

New Intelligent Power Modules (R Series)

Atsushi Yamaguchi
Hiroaki Ichikawa

1. Introduction

The equipment of power electronics application is comprised of general use inverters, numeric control (NC) machine tools, and industrial robots. Recently, the requirements of lower noise, higher efficiency, advanced functions, lower price, and downsizing for these items have been growing.

The power devices used as the equipment of power electronics applications are progressing toward lower loss and higher frequency, and the IGBT (insulated gate bipolar transistor) rather than the bipolar transistor is gaining popularity.

On the other hand, together with lowered loss for the IGBT, intelligence is achieved by locating the peripheral circuits such as the driving circuit and various protective circuits inside the module. It then becomes possible to shorten the design time at the power circuit and contributes to downsizing and advanced equipment function.

In keeping step with the trends of making the power devices intelligent, Fuji Electric announced the bipolar transistor type of intelligent power modules

(BJT-IPM) in 1989. In 1992, the J series of IGBT-IPM (J-IPM) that pursued lower loss was developed and in 1995 the N series of IGBT-IPM (N-IPM) aimed at lower price and lower noise was developed and produced. This time, the R series of IGBT-IPM (R-IPM) pursues higher cost performance, higher reliability and advanced functions.

The line-up and features of Fuji Electric's IGBT-IPMs and the R-IPM are introduced in the following.

2. Fuji Electric's Conventional IGBT-IPM Line-Up and Problems

The line-up, performances and features of both the J-IPM and N-IPM are shown in Table 1. The J-IPM was developed with particular attention to low loss. The N-IPM realized low noise (soft switching) and low loss in order to respond to the market needs of EMC (electro magnetic compatibility) regulations and to match the CE mark. Furthermore, the N-IPM is an IPM with a lower price and higher reliability made possible by the adoption of new construction and new materials. The integrated functions are shown in

Table 1 The J-IPM and the N-IPM

| Series | Type | Inverter | | | Dynamic brake | | | Features |
|--------|--------------|---------------|-----------|-----------|---------------|-----------|-----------|--|
| | | V_{CES} (V) | I_C (A) | P_C (W) | V_{CES} (V) | I_C (A) | P_C (W) | |
| J-IPM | 6MBP15JB060 | 600 | 15 | 40 | – | – | – | Low loss High speed switching |
| | 6MBP20JB060 | 600 | 20 | 50 | – | – | – | |
| | 6MBP100JA060 | 600 | 100 | 240 | – | – | – | |
| | 6MPB150JA060 | 600 | 150 | 450 | – | – | – | |
| | 6MBP200JA060 | 600 | 200 | 600 | – | – | – | |
| | 6MBP100JA120 | 1,200 | 100 | 600 | – | – | – | |
| | 7MBP50JB060 | 600 | 50 | 150 | 600 | 30 | 80 | |
| | 7MBP75JB060 | 600 | 75 | 195 | 600 | 30 | 80 | |
| N-IPM | 7MBP50JA120 | 1,200 | 50 | 240 | 1,200 | 15 | 80 | Low loss Soft switching High reliability |
| | 6MBP50NA060 | 600 | 50 | 198 | – | – | – | |
| | 6MPB75NA060 | 600 | 75 | 320 | – | – | – | |
| | 6MPB100NA060 | 600 | 100 | 400 | – | – | – | |
| | 7MBP50NA060 | 600 | 50 | 198 | 600 | 30 | 120 | |
| | 7MBP75NA060 | 600 | 75 | 320 | 600 | 50 | 198 | |
| | 7MBP100NA060 | 600 | 100 | 400 | 600 | 50 | 198 | |

