Intelligent Power Modules

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1. Introduction

With advances in power electronic equipment such as general purpose inverters, numerically controlled (NC) machine tools, and industrial robots, demands for high efficiency, low noise, advanced functions, and downsizing have increased. To meet the requirements of low loss and high frequency power devices, conventional bipolar transistor have been replaced by insulated-gate bipolar transistors (IGBTs) which belong to the metal-oxide-semiconductor (MOS) transistor family. This has resulted in improved high-frequency and low-loss characteristics.

At the same time, to meet requirements for advanced functionality and downsized power devices, intelligence enhancement is being performed through the incorporation of peripheral circuits such as pre-driver and a protection circuits into the module and IGBT loss is being reduced. These can reduce the number of IGBT peripheral circuits and parts as well as shorten design time for the power section, contributing to device downsizing and function advancement.

Using the third-generation IGBT with its high-speed, low-loss characteristics as the output stage power device and applying a newly developed custom IC to the control circuit, Fuji Electric has realized an optimum IGBT driver and developed a series of high-speed, low-loss, IGBT output, intelligent power modules (IPMs) with various internal protective functions, ranging from 15A to 200A for the 600V series and from 50A to 100A for the 1,200V series.

2. Merits of the IPM

Fuji Electric's IPM development was based upon the needs of users as shown in **Table 1**. The merits of the IPM are as follows:

(1) Resistance to damage in abnormal conditions

Table 2 shows the causes of IGBT damage and protection for the IPM. With its optimized predriver and protection circuits, the IPM device is resistant to damage.

(2) Low loss, high-speed switching

Low loss was realized by using a third-generation IGBT as the output IGBT.

Table 1 User needs and IPM development items

Inverter user needs		Device requirements	IPM development items
Use of high frequency		High-speed switching	Third-generation IGBT with current sensing function
Down-sizing	Cooling fins	Low loss	
	Circuits	Compactness	New packages
Shortening of design time		Built-in control and protection circuits	-IGBT with current sensing function -Compact circuit design
High reliability		Reliable detection and protection	-Development of custom ICs -Optimum circuit design

Table 2 Causes of IGBT damage and measures of protection for IPMs

Cause of IGBT damage	Measures of protection for IPMs
Overcurrent	Overcurrent protection
Short-circuit current	Short-circuit current protection
Undervoltage of pre-driver	Undervoltage protection
Gate voltage oscillation	Optimum design by incorporating the pre-driver circuit
Overvoltage of gate	
Static electric breakdown of gate	
Pre-driver circuit mal-function due to noise	Optimum design of the custom IC and peripheral circuits
Abnormal temperature	Overheat protection
Overvoltage (RBSOA surge voltage)	-Improvement of IGBT and FWD chips -Optimum package design

(3) Highly integrated, compact design

High integration and compactness were achieved through special IC development and new packaging technology.

3. IPM Configuration

Figure 1 shows a function block diagram for the inverter. This IPM consists of an inverter section, a brake section (used in certain models), a pre-driver circuit, and a protection circuit.

