Present View and Outlook for System Control and Drive Components

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1. Introduction

The control systems that have realized continuous improvements in such applications as automation of manufacturing system and energy saving of facility operation have been supported by advances in major components, such as drive system devices typified by general-purpose inverters and servo systems, and control, operation and display devices typified by general-purpose programmable controllers (PLCs), and programmable operation displays (PODs).

These system control devices are fundamentally required to exhibit high performance, multi-functionality and low cost as a standalone device, and additionally required to provide expandability and flexibility when integrated into a system configuration. Recently, reliability and safety have become important evaluation criteria when selecting devices with which to construct a system.

This paper describes general technical trends overlooking new technologies of system control devices presented in this special issue and introduces Fuji Electric's corresponding product lines.

2. Technical Trends of System Control Devices

2.1 Technical trends of drive system devices

(1) Performance enhancing technology

Requirements of the drive system include not only motor speed and position control, but also the ability to realize energy savings in the whole system, including load, and high-speed responsiveness, which correlating to a reduction of takt time in consideration of structure of the load machine and rigidity of the part for mounting.

Fuji Electric's servo systems are equipped with vibration suppression control as a fundamental function to increase responsiveness of the whole system. With this function, multi-inertia model that includes model of load machine is stored within servo amp, and compensation is performed to minimize the vibrations of this model in order to realize high-speed response in machinery, such as robotic arm having relatively low rigidity. To utilize the vibration suppression control function, an accurate capture of transfer function of the mechanical system is needed, and for this purpose a servo-analysis function has been developed. The servo-analysis function can analyze resonance frequency and anti-resonance frequency of the mechanical system to facilitate the user's task of parameter setting. Such mechanical system analysis is performed either offline during an initial operating mode that differs from the usual operation, or online during usual operation. Fuji Electric's easy tuning function operates offline to analyze the transfer function of complex mechanical systems and to auto-tune control system parameters optimally for facilitating user settings. Future development of online full auto-tuning function suitable for applications in which the transfer function changes during operation is anticipated, and such development will require a detailed algorithm capable of safe operation and stopping during operating modes other than usual operation.

Meanwhile, inverters for elevator applications are equipped with imbalance load compensation function that suppresses the phenomenon of rollback when an elevator car's mechanical brake is released. This function detects the speed of elevator motor and generates compensating torque in response to abrupt changes of motor speed, and yet there is a need for robust control capable of freely responding to changes of loaded mass of the car or of rope mass due to landings at different floors.

(2) Capacity enlargement technology

In recent years, general-purpose inverters have been advancing toward larger capacities, and Fuji Electric has expanded its product line to include a 400 V input voltage standard converter/inverter series that have a single-unit capacity of 800 kW (stack type) maximum.

In order to increase capacity of inverters having limited input voltage, it is necessary to increase motor current, and for this purpose, appropriate insulated gate bipolar transistor (IGBT) modules and other main circuit parts must be arranged in parallel. Applicable technologies here are current balancing in steady state among devices and equalization of switching speed in transient state. For this purpose, in addition to

uniformity of device characteristics, consideration of wiring inductance and stray capacitance corresponding to device layout is also important. For such kind of design, three-dimensional electromagnetic field analysis and thermal analysis are indispensable, and by using such analysis techniques, twelve parallel connections of 1,200 V/400 A IGBT modules were realized.

(3) Noise reduction technology

Since main circuits of general-purpose inverters and servo amplifier have voltage-type inverter configuration, by controlling DC voltage with pulse width modulation (PWM) control, variable voltage and variable frequency output is obtained. Therefore, increase of noise level cannot be avoided comparing to commercial power supply, and noise-reduction combined with input harmonic current suppression technology is needed. Noise-reduction technology suppresses either generation of noise or transmission and radiation of generated noise. The former reduces voltage change rate dv/dt of switching device used for main circuit or for control power supply. The latter is realized with filter components and case shield material.

Recently, noise reduction technology has been actively researched with the aim of increasing motor reliability. It is known that when a long wire is used to connect inverter with motor, surge voltage will be generated at the motor input terminal. This effect is due to the difference between wire impedance and motor impedance, which generates reflected wave at the motor input terminal and suddenly boosts the voltage higher than inverter output voltage. In some cases, this surge voltage may accelerate the degration of motor insulation. As a countermeasure, surge-suppressing cable containing a function to bypass only high harmonic frequencies that cause reflection, and surge-suppressing unit that can be easily attached to existing motor have been developed.