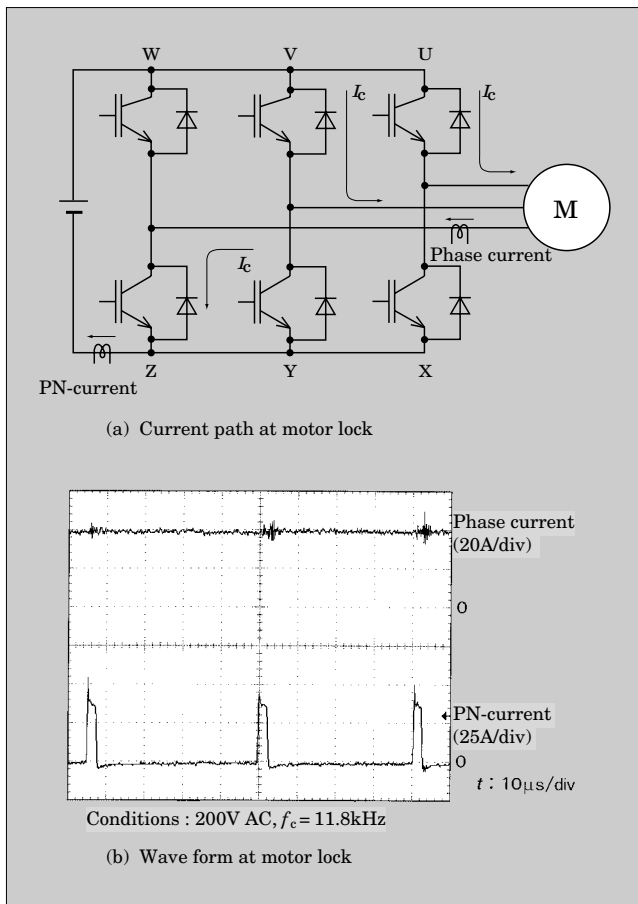
Table 2. The functions of the J-IPM and N-IPM are identical, and the protection functions against short circuit, overcurrent, drive power supply under-voltage and overheating are integrated.

However, since both the J-IPM and the N-IPM are constructed of many types of electronics parts, there are of course some limits to downsizing and low price. To protect against overheating the temperature of the insulation substrate mounted with the IGBT chips was detected by thermistors. But it became problematic in applications where the current was concentrated into a few chips like motor lock mode, as shown in Fig. 1.

Table 2 Protective functions of the IPM

| Function | Description |
|---|--|
| Overcurrent protection | Monitor collector current of every IGBT, and protect against overcurrent by cutting off the current |
| Short circuit protection | Protects against short circuit current by cutting off the current by the same means as overcurrent protection |
| Drive power supply under-voltage protection | Detects drive power supply voltage, and protect in order to avoid destruction caused by under-voltage in case of lowering of voltage |
| Overheat protection | Stores precise thermistor as temperature sensor and protects against abnormal temperature rise by rejection of output |

Fig.1 Current path and waveform at motor lock



When the current was concentrated to the chip which was located on the far side from the sensor on the substrate, the sensor could not follow the rapid temperature risings and could not protect it. In order to solve these problems and to realize higher performance as well as higher cost performance, the R-IPM was developed.

3. The R-IPM

The line-up, characteristics and integrated functions are shown in Table 3. The R-IPM has been applied the 3rd generation IGBT chip, which $V_{CE(sat)}$ is 2.3V typically, thereby achieving lower loss. Furthermore, they are comprised of the T_j detecting overheat protection function in addition to the former IPM's functions. Outlines, external view and internal equivalent circuit are shown in Figs. 2, 3 and 4 respectively.

Because it is composed of a wide range including the ratings of 600V/50 to 300A and 1,200V/25 to 150A