3.1 Inverter section

For the power device of the inverter section, the IPM

Fig. 1 Function block diagram for the inverter

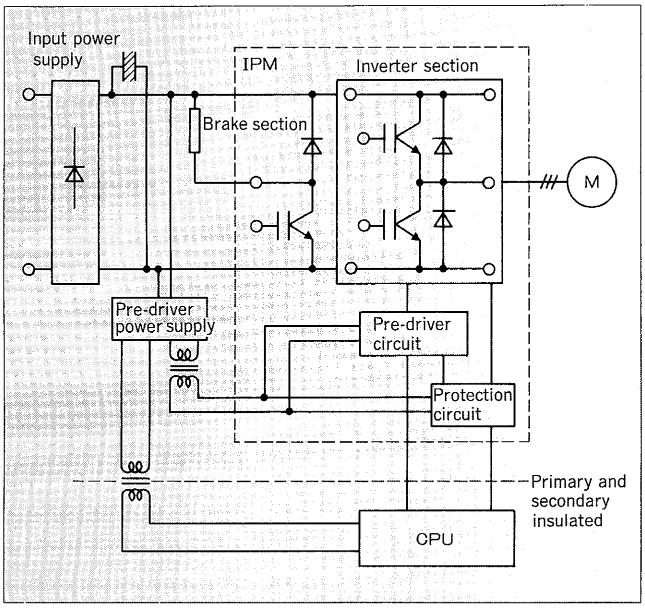


Fig. 2 Power loss during IPM inverter operation

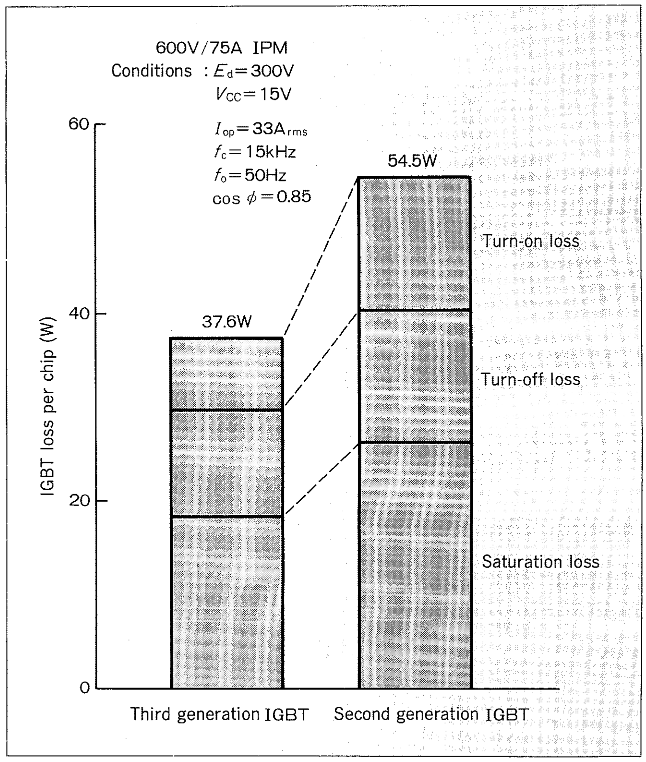


Table 3 Characteristics of the IPM power section
(a) 600V series

Item	Symbol	Conditions	Specification
Collector-emitter saturation voltage	$V_{CE(sat)}$	V_{CC} = 15V, I_C = rated, T_j = 25°C	2.5V max.
Turn-on time	t_{on}	V_{DC} = 600V, V_{CC} = 15V, I_C = rated, T_j = 25°C	2.0μs max.
Turn-off time	t_{off}		3.0μs max.
	t_f		0.5μs max.

(b) 1,200V series

Item	Symbol	Conditions	Specification
Collector-emitter saturation voltage	$V_{CE(sat)}$	V_{CC} = 15V, I_C = rated, T_j = 25°C	3.0V max.
Turn-on time	t_{on}	V_{DC} = 300V, V_{CC} = 15V, I_C = rated, T_j = 25°C	2.0μs max.
Turn-off time	t_{off}		3.0μs max.
	t_f		0.5μs max.

V_{CC} is pre-driver voltage.

Table 4 Characteristics of the IPM protection circuit (600V/75 A, Typical model)

Item		Symbol	Conditions	Specification			Unit
				Min.	Std.	Max.	
Overcurrent protection trip level		I_{OC}	V_{CC} = 15V, T_j = 25°C	115	–	–	A
Short-circuit current protection trip level		I_{SC}		–	300	–	A
Under-voltage protection	Trip level	V_{UVT}	T_j = 25°C	11.0	–	12.5	V
	Hysteresis	V_H		0.2	–	–	V
Overheat protection	Trip level	T_{OH}	V_{CC} = 15V	100	–	125	°C
	Hysteresis	T_H		–	10	–	°C
Alarm signal hold time		t_{ALM}	V_{CC} = 15V, T_j = 25°C	–	2	–	ms

uses a third-generation IGBT in which the trade-off relation between saturation voltage $V_{CE(sat)}$ and switching time was improved to realize low loss and high-speed switching. **Table 3** shows the characteristics of the IPM power section.

