Downsizing Technology for General-Purpose Inverters

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1. Introduction

General-purpose inverters are products suited for function advancement, energy savings and labor savings in field of general-purpose industrial equipment. The market for general-purpose inverters is expanding year after year.

This trend is the result of downsizing, price reduction, function advancement, and improved reliability. In particular, the progress in downsizing has been amazing. For example, as shown in Fig. 1, the volume of general-purpose inverters has decreased to less than 1/10 the volume of the first general-purpose inverters that came onto the market. This fact has greatly contributed to the increased range of applications for general-purpose inverters.

A summary of typical downsizing technology that has been cultivated by Fuji Electric is described in this paper.

2. Downsizing Technology for Control Circuit

2.1. Development of one-chip MPU

When general-purpose inverters were first introduced, the exclusive area for control circuitry was rather large because all functions were realized by hardware. Thereafter, with the introduction of microprocessors (MPUs), most processing of general-purpose inverters was performed by software, and sections where processing by software was too slow, such as the PWM generating unit, were realized by hardware. Thus, general-purpose inverters with advanced functions were realized through a simple hardware construction. Furthermore, in contrast to prior MPU+ASIC (application specific integrated circuit) control circuit construction, development of LSI process technology and integration technology from mi-

Fig.1 Downsizing trend of general-purpose inverters (0.75kW)

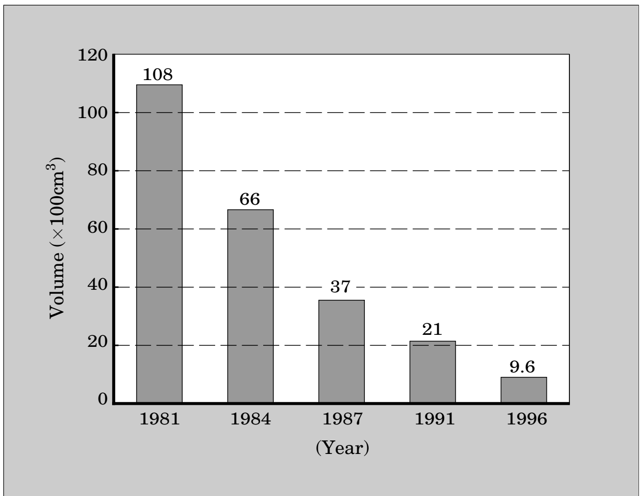

Fig.2 Voltage/current detection (non-isolated)

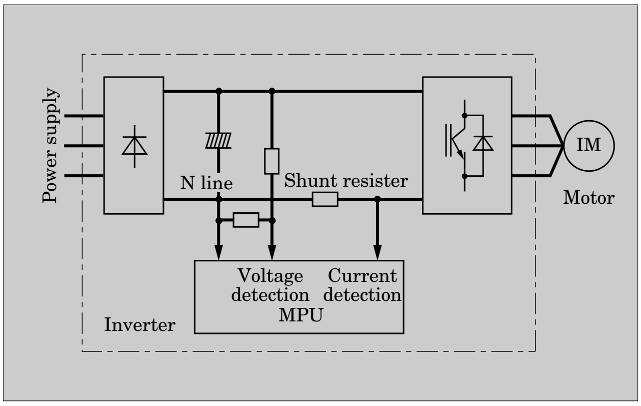

Fig.3 External view of control circuit for small inverter

cron-order to sub-micron-order has enabled general-purpose inverters to be controlled by one chip. With this technology, the actual mounting area has become less than half that of the MPU+ASIC configuration.

2.2 Downsizing of detection circuit

All detection of main circuit current and DC link circuit voltage was performed via an isolation device. As shown in Fig. 2, a non-insulated method in which the MPU itself is connected to the N line of a DC link circuit has been utilized in small-size general-purpose inverters. This method enables direct input of the current and voltage to be detected to the A-D converter of the MPU. Through this method, not only has the isolation device and accompanying isolated power supply become unnecessary, but since the interface for voltage and current detection can be constructed from a simple circuit such as a voltage divider or a shunt resistor, remarkable downsizing has become possible.