Fig.2 Package outline drawing of the R-series IPM

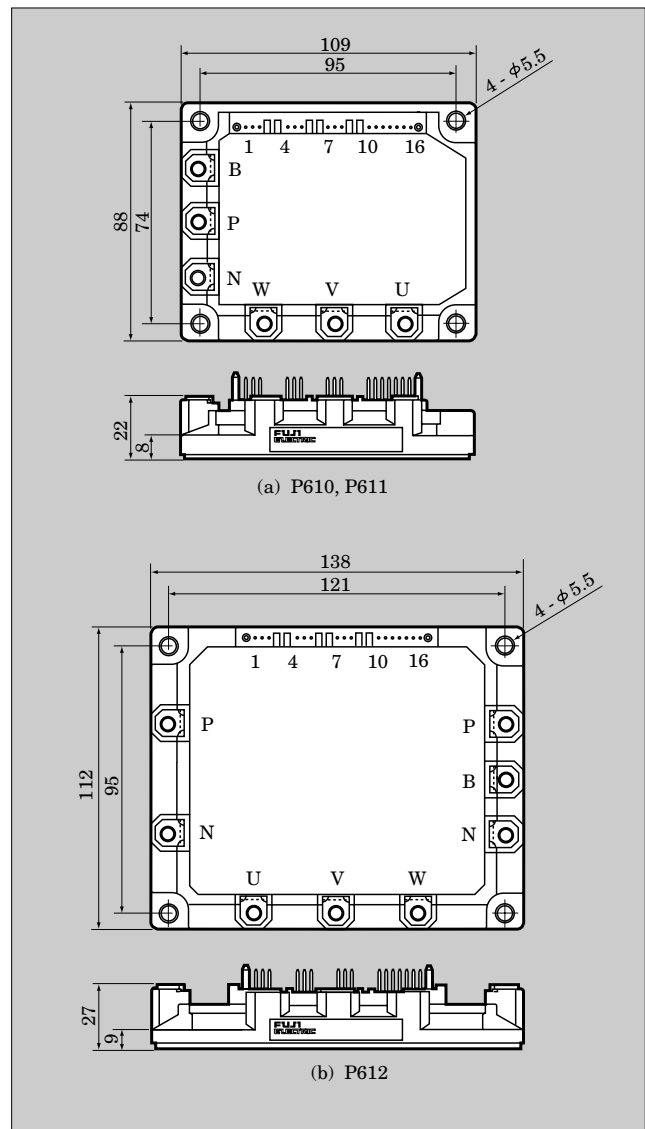


Table 3 Line-up and integrated functions of the R-IPM
(a) 600V series

| Type | Inverter | | | | | Dynamic brake | | | | Integrated functions | | | | | | Package |
|----------------|---------------------|----------------------|--------------------|--------------------|----------------------------------|----------------------|--------------------|--------------------|--------------------------|----------------------|-----|-----|-----|---------------------|---------------------|---------|
| | V _{DC} (V) | V _{CES} (V) | I _C (A) | P _C (W) | V _{CE(sat)} Typical (V) | V _{CES} (V) | I _C (A) | P _C (W) | Diode I _F (A) | Dr | UVT | OCT | SCT | T _c -OHT | T _j -OHT | |
| 6MBP50RA060 | 450 | 600 | 50 | 198 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P610 |
| 6MBP75RA060 | 450 | 600 | 75 | 320 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P610 |
| 6MBP100RA060 | 450 | 600 | 100 | 400 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P611 |
| 6MPB150RA060 | 450 | 600 | 150 | 600 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P611 |
| 7MBP50RA060 | 450 | 600 | 50 | 198 | 2.3 | 600 | 30 | 120 | 30 | ○ | ○ | ○ | ○ | ○ | ○ | P610 |
| 7MBP75RA060 | 450 | 600 | 75 | 320 | 2.3 | 600 | 50 | 198 | 50 | ○ | ○ | ○ | ○ | ○ | ○ | P610 |
| 7MBP100RA060 | 450 | 600 | 100 | 400 | 2.3 | 600 | 50 | 198 | 50 | ○ | ○ | ○ | ○ | ○ | ○ | P611 |
| 7MBP150RA060 | 450 | 600 | 150 | 600 | 2.3 | 600 | 50 | 198 | 50 | ○ | ○ | ○ | ○ | ○ | ○ | P611 |
| 6MBP200RA060 * | 450 | 600 | 200 | 735 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P612 |
| 6MBP300RA060 * | 450 | 600 | 300 | 1,040 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P612 |
| 7MBP300RA060 * | 450 | 600 | 300 | 1,040 | 2.3 | 600 | 100 | 400 | 100 | ○ | ○ | ○ | ○ | ○ | ○ | P612 |
| 7MBP200RA060 * | 450 | 600 | 200 | 735 | 2.3 | 600 | 75 | 320 | 75 | ○ | ○ | ○ | ○ | ○ | ○ | P612 |

