Present Status and Future Prospects for General-Purpose Inverter Technologies

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1. Introduction

Variable-speed drive systems, typically represented by general-purpose inverters and servo systems, are used in many industrial fields. They contribute to the energy savings, automation, labor savings, and high-efficiency operation of machines and equipment. Both inverters and servo systems have improved economically since the advent of power transistors. They have made rapid progress with the spread of energy-saving measures due to the oil crisis.

This paper outlines the basic technologies that have driven these developments, modern technologies for future development, and Fuji Electric's perspective. Our abundant product line is also introduced.

2. Modern Technologies of General-Purpose Inverter

2.1 Power conversion circuit technologies

Variable-speed drive systems typically represented by general-purpose standard inverters have realized small size and high efficiency through the use of low-loss power devices such as insulated-gate bipolar transistors (IGBTs), a high-efficiency cooling technology, and a large-scale integration technology using metal-based printed circuit boards. These developments will be pursued and should prove successful in the future.

From the viewpoint of main circuit systems, most drive systems are composed of a diode rectifier circuit and a PWM inverter circuit, as shown in Fig. 1. This combination has been used since its inception and seems to be well established technically and economically. However, it requires a dynamic braking circuit to dissipate the regenerated energy during braking and harmonic current generated in the input power source. One general method of reducing harmonic current is to connect a DC or AC reactor, as shown in Fig. 1.

To efficiently return regenerated energy to the power source during braking and to greatly reduce input harmonic current, the PWM converters shown in Fig. 2 have come into use. However, this method requires an AC reactor on the power supply side. In addition, according to the condition of the power source, an LC filter must be added. Therefore, this method requires further amplification and cost reduction.

To meet these requirements, Fuji Electric studied a direct AC-AC converter system as a new main circuit system. We proposed a system to greatly reduce input harmonic current without an additional reactor by regarding the motor winding and converter circuit as a unified system. This currently being studied for future production. (For further details, please see "Novel Technologies for Power Conversion Circuits" in this special issue.)

Fig.1 Typical main circuit of general-purpose inverter

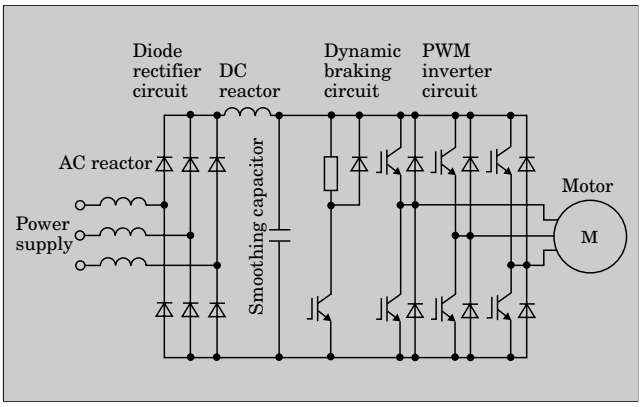
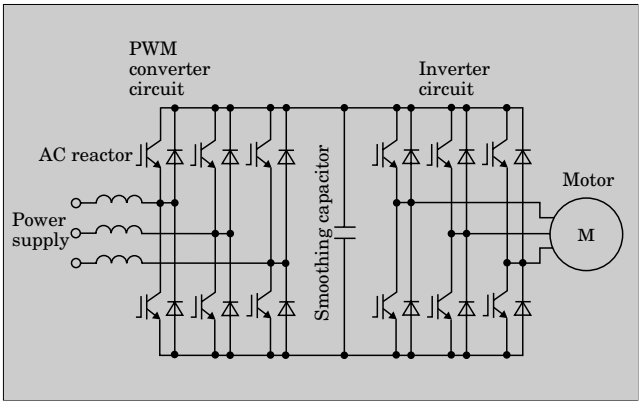


Fig.2 Inverter circuit with PWM converter



2.2 Noise reduction methods

Electronic equipment such as inverters and servo systems performs high-efficiency power conversion by high-speed switching with IGBTs. But this high-speed switching causes high frequency noise.

In other countries and regions around the world, this noise has come under regulation based on the recommendation of the IEC (International Electrotechnical Commission).

Figure 3 shows an example of noise terminal voltage measured in an inverter and the limit values. The curve with a note of CISPR class B ③ shown between the data without the noise filter ① and with the noise filter ② is the limit value (recommended value) for connections to power sources in residential and commercial districts. The present method of satisfying these limits in inverters and servo systems is to connect a filter in the power supply circuit and uses shielded wires on the main circuit to the motor.