2.3 Mount technology for control circuit

High density mounting in the periphery of the MPU and analog ICs is realized through the introduction of COB (chip on board) technology in which bare IC chips are mounted directly onto a printed circuit board. COB enables not only a reduction of mounting area, but also a lowering of mounting height. Therefore, further downsizing is possible by stacking the control printed circuit boards. Figure 3 shows an external view of a control circuit board for a small-size inverter that utilizes COB technology. All control circuits for the small-size general-purpose inverter are constructed with dimensions of 74.5 × 65 × 13 (mm) and two printed circuit boards are stacked.

3. Miniaturization of Control Power Supply and Gate Drive Circuit

As shown in Fig. 4, in the case of conventional control power supplies, a 5V power supply that drives digital circuits such as the MPU, and other various power supplies that drive the high-side IGBTs and low-side IGBTs were constructed by a DC-DC converter from a DC power supply which is an output of the rectifier. Power supplies were isolated from each other. A gate drive circuit controls six IGBTs by transmission of PWM signals from the MPU through photo-couplers. To downsize these circuits, miniaturization of each part is an obvious solution, but it is also important to standardize and clarify the role of each circuit.

3.1 Reduction of the number of control power supplies, introduction of gate drive IC

By replacing transistors used in the switching element of DC-DC converter with MOSFET, the switching frequency was increased from several tens of kHz to one hundred and several tens of kHz. This enabled miniaturization of the transformer core size and reduction of the smoothing capacitor capacity. However, since many types of control power supplies are required for general-purpose inverters, this measure alone did not result in miniaturization of the transformer bobbin that correspond to increases of the