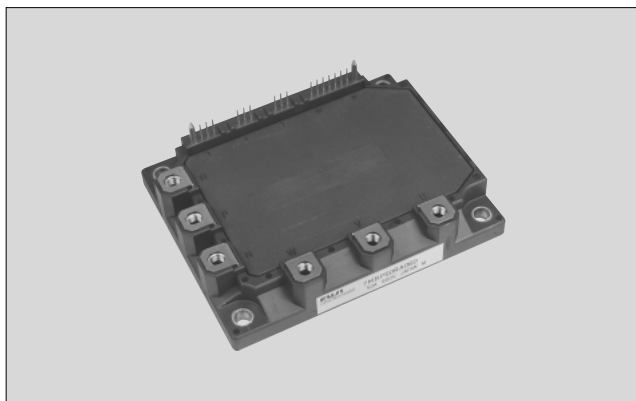
(b) 1,200V series

| Type | Inverter | | | | | Dynamic brake | | | | Integrated functions | | | | | | Package |
|----------------|---------------------|----------------------|--------------------|--------------------|----------------------------------|----------------------|--------------------|--------------------|--------------------------|----------------------|-----|-----|-----|---------------------|---------------------|---------|
| | V _{DC} (V) | V _{CES} (V) | I _C (A) | P _C (W) | V _{CE(sat)} Typical (V) | V _{CES} (V) | I _C (A) | P _C (W) | Diode I _F (A) | Dr | UVT | OCT | SCT | T _c -OHT | T _j -OHT | |
| 6MBP25RA120 * | 900 | 1,200 | 25 | 198 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P610 |
| 6MBP50RA120 * | 900 | 1,200 | 50 | 400 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P611 |
| 6MBP75RA120 * | 900 | 1,200 | 75 | 595 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P611 |
| 7MPB25RA120 * | 900 | 1,200 | 25 | 198 | 2.3 | 1,200 | 15 | 120 | 15 | ○ | ○ | ○ | ○ | ○ | ○ | P610 |
| 7MBP50RA120 * | 900 | 1,200 | 50 | 400 | 2.3 | 1,200 | 25 | 198 | 25 | ○ | ○ | ○ | ○ | ○ | ○ | P611 |
| 7MBP75RA120 * | 900 | 1,200 | 75 | 595 | 2.3 | 1,200 | 25 | 198 | 25 | ○ | ○ | ○ | ○ | ○ | ○ | P611 |
| 6MBP100RA120 * | 900 | 1,200 | 100 | 735 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P612 |
| 6MBP150RA120 * | 900 | 1,200 | 150 | 1,040 | 2.3 | – | – | – | – | ○ | ○ | ○ | ○ | ○ | ○ | P612 |
| 7MBP100RA120 * | 900 | 1,200 | 100 | 735 | 2.3 | 1,200 | 50 | 400 | 50 | ○ | ○ | ○ | ○ | ○ | ○ | P612 |
| 7MBP150RA120 * | 900 | 1,200 | 150 | 1,040 | 2.3 | 1,200 | 50 | 400 | 50 | ○ | ○ | ○ | ○ | ○ | ○ | P612 |

*: Under development

Dr: Drive circuit. UVT: Control power supply under voltage protection, OCT: Overcurrent protection, SCT: Short circuit protection
T_c-OHT: Case overheat protection, T_j-OHT: Device overheat protection

Fig.3 External view of the R-IPM



as well as 6-pack and 7-pack (including a dynamic brake circuit), this series is able to respond to the various market needs.

