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CURRENT STATE AND TREND OF FUJI INVERTER SYSTEMS AND SERVO SYSTEMS FOR GENERAL USE

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1. FOREWORD

Various high-performance and multi-function variable speed drive systems which drive AC motors a variable speed are being accepted by the market and are increasing with the prosperity of the industrial world.

Transistor inverter systems and servo systems for general use are getting more advanced functions and smaller and lighter, as well as easier to use, and their use is spreading.

These general use systems were first adapted for energy-saving. That is, they had simple functions for driving pumps, blowers, and other fluid machineries. However, with the development of the industrial structure, systems with advanced functions suitable for FA equipment and industrial machinery became the mainstream.

Various technologies were developed for more advanced functionalization. First, the power transistor was modularized and compounded as a AC power converter. Then, high-speed elements, for example, the IGBT (Insulated Gate Bipolar Transistor) and MOSFET (Metal Oxide Semiconductor Field Effect Transistor), were used and fast response systems and low acoustic noise inverters were developed.

For the control circuit, high-speed digital processor has become the mainstream. The 32-bit DSP (Digital Signal Processor) was used. Also, important functions were duplexed and safety and reliability were improved simultaneously with the mounting of multiple CPUs and complex calculations and high-speed control were executed.

Processing of numerous complex commands and detailed display of operating conditions, storage and display of operation data and trouble contents, data transmission, and other functions were enhanced.

Modern control theory is amply reflected in new products. For example, current decoupling control, feedforward control, autotuning, impact drop compensation, etc.

For variable speed equipment for general use, data coupling with a general-purpose programmable controller (PC) and the man-machine interface are stressed. That is, optimum setting of many times more functions than in the past is of paramount importance and is indispensable in amply displaying the capability of the equipment. A touch panel is built into each variable speed system and the display is visualized. Various data are shown by graphics and diagrams, etc. for error-free, optimal setting.

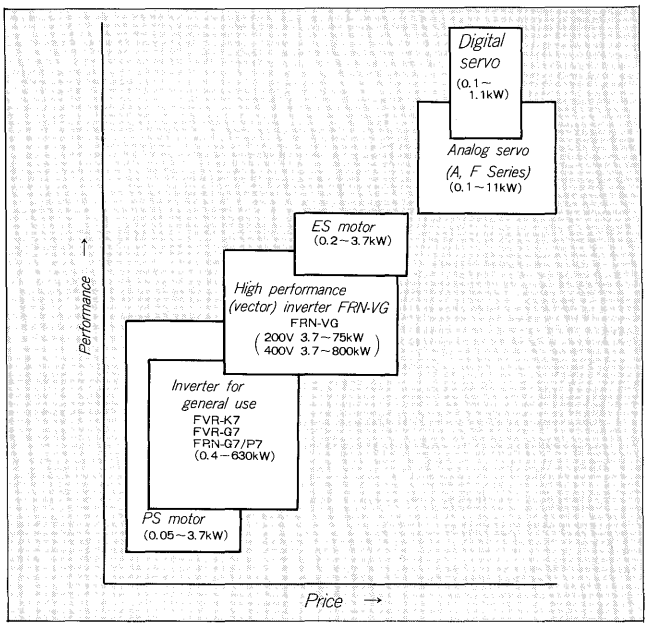
The basic concept, technological organization, product series, etc. of Fuji Electric's newest transistor inverters for general use are described.

2. ORGANIZATION OF FUJI TRANSISTOR INVERTER SYSTEMS AND SERVO SYSTEMS FOR GENERAL USE

In 1977, Fuji Electric developed the industries first transistor inverter. This all-digital inverter was highly evaluated for its high performance, multiple functions, and ease of use.

At that time, the mainstream of variable speed drive systems was the simple variable speed inverter. However, sophisticated and discriminating market demands were received and the functions of the inverter for general use were increased. At the same time, special inverter series for machine tools, air conditioners, low acoustic noise, etc., a series of large capacity units up to 1,000kVA, and many

Fig. 1 Organization of Fuji variable speed drive equipment for general use



other series were developed. The number of models in the servo system series was also increased and an enhanced series was completed for FA equipment and automation equipment.

