Views on the Technology for General-Purpose Inverters and Servo Systems

Masaru Yamazoe
Shinobu Kawabata
Shigefumi Kurita

1. Introduction

Variable-speed motor drives such as general-purpose inverters and servo systems have contributed to the downsizing of machines and equipment, energy saving, automation, and reduction in labor. From applications in many fields, plenty of new needs have been brought forth, including increased response speed for high-performance drives and size and price reduction for standard drives. Common new needs for all drives are: compliance with international regulations against noise and harmonics, production of systems for controlling many pieces of equipment by serial data transmission, and prolonged life span as well as provision of a life expectancy prediction function to facilitate equipment maintenance.

This paper describes the latest technologies to meet these new needs at low cost and Fuji Electric's products that incorporate these latest technologies.

2. Trends of the Latest Technologies

The requirements of inverters and servo systems have diversified as the application range has expanded. The range of technologies to satisfy these demands is so wide that this paper describes the latest technologies according to their classification such as power circuits, control circuits, sensors, advanced functions, downsizing, and systematization.

2.1 The latest power circuit technology

The effort to satisfy demand for reduction in the size of inverters and servo amplifiers can be called a war on loss. The insulated-gate bipolar transistor (IGBT) that contributes 50 to 70% of the power circuit loss has made great progress, followed by the fourth-generation IGBT in which collector-emitter saturation voltage ($V_{CE(sat)}$) has been greatly reduced by using trench-gate and non-punch-through technologies. The application of new devices is expected to reduce loss further. The intelligent power module (IPM) has been used for power circuit modules with the aim of reducing size, improving protective functions, and reducing cost.

On the other hand, the use of a high switching frequency (10 to 15kHz) to reduce motor noise has become commonplace, resulting in a noise problem with the peripheral equipment. A method to solve this problem has been established by drive technology that suppresses switching voltage variation to about 5,000V/μs. With regard to the DC-DC converter for control power, another noise source, the adoption of quasi-resonance switching is expected to solve the problem. Figure 1 is an example of radiation noise measurement to demonstrate the effect of noise suppression technology. Reduction by 15 to 20dB is observed particularly in the band of 30 to 50MHz.

Further, another requirement of the power circuit is the suppression of input power line harmonic. The power supply circuits of general-purpose inverters

Fig.1 Example of radiation noise measurement

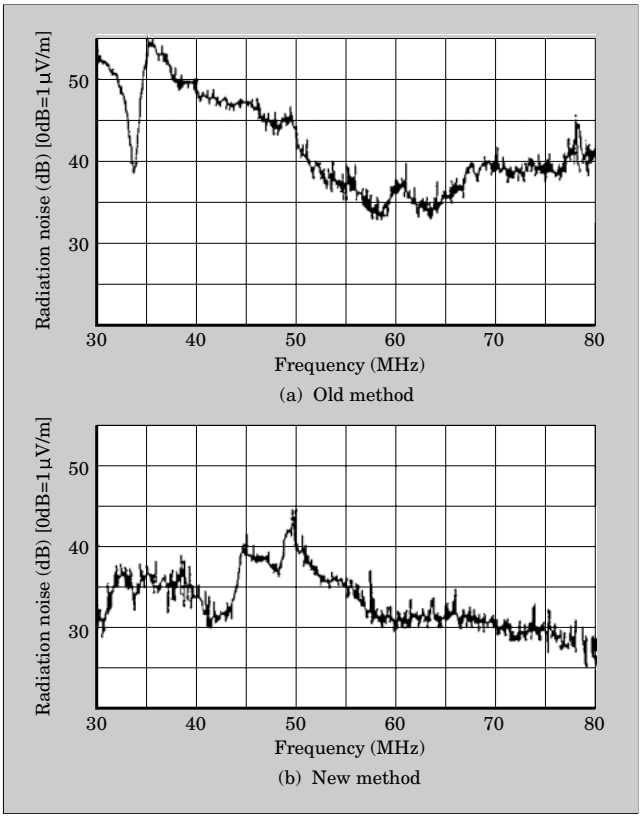


Fig.2 Power circuit diagram of a general-purpose inverter

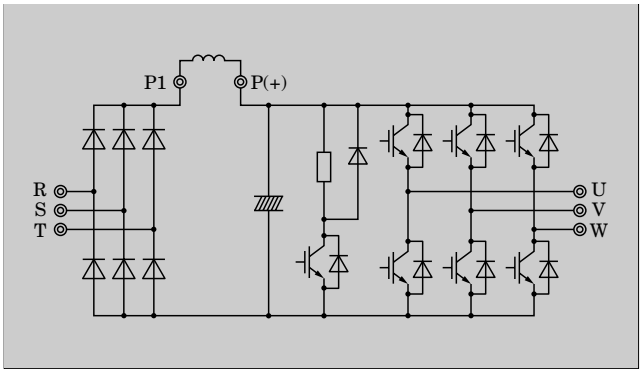
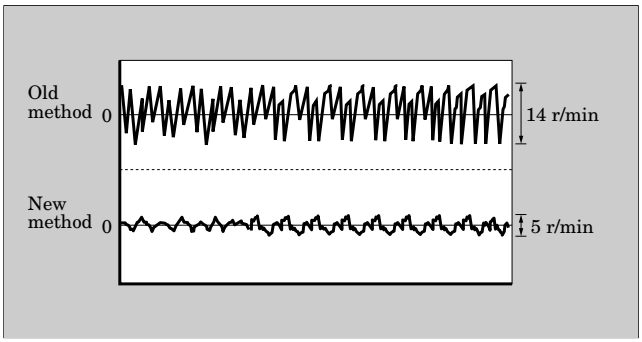


Fig.3 Example of rotational irregularity measurement (at 1Hz, no load)



mainly use diode rectifiers, and it is known that this causes harmonic current in the power supply. A regulation in Japan, "Guideline of limits for harmonics emissions on general-purpose and household electric appliances," was issued in 1994, and we are faced with the necessity of harmonic suppression. Fuji Electric equips all types of apparatus, including compact inverters, with "DC reactor connection terminals" as standard for economical suppression of harmonics (Fig. 2).

2.2 The latest control technology

Quick response and high performance are strongly required not only by servo systems but also by general-purpose inverters, and Fuji Electric has developed products to meet these requirements. One factor enabling the realization of high-speed control is the advance in microprocessor performance. In inverters several generations ago, the use of 16-bit microcomputers meant high speed. Recently, 32-bit RISC (reduced instruction set computer) processors have greatly raised processing speed, and control data processing speed has more than doubled. In servo systems, operations formerly processed with software have been processed with hardware through utilization of application specific integrated circuits (ASICs), for example, and the control period has been made about 10 times faster. Consequently, response characteristics of the total control system have greatly improved, and a high-speed response approximately 5 times faster than before has been realized with the speed control system.

From the viewpoint of the control method, it has become expected that vector control be used for general-purpose inverters. In high-performance types of apparatus, vector control with pulse generator (PG) feedback is made possible by mounting a simple optional circuit board. Now, high-performance vector control can be offered at low price.

The performance of vector control depends on how accurately driven motor constants are comprehended. A standard tuning function for measuring motor constants has been installed for this purpose, and on-line tuning to detect the variation of motor constants due to temperature changes during operation has been used in addition to off-line tuning while the equipment is halted.

In servo systems, real-time tuning technology for load inertia has been developed, enabling a proper control response that corresponds to the load.

Fuji Electric has developed an original torque vector control for the control system of general-purpose inverters and has improved control performance. As the application range has widened, higher accuracy of torque operation in the region of low-speed operation has been anticipated. The performance of low-speed control has been improved by performing iron loss compensation in consideration of motor hysteresis loss. With regard to the rotational irregularity that sometimes caused problems in the low-speed region, inverters have been greatly improved by applying compensated control to the output voltage distortion that causes irregularity.

Figure 3 shows measurement of the rotational irregularity of a 3.7kW motor operated at 1Hz with no load. The component at six times the output frequency is greatly reduced.

2.3 The latest sensor technology

In servo systems, the rotary encoder as well as high-speed data processing and high-performance systems are essential factors that control the total system performance. The 16-bit encoder is currently most common for the requirement of high resolution and high performance. To avoid a pulse frequency increase due to increased resolution, serial data transmission has come to be used for connection between encoders and servo amplifiers in place of the former parallel data transmission system.

2.4 Advanced function technology

Recently, market needs for maintenance functions have increased. In recent mechanical equipment that use many electronics devices, there is the fear that device failure will lead to failure of the whole equipment. To avoid this, advice on maintenance and inspection prior to the failure of each individual device is expected.

Fuji Electric has developed inverters having a

Table 1 List of Fuji Electric inverter model types and series

Model type	Series	Supply voltage	Capacity (kW) 0.1 1 10 100 1,000	Frequency control range (Hz) 100 1,000 10,000	Main advantages
General-purpose inverters	FVR-S11	Three-phase 200V Single-phase 200V	0.1 – 0.75 0.1 – 0.4	120 120	Inverters for simple variable-speed drive ◦Three types of volume tuning, terminal-board signal control, and serial-transmission control available
	FVR-C11	Single-phase 200V Three-phase 200V	0.1 – 2.2 0.1 – 3.7	120 120	Compact inverters ◦PID control equipped as standard ◦Frequency setting volume equipped as standard.
	FVR-E9	Single-phase 100V Single-phase 200V Three-phase 200V Three-phase 400V	0.1 – 0.75 0.1 – 2.2 0.1 – 3.7 0.4 – 3.7	400 400 400 400	General-purpose inverters ◦Starting torque: 200% ◦RS-485 equipped as standard ◦PID control equipped as standard
	FRENIC 5000G11	Three-phase 200V Three-phase 400V	0.2 – 90 0.4 – 400	400 400	High-performance, multifunctional inverters ◦Starting torque: 200% ◦RS-485 equipped as standard ◦PID control equipped as standard ◦Auxiliary control power supply equipped as standard ◦High-performance vector control with the optional card and a PG-mounted motor
	FRENIC 5000P11	Three-phase 200V Three-phase 400V	5.5 – 110 5.5 – 500	120 120	Exclusively for variable torque loads ◦PID control equipped as standard ◦Auxiliary control power supply equipped as standard ◦RS-485 equipped as standard ◦High-efficiency operation by the automatic energy-saving function
	FRENIC 5000H2	Three-phase 200V	0.75 – 22	5,000	For superhigh-speed motor drive
General-purpose vector control inverters	FRENIC 5000VG5	Three-phase 200V Three-phase 400V	0.75 – 90 3.7 – 220	120 120	High-performance vector control inverters for general industries ◦Quick-response speed control ◦Torque control
Inverters for machine tool spindle drive	FRENIC 5000MS5 M5 V5	Three-phase 200V Three-phase 200V	0.75 – 22 1.5 – 45	270 270	Inverters for machine-tool spindle drive ◦M5 (torque vector control without PG) ◦V5 (vector control with PG) ◦Converter separated (dynamic or regenerative braking selectable)
Regenerative PWM converters	RHC	Three-phase 200V Three-phase 400V	7.5 – 55 7.5 – 400	50 – 60 50 – 60	Regenerative converters ◦High-efficiency regeneration ◦Reduction in input harmonic current

(Under development)

function to measure the electrostatic capacity, operation time, and ambient temperature of deteriorating component parts and predict their life expectancy. These inverters have been well received.

With regard to the function of operating a high-inertia load, smooth operation without any shock is required when restarting after an instantaneous power interruption or when drawing into inverter operation a blower being rotated by external wind. Technology has been developed to produce self-oscillation based on proper positive feedback from the control when starting the inverter and to predict the rotating speed from its frequency. Because this method can predict speed, including the rotating direction, it has the advantage of being able to start an inverter without a shock irrespective of the current rotating direction, forward or reverse.

2.5 Downsizing technology

Downsizing technology has rapidly advanced in general-purpose inverters, and this trend excludes neither the amplifiers nor motors of servo systems.

(1) Downsizing of inverters and servo amplifiers

Cooling technology is very important for the down-

Table 2 List of Fuji Electric servo system series

Series	Motors	Capacity (kW) 0.1 1 10	Max. speed (r/min) 2,000 3,000 4,000	Main advantages
FALDIC–α ①L–type (for linear positioning) ②R–type (for rotational positioning) ③V–type (for speed control)	GRC motors (low–inertia, cubic type) GRS motors (low–inertia, slim type)	0.1 1.5 0.03 1.5 5.0 (Under development)	3,000/ 5,000 3,000/ 5,000	①Frequency response at 500 Hz, top-level in the industry ②Two low-inertia motor types are selectable as either a cubic type with min. axial length or a slim type with min. diameter ③Amplifier types (V, L, and R) prepared for different uses ④Reduction in wiring by serial transmission between the encoder and amplifier ⑤High–speed serial bus connection between Fuji Electric's PLC and the amplifier
FALDIC–Ⅱ ①L–type (for linear positioning) ②R–type (for rotational positioning) ③V–type (for speed control)	GRH (medium–inertia) motors GRK (high–inertia) motors	0.3 2.7 0.05 3.7	3,000 2,000/ 2,500	①Frequency response at 100 Hz ②Medium-inertia motors used, high rigidity compliant ③Model types (V, L, and R) prepared for different uses ④Reduction in wiring by serial bus connection between Fuji Electric's PLC and the amplifier
FALDIC–IM	MPF series motors (exclusive–use induction motors)	2.2 37	1,500/2,000	①Positioning of a large machine ②Frequency response at 80 Hz ③Reduction in wiring by serial bus connection between Fuji Electric's PLC and the amplifier
Digital ES motors (for speed control)	GRK (high–inertia) motors	0.05 3.7	2,000/ 2,500	①Applied to machines that handle loads with large moment of inertia ②Speed control and pulse train positioning possible ③Motors are interchangeable with standard motor

sizing of inverters and servo amplifiers. Aluminum die-cast cooling fins were formerly the mainstream; however, caulked fins and brazed fins have come into use due to their efficient cooling. Also, technologies for parts integration and high-density mounting have greatly contributed to downsizing. Future technical problems to be tackled are technologies for bare-chip mounting and advanced system LSI (large-scale integration).

(2) Downsizing of motors

It is an important to be able to reduce the size of servomotors without reducing efficiency. Main technologies for reducing servomotor size are: ① use of rare-earth magnets, ② improving the coil filling, and ③ cooling technology using high heat-conductive resin molding. As the result of these technical developments, the motor has reduced its volume to about one third of the former type.

2.6 Systematization technology

As general-purpose inverters advance in performance and servo systems increase in response speed, there is a growing demand for system compatibility so that upper-level programmable logic controllers (PLCs) can be connected by serial data transmission.

General-purpose inverters are equipped with RS-485 as a standard function; however, there is demand for compatibility with not only Fuji Electric's private link but also open bus systems. There are different types of open bus systems depending upon the industry and district, and the goal of technical development is make it easier to connect an inverter to an open bus system.

To utilize most effectively the greatly improved high-speed response of servo amplifiers, they can be connected to the PLC by a high-speed serial bus. This bus is of a 25MHz, 3V drive type, and noise suppression technology is fully utilized to realize high-speed control for servo systems.

3. Fuji Electric's Product Lines

Fuji Electric provides diverse product lines ranging from inverters for very simple speed control to servo systems for high-response, high-precision positioning control. Therefore, it is possible to select the most economical product for each use.

The product series are described below.

3.1 Inverter product lines

Table 1 shows Fuji Electric inverter model types and series.

In the group of general-purpose inverters, the inverters are undergoing a model change to the 11 series, and in addition, the simplest variable-speed inverter "FVR-S11S" series has newly been added to facilitate the use of inverters in fields that formerly abandoned inverter use for economic reasons.

The main type “FRENIC5000G11S/P11S” series is equipped with an auxiliary control power supply, PID (proportional, integral, and derivative) control, and RS-485 serial data transmission as standard. These were formerly optional items. The wide reduction of rotational irregularity in the low-speed region and the function of life expectancy prediction are worthy of special mention.

In addition, because high-performance vector control is made possible by using the optional card and motors with PG, the G11S series has greatly expanded its application range.

3.2 Servo system product lines

In servo systems, both servo amplifiers and motors have realized drastic reduction in size and high performance by using innovative technologies. This enabled Fuji Electric’s servo systems to be utilized in the fields of high-speed response where servo systems had not been used, such as multiple-axis machine tools, robots, semiconductor manufacturing equipment, and electronic parts processing machines, and greatly expanded the application range.

Table 2 shows the Fuji Electric servo system series. The new “FALDIC-α” series servo system has been added. This new series has realized the top-level high-speed response in the industry by reducing the motor size and the moment of inertia.

This new series, along with the three series of: the “FALDIC-II” series that improve mechanical rigidity by combination with a motor of medium moment of inertia, the “FALDIC-IM” series that covers the range of medium and large capacities, and the “digital ES motor” series that is easy to use and suitable for building economical systems, have formed a powerful four series system.

On the other hand, servo systems are generally used in combination with positioning control equipment. Therefore, to comply with comparatively simple positioning systems, a series of “servo amplifiers with built-in positioning function” that can internally register 100 steps of position data have also been provided. In the case of multi-axis advanced-function positioning control, the use of the “advanced-function module” of Fuji Electric’s PLC (MICREX series) is recommended.

4. Conclusion

The trends of variable-speed drive systems toward small size, high performance and multiple functions have continued, and technical developments in line with these trends has been touched on. As for new trends, from the viewpoint of “user friendliness,” the automatic tuning of control constants and small, easy-to-operate inverters have been introduced. From the viewpoint of the environment, noise suppression technologies for power circuits and control power supply circuits have been introduced, and from the viewpoint of higher reliability, a trend such the life expectancy predicting function, has been described.

These new items are in their beginning stages and will require further efforts in the future. Please directly inform Fuji Electric of your needs, including items other than the above, from the standpoint of an actual user of variable-speed drive equipment. We appreciate your cooperation.