(4) Main circuit technology

With the introduction of new devices for main circuits, power electronics field has been changing dramatically, and at present, reverse blocking IGBTs are being used in practical applications. One typical application is matrix converter, the main circuit configuration of which is shown in Fig. 1. Two reverse blocking IGBTs are connected in anti-parallel configuration to form bidirectional device, and three of these devices are arranged for each phase to realize matrix converter. This circuit is suitable for applications requiring suppression of power supply high harmonic frequencies and requiring power supply regenerative operation. Fuji Electric is planning to accommodate wide range of applications, beginning with elevator applications. Figure 2 shows example characteristics of a 400 V, 22 kW matrix converter. Both high power factor and high efficiency can be achieved.

2.2 Technical trends of control and operation display devices

(1) Highly efficient programming technology

Fig.1 Matrix converter main circuit

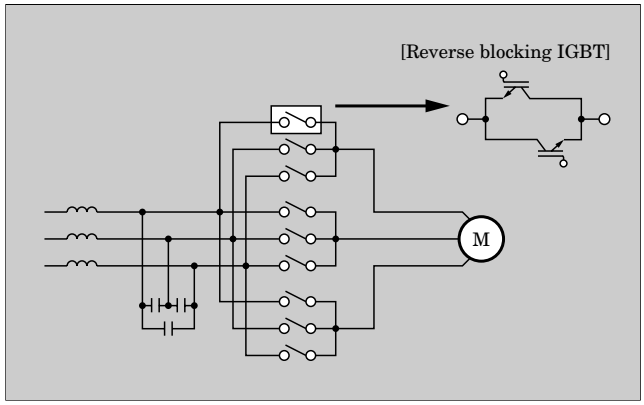
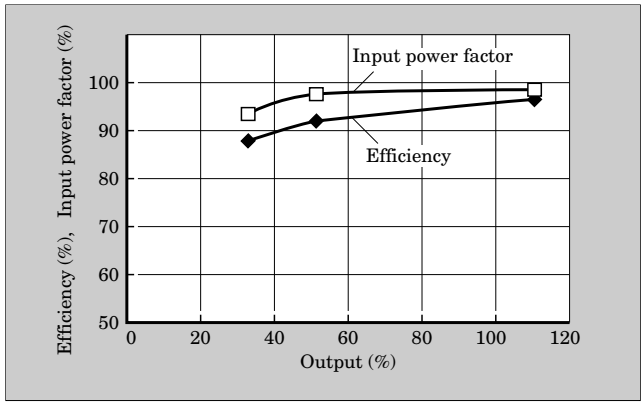


Fig.2 Example of matrix converter characteristics



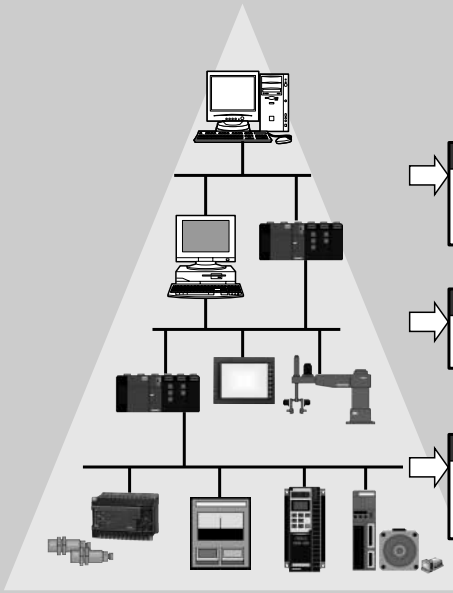
Application programs in controller field are becoming larger in scale and more complex, and improved efficiency for program development is highly sought. Since first being introduced to market, MICREX-SX series of integrated controllers have been provided with SX Programmer Expert programming tool that fully conforms to international PLC programming language standard IEC61131-3. As a result of software reuse, facilitated by the trends toward structured development and modularization of programs promoted by IEC standards, software production has become more efficient. In particular, modular programming structure of function blocks (FBs) have a large effect in increasing efficiency.

Accompanying the widespread penetration of IEC standards, mutual use of application programs among PLCs of different suppliers is becoming desirable. Fuji Electric, in cooperation with PLCopen Japan, is working to realize practical applications of reusable software programs written by different manufacturers and running on different machines using extensible markup language (XML).

