Large-Capacity Variable-Speed AC Drive

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1. Introduction

With the increasing range of applications for motor driver inverters and customer satisfaction with their high performance, multi-functionality, small size, low price, etc., the demand for inverters that can drive larger capacity motors has increased.

Fuji Electric has developed large capacity power converters corresponding to the FRENIC5000G9S/P9S and VG5S inverter series and the PWM converter RHC series, which were widely utilized as inverters for general industries. In this paper, we will present an overview of these large capacity power converters.

2. Main Circuit Configuration and Structure

2.1 Basic concept and features

Besides offering enlarged capacity, since these converters are installed in important equipment, these power converters should exhibit improved maintainability and have the following features.

(1) Functionality and performance that is standardized with the smaller capacity series

Using these converters, we attempted to enlarge the capacities of the FRENIC5000G9S/P9S and VG5S inverter series and the PWM converter RHC series. Because we provided large capacity inverters with the same control system and functions as those of the mid and small capacity inverters currently available on the market, a consistent system configuration can be established throughout from small to large capacity inverters.

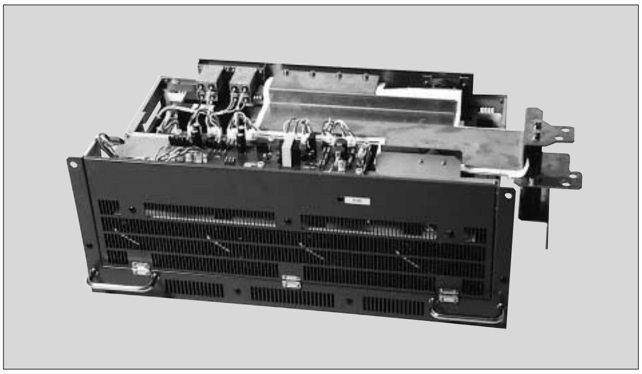
(2) Improved maintainability

In the main circuit of the inverter, rectifier diodes and IGBT parts for each phase are separated onto individual trays, and stored on a rack inside the panel. With this configuration, if a failure should occur in an inverter, the inverter can be restored within a short time simply by pulling out the failed tray and replacing it with the spare tray.

Figure 1 shows the panel structure applied to an inverter. The uppermost stage contains a rectifier diode tray; the second stage, an IGBT tray of U phase; the third stage, a control printed circuit board; and the fourth and fifth stages, IGBT trays of V and W phases. These trays can be easily pulled out toward the front side by detaching the connections to the main circuit conductors and the connector to the control wires.

Fig.1 Inverter panel

Fig.2 IGBT tray



Improved cooling efficiency has enabled the inverter size to be decreased. The depth dimension for all models has been standardized at 600mm, saving space and allowing maintenance to be performed at the front side. These measures remarkably facilitate inspection and maintenance.

(3) Enriched protection function

In addition to inheriting the protection functions of the mid and small capacity series, these power converters are provided with semiconductor protection fuses in each phase of the main circuit and in each phase of the IGBT to limit the propagation of a failure.

Further, each tray is provided with a fault indication function to facilitate the identification of faulty trays.

2.2 Main circuit configuration

Each arm of the three-phase bridge in this large capacity power converter has a maximum of eight IGBT modules (300A, 1,200V) connected in parallel to achieve large capacity. This configuration might have a problem with distributing current among the IGBT modules. However, the current balance between the modules is maintained at 0.8 or more by reducing the inductance of the wiring bars between the modules, controlling the module characteristics, etc.

The IGBT tray is shown in Fig. 2. The tray, which contains the IGBTs of one phase, also contains the power supply circuit and driving circuits necessary for driving the IGBTs, and a fault indication function.

The cooling fan for IGBTs is configured such that it can be easily replaced by opening the front cover without pulling out the tray.

3. Application of the Large Capacity Power Converter to Various Inverter/Converter Series

3.1 Application to inverters

The main specifications of inverter/converter that use this large capacity converter are shown in Table 1. Since all of these products have the same control system and functions as those of the mid and small capacity inverters that currently are on the market, a consistent system configuration can be established from small to large capacity inverters. Figure 3 shows schematic diagrams of the main circuit for single-unit and multi-unit systems.