Fig.4 Conventional control power supply and gate drive circuit

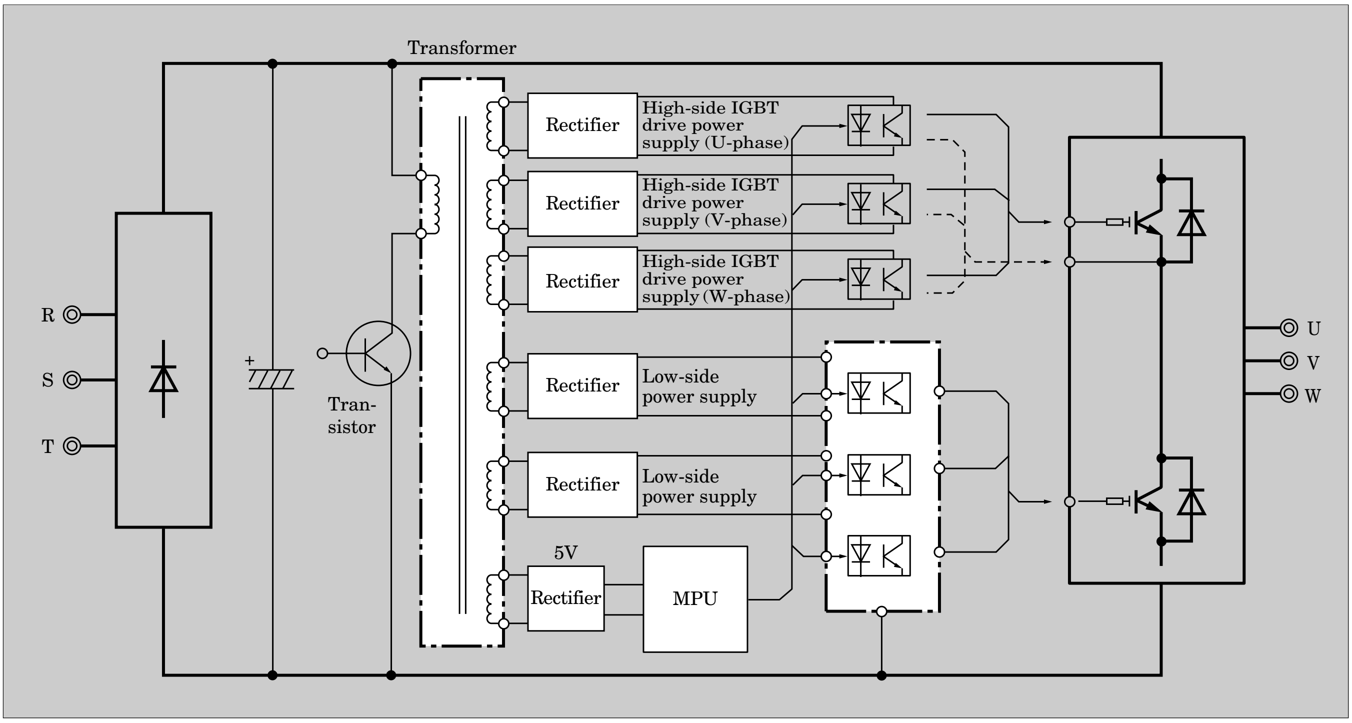

Fig.5 Simplified control power supply and gate drive circuit

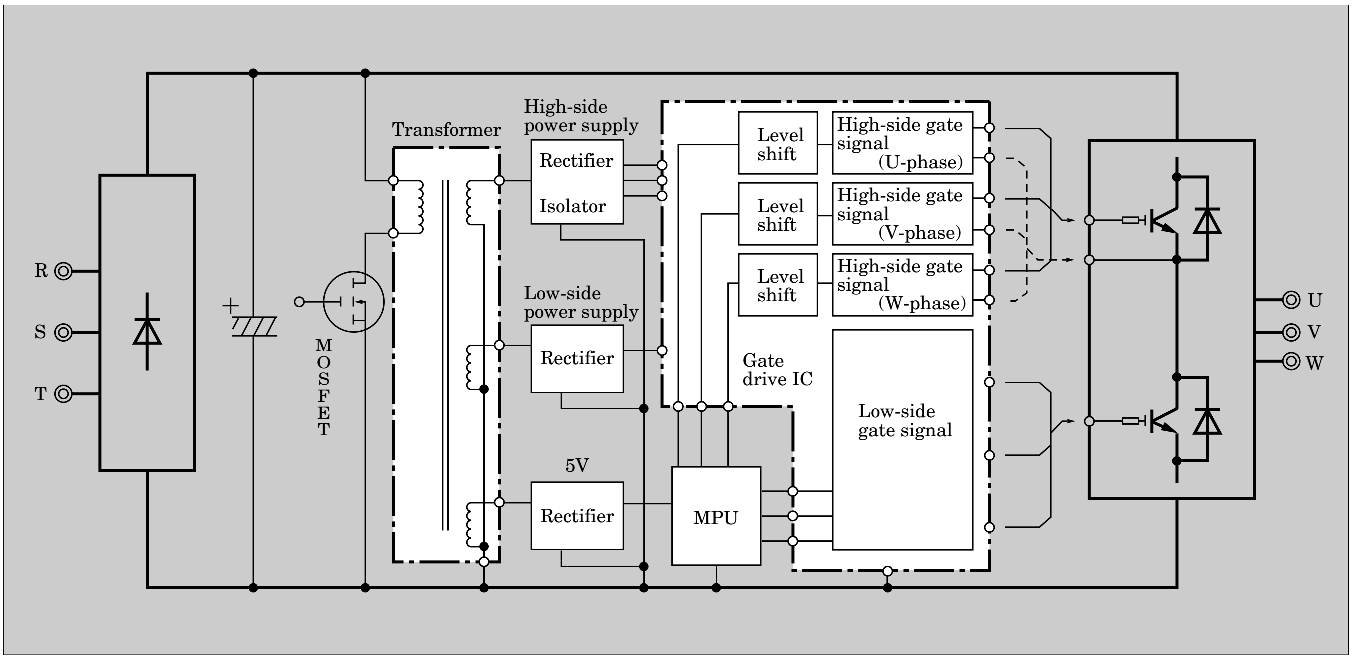

Table 1 Comparison between solid capacitor and aluminum electrolytic capacitor

Item \ Classification	Solid capacitor	Aluminum electrolytic capacitor
Capacitance ratio	1	33
Volume ratio	1	6