The standard series of Fuji variable speed drive systems for general use is shown in *Fig. 1*. A complete series of systems used as a power supply, for example, induction cooking ranges, is available as inverter-applied systems.

3. ELEMENT TECHNOLOGY OF STANDARD SERIES OF VARIABLE SPEED DRIVE SYSTEMS AND ITS TRENDS

In the development of variable speed drive systems, element technology is related to a wide range of technology, from microelectronics to product application technology. The relationship between function element and technology in the standard series variable drive systems is shown in *Fig. 2*. Here, power semiconductor element and inverter and AC servo control technology, which are advancing noticeably, are taken up and their recent trends are outlined.

3.1 Power semiconductor element

The bipolar transistor is mainly used as a power semiconductor element in the standard series of inverters and their power converters, and the main circuit technology which supports the power part of the power converter has developed with the advance of the bipolar transistor. The demand for smaller, more efficient, cheaper, and lower acoustic noise is increasing and improvement and development of power semiconductor elements is advancing to meet this demand. Recent trends are summarized below.

(1) Improvement of functions and characteristics of the bipolar transistor
(2) Practicalization of new device: IGBT
(3) Practicalization of the intelligent power module

The bipolar transistor which has advanced functions is realized. For example, Z series transistor which has a current limiting function in the element itself and expand the short-circuit overload safety operation area, or module transistor which include the zener diode with new snuber circuits and simplified the equipment structures. Moreover, to meet the need for simplification of drive circuits and drive power supplies, a high h_{FE} transistor with high DC current amplification ratio which can be driven by a base current of all series 100 mA was developed and is beginning to be employed.

The Fuji IGBT module product series is shown in *Table 1*. The IGBT is a new device with the performance of a bipolar transistor and power MOSFET. Elements with the same voltage and current ratings as the bipolar transistor have been practicalized. These elements can be used at a switching frequency of 10 to 15 kHz. Their use begins from applications which demand low acoustic noise.

The process of highly integrating the power devices which are used in the standard series inverters is shown in *Fig. 3*. Application of intelligent power models centered about the low capacity range in beginning. An intelligent module is a component which houses all the power devices making up the converter section and integrates the power device drive, protection, and other functions. Much is expected of it as a means of making equipment smaller and lighter. The development of the IGBT and high h_{FE} transistor has made it possible to reduce the size of the drive section. The range of the intelligent power module now limited to low capacities, is expected to expand rapidly in the future.

Fig. 2 Standard series variable speed drive system element technologies

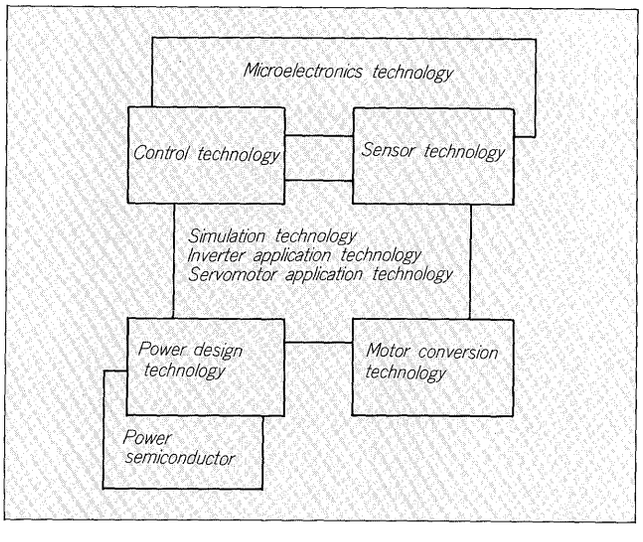
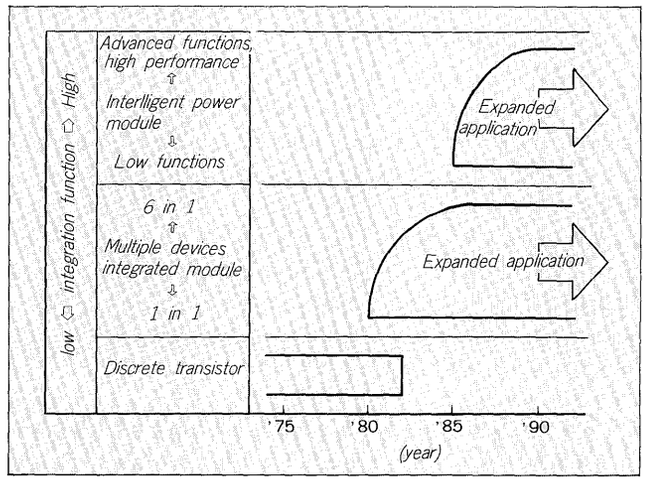


