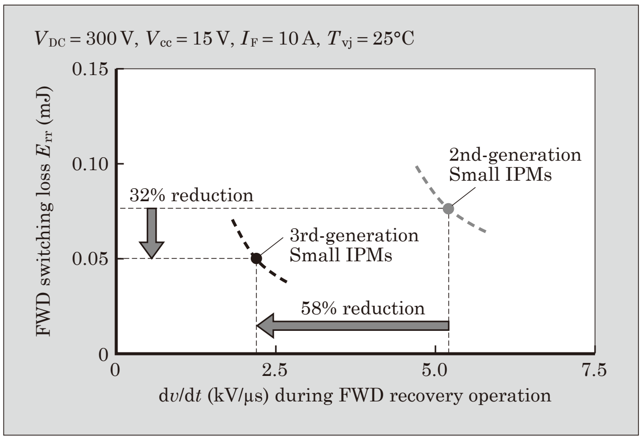

Fig.6 Trade-off between d*v*/d*t* and loss during FWD recovery operation

FWD's recovery current peak I_{RP} reduced to one-third of the 2nd-generation small IPMs, resulting in a more moderate current recovery waveform past the peak value. This reduced switching losses by 32% and d*v*/d*t* by 58% compared to the 2nd-generation small IPMs during the FWD recovery operation shown in Fig. 6.

4. Improved Malfunction and Breakdown Capability

External surges caused by lightning and static electricity, as well as conduction noise generated by other equipment, propagate through the output lines and power lines to which the load motor is connected, and are thereafter applied to the small IPM (see Fig. 2). In the next section, we will describe the improvement in withstand capability against external surges applied to the output and power lines.

4.1 Improved tolerance for output line noise

External surges propagated through the output line may enter the internal circuit of the 3ch-HVIC of the small IPM directly or through a capacitor in the high-side driver's power supply, causing malfunction of the 3ch-HVIC and other damage.

The 3rd-generation small IPM 3ch-HVIC applies a newly developed technology[(4)] to suppress the unexpected operation of the parasitic pnp/pnp transistor formed in the internal circuit, thereby improving the malfunction capability due to external surges. Details are described in "3ch-HVIC Technology for Next-Generation Small IPMs" on page 257.

4.2 Improved electrostatic discharge withstand capability for power lines

Power lines are connected to both the HVIC and LVIC. This means that there is risk of HVIC or LVIC damage due to electrostatic discharge (ESD) when using the small IPM or during soldering process. Figure 7 shows the block circuit diagram of the LVIC. An ESD protection circuit with low impedance is con-

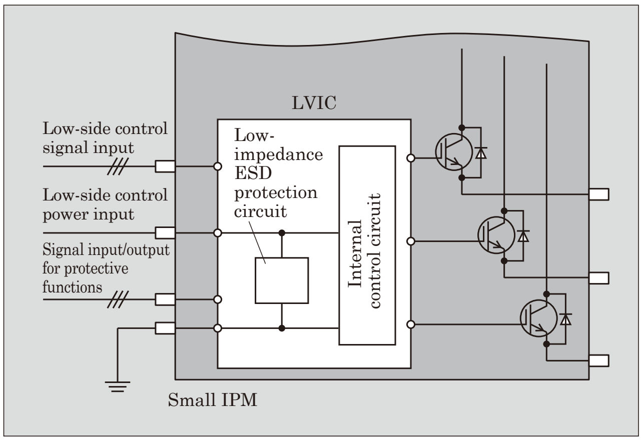

Fig.7 LVIC block circuit diagram

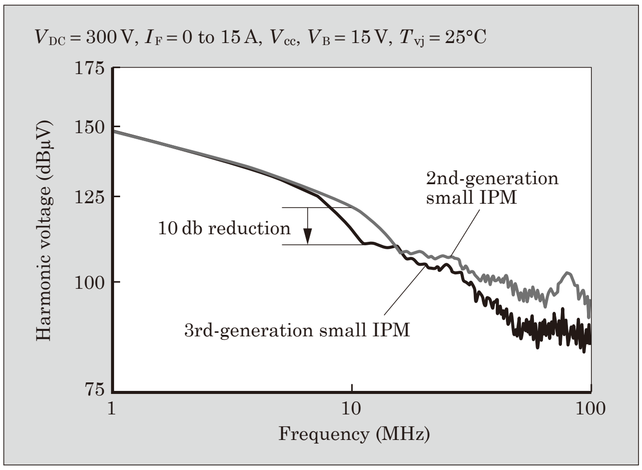

Fig.9 Harmonic voltage frequency analysis results of FWD recovery operation

nected in parallel with the internal circuit of the LVIC to quickly clamp the surge voltage of the applied electrostatic discharge and attenuate the voltage propagating to the internal circuit, thereby preventing the internal circuit from being damaged by the surge. The same protection circuit is also built into the HVIC. As a result, the 3rd-generation small IPMs have an electrostatic discharge withstand capability of 2.5 kV, more than twice that of the 2nd-generation small IPMs.