3.1.1 Single-unit system

Maximum capacities of the standard motors, which can be driven by the single-unit system, were increased to 400kW for a constant torque load (G9S), 500kW for a variable torque load (P9S), and 400kW for a high-performance vector-control inverter (VG5S).

Previously, these capacity ranges were achieved by operating two inverters in parallel. With the increased capacity, dimensions of the panel can be dramatically reduced.

3.1.2 Multi-unit system

In order to drive motors having a capacity of

Table 1 Large capacity inverter/converter specifications

Item \ Series name	Inverter FRENIC5000			PWM converter RHC
	G9S	P9S	VG5S	
Range of capacity	to 400kW	to 500kW	to 400kW	to 400kW
Overload capacity	150%	120%	150%	150%
Control system	Sinusoidal PWM control (with torque vector control)		○ Vector control ○ ASR control with ACR minor loop	○ Sinusoidal PWM control ○ Constant DC voltage control ○ Power factor control
Power supply voltage	380 to 420V/50Hz 380 to 480V/60H		380 to 420V/50Hz 380 to 480V/60Hz	380 to 420V/50Hz 380 to 440V/60Hz

Fig.3 Schematic diagrams of large capacity IGBT inverters

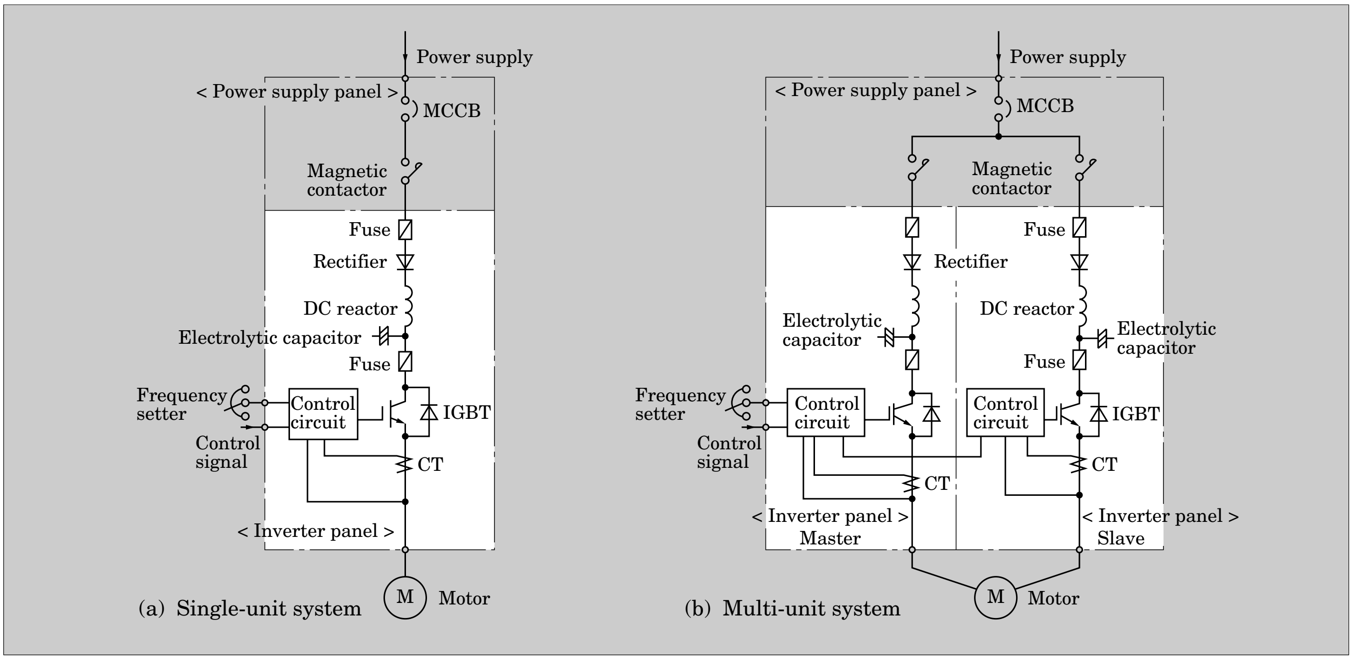
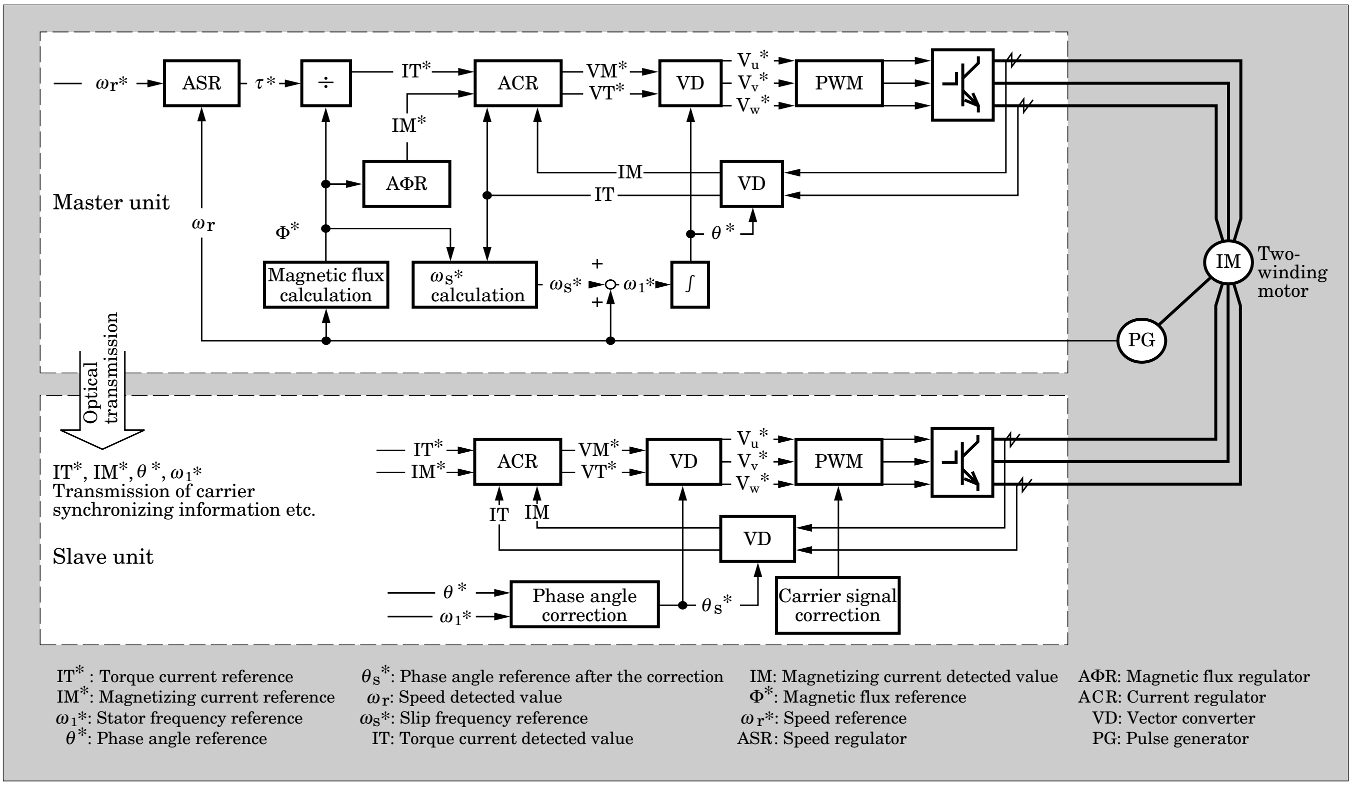


Fig.4 Control circuit block diagram of multi-unit system



greater than 400kW, we developed a multi-unit system in the VG5S series. In a multi-unit system (up to a maximum of six units), the motor is provided with multiple windings and an inverter is provided for each winding.

A block diagram of the control circuit for driving a two-winding motor is shown in Fig. 4. The master unit performs speed control, vector calculation and current control in the same manner as in a single-unit system. The slave unit performs only current control in response to each reference value sent from the master unit.

Because of requirements for reduced wiring, immunity to noise and high-speed, a serial communication system with optical fiber is utilized for the exchange of control information between the master and slave units.