Figure 2 compares the power loss during inverter operation of an IPM equipped with a second-generation IGBT and a third-generation IGBT. The third-generation IGBT realizes a 30% reduction in power loss compared to the second-generation IGBT. As a result, the inverter can raise efficiency, reduce size, operate at the carrier frequency of 15 kHz, and satisfy user demands for quieter inverter operation.

3.2 Brake section (used in certain models)

The models with a built-in dynamic braking circuit can be used in applications of high energy regeneration.

3.3 Pre-driver circuit

The driver circuit was optimized to fully utilize the merits of the IGBT.

Use of the IGBT can keep power consumption of the pre-driver circuit low, restrain heating of the control circuit, and increase reliability.

The control circuit requires three isolated power supplies for the upper arm and one for the lower arm. (Certain models require three isolated supplies for the lower arm.)

3.4 Protection circuit

Each IGBT can be protected by the protection circuit which incorporates functions for overcurrent protection, short-circuit protection and pre-driver undervoltage protection. In addition, the lower arm is equipped with overheat protection and alarm signal output functions. (Certain models have an alarm output function also on the upper arm.) **Table 4** shows an example of IPM protection circuit characteristics.

3.4.1 Overcurrent protection

The current sensing function of the IGBT applied to the power device is used to monitor each IGBT's collector current. Each IGBT may be protected activating the protection circuit to break overcurrent due to overload.

3.4.2 Short-circuit current protection

This function monitors the collector current with the same method as for overcurrent protection. It instantaneously detects a short-circuit and protects the IGBT by activating the protection circuit to break the current.

3.4.3 Control power supply undervoltage protection

This function monitors the control power supply voltage which drives the custom IC used in the IPM. When the voltage drops, the protection circuit is activated to stop the output. This prevents IGBT damage due to driver undervoltage.

3.4.4 Overheat protection

A high precision thermistor, used as a temperature sensor, activates the protection circuit to stop the output when there is an abnormal temperature rise.

3.4.5 Alarm signal output function

This function outputs alarm signals to external devices when the overcurrent, short-circuit current, control power undervoltage, or overheat protection circuit on the lower arm is activated. (Certain models have this function also on the upper arm.)

The incorporation of these functions in the IPM prevents power device damage under abnormal condition, and makes it possible to reduce inverter size and shorten design time.

4. IPM Product Line

Table 5 shows the line of IPM products and their built-in functions, **Figure 3** shows the block diagrams, **Figure 4**, the dimensions, and **Figure 5**, the exterior views of these products.

4.1 Super mini types (600V/15 to 20A)

Light weight, thin and compact size has been achieved by mounting power chips and electronic parts for control circuits on an insulated aluminum substrate and by using a case with built in terminals.

4.2 Medium capacity types (600V/50 to 100A, 1,200V/50A)

A double-deck construction which separates an insulated substrate for power chips and a printed substrate for control circuits has resulted in a reduced installation area.

4.3 Large capacity types (600V/150 to 200A, 1,200V/75 to 100A)

These have the same construction as the medium capacity types. Additional features are as follows:

(1) The control power supply can be connected during each phase to the lower arm, resulting in improved noise immunity and resistance to malfunctions.

Table 5 IPM product line and built-in functions

(a) 600V series IPMs

Model	Rated voltage	Rated current		Built-in functions					Block diagram	Package
		Inverter section	Brake section	Dr.	OCT	SCT	UVT	OHT		
6MBP15JB060	600V	15A	–	○	○	○	○	○	No. 1	P602
6MBP20JB060	600V	20A	–	○	○	○	○	○	No. 1	P602
7MBP50JA060	600V	50A	15A	○	○	○	○	○	No. 2	P603
7MBP50JB060	600V	50A	30A	○	○	○	○	○	No. 2	P604
7MBP75JB060	600V	75A	30A	○	○	○	○	○	No. 2	P604
6MBP100JA060	600V	100A	–	○	○	○	○	○	No. 3	P604
6MBP150JA060	600V	150A	–	○	○	○	○	○	No. 4	P605
6MBP200JA060	600V	200A	–	○	○	○	○	○	No. 4	P605

