Optimized inverter design by DIPIPM+

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1. Introduction

Mitsubishi Electric Corporation has commercialized the CIB-type insulated gate bipolar transistor (IGBT) module in which the power chips for the converter circuit, brake circuit, and three-phase inverter were integrated to meet various market demands. Mitsubishi has also commercialized the DIPIPM in which the power chips for the three-phase inverter and control ICs were integrated and transfer-molded. DIPIPM+ (DIPIPM plus) is a new type of power module that combines these two modules. The DIPIPM+ is an innovative power device that can reduce labor-intensive design work by engineers who develop inverters, while also reducing the size of the inverter equipment. A previous paper(1) discussed the performance of the DIPIPM+. This paper describes main features of DIPIPM+ about integration of power devices and control circuit and optimization of inverter system design brought by the appropriate structural characteristics (e.g. optimal terminal arrangement).

2. DIPIPM+

2.1 Internal structure

Figure 1 illustrates the block diagram of the DIPIPM+. As shown in the figure, the DIPIPM+ integrates main inverter circuit, which is three phase bridge connection by six pairs of IGBT and FWDi (free wheeling diode), brake circuit consists of series-connected IGBT and Diode, and three phase diode bridge for converter circuit.

For the gate driving of the IGBTs in the inverter and brake circuits, ICs are connected to the circuits. The IC for driving the upper arms in the inverter circuit (high-voltage integrated circuit (HVIC)) has a high-voltage level shift circuit. The HVIC can receive control signals from the microcomputer (MCU) without an insulation element (e.g., photocoupler). It also has a protection function for control supply undervoltage (UV). The IC for driving the lower arms (low-voltage integrated circuit (LVIC)) has a circuit for driving the IGBTs as well as UV and short circuit (SC)

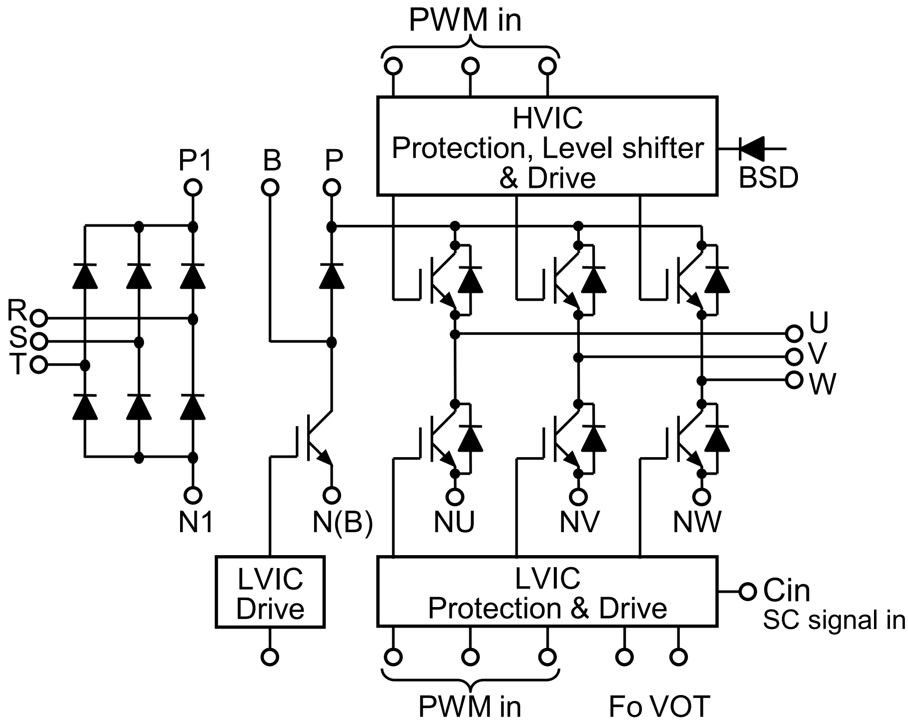


Fig. 1 Internal block diagram of DIPIPM+

protection functions. For the SC protection, the lower arm IGBT is quickly shut off by inputting the voltage drop of the external resistor connected to the main circuit's lower arm emitter terminal at the time of an overcurrent. When the LVIC's protection function is activated, fault-out (FO) signal is output for external notification of an abnormality.