Fig.3 Example of noise terminal voltage (measured and limit values)

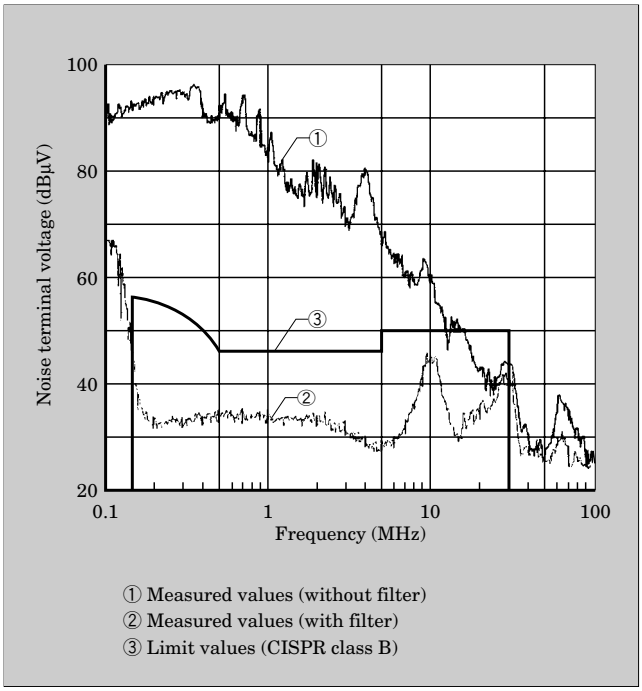
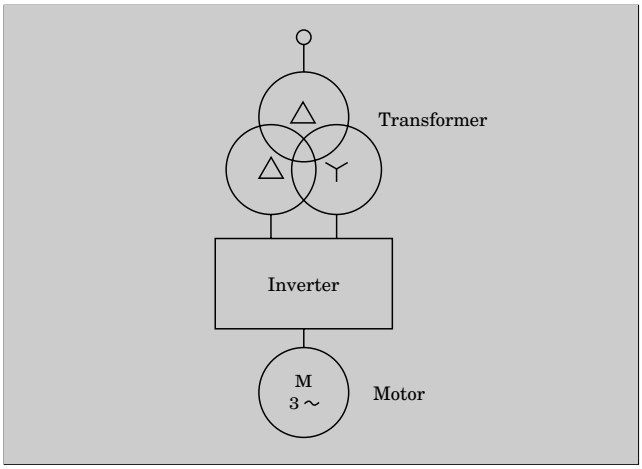


Fig.4 A 12-pulse connection for a large-capacity inverter



Fuji Electric is actively researching the noise generation mechanism and transmission process, IGBT soft switching methods to suppress noise, and noise reduction methods for DC-DC converters for the control power supply. (Please refer to "Noise Reduction Methods for Power Electronics Equipment" in this special issue.)

2.3 Control technologies

Due to progress in microprocessor and gate array LSI technologies and technical development in motor control techniques, the control technologies of inverters and servo systems have been advancing every year.

In addition to technologies that improve motor torque controllability such as sensorless vector control and torque vector control, technical developments that improve application performance such as the tuning of motor control parameters and adaptability control including matching the mechanical system are in progress. In the future technologies for further improving handling ease and for high-efficiency vector control using a general-purpose standard inverter and a general-purpose motor will be developed.

To obtain a smooth rotation at a low speed with *V/f* (voltage/frequency) controlled inverters, many control systems that reduce output voltage distortion and offset have been devised. For example, Fuji Electric developed a special LSI-based digital AVR technology which realized smooth rotation characteristics.

In addition, a variable-speed drive with general-purpose inverters has up to now been mainly intended for induction motors. But to improve operation efficiency, the latest trend is toward driving permanent magnet type synchronous motors (PM motors). However, as demonstrated by conventional servo systems, magnetic pole position or speed sensors are generally used for the PM motor drive. As introduced in the article "Recent Variable-Speed Drive Technology" in this issue, Fuji Electric is researching PM motor drive systems that do not require magnetic pole position or speed sensors.

2.4 Harmonic current reduction methods for large-capacity inverters

Harmonic current reduction methods for converters are as described in 2.1, above. However, a transformer is supplied for use by the large capacity converter. The 12-pulse connection system shown in Fig. 4 is the most economical harmonic current reduction method.

Fuji Electric produces a large-capacity inverter series that can meet 12-pulse connection by the six input terminals of its input rectifier that is divided into two parts. (For details, see "Large-Capacity Variable-

Speed AC Drive" in this issue.)

3. Fuji Electric's Variable-Speed Drive System Series

Fuji Electric's abundant product series of inverter for simple variable-speed drive to servo systems for high-precision, quick response control allows the most economical selection for any variable-speed drive use.

An outline of the product series is described below.

Fuji Electric's typical inverter series are shown in Table1.