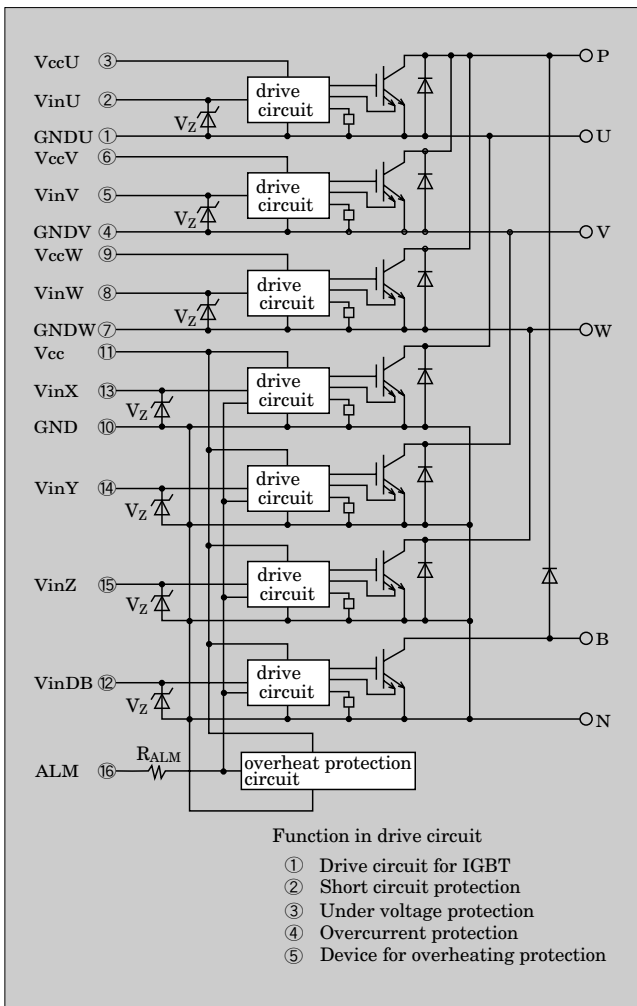
4. Features of the R-IPM

The features of the R-IPM can be summarized as follows:

- (1) Low loss and soft switching by using the third generation IGBT chips
- (2) Realization of high reliability, pursuing higher performance of the IGBT by means of the protection by directly detecting the IGBT chips temperature
- (3) Realization of high reliability and high cost performance by means of integrating all control circuits into the IC chips
- (4) A wide line-up together with the adoption of a compatible package (P610, P611) with Fuji's conventional IPM
- (5) Accomplishment of good noise immunity against malfunction due to switching noise

The key technical points concerning the develop-

Fig.4 Internal equivalent circuit of the R-IPM (a 7 set example)



ment are introduced below.

4.1 Improvement in performance of overheat protection function

In addition to the conventional case overheat protection, the device overheat protection function is integrated in the R-IPM.

The conventional case overheat protection function is indispensable. It was certainly effective against relatively slow temperature risings when overload occurred or a fan broke down.

However, since protection is insufficient against the phenomenon of rapid temperature rise of the IGBT chips, like the motor lock mode mentioned in section 2, the T_j detecting overheat protection function is applied in the R-IPM.

In an experiment simulation a motor lock mode, the junction temperature of the IGBT chip which located on the farthest position from the sensor and temperature of the sensor were measured when the IGBT chip was applied power loss and heated using a conventional IPM. The results are shown in Fig. 5. Since the temperature of the IGBT chip exceeded 150°C before the temperature sensor reached the