In addition, a function is provided that detects the temperature of the module with a thermal sensor on the LVIC and outputs it as analog voltage signal (voltage output of temperature (VOT) function).

2.2 Terminal arrangement

The DIPIPM+ has a well-configured terminal arrangement so that wiring on a printed circuit board (PCB) of the inverter equipment is easy and the assembled inverter equipment can work efficiently and stably for an extended period of time.

As shown in the external connection diagram in Fig. 2, the main circuit terminals (AC three-phase input, brake, and three-phase output terminals) are arranged in a line on the long side of the package so that they can be connected in the shortest distance to the terminal block of the inverter equipment. The terminals for connecting a smoothing capacitor and for control input/output are arranged in a line on the other long side.

3. Optimization of the DIPIPM+ Connection Circuits

3.1 Optimization of the DIPIPM+ main circuit wiring

The DIPIPM+ main circuit terminals have been arranged in accordance with the arrangement on the inverter equipment's terminal block for external connection, so the main circuit wiring on the PCB can be dramatically simplified compared to the conventional wiring using a CIB-type IGBT module (Fig. 3).

Figure 4 illustrates the wiring in which a DIPIPM is combined with a three-phase diode rectifier. Because the wiring is simpler, it has an advantage compared to the IGBT module shown in Fig. 3. However, it is obvious that the wiring on a PCB using the DIPIPM+ shown in Fig. 2 is the simplest because there are no cross wires.

Complicated main circuit wiring on a PCB including cross wires may be a main cause of insulation problems, noise, and many other problems. Therefore, simplifying the main circuit wiring maintains and improves the functions and performance of the inverter equipment. The simple terminal arrangement of the DIPIPM+ has the following advantages in main circuit wiring:

- The pattern wire length can be reduced;
- No jumper wire is required;
- Double-sided PCB can be used (no multilayer PCB is required);
- The creepage distance can be reduced and the dead space is significantly reduced; and
- These advantages greatly reduce the PCB size.

3.2 Optimization of the DIPIPM+ control circuit wiring

The DIPIPM+ has an LVIC that drives the brake circuit and an HVIC and another LVIC that drive the inverter circuit and that have the protection function. Their drive capability has been optimized to realize low radiation noise and low power loss, so the gate resistance does not