Table 1 Fuji IGBT module product series

Voltage class	Construction	Current capacity (A)												
		8	10	15	20	25	30	50	75	100	150	200	300	400
600V	1in1													▨
	2in1							▨	▨	▨	▨	▨	▨	
	6in1		▨	▨	▨		▨							
1,200V	1in1												▨	▨
	2in1					▨		▨	▨	▨	▨			
	6in1	▨		▨		▨		▨						

Fig. 3 Power device high integration transition



3.2 Control technology

The tremendous growth of electronics technology has made it possible to realize complex calculations and advanced control by introducing the microcomputer and DSP into variable speed drive system control. Control circuits which require faster processing are integrated by using gate arrays, etc. This section describes the instantaneous current limiting function and torque computation function in a V/F constant control inverter method, current control in a vector control inverter and improvement of the performance of the AC servo by digitalization as examples of the technologies made available to control of the standard series of variable speed drive systems by the advance of microelectronics.

(1) Instantaneous current limiting function

When a motor is accelerated and decelerated quickly and when the load increases abnormally for some reason, a V/f constant control inverter cannot suppress a current increase with the conventional stall prevention function and the inverter is tripped by an overcurrent. The instantaneous current limiting function suppresses such overcurrent tripping. The inverter output current is monitored by a fast response current detector and when the instantaneous value of the output current reaches the limit level, the inverter output voltage vector is immediately switched according to the direction of the current vector and the load power factor at that time and the current is reduced smoothly and a current increase is suppressed while maintaining a small torque ripple.

(2) Torque calculation function

The V/f constant control inverter changes the rotating speed of a motor by controlling the primary frequency which is supplied to the motor. However, the recent trend is toward simple control of the generation torque.

If the flux vector is made ϕ_1, the current vector is made I_1, the voltage vector is made V_1, and the primary resistance is made R_1, the generation torque τ of an induction motor is given by the following equation:

$$\tau = \phi_1 \times I_1 = \int (V_1 - R_1 \times I_1)\, dt \times I_1 \quad \ldots\ldots\ldots \quad (1)$$

The generation torque of an induction motor can be found by solving Eq. (1) with a microcomputer. In this case, imperfect integration is generally performed to avoid the affect of detector offset.

When detection of the generation torque becomes possible, the output torque of the motor can be controlled and operation can be continued while maintaining maximum torque even when the load torque increases abruptly at sudden acceleration and deceleration drive operation, when an impact load is applied, etc. The torque calculation function is contributing to higher inverter performance, such as changing of the inverter output frequency according to the motor torque and speed characteristics by using the torque detected value, slip compensation, etc.

(3) Current control

A vital factor in vector control is how much the current control system control error and offset and unbalance between phases can be reduced. One countermeasure is to build a current control system with digital circuits and control the current by converting AC current to a DC quantity. Such a system can be realized easily by using a DSP.

(4) Digitalization of the AC servo

Fast control response is demanded of a servomotor in torque and speed control. In the past, analog circuits were widely used in its control section. However, analog circuit have such disadvantages as rotating ripple caused by offset and drift, simple generation of posetioning error when positioning control is executed, complex adjustment is necessary to obtain optimum performance, etc.