Fig.5 Temperature rise of the IGBT chip and the temperature sensor

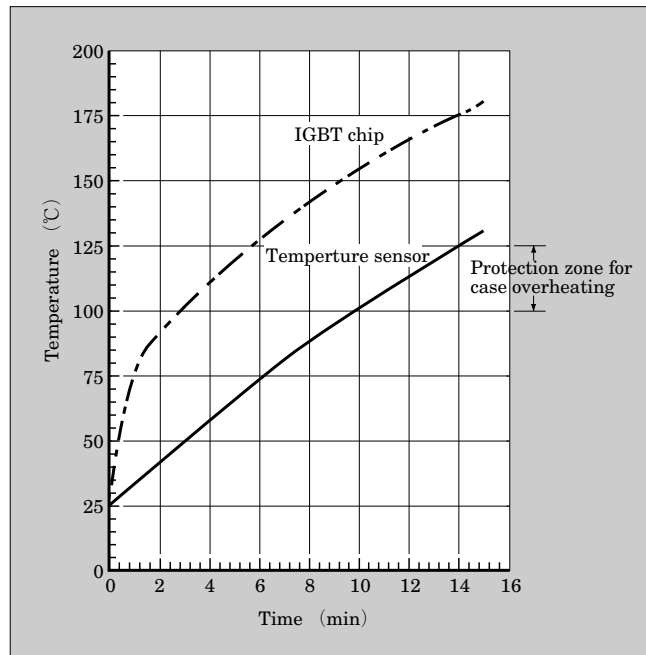
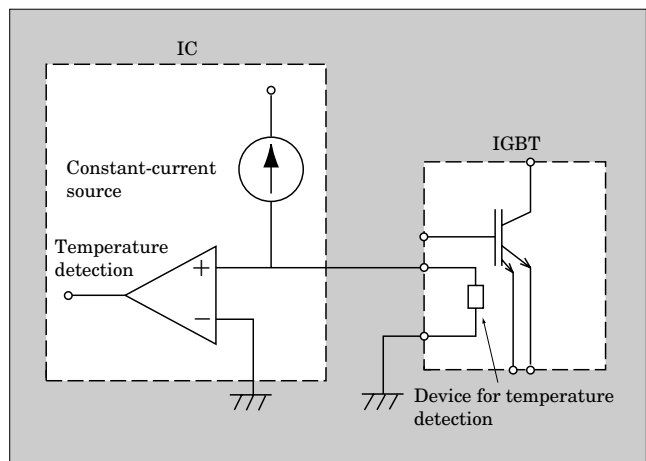


Fig.6 Overheating protection device



temperature for case protection, there is the possibility that the IGBT chips may be destroyed if this operating condition continues. It is clear that the device overheat protection function is indispensable.

The device overheat protection function differs from the case overheat protection of conventional IPMs. It protects against thermal destruction of the IGBT chips by directly detecting the junction temperature of the IGBT chips in which the temperature sensor is embedded.

In order to achieve this function, the temperature detection device is made on the IGBT chip as shown in Fig. 6. Detection of the IGBT chips temperature is performed utilizing the dependance of this device on temperature.

This device is embedded by using poly-silicon on insulator technology to prevent the influence of the