In the slave unit, the phase angle data of the vector converter (VD), which determines the phase of current, is corrected based on the phase angle reference (θ*), stator frequency reference (ω_1*), transmission delay time and transmission period. Then, the shift of phase angles between both units is cancelled. As a result, the current balance between the windings can be achieved.

In conventional systems, there was a problem that the carrier signals of the master and slave units cannot be synchronized. Therefore, an AC reactor is inserted between the inverter and motor as a means to prevent an increase of the current ripple. However, in this system, the information of the time difference between the communication reference signal and carrier signal of the master unit is sent from the master unit to the slave unit, and the slave unit corrects the period of the carrier based on this information. This synchronizes the carrier signals between both units.

3.2 Harmonic suppression technology

As is well known, a typical input circuit consists of a three-phase rectifying bridge network constructed from diodes. After smoothing with a capacitor in the link circuit, an AC voltage of variable voltage and variable frequency is obtained via the PWM inverter on the output side.

Since low harmonic currents are generated by the rectifying and smoothing processes of this input AC power supply circuit, these harmonics are suppressed in accordance with the Japanese guidelines.

We will introduce means to suppress harmonic currents in the converter itself or in the power supply transformer.

3.2.1 Twelve-pulse rectifier

The three-phase bridge method (with a smoothing capacitor) generates harmonic current having the orders of $6n \pm 1 (n=1, 2, 3, \cdots)$. The lower the order, the greater the values become. This system is also called a 6-pulse rectifier since the ripple frequency in the rectified output is six times of the power supply frequency.

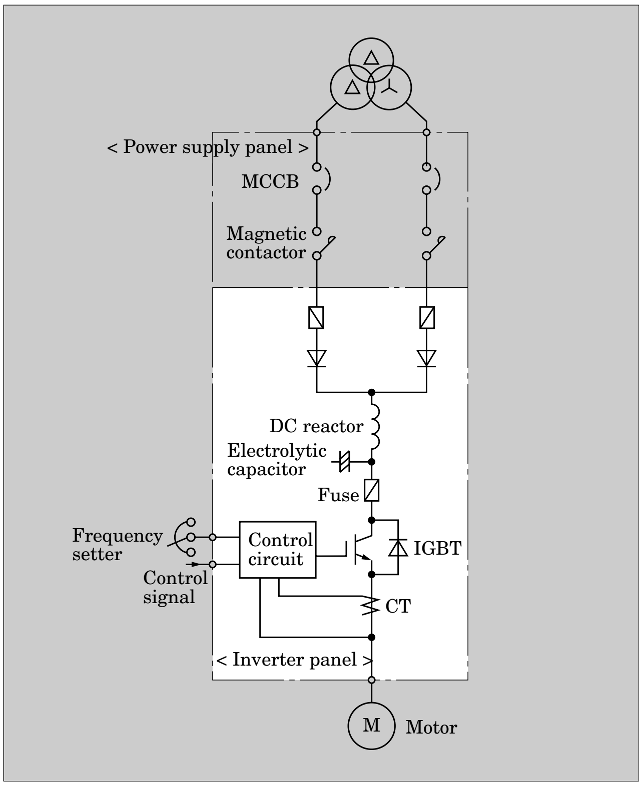
When the rectifier circuit is divided into two

Table 2 Example of harmonic current

Object \ Order	5	7	11	13	17	19	23	25
12-pulse rectifier circuit	3.4	1.6	7.0	4.0	0.4	0.4	1.4	1.2

(Unit: %)

Fig.5 Schematic diagram of inverter with 12-pulse rectifier



circuits as shown in Fig. 5 and AC voltages having a phase difference of 30° are supplied through a 3-winding transformer where the 2 secondary windings have separate connection systems, a so-called 12-pulse rectifier circuit is constructed. In this circuit, if harmonic current components in the right and left circuits are ideally balanced, only the currents of the fundamental component and $12n\pm1(n=1, 2, 3,\cdots)$ order components will flow through the primary winding of the transformer. This completely eliminates components of the orders of 5, 7, 17, 19, etc.

In practice, however, some components remain due to differences in the impedance and voltages of both windings. For a 400 V class transformer where

○ the voltage error is 2V or less,
○ the impedance is 2.7% or more, and
○ the amount of impedance scattering is 10% or less,

residual amounts can be calculated using the values in Table 2.