(b) 1,200V series IPMs

Model	Rated voltage	Rated current		Built-in functions					Block diagram	Package
		Inverter section	Brake section	Dr.	OCT	SCT	UVT	OHT		
7MBP50JA120	1,200V	50A	15A	○	○	○	○	○	No. 2	P604
6MBP75JA120	1,200V	75A	–	○	○	○	○	○	No. 4	P605
6MBP100JA120	1,200V	100A	–	○	○	○	○	○	No. 4	P605

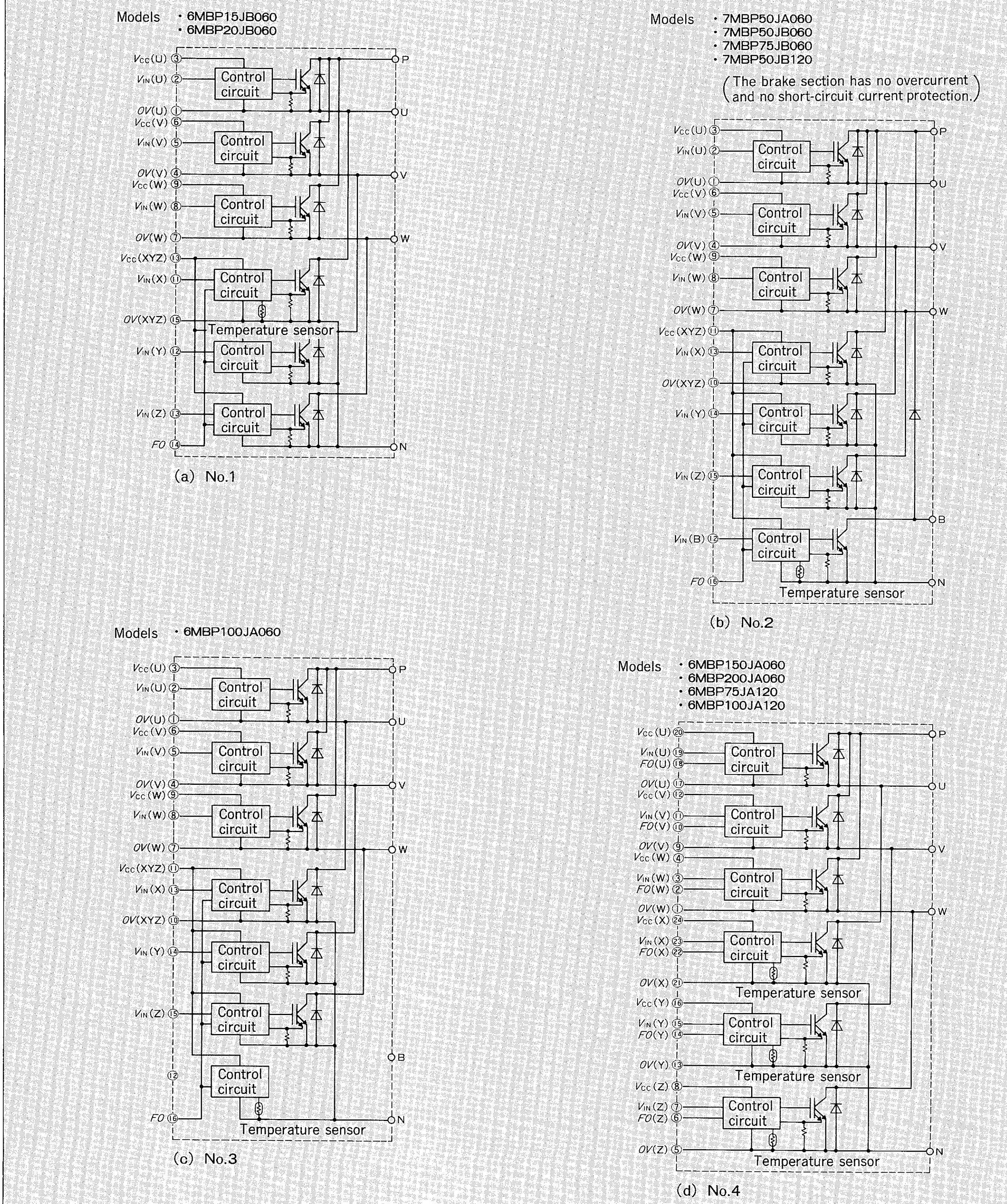
-All the inverter sections are of a 6-element pack type.