The general-purpose standard inverters, based on Fuji Electric's original torque vector-controlled, high-performance, multi-function FRENIC5000G9S series, cover the entire range of small to large capacities. The FRENIC5000P9S series, its sister series, is economical for fan and pump loads.

A distinctive feature is that many series prepared for small capacity ranges allow selection from a broad cost performance to meet diversified needs. The FVR-E9S series, equipped with torque vector control like the FRENIC5000G9S, is capable of quick response control and suitable for frequent acceleration and deceleration. The FVR-C11S series is very small and exceedingly economical for simple variable-speed drive use.

General-purpose vector control inverters, equipped with high-performance vector control and utilized like general-purpose standard inverters, are widely used in elevators and multistory parking lots. When the driven motor is not equipped with a pulse encoder, it is also possible to convey the function to sensorless vector control.

The series for the machine tool drive is described in detail in "FRENIC5000MS5 for Machine Tool Spindle Drive" in this special issue. It is a new series, greatly improved in both structure and performance. From the viewpoint of control performance, there are two series; the FRENIC5000M5 used for NC lathes and the FRENIC5000V5 used for machining centers. Both have the advantage that the adoption of a separate structure for the converter and inverter sections enables the free selection of a high-efficiency power regeneration converter and an economical dynamic braking system.

A power regenerating PWM converter connected to the main circuit DC-bus terminals of the inverter performs high-efficiency power regeneration and maintains input current to a sinusoidal current. It is generally used for elevator loads with frequent dynamic braking. Further more, demands for it is rapidly increasing because its use greatly reduces input harmonic current. The principle that "the transfer coefficient for a 6-pulse converter equals zero" is applied according to the "Guidelines for the control of

Table 1 Fuji Electric's typical inverter series

Category	Series	Supply voltage	Capacity range (kW) (0.1 1 10 100 1,000)	Frequency control range (Hz) (100 1,000 10,000)	Main features
General-purpose standard inverters	FVR-C11S	Single phase 200V 3-phase 200V	0.1 – 2.2 0.1 – 3.7	120 120	Miniature type for simple variable-speed drive
	FVR-E9S	Single phase 100V Single phase 200V 3-phase 200V 3-phase 400V	0.1 – 0.75 0.1 – 2.2 0.1 – 3.7 0.4 – 3.7	400 400 400 400	High-performance, general-purpose inverters ○ Standard enclosure IP40 ○ Enclosure IP65 available
	FRENIC 5000G9S	3-phase 200V 3-phase 400V	0.2 – 90 0.4 – 400	400 400	High-performance, multi-function inverters ○ Standard enclosure IP40 (for 22kW or less) ○ Enclosure IP56 available (for 22kW or less)
	FRENIC 5000P9S	3-phase 200V 3-phase 400V	5.5 – 110 5.5 – 500	120 120	For variable torque load ○ Provided with automatic energy-saving operation mode most suitable for fan and pump loads (factory setting)
General-purpose vector control inverters	FRENIC 5000VG5	3-phase 200V 3-phase 400V	0.75 – 90 3.7 – 400	120 120	General industrial high-performance vector control inverters ○ For speed control with quick response ○ Capable of torque control with external analog signals
Machine tool spindle drive inverters	FRENIC 5000M5 FRENIC 5000V5	3-phase 200V 3-phase 400V	0.75 – 22 1.5 – 45	270 270	Machine tool spindle drive inverters ○ M5 (torque vector control without PG) ○ V5 (vector control with PG) ○ Selection between dynamic or regeneration braking for the converter possible
Regeneration PWM converters	RHC	3-phase 200V 3-phase 400V	7.5 – 55 7.5 – 400	50 – 60 50 – 60	Regeneration converters ○ High-efficiency power regeneration ○ Reduction in input harmonic current

harmonics by consumers of high or very high voltage power supplies" in Japan.

4. Conclusion

Demands for variable-speed drive, including energy-saving operation and utilization aiming at automation and saving labor have increased. Sophisticated and diversified systems have more often included variable-speed drive.

Up to now, developments have attached importance to improvements in performance and multiple functions. However, factors such as "user-friendly", "environment-friendly" and "high reliability" are likely to have priority with regard to drive systems in the future.

From the viewpoint of user friendliness, the simplification or automation of setting work during equipment setup and matching work of control parameters with the mechanical system are key points.

From the viewpoint of environmental friendliness, in addition to the problem of materials used for packaging and parts, technical developments to reduce electric noise and harmonic current more economically are the next issues.

From the viewpoint of reliability, the fundamental topics are to complete the protective functions and a design that extends the lifetime for each part. Of course, there are difficulties in balancing lifetime with economical efficiency. Functions such as a forecasting function for life expectancy before equipment failure are desired.

Fuji Electric will continually tackle these subjects to offer perfect variable-speed drive systems. We would appreciate your views as an actual user or a planner on our products.