(2) Large capacity data processing technology

With their higher performance and greater functionality, application range of PLCs has expanded dramatically. In recent years, in addition to applications in machines and equipment used to configure production systems, demand for PLCs has increased

Fig.3 Network hierarchy of system control components



Plant level
Optimal application for factory equipment and production lines

Controller level
Cooperation between machines and line controllers

Device level
Sense/drive and operation/ display functions for machines/production lines

Open network	Original network	PLC	POD	Inverter	Servo
Ethernet*1		○	○		
ADS-net		○			
Ethernet		○	○		
FL-net		○	○		
	P/PE-link	○			
	LE-net	○			
OPCN-1		○	○		
PROFIBUS-DP*2		○	○	○	
DeviceNet*3		○	○	○	○
Interbus-S				○	
Modbus			○	○	
CANopen				○	
	T-link	○	○	○	○
AS-i		○			
LONWORKS*4		○		○	

∗1 : Ethernet is a registered trademark of Xerox Corp. in the US and other countries.
∗2 : PROFIBUS-DP is a registered trademark of the PROFIBUS User Organization.
∗3 : DeviceNet is a registered trademark of the Open DeviceNet Vendor Association (ODVA).
∗4 : LONWORKS is a registered trademark of Echelon Corp. in the US and other countries.

especially in so-called data-oriented fields, to improve traceability, to manage electricity and water for energy-savings and so on, based on the need for data management of the production items and for compliance with legal regulations. The use of PLCs was originally driven by the need to realize efficient sequence control systems. However, since PLCs are poorly suited for applications requiring the efficient processing of large quantities of data, improved functionality that supports the expanded range of applications is now needed. MICREX-SX supports not only a ladder language for sequence control, but also a structured text language (ST language) and structured data types such as arrays and structures based on IEC61131-3. Even in applications involving a high-level of data processing, MICREX-SX is able to realize a development environment suitable for shop floor locations, where PC is poorly suited, and thereby it has dramatically increased the range of applications. Recently, a new CPU that further improves data processing performance has been added to MICREX-SX series.

(3) Network technology

Figure 3 shows network hierarchy composed of Fuji Electric's system control components. This network technology is compatible with all major open networks worldwide and also supports Fuji Electric's long-established original networks (P/PE-link and T-link). Optimal systems, ranging in size from small-scale systems embedded in machines to large-scale hierarchical distributed systems, can be configured seamlessly.

(4) Higher reliability technology

With the expanded range of applications for PLCs, there is demand for reliability equivalent to that of a plant controller, in other words, the ability to maintain continuous system operation 24-hours-per-day without downtime even when failures occur is required.

Since first being introduced to the market, MICR EX-SX has provided CPU redundancy with a 1-to-1 warm-standby feature. This redundant technology consists of both active and backup systems, and enables continuous operation without system downtime even when CPU malfunction occurs.

New developed LE-net controller level network realizes redundant network through the use of redundant network modules and loop topology (See Fig. 4). Moreover, with hot plug-capable baseboard, MICREX-SX system realizes high reliability class of distributed control system (DCS) at low cost associated with PLC.

(5) Human-machine interface (HMI) technology

Programmable operation display (POD) units were first introduced to the market around 1990. As a highly rated device that enables the creation of operation display screen without requiring any knowledge of programming, PODs continue to remain popular. Originally, PODs were used mainly as replacements for operation display panels which were constructed from switches, LEDs, and so on. However, as a result of improvements in the expressive ability and response speed of screens, a trend toward larger screen sizes, and improved ease of interfacing with various networks, the range of applications is presently ex-

Fig.4 LE-net redundancy

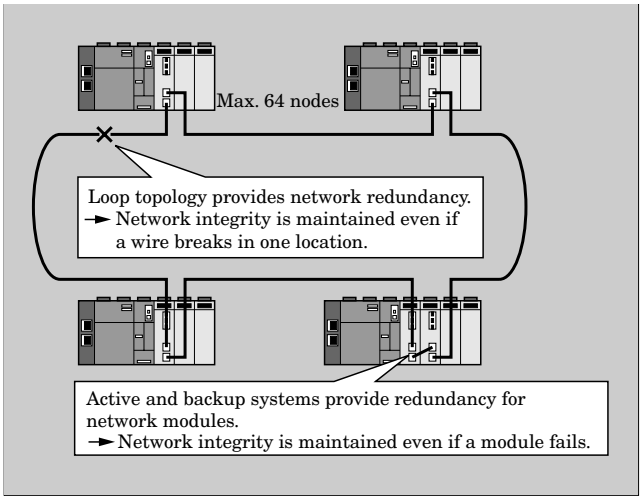
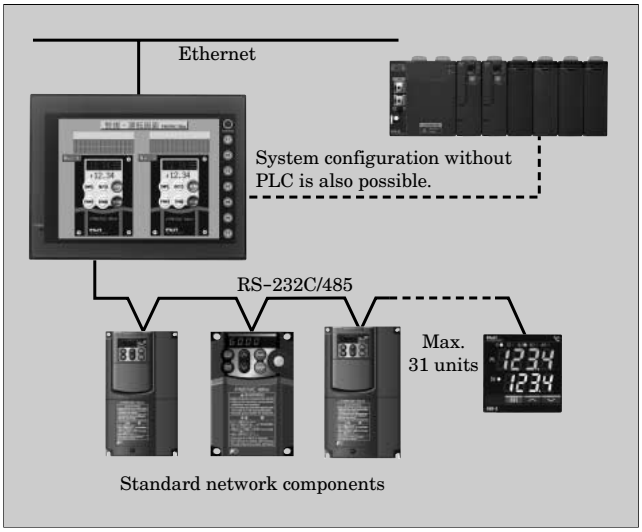


Fig.5 POD connectivity for standard network components



panding to acquisition and more realistic display of production shop floor information, accumulation of production management data, exchange of information through data networks, support of Internet-based services, and so on.