-The ○ mark indicates a built-in function.

-The – mark indicates a function that is not built-in.

-Dr.: Pre-driver circuit, OCT: Overcurrent protection, SCT: Short-circuit current protection, UVT: Control power supply undervoltage protection, OHT: Overheat protection.

Fig. 3 Block diagrams (corresponding to Block diagrams No. 1 to 4 in Table 5)



Remarks (1) The control circuit includes the following circuits:
① pre-driver ② overcurrent protection ③ short-circuit current protection ④ control power supply undervoltage protection.
(2) The control circuit connected to a temperature sensor includes an overheat protection circuit.

(2) Three built-in temperature sensors for overheat detection provide more reliable overheat protection.

(3) Each individual element is equipped with an alarm signal output function. This enables alarm signals to also be output from the upper arm. Alarm signals of overcurrent flowing only in the upper arm can be

Fig. 4 Dimensions (corresponding to Packages P602 to P605 in Table 5)

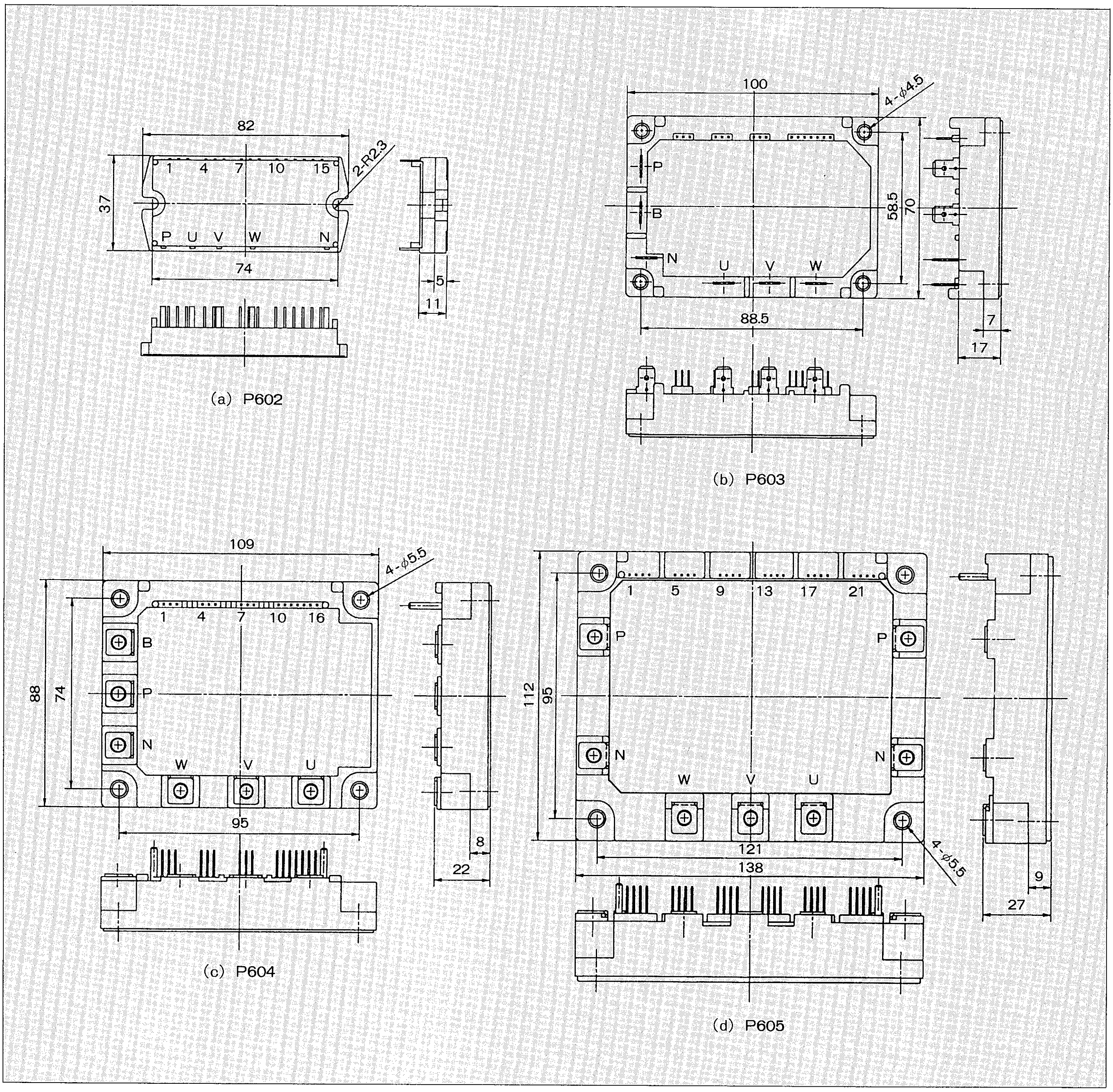
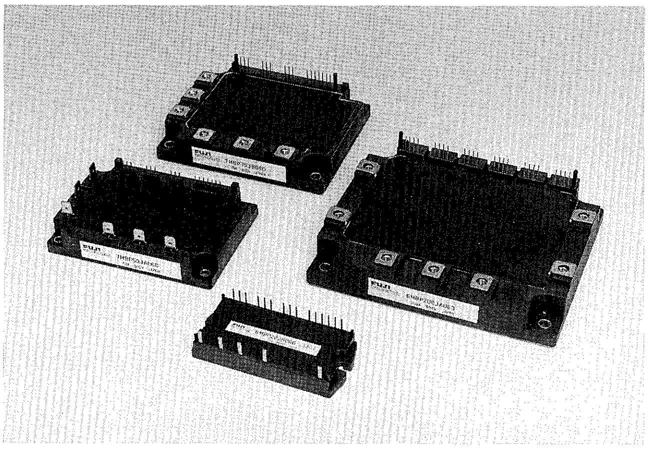