Note) Switching frequency: 100kHz

switching frequency. Therefore, as shown in Fig. 5, in order to miniaturize the transformers, the number of bobbin pins was reduced by making the ground potential common for the primary side of the transformers, the 5V power supply, and the power supplies for high and low-side IGBT. Previously these grounds had been isolated from one another. Furthermore, six photo-couplers are eliminated by utilizing a gate drive IC in which three kinds of high-side potentials and one low-side potential are isolated from one another inside each chip.

3.2 Introduction of solid capacitors

Although aluminum electrolytic capacitors are popular as smoothing capacitors in control power supplies, they result in an inefficient use of space since their area and volume are larger than that of other parts on the printed circuit board. The efficient utilization of space inside general-purpose inverters is important to realize miniaturization, hence a small size capacitor is required. Under the worst conditions for general-purpose inverters, the temperature surrounding the capacitors is 80 to 85°C. Even under such high temperatures, the life span of the capacitors must be made to approximately equal that of the aluminum electrolytic capacitors. To satisfy this requirement, a solid capacitor was introduced which is small in size and in equivalent series resistance, and high in allowable ripple current. Table 1 shows a comparison of capacitance and volume between a solid capacitor and a aluminum electrolytic capacitor having equivalent performance characteristics.

As described above, through miniaturization of the parts themselves and reduction of the number of parts (particularly large parts for isolation such as the photocoupler), the printed circuit board area of both the control power supply circuit and the gate drive circuit was reduced to approximately half of its conventional size.

4. Downsizing Technology for Main Circuits

A metal based circuit board, originally developed by Fuji Electric as an essential element of general-purpose inverters, is described below with respect to its background, structure, performance and merits.

4.1 Development of multi-zone metal based circuit boards

The efficiency of general-purpose inverters is approximately 95%, with the remaining 5% loss required to finally dissipate heat into the atmosphere. Reduction of this loss or improved cooling performance is a key to the realization of downsizing. In spite of the advent of low loss power devices in the current trend of power semi-conductors, a reduction of generated loss cannot be expected easily because of market demands for the suppression of noise emitted by general-purpose inverters or for the achievement of low motor noise

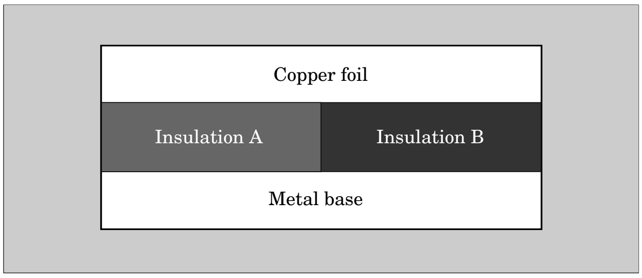

Fig.6 Structure of multi-zone metal based circuit board

Table 2 Typical characteristics of multi-zone metal based circuit boards

Classification / Item	Insulation A (power zone)	Insulation B (control power supply)
Dielectric breakdown voltage	10kV or more	
Thermal resistance*	14	100
Dielectric constant*	100	65

* Thermal resistance and dielectric constant values are indicated as ratios with each insulation material.

through high speed switching. These market demands are inversely related to the reduction of loss. Furthermore, if the mounting density of parts is increased to realize downsizing, problems may result because the generated loss per unit area will increase and some parts will exceed their maximum allowable temperature. To solve this problem, the development of a novel circuit board with low thermal resistance, enabling efficient dissipation of generated loss in general-purpose inverters and allowing high density mounting, is necessary.