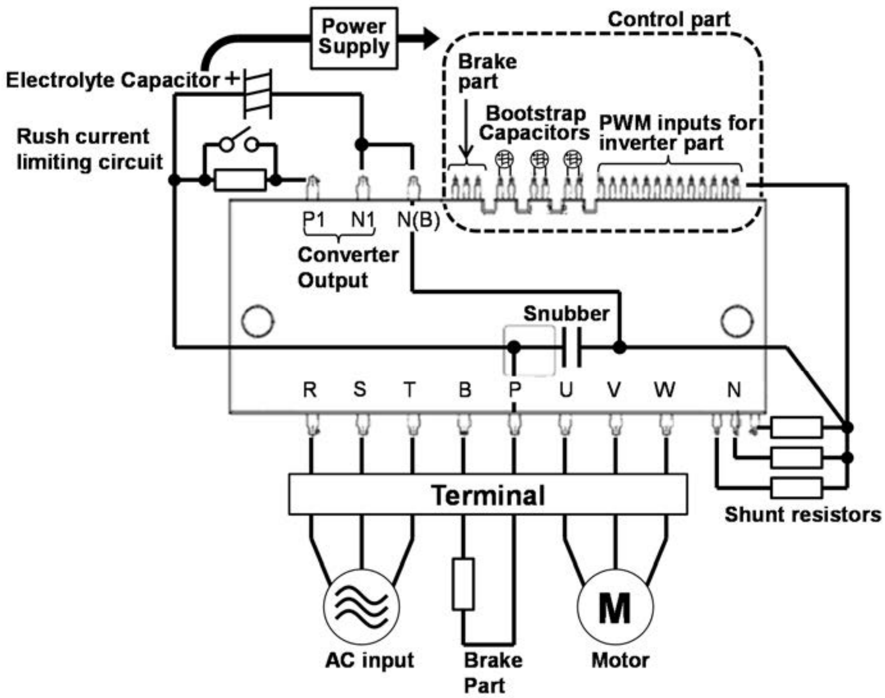


Fig. 2 External connection of DIPIPM+

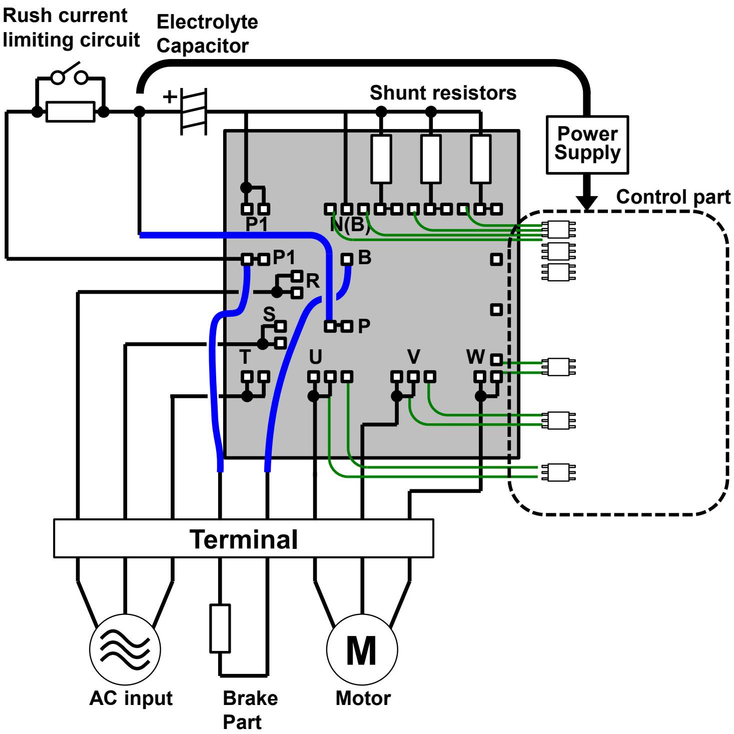


Fig. 3 External connection of CIB-type IGBT module

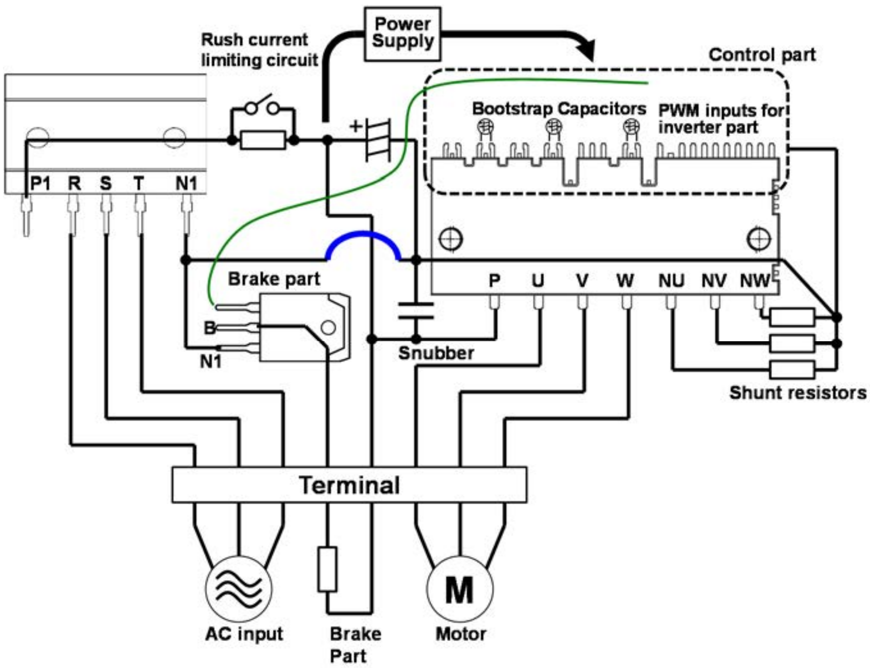


Fig. 4 External connection of DIPIPM and diode rectifier

need to be adjusted in the design of the control part. These control terminals taken out from the DIPIPM+ are concentrated on one side of the DIPIPM+. Shortening the wiring to the microcomputer that handles small signals can minimize the possibility of exposure to noise from the surrounding circuits, which makes it easier to improve the reliability of the inverter equipment.