Fig. 5 Exterior view of IPMs



sent to external devices.

5. Control and Protective Operation

Figure 6 shows a function block diagram for the IPM.

5.1 Switching operation

Switching operation is controlled by input voltage. When at the L level, the IGBT gate-emitter is forward-biased to 14 to 15V (when V_{CC}=15V) and is in the on-state. When input voltage is at the H level, IGBT gate-emitter is shorted through the gate resistance by the transistor and is in the off-state. **Figure 7** shows IPM switching waveforms. The IPM has been designed with gate resistance optimized to prevent the output IGBT from being wrongly activated by noise and to reduce the circuit inductance. The input section is designed to be resistant to self-induced or external noise.

Fig. 6 IPM Function block diagram

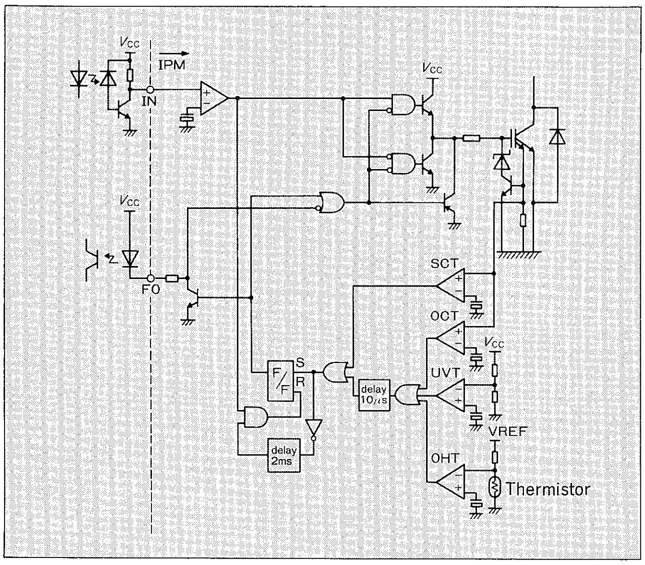
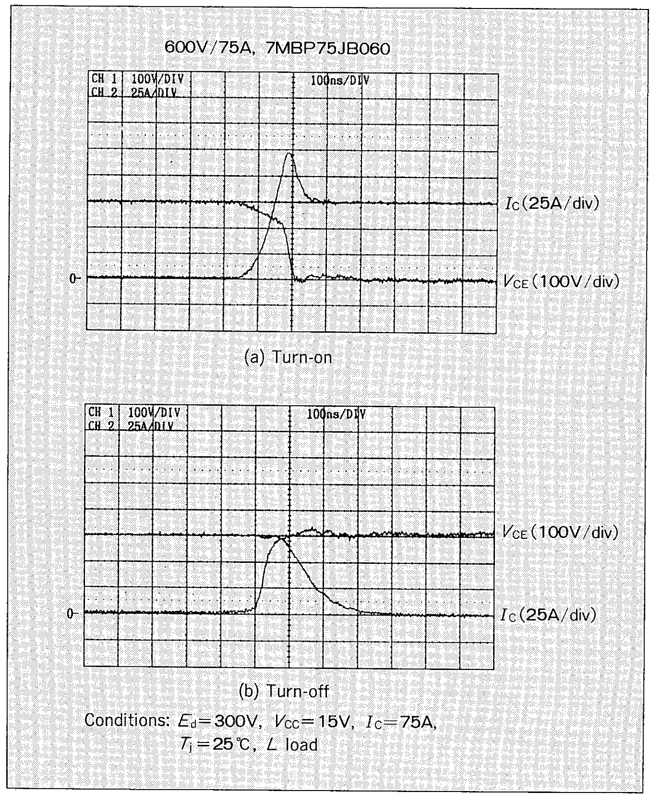