Fig.7 Timing chart of protection function

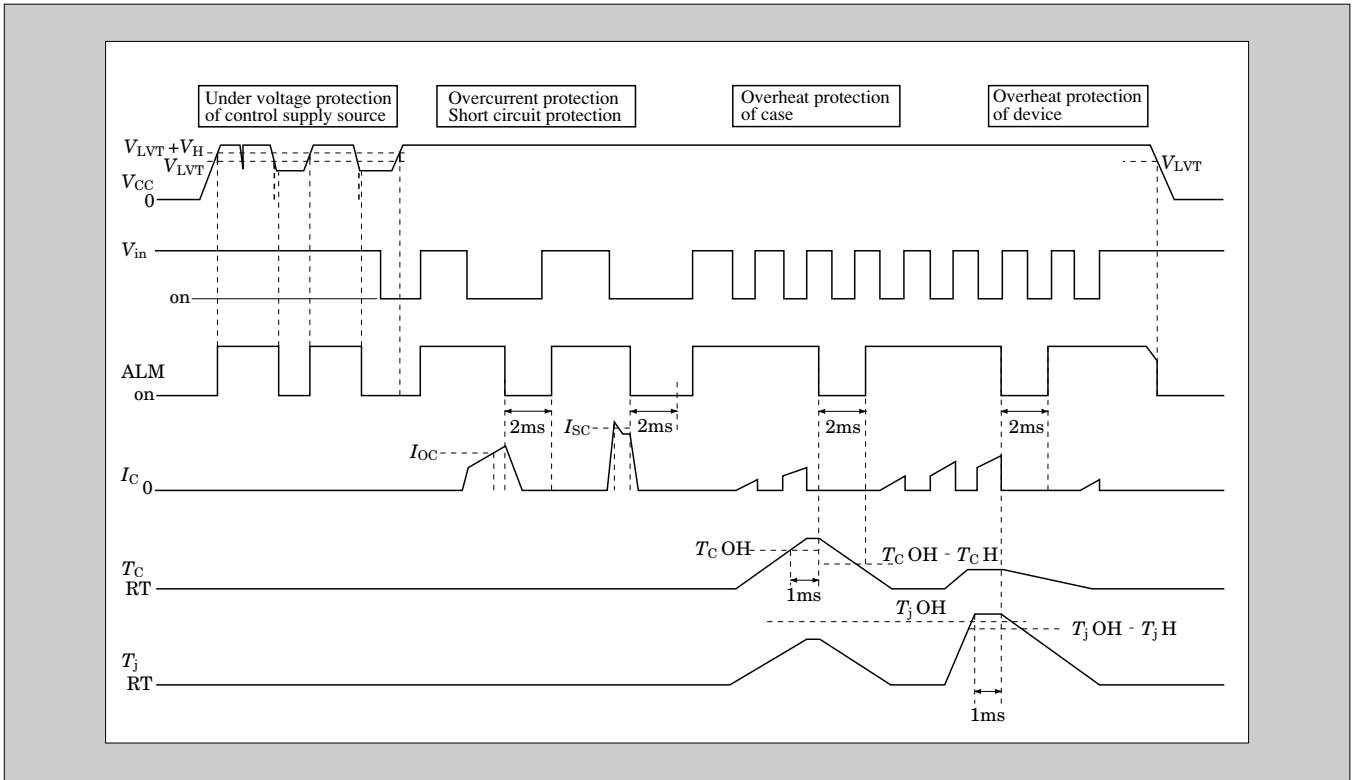


Fig.8 Switching waveforms of the R-IPM and the J-IPM

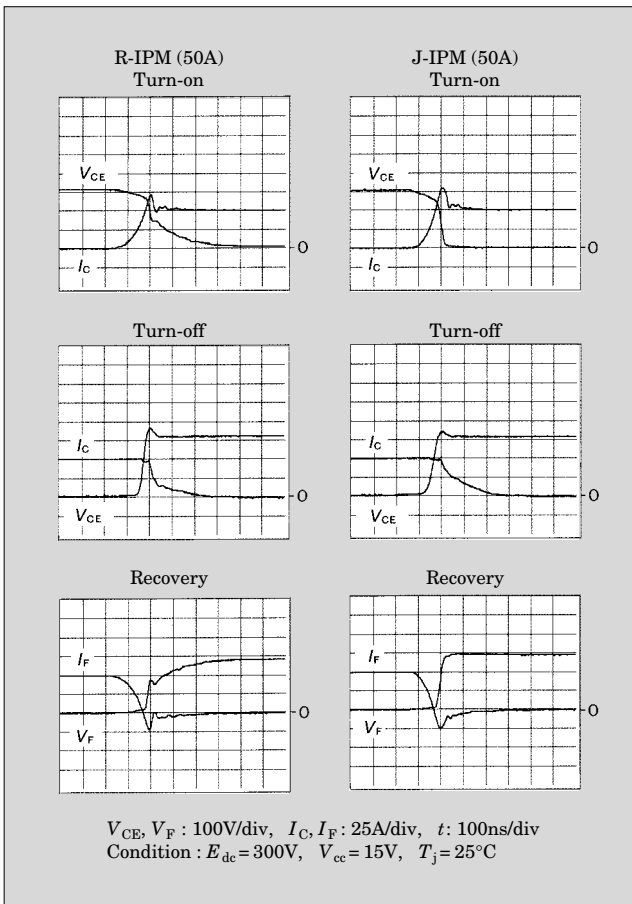
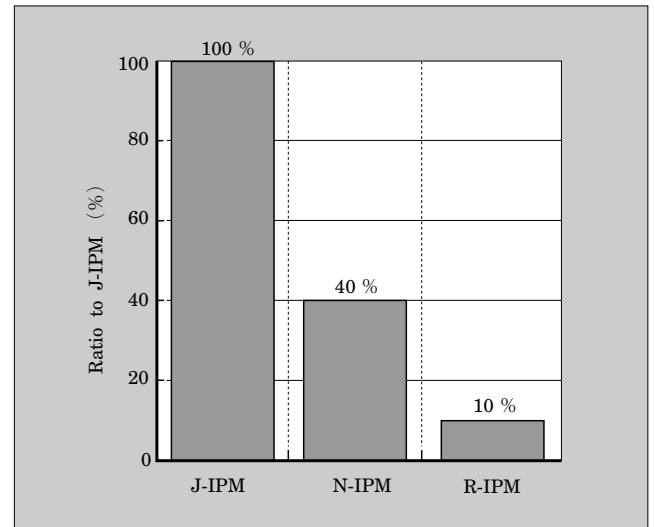