3.3 Optimization of the control supply circuit

The electric potential of the power supply for driving the IGBTs on the inverter circuit's upper arms needs to be independent from that of other control supply.

For IGBT and similar modules, multiple transformer windings are provided to generate power supply. However, such power supply becomes larger due to the insulation between the transformer output terminals. In addition, attention is required for the insulation (e.g., isolation using a separator) in designing to ensure that a displacement current at the time of IGBT switching does not propagate to any other control supply via parasitic capacitance between the transformer windings.

Given the small power consumption of the Mitsubishi HVIC used for the DIPIPM+. a bootstrap circuit can be used for the power supply for driving the IGBTs on the upper arms. Thus, for the transformer, only a 15 V output for the inverter circuit and another power supply for the secondary side are required. This allows the design of transformer to be simple (e.g., laminated winding) (Fig. 5).

In addition, the DIPIPM+ has high-voltage bootstrap diodes (BSDs) for bootstrap circuits, so the power supply wiring on a PCB becomes simpler and its footprint can be smaller.

3.4 Optimization of the system cost

For the main circuit wiring on a PCB for inverter equipment, it is necessary to secure the pattern width based on the flowing current and the insulation distance based on the voltage. As the wiring is longer, the area of the PCB needs to be larger. A PCB can be downsized by multi-layering the boards. Generally, however, the price of a board increases as the number of layers increases. In addition, the transmission of noise via parasitic capacitance between the layers has a harmful influence.

Figure 6 illustrates example configurations of an inverter system using an IGBT module and of inverter equipment using the DIPIPM+. For the DIPIPM+ solution, the number of photocouplers can be reduced by connecting the motor control MCU and DIPIPM+ without isolation lines: a low-cost low-voltage digital isolator with a longer operating life can be used instead. Inputting the voltage drop of the shunt resistor to the MCU can reduce the number of current sensors. Inputting the divided the voltage drop to the DIPIPM+ can provide accurate protection at the time of a short circuit by the SC protection function. On the other hand, the desat method, which is generally proposed for the IGBT module solution, uses the power device's active region characteristics that are very close to the limit for breakage. In addition, a complicated design is required that takes into account operation delays during On/Off.

When considering an entire inverter system, the SC protection function of the DIPIPM+ can also work as protection against motor demagnetization, thus reducing the cost of the current detection circuit.

The aforementioned downsized power supply transformers and reduction of the main circuit wiring including jumper wires can improve the reliability and reduce the system cost significantly.

4. Conclusion

The improved performance of silicon power semiconductors has been approaching its theoretical limit, so expectations for silicon carbide (SiC) and other materials have been increasing. However, as power modules do not consist of only power devices, they can be further optimized including their structures.

We recognized the importance of the interfaces to PCBs through which power modules are implemented and have established the structure and terminal arrangement for realizing low-cost and highly reliable inverter systems and making best use of the power semiconductors in the DIPIPM+.