In addition to having port for connection to PLC, Fuji Electric's UG30 POD series is also provided with single-channel serial port that supports various communication protocols. This port can be connected to various components such as a temperature controller or inverter equipped with a communications function, and even if those components are made by different manufacturers, standard protocol can be used to monitor the components or to set parameters (See Fig. 5).

2.3 Environment-friendly technology

Since in recent years, beginning in Europe, there have been increases in the enactment of legal regulations to protect the environment and in the employment of green procurement policies, system control components have also become more responsive to environment. Environmental responsiveness can be accomplished in two ways, by effectively utilizing natural resources through extending the service life of products, and by eliminating environmentally hazardous substances from the materials of which products are made, and then by promoting the reuse of those products. Fuji Electric's system control components actively contribute to these efforts by extending the service lives of electrolytic capacitors and cooling fans, and by using a construction that allows easy component replacement. Moreover, in response to requests for cooperation with green procurement, Fuji Electric will lead the way with its newly developed products but also plans to steadily move its existing products to comply with RoHS directive*5. In particular, since there are many problems associated with the use of lead-free solder on PLC printed circuit board and inside the main circuit module in drive system, Fuji Electric intends to solve those problems through the use of materials having low elastic coefficient, by optimizing the temperature profile of solder bath, and so on.

3. Fuji Electric's System Control Components

Fuji Electric provides an abundant variety of system control components, and these components can be combined in various ways to realize optimal system configurations for a wide variety of applications.

3.1 Inverter product lines

Table 1 lists Fuji Electric's inverter product lines. General-purpose inverter product line is characterized by addition of new models, such as the FRENIC-Eco series and FRENIC-Lift series, for specified applications. These models are provided with optimal performances and features for their intended applications, and are more cost effective and easier to use than previous models. Fuji Electric's newest product, FRENIC-Multi series, is high-performance and compact inverter suitable for wide range of applications, and has been designed as a global product for worldwide use. FRENIC-Multi series also includes several semi-standard series of inverters having built-in filter or various built-in cards, and is capable of accommodating wide range of requests within short lead-time. FRENIC5000G11 and FRENIC5000P11 series have a track record of stable operation, and with a single-unit capacity that can be increased up to 800 kW, they have made significant contributions to the expansion of application range for general-purpose inverters.

FRENIC5000VG7 and FRENIC5000VG7F high-

*5: RoHS directive is restriction on the use of certain hazardous substances in electric and electronic devices.

Table 1 Fuji Electric's inverter product lines

Model type	Series	Supply voltage	Capacity range (kW) 0.1 1 10 100 1,000	Frequency control range (Hz) 100 1,000 10,000	Main specifications
General-purpose inverters	FRENIC -Mini	Single-phase 100 V Single-phase 200 V 3-phase 200 V 3-phase 400 V	0.1 – 0.75 0.1 – 2.2 0.1 – 3.7 0.4 – 3.7	400 400 400 400	Compact inverter ○ 400 Hz max. output freq. ○ Side-by-side mountable ○ Supports global standards (400 V input)
	FRENIC -Multi	Single-phase 200 V 3-phase 200 V 3-phase 400 V	0.1 – 2.2 0.1 – 15 0.4 – 15	400 400 400	High-performance compact inverter ○ Start torque: 200 % ○ Optional card supports PG feedback control ○ Wide variety of models
	FRENIC -Eco	3-phase 200 V 3-phase 400 V	0.75 – (110) 0.75 – (500)	120 120	Inverter for fan and pump applications ○ Energy-savings operation ○ Various functions for HVAC use ○ Long-life design, simple maintenance
	FRENIC 5000G11S	3-phase 200 V 3-phase 400 V	0.2 – 90 0.4 – 800	400 400	High-performance, multi-functional inverter ○ Start torque: 200 % ○ PID control & RS-485 provided as standard equipment ○ Optional card supports vector control
	FRENIC 5000P11S	3-phase 200 V 3-phase 400 V	5.5 – 110 5.5 – 800	120 120	Inverter for variable torque loads ○ PID control & RS-485 provided as standard equipment ○ Control power supply aux. input provided as standard equipment ