Present Status and Future Prospects for General-Purpose Inverters and Servo Drive Systems

Shigefumi Kurita
Takao Yanase

1. Introduction

It is commonly believed that variable speed control systems using power electronic technology have reached maturity. However, from the customer's viewpoint, there are still many problems with general-purpose inverters and servo drive systems, including the pursuit of advanced functions, improved performance, miniaturization and lower costs, that need to be addressed.

The applications for AC variable speed control systems have expanded from simple variable speed control aiming at saving energy during the initial stage to variable speed control with multi-function and high-performance for general industrial equipment. Multi-function and high-performance are also being continuously pursued in general-purpose inverters. Functions such as "Automatic torque boost," "Torque vector control," "Slip compensation," "On-delay compensation," "Restart after momentary power failure," "Serial link operation" etc. are used to achieve better performance and increase reliability of the inverters as well as require less wiring. They have been remarkably successful. As for miniaturization, the size of the inverter has been reduced by 1/10 in the last ten years, owing to technical innovations such as the adoption of a low switching loss power device (IGBT: Insulated Gate Bipolar Transistor), a compound insulation metallic board and highly integrated control devices.

In addition, sensorless vector control, auto-tuning technology and adaptive control technology are innovations in control technology that have further improved performance as well as achieved automatic adjustment.

As mentioned above, technical innovations in general-purpose inverters and servo drive systems are continuously progressing. Their development status, models and product series are introduced below.

2. Types of General-Purpose Inverters and Servo Drive Systems

In 1977 Fuji Electric was the first to produce transistor inverters for the electrical industry. Since then, we have led the industry in totally digitizing, miniaturizing and adding functions to the general-purpose inverter. In the servo system family, we have developed a series of economical ES motors that can be easily serviced, contributing to better performance and reduced cost of general industrial machines. Furthermore, development of the servo system with position control has minimized wiring between apparatuses, decreased the size of the equipment and improved system reliability.

Fig. 1 Fuji Electric's general-purpose variable speed control systems

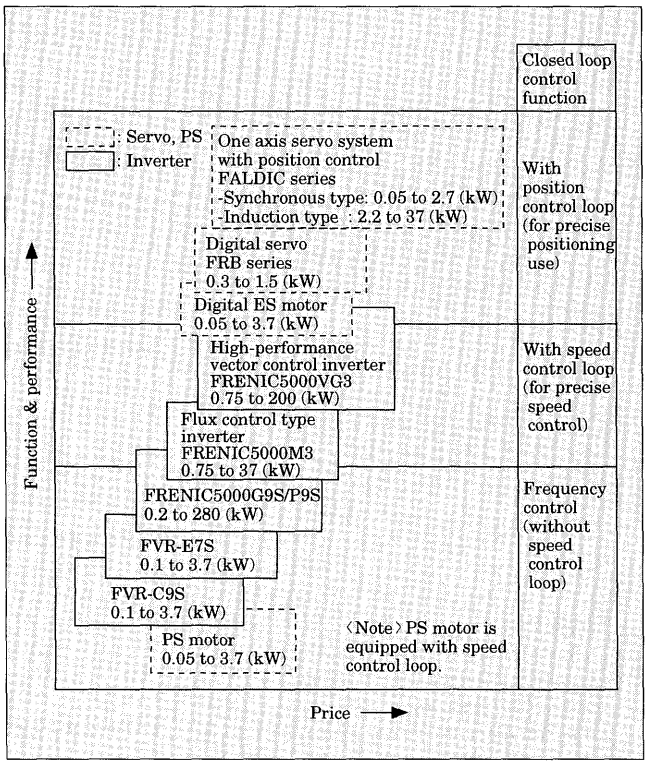


Figure 1 shows different types of general-purpose variable speed control systems made by Fuji Electric . The figure consists of a general inverter group (FVR-C9S, FVR-E7S and FRENIC5000G9S / P9S) which performs frequency control, digital ES motors and a high-performance vector control inverter group, which can precisely control speed and a servo system group which can perform precise positioning. These groups can be

selected to correspond widely to market requirements.

3. The Technical Trend in Inverters and Servo Systems

Variable speed drive technology for general-purpose drive equipment has made rapid progress due to the development of power semiconductor devices and electric control devices, such as the microcomputer. In the following, we describe the challenges that faced Fuji Electric in the development of the technical elements which make up the foundation of technological advances.

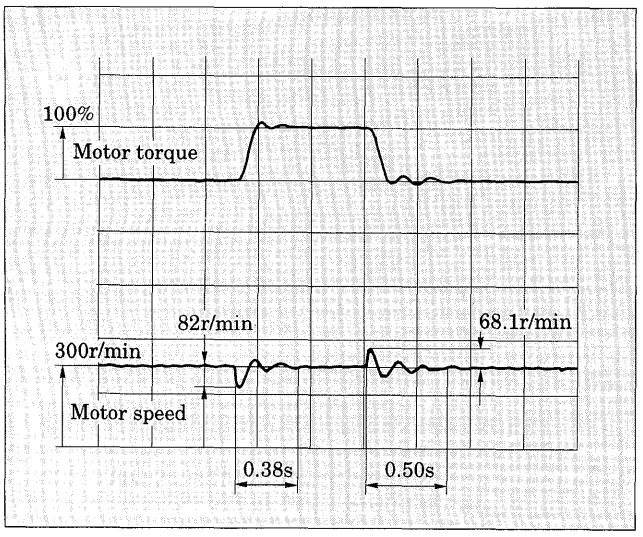
3.1 Torque vector control

Vector control is a control system by which an induction motor, which is controlled in a manner similar to that of a direct current motor, attains greater than 150% of the rated torque from zero speed. This control method requires the motor's design constants and the rotation speed of the motor by pulse encoder. Therefore, specialized motors have been used in the past. The sensorless vector control system and the flux vector control system are examples of systems which take advantage of the merits of the vector control by using a general-purpose inverter and a general-purpose induction motor.

Fuji Electric's newly developed vector control system is a part of the sensorless vector control system. In this system, an instantaneous motor current is detected and then separated to its flux and torque current components. Therefore, by applying a general-purpose induction motor, a torque of greater than 150% is obtained at 1 Hz operation without the use of a pulse encoder.

Furthermore, the dynamic characteristics of the drive system can be improved as compared with the conventional V/f control method. For example, an impact torque response is shown in Fig. 2. In this figure, the output torque (measured with a torque meter) and rotating speed are shown when the output frequency is set at 10 Hz and the full load is suddenly added and removed. When applying full load, speed stabilization is achieved by only several hundred milliseconds.

Fig. 2 Impact torque response



3.2 Auto-tuning function

In the torque vector control system, motor constants must be set for every motor in order to get an optimum performance. The motor constants, which are required for set-up, differ somewhat depending upon the control system. But in either case, resistance of the stator winding must be set. This value differs for every motor and is affected not only by the length of the wiring between the inverter and motor, but also by the temperature change in the motor. The automatic setting of the motor constants is achieved by the auto-tuning function.

This newly developed system have a several merit, for example to be performed auto-tuning of motor constants without motor rotating. Figure 3 shows a block diagram of the stator winding resistance auto-tuning system. In addition, automatic compensation functions, which have robust characteristics, are provided for the change in the resistance due to temperature.

3.3 Reducing rotating fluctuation

In PWM (Pulse Width Modulation) inverters, an on-delay time control is performed to prevent a short

Fig. 3 Block diagram of stator winding resistance tuning

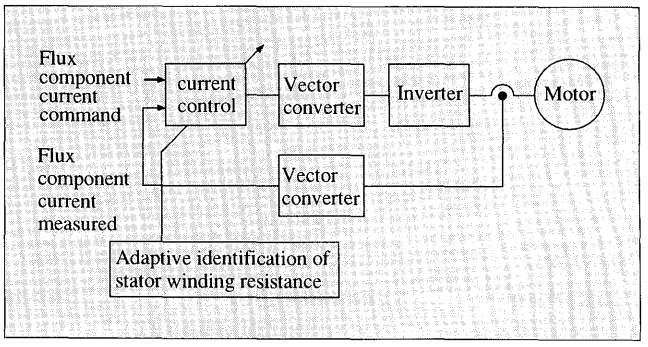
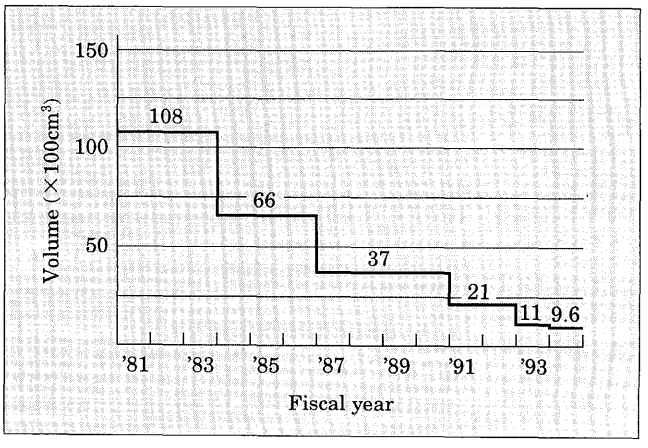


Fig. 4 Change in inverter size (0.75kW)



circuit between the upper and lower arms. Due to this effect, distortion of the motor current increases, and rotating fluctuation of the motor may occur, especially during low speeds. This distortion may cause a so-called current oscillation phenomenon, reducing the stability of the motor's rotating speed within a specific range of frequencies. To suppress this phenomenon, we applied on-delay compensation, using the instantaneous current of the motor, to reduce the distortion of the inverter output voltage caused by the on-delay time control.

Furthermore, to actively suppress the current oscillation phenomenon, an exciting current damping control is utilized. This detects fluctuation of the exciting current and feeds this signal back to the control system. Moreover, an instantaneous voltage vector control, which uses an instantaneous output voltage of the inverter, and a flux control method, which controls the motor by using a flux component of the motor calculated by integrating the output voltage of the inverter, have already been put into use.

3.4 Miniaturization

One of the strong requirements for the inverter is miniaturization. Though inverter is the equipment generating substantially much heat because it handles main circuit power, we have achieved, in order to realize the miniaturization, the utilization of parts in the main circuit with low switching loss such as IGBTs, the empolyment of highly efficient cooling technology, the application of IPM (Intelligent Power Module) and combined metal substrates with different insulation, and the high integration of control devices.

Figure 4 shows the change in the inverter's size. In the past ten years, the inverter has been reduce to less than 1/10 its original size. For example, the ultra-compact inverter FVR-C9S for 0.75kW use measures 12cm in height and 8cm in width, and its volume is less than 1,000 cm^3 (1 liter).

3.5 Adaptive control in the servomotor

Up until now, in order to achieve the best response, the servo system required special knowledge and experience, which prevented application to general industrial machines. Now, an auto-tuning system which automatically adjusts the control system has been developed and put into use. Mounted on the servo system, the auto-tuning system has contributed to shortening the user's set-up time by reducing adjustment labor.

Recently, auto-tuning requirements include not only automatic adjustment before operation, but also changes in parameters during operation or even no adjustments at all. In response to these requirements, Fuji Electric has developed a system based on adaptive identification. In this system, an inertia of load is identified during operation, and the control system's gain is optimally adjusted, automatically performing a series of these operations. Further, in regards to improvement in system flexibility, countermeasures against

Table 1 Fuji Electric's inverter product line

Product classification	Series designation	Voltage of power supply	Capacity range (kW) 0.1 1 10 10^2 10^3	Control range of frequency 10^2 10^3	Main features
General-purpose inverter	FVR-C9S	Three-phase 200V	0.1 – 3.7	120Hz	- Ultra-compact - Simple operation - Ultra low noise
	FVR-K7S	Single-phase 100V Single-phase 200V Three-phase 200V	0.2 – 0.75 0.2 – 2.2 0.2 – 3.7	120Hz 120Hz 120Hz	- Totally enclosed - Simple operation - Small size
	FVR-E7S	Single-phase 200V Three-phase 200V Three-phase 400V	0.1 – 2.2 0.1 – 3.7 0.4 – 3.7	400Hz 400Hz 400Hz	- Multi-function, general-purpose use - Small size -Ultra low noise - Powerful, trip-less
	FRENIC 5000G9S	Single-phase 200V Three-phase 200V Three-phase 400V	0.2 – 2.2 0.2 – 90 0.4 – 220	400Hz 400Hz 400Hz	- High-performance, multi-function - Ultra low noise - Powerful, trip-less
	FRENIC 5000P9S	Three-phase 200V Three-phase 400V	7.5 – 110 7.5 – 280	120Hz 120Hz	- High-performance, multi-function (for square torque load) - low noise
	FRENIC 5000H2	Three-phase 200V	0.75 – 22	5,000Hz	- for super high-speed motor - PAM* control system
General-purpose vector control inverter	FRENIC 5000VG3	Three-phase 200V Three-phase 400V	0.75 – 90 3.7 – 200	120Hz 120Hz	- High-performance vector control
	FRENIC 5000VG3N	Three-phase 200V Three-phase 400V	0.75 – 22 5.5 – 45	120Hz 120Hz	- High-performance vector control - Ultra low noise
Spindle drive for machine tool	FRENIC 5000M3	Three-phase 200V	0.75 – 37	200Hz	- Flux control - Low noise
	FRENIC 5000V3	Three-phase 200V	1.5 – 45	267Hz	- High-performance vector control - Low noise
Regenerative braking control	RHR	Three-phase 200V Three-phase 400V	15 – 55 15 – 55	50 – 60Hz 50 – 60Hz	- Specifically for regenerative braking

<Note> *PAM: Pulse Amplitude Modulation

Table 2 Fuji Electric's servo system product line

Product classification		Series designation	Capacity range (kW) 0.05 0.1 0.5 1 5 10 50	Maximum rotating speed (r/min) 2,000 2,500 3,000	Main features
Servo for speed control	Analog servo	FRH (Amp.) GRH (Motor) series	0.3 – 1.1		- Ultra-low noise - Frequency response ≧ 100Hz (J_M=J_L) - Max. resolution 8,000 pulse/rev. - Speed control range 1 : 2,000
	Digital servo	FRB (Amp.) GRH (Motor) series	0.3 – 1.5		- All digital Amp. with bus coupling - Ultra-low noise - Max. resolution: Same as above - Frequency response ≧ 100Hz (J_M=J_L) - Speed control range 1 : 5,000
Servo for position control	Servo system with position control	FALDIC series (Motor: Synchronous or Induction)	0.05 – 2.7; 2.2 – 37	Syn-chro.; Induction	- Wide capacity range - Position control of 100 steps point by point - Serial communication with PLC (T link) and PC - Less wiring
	Controller for flying shear	POSIROL-JIN	Can be applied to FRH and FALDIC series.	Same as above.	- Searing of high accuracy - Serial communication with PLC (T link) - Applicable to 4 types of machines (Flying shear, etc.)
	Substituting controller for mechanical cam	POSIROL-CAM	Same as above.	Same as above.	- Electronically acting cam - Registerable max. of 8 cam patterns - Setting 0 to 359° by 1° for spindle angle
	Multi-axis position controller	Machine controller	Can be applied to FRH, FRB (digital servo) and FALDIC series.	Same as above.	- Simultaneous control of spindle + servo 4 axes (max. 8 axes) - Opened protocol of MMI part to users
ES motor	Digital ES motor	DES (Amp.) GRK (Motor) series	0.05 – 3.7		- Ultra-low noise - Frequency response ≧ 50Hz (J_M=J_L) - Auto-tuning function

<Note> J_M: Motor inertia, J_L: Load inertia at motor shaft

resonant phenomenon caused by stiffness of the load machine are automatically taken when resonant oscillation is detected.

4. Fuji Electric's General-Purpose Variable Speed Control System Product Line

Fuji Electric produces general-purpose as well as specialized inverters and servo systems to respond to every market need, including those of automation and labor reduction. A summary of the product line is detailed below.

4.1 Inverter product line

Table 1 shows a list of Fuji Electric's inverter products. These products are divided into three broad groups: general-purpose inverters, general-purpose vector control inverters and specialized inverters for the spindle drives of machine tools. In addition, regenerative braking units are commonly provided for these inverter groups, which are equipped to handle large regenerative power loads.

The general-purpose inverters based on the newly developed FRENIC5000G9S series are high-performance and have a variety of functions, covering the range of small to large capacities. Features of this inverter include the adoption of IGBTs over the entire range to reduce noise, and use of Fuji Electric's original torque vector control to achieve high starting torque. The FRENIC5000P9S series is suitable for fans or pumps with low overload, the FVR-E7S series is suitable for transfer machine, and the newly developed FVR-C9S series is economical and ultra-compact for simple variable speed control. These are the basic product series, having nearly identical characteristics as the FRENIC5000G9S series.

The general-purpose vector controller is a high-performance inverter but can be easily used as same as the general-purpose inverter. This controller is applied mostly in cases requiring precision speed control and control response, and comes in two types: standard and low noise.

For the spindle drive of the machine tool, two product series have been prepared. The FRENIC5000V3 series is high-performance equipment with vector control, widely applied to machine tools including machining centers. The FRENIC5000M3 series has adopted flux control and realized large starting torque as well as rapid acceleration and deceleration. This series is used mainly for small to medium lathes and grinders, as this is more economical than the vector control series.

4.2 Servo system product line

The servo system's application range is expanding from specialized uses in machine tools and robots to general industrial uses in automation including trans-

fer, packing and assembling machines. Fuji Electric has prepared a series of servo apparatuses aiming at expansion of the application range based on this uses.

In Table 2, a representative of Fuji Electric's servo system product series is listed. The FALDIC series with position control loop covers a wide range of motors from small capacity (synchronous motor types) to large capacity (induction motor types). The ES motors are Fuji Electric originals which can be used to create a simple and economical system. Both the FALDIC series and the ES motors have been totally digitalized, thus enriching the product series. On the other hand, since automated systems are showing a tendency to be more advanced and complex, a machine controller has been developed. This machine controller can simultaneously control a maximum of 8 axes in addition to a spindle drive, and is provided with a user-friendly MMI (Man-Machine Interface) by a CRT (Cathode Ray Tube). Furthermore, the controller unit for the flying shear and the mechanical cam's substituting controller, etc. have been developed as a single product line, and favorably received by users.

5. Conclusion

In this paper we have described the present status and future prospects for general-purpose inverters and servo systems.

In the field of general-purpose variable speed control, it is expected that demand will increase with the acceleration of FA (Factory Automation). At that time, we will attempt to make the equipment even smaller, and improve performance and reliability in response to market needs. In FA systems, needs for downsizing require prompt response.

In response to these needs, we will systematize and integrate the sensors, the programmable logic controller (PLC) and the personal computer (PC) based on the inverters and servo systems. We also plan to enrich and strengthen system compatibility according to packaging requirements.