Further, when a transformer similar to that described above is applied to the circuit shown in Fig. 3 (b) and the secondary windings of the transformer are separately connected to the master and slave circuits, the inverter side is controlled such that the divided windings are always supplied with the same amount of power. Since both secondary windings of the transformer consume the same power, the difference in the transformation ratios of both windings is cancelled.

Residual components are determined by the voltage differences and the impedance in the transformer in Fig. 5. However, when a 12-pulse rectifier is utilized in the circuit of Fig. 3 (b), the amount of residual components is determined by the precision of the control on the inverter side.

3.2.2 PWM converter

Fuji Electric has supplied PWM converters of 5.5 to 220kW for inverter to the market. The range of

Fig.6 Schematic diagram of inverter with PWM converter

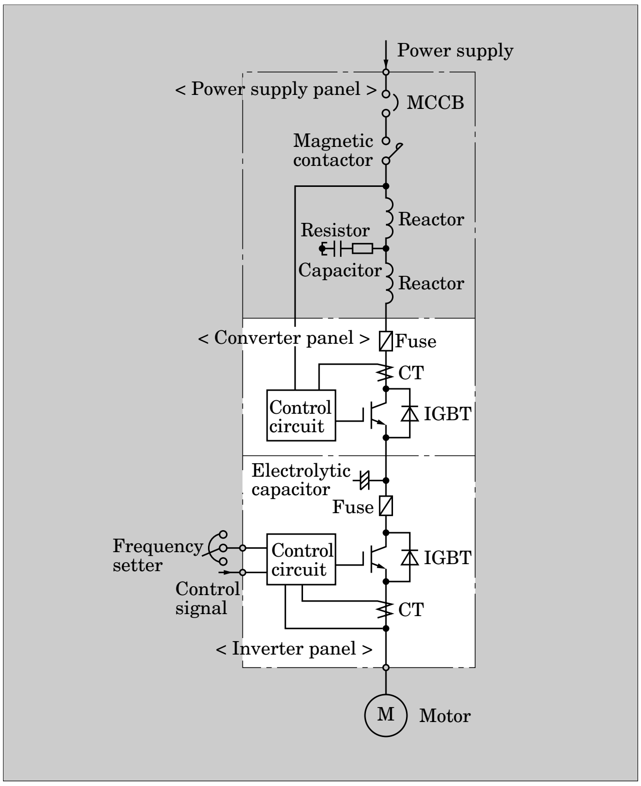
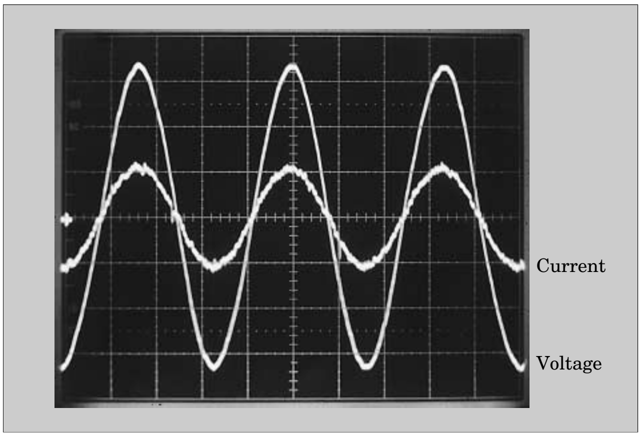


Fig.7 Input current waveform of PWM converter



application for these converters is increasing. In addition to enlarged inverter capacities, these PWM converters are also designed to be compatible with the enlarged inverter capacities.

A schematic diagram of an inverter with PWM converter is shown in Fig. 6. Since the three-phase bridge with IGBTs performs PWM control instead of the diode rectifier, the input current waveform is made sinusoidal and the power factor can be controlled to approximately 1. Figure 7 shows the waveforms of the input current and phase voltage when this PWM converter is utilized.

Since this PWM converter not only reduces harmonic current, but can also return regenerative energy to the power supply side, it has been favorably received in applications to lifting devices such as cranes and elevators.

4. Conclusion

In this paper we have introduced the large capacity power converter.

Fuji Electric will continue to respond to market needs by supplying highly reliable inverters and optimal systems, including higher capacities for an expanding range of applications and countermeasures against harmonics which have recently been problematic.