Fig. 7 IPM switching waveforms

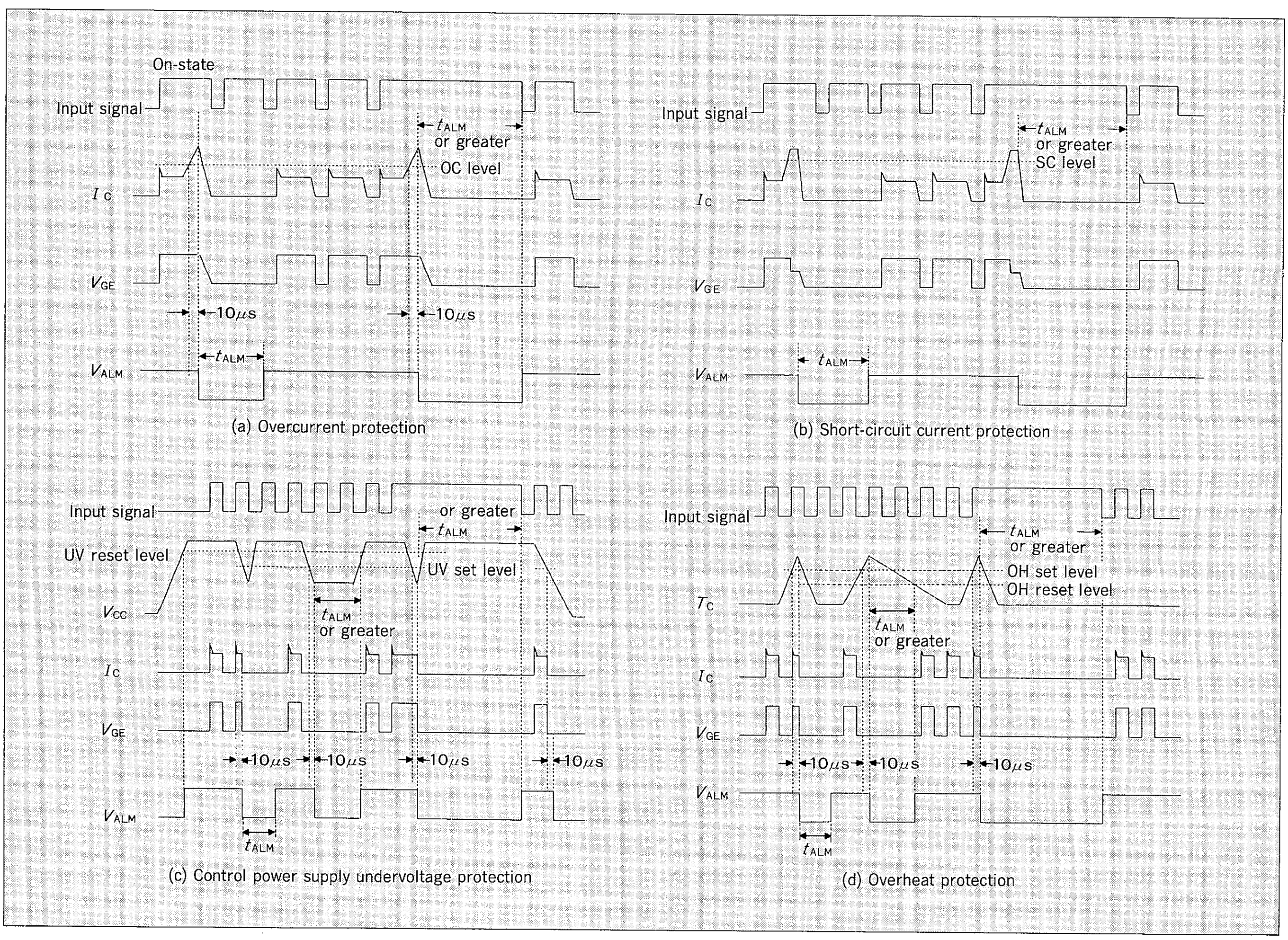


(a) Turn-on

(b) Turn-off

Conditions: E_d=300V, V_{CC}=15V, I_C=75A, T_j=25℃, L load

Fig. 8 Timing charts of protective functions



(a) Overcurrent protection

(b) Short-circuit current protection

(c) Control power supply undervoltage protection

(d) Overheat protection

5.2 Protective operation

Figure 8 shows the operation timing charts of the IPM protective functions. Descriptions of the operation are given below.

5.2.1 Overcurrent protective function

The collector current of each IGBT is monitored. When overcurrent trip level current (I_{OC}) lasts 10 μs or more, this protective function is activated to break the overcurrent. To suppress surge voltage caused by steep *di*/*dt* when the collector current is broken, a soft-breaking circuit is also built-in.

When activated, the overcurrent protection circuit simultaneously enters the alarm output and protection states, which last t_{ALM}. The alarm output and protection states are reset by the off input signal.

5.2.2 Short-circuit current protective function

This function monitors each IGBT collector current with the current sensor. When a short-circuit trip level current (I_{SC}) is detected, the protection circuit is activated and soft breaking is performed simultaneously with alarm output. The alarm output duration and reset are the same as for overcurrent protection. When a short circuit occurs, the current limiting circuit composed of a Zener diode and a transistor connected between the gate and emitter, as shown in **Figure 6**, functions to instantaneously lower gate-emitter voltage to intermediate voltage level and to limit the current.

5.2.3 Pre-driver undervoltage protective function

This function monitors the pre-driver voltage. When a voltage equal to or less than the under-voltage trip level (V_{UVT}) lasts 10 μs or longer, this function soft breaks the current and simultaneously outputs the alarm. The alarm output lasts t_{ALM}, the same as for overcurrent protection. Reset is performed after time t_{ALM} passes and when conditions are met that the input signal is an off signal and supply voltage is the reset voltage.

5.2.4 Overheat protective function

This function becomes active when the overheat set level temperature lasts 10 μs or more to soft break the current. The moment the protection circuit operates, the eqiupment enters both the alarm output and protection states. The alarm output and protection states are reset when the input signal is an off signal and temperature is at the overheat reset level.

6. Conclusion

The merits, built-in functions and operation of the newly developed IPM product line have been introduced. We believe these IPMs can meet the needs of the general purpose inverter industry which requires downsizing, advanced functions and low noise. In the future, we will make efforts to improve built-in power chip performance and develop high level, multifunctioned, and sophisticated control circuits.