On the other hand, the digital circuit can solve these problems but at the expense of control performance. Fuji Electric has realized the same, or better, response as the analog circuit with an optimum control system backed by high-speed arithmetic processing using a DSP, automatic current control system offset adjustment, high performance and high speed detection by ASIC, and other microelectronics technology when digitalizing the control circuit. Feedforward control was made adjustment-free and other AC servomotor control performance were vastly improved.

4. ORGANIZATION OF FUJI ELECTRIC VARIABLE SPEED DRIVE SYSTEMS FOR GENERAL USE

Fuji Electric has also serialized servo systems, together with inverters for general use and special inverters. The product group of the standard series of inverters for general use is shown in *Table 2* and the product group of the servo system series is shown in *Table 3*. Typical products of each group are outlined below.

(1) Low capacity inverter for general use (FVR-G7S)

This is a typical newly developed inverter for general use using all digital control. It is a PWM type inverter with 32-bit DSP and can drive control of low to medium capacity motors. It is equipped with as many functions as possible. Each function is accurate and easy to use so that the FVR-G7S can be used with all industrial machines. Visualization of the touch panel to avoid erroneous operation and setting of its many functions is worthy of special mention.

(2) Compact type inverter (FVR-K7S)

Simple operation and compact size is the biggest feature of the FVR-G7S series described above. The FVR-K7S is a popular type inverter with limited functions which can be used with almost all ordinary industrial machines.

(3) Inverter for general industrial use (FRENIC 5000G7/P7)

Two series are available: the FRENIC5000G series for constant torque load designed for general industrial applications and the FRENIC5000P series for energysaving use. This new series is overflowing with many more functions than the old FRENIC5000G5 series.

The control basics are instantaneous current limiting control, flux control, and torque control. That is, very small torque ripple operation, high performance slip compensation operation, and torque limiting operation are possible by this torque control so that it is suitable for many industrial machines.

Table 2 Typical Fuji transistor inverter product series

Series name (voltage series)	Output capacity (kVA or kW)	Frequency control range (Hz or rpm)	Remarks
	1 10 10^2 10^3	10^2 10^3 10^4	
FVR-G7S (200V)	33kVA	400Hz	• Low capacity general use inverter • Multi-function general use type
FVR-G7S (400V)	33kVA	400Hz	
FVR-K7S (200V)	7kVA	120Hz	• Compact type inverter • Small, simple operation
FRENIC 5000G7/P7 (200V)	153kVA	400Hz	• Inverter for general industry • Multi-function general use type • Flux control use
FRENIC 5000G7/P7 (400V)	1,000kVA	400Hz	
FRENIC 5000VG (200V)	75kW	120Hz	• High-performance inverter for industrial use • High-performance general use type • Vector control
FRENIC 5000VG (400V)	400kW	120Hz	
FVR-H5 (200V)	13kVA	1,000Hz	• High frequency output inverter • PAM + PWM control
FRENIC 5000H2 (200V)	30kVA	5,000Hz	• High frequency output inverter • PAM control
FRENIC 5000G6N (200V)	33kVA	200Hz	• Ultra-low acoustical noise type inverter • High frequency carrier PWM control
FRENIC 5000M2 (200V)	30kW	6,000rpm	• Machine tool spindle drive inverter • Flux control type PWM control
FRENIC 5000W (200V)	22kW	6,000rpm	• Machine tool spindle drive inverter • Flux control type PWM control • Wide range output characteristic
FRENIC 5000V3 (200V)	45kW	8,000rpm	• Machine tool spindle drive inverter • Vector control
FRENIC 5000VH2 (200V)	7.5kW	12,000rpm	• Machine tool spindle drive inverter • Vector control
FRENIC 4000VM2 (400V)	400kVA	120Hz	• Inverter for accurate, fast response control • Vector control
FRENIC 4000T2 (400V)	150kVA	300Hz	• Inverter for chemical textile

Note: Frequency control range differs with the output capacity.