5. Application Benefits for Air Conditioners

Figure 8 shows the simulation results for power loss when using a residential air conditioner. The 3rd-generation small IPM represented lower loss than conventional products when operating at minimum to intermediate loads. This operating conditions can have a significant impact on the annual performance factor (APF)* for air conditioners. Figure 9 shows the frequency analysis results of harmonic voltages that affects emission noise during FWD recovery operation, which is one cause of generated noise. The 3rd-generation small IPM produces approximately 10 dB (one third) less noise than the 2nd-generation products, mainly in the 10 MHz bandwidth. These results show that the 3rd-generation IPMs have significantly lower noise than our previous products while also decreasing loss.

In addition, we conducted an electrical fast transient/burst immunity test (IEC 61000-4-4) with the circuit configuration shown in Fig. 10 to evaluate the external surge withstand capability. Table 2 shows the results of testing the 3rd-generation small IPM on

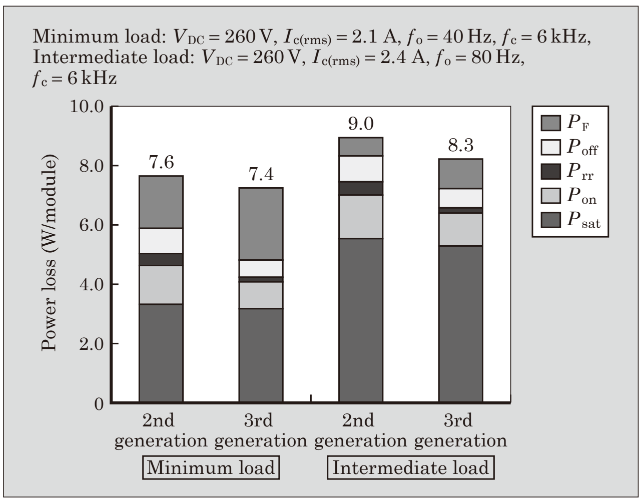

Fig.8 Comparison of power loss simulation results

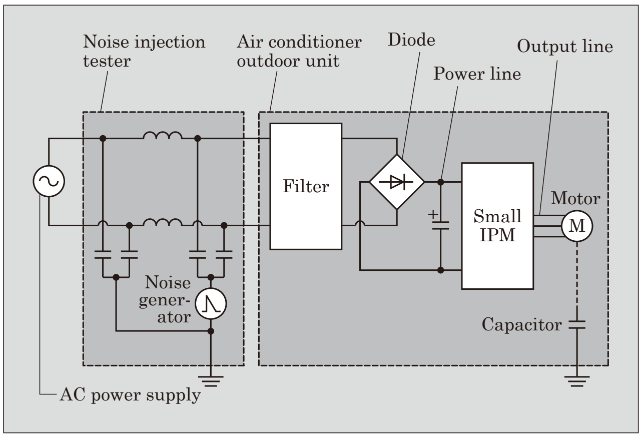

Fig.10 Circuit configuration of electrical fast transient/burst immunity testing

Table 2 Testing results in surge voltage injection

Item		Surge voltage level (kV)						
		1.0	1.5	2.0	2.5	3.0	3.5	4.0
Positive voltage	2nd-generation small IPM	○	○	○	○	△	–	–
	3rd-generation small IPM	○	○	○	○	○	○	○
Negative voltage	2nd-generation small IPM	○	○	○	○	△	–	–
	3rd-generation small IPM	○	○	○	○	○	○	○

○: No malfunction, operation continues
△: Malfunction, operation stoppage

* Annual performance factor (APF): (Annual cooling capacity + heating capacity)/power consumption

the outdoor unit of a commercial residential air conditioner, with surges superimposed on the AC power line from a noise injection tester. This test confirmed that the 3rd-generation small IPMs did not malfunction even when applied with a disturbance voltage that simulated a high external surge voltage of 4 kV or higher, as well as they had a noise tolerance that was at least 1 kV higher than that of the 2nd-generation small IPMs and could operate continuously without errors or failures.

6. Postscript

In this paper, we described the "P633C Series" 3rd-generation small IPMs. We reduced loss and generated noise for the small IPMs by optimizing the FWD chips through utilization of our 7th-generation FWD chip technology. In addition, we have optimized the HVIC to ensure improved breakdown and malfunction capability against external and electrical surges, enabling it to meet market needs not only for air conditioners, but also for compressors, fans, servomotors, and other drive equipment that are increasingly being used to achieve inverter functionality.

Moving forward, we will continue to develop products that contribute to a more energy-efficient society.

References

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