Fig.9 Ratio of electronic parts (IC inclusive)



switching noise of the IGBT chips. A dead time of 1ms is provided when detecting the IC side so that false detection by noise is prevented.

The timing chart of the protection functions are shown in Fig. 7. Overheat protection goes into effect and softly shut down the current when a certain condition continues for 1ms. This condition entails that overheat protection of both the case and the device reach the detection level. At the same time, the alarm's output and the protection state are engaged. The alarm output and protection state are reset when

the input signal is off state and the temperature reaches reset level.

4.2 Integration of the control circuit to the IC

The control circuit of IPMs were designed and evaluated, combining with IGBT chips after ICs were designed. Therefore, it had to adjust a drive ability of an IGBT and various protection functions and accomplish good noise immunity by using additional parts other than ICs. It is impossible to achieve a single chip IC which is not adjustable and has adopted a hybrid construction combined with various electronics parts. Consequently, the further downsizing or lowering of costs is deviously limited. However, the R-IPM solves these problems through experiments cultivated by the development of the conventional IPM and the technologies to be described below.

Integration of the IPM control circuit with the IC involves an adjusting method with the IGBT and measures against noise. With the following technologies, the integration of the control circuit to the IC is successful.

- (1) Through simulation technology conducted by a combination of IGBT characteristics and IC characteristics, the most suitable design is determined by theoretical study and review of such factors as the necessary capabilities required for the IC.
- (2) The noise immunity is improved by insertion of a filter on the reference power supply of each circuit block, and by incorporating a filter into the IC, formerly provided externally, which results in less noise on the circuit pattern.
- (3) Malfunction are prevented by reducing noise inflow. This is achieved by separating the noise sensitive IGBT ground from the sensing and protection circuit grounds.
- (4) The noise immunity increased remarkably by the reduction of wiring volume of the control circuit compared with the conventional IPM through the integration of the control circuit within the IC.
- (5) Low loss and soft switching are realized through the prevention of influence from outside noise by locating the IGBT and the IC as close as possible and through the optimization of the IC so that it

can efficiently drive the IGBT.

The switching waveforms of the J-IPM and the R-IPM are shown in Fig 8. In particular, the R-IPM restricts di/dt , dv/dt at the time of turn-on and recovery, and realizes soft switching.

Through the measures mentioned above, the number of electronics parts have been reduced to 1/10 that of the J-IPM, as shown in Fig. 9.

4.3 Package construction

Facilitated use is taken into consideration for the newly designed package, maintaining compatibility.

The features are as follows.

- (1) Preservation of compatibility of the mounting, main terminal and control terminal position (P610, P611 package)
- (2) Preservation of endurance against bending fracture through the adoption of metallic guide pins for the control terminals
- (3) Dissolution of a terminal deformation through the shortening of control terminals
- (4) Realization of a thin shape and light weight through optimization of the internal construction

5. Conclusion

Fuji Electric's IPMs and the series and features of the recently developed the R-IPM have been introduced. The R-IPM is the first product to comprise the IPM utilizing only silicon semiconductors. In addition, the function which directly detects the temperature of the IGBT chips has been newly built-in. We firmly believe that application of the R-IPM contributes to the downsizing and high reliability of the equipment by a considerable degree.

Furthermore, making the power devices intelligent will be promoted more often in the future, together with the progress of IC technology, corresponding to the needs for reduced total system costs, downsizing and high reliability of application products. We resolve to strive for the development and production of such products so that we are able to fully respond to the market's needs.





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