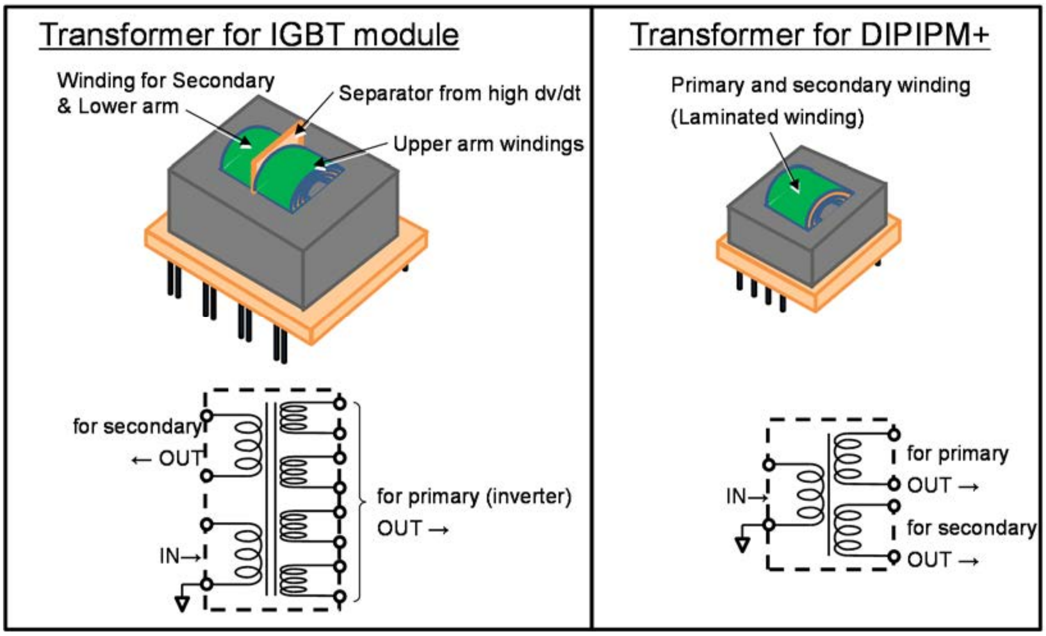
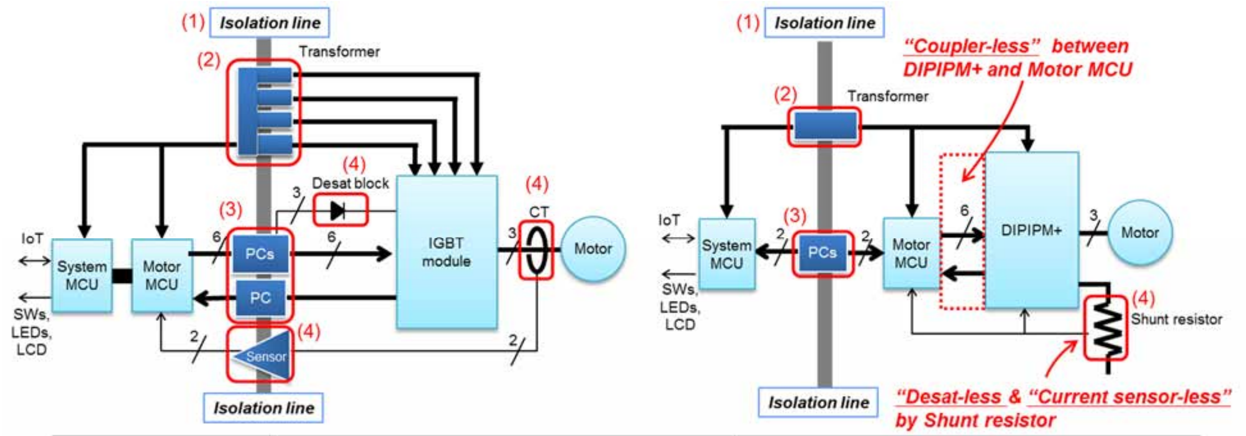


Fig. 5 Comparison of transformer for IGBT module and DIPIPM+



	IGBT module solution	DIPIPM+ solution
(1) Isolation line	Between IGBT module and Motor MCU	Between System MCU and Motor MCU
(2) Control power supply (Transformer)	Primary floating output x 4 + Secondary output x 1	Primary output x 1 + Secondary output x 1
(3) Photo coupler	High speed and high CMR photo coupler x 6 + Normal transistor photo coupler x 1	Digital isolator (bidirectional) (3.3V or 5V) x 1
(4) Current detection	Desaturation detection by high voltage and high speed diode for SC protection with Current feedback function by CT	Both SC protection and Feedback current detection by shunt resistor

Fig. 6 Comparison between IGBT solution and DIPIPM+ solution

5. Reference

(1) Yamaguchi K., et al.: All-in-One Type DIPIPM with Built-In Converter, Inverter and Brake, Mitsubishi Electric ADVANCE, Vol. 155, 18–21 (Sep. 2016)