Table 3 Typical Fuji servo system product series

Type	Series name	Control method	Capacity range [maximum applicable motor capacity (kW)] 0.1 0.3 1 3 10 30	Application
AC servo	FRS series	Primary frequency control Sine wave PWM		• Robot • Machine tool feed • Conveyer
AC servo	FRC series	Same as above		• Press feeder • Packaging Machine • Industrial knitting machine and loom
AC servo	FRP series	Same as above		• X-Y table drive • Fixed length cutter • Robot
AC servo	FRF series	Primary frequency control Square wave PWM		• Press feeder • Machine tool • Indexing machine
AC servo	FRD series (digital)	Primary frequency control Sine wave PWM		• X-Y table • Fixed length cutter • Indexing machine
ES motor	FRK series	Primary frequency control Square wave PWM		• Machine tool • Printing press • Foodstuffs machinery

(4) Digital AC spindle drive system (FRENIC 5000V3)

This is an inverter for driving the spindle of high performance, multi-function machine tools. Fast response and low torque ripple were realized by making it all-digital. Power supply regeneration and four quadrant operation are also possible. High precision orientation performance is also displayed.

(5) Standard series inverter for machine tools (FRENIC 5000M2/W)

These are imverters for lathe, and other general use machine tool spindle drive. Low torque ripple operation is realized by flux control and short acceleration/deceleration time operation is realized by curve acceleration/deceleration speed setting.

(6) Industrial use vector inverter
(FRENIC 5000VG, FRENIC 4000VM2)

These are vector control inverters for advanced functions operations for industrial use. High precision speed control, torque control, etc. are possible. These inverters are praised as replacements for conventional DC machine and compound system drive systems.

(7) Special inverters

Fuji Electric manufacturers various special inverters, in addition to the above. For details, see the separate article in this special issue.

(a) Ultra low acoustic noise inverter
(FRENIC5000G6N)
Ultra low acoustic noise is realized by using an IGBT as the AC power conversion element.

(b) Air conditioner inverter (FVR-A)

(c) High frequency inverter (FRENIC5000H2, FVR-H5)
Outputs a maximum frequency of 1 to 5 kHz. Suitable for ultra high speed operation.

(8) Power supply inverter

Inverter technology is also applied to various power supply equipment, in addition to motor drive applications. These are high frequency power supply equipment or miniaturization of the power supply size by high frequency, etc. A typical example is induction heating equipment. Many of these inverter have already been applied to commercial induction cooking ranges.

(9) Servo systems

Fuji Electric offers a complete series of AC servo systems which can be used in numerous applications.

The digital series (FRD), in particular, is an advanced functions and high performance series which performs high-speed digital control by using a DSP. The ES motor has a performance between that of an inverter and a servo. Many have been supplied as servo systems for speed control.

A system which connects directly to a PC, simple 1-axis control, and various multi-axis control which performs various calculations are also serialized as servo systems for position control.

5. CONCLUSION

The current state and trend of Fuji inverter systems and servo systems for general use were described.

Much is expected of this field in the future. In other words, industrial world production structure change, rapid advance to FA and CIM, growth of automation between human space and living space and unlimited application are expected to spread.

Various research and development will be conducted on variable speed control systems to cope with this. First, fast response and low acoustic noise will be advanced by the application of new semiconductor devices. Digitalization will be advanced by the use of high-speed control elements and an data transmission system will be established. Especially, safety and reliability will be improved and the RAS (Reliability, Availability, Serviceability) function will be completed by improving the monitoring ability. At the same time, the development of software for optimal setting of the various operation parameters will also advance. Moreover, the establishment sensor-less technology reduces wiring man-hours and can achieve a compact system. Furthermore, research on a low electromagnetic interference (EMI) main circuit system and capacitor, with its life problem, is accelerated. Production facilities which produce these microelectronics products are an important factor in reliability and product quality improvement and production control is being researched and developed. The research above is developing new variable speed drive systems.

On the other hand, compounding of the variable speed drive system provides a package system by connecting a PC, personal computer, etc. This, of course, encompasses measuring equipment and sensors and at the same time, data transmission between inverter and servo also becomes important. The functions and structure system product which groups these will be evaluated at the next age.

We will make further efforts to realize units and systems which are amply suitable to and exhibit their capacity with the variable drive system which is expected to grow in the future.