It is desirable that high loss parts such as IGBTs or rectifier diodes are mounted on an insulated circuit board with low thermal resistance, and relatively low loss parts such as control power supply circuit parts or control circuit parts are mounted on an insulated circuit board with low dielectric constant to minimize the effect of stray capacitance. The multi-zone metal based circuit board is a metal based circuit board that combines different insulation properties to realize downsizing and reduce costs.

4.2 Structure and characteristics of multi-zone metal based circuit boards

As shown in Fig. 6, in the multi-zone metal based circuit board two types of insulating materials with different characteristics are placed on a metal base plane, copper foil is laid on top, and then the board is manufactured by a vacuum heat press process. Insulation materials consist of insulation-A with gives priority to low thermal resistance by increasing the amount of filler to exceed 75% and insulation-B which gives priority to a low dielectric constant by reducing the

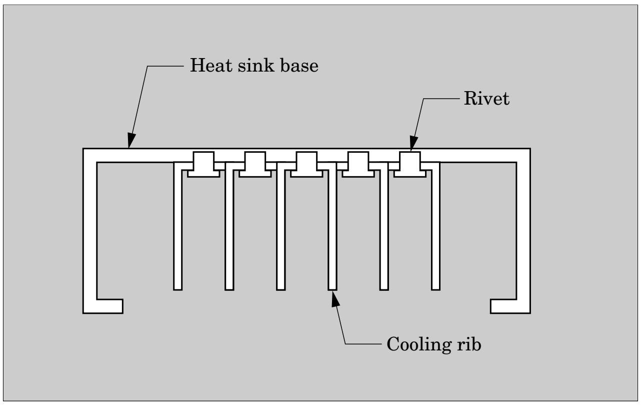

Fig.7 Cross section of heat sink with riveted cooling ribs

amount of filler to 0%. Typical characteristics of the multi-zone metal based circuit board are shown in Table 2. Usually the base of the multi-zone metal based circuit board is set to earth potential, and the dielectric break down voltage between the base and the copper foil pattern is prescribed as 10kV or more, a margin of approximately 10 times the actual applied voltage.

4.3 Merits of multi-zone metal based circuit boards

Since the thermal resistance of multi-zone metal based circuit boards is remarkably low compared with glass epoxy circuit boards, the following merits are can be listed.

(1) Volume reduction of mounted parts

Since the thermal resistance of metal based circuit boards (in the case of insulation B) is approximately 1/4 compared to glass epoxy circuit boards, resistance of 1/4W is sufficient where a resistance of 1W was used previously. Therefore, high-density mounting can be realized.

(2) Narrowing of conductor width

In addition to the mounting parts, temperature rise of the conductor on the circuit board surface due to heat generation can also be reduced by low thermal resistance. Higher current is allowed for a conductor with identical width and in thickness. On the other hand, the conductor can be made narrower for an identical current.

5. Downsizing of Heat Sink

In addition to the metal based circuit board, there are heat sinks used to effectively radiate the heat generated in general-purpose inverters. The heat radiation capacity of the heat sink has a large affect on the external dimensions of small-size general-purpose inverters.

Until now, aluminum die-cast heat sinks were generally used. However, the manufacture of compact heat sinks with high radiation efficiency is difficult by the die casting method and is restricted by following items.

(1) The die strength determines the upper limit of cooling rib height.

(2) The fluidity of melted metal determines the lower limit of cooling rib thickness.

To solve these problems, a cooling rib that utilizes press technology has been developed. Figure 7 shows the construction of a pressed heat sink with riveted cooling ribs. The heat sink with riveted cooling ribs increases the heat radiation surface area of the entire heat sink by riveting thin aluminum plates to the base.

By utilizing riveted cooling ribs, downsizing of 41% in volume and weight reduction of 57% are attained compared with the conventional die-cast heat sink.

6. Conclusion

A summary of downsizing technology for general-purpose inverters has been presented. To expand the scope of the market even more, further downsizing and the price reductions will be necessary. Fuji Electric will continue to develop this technology to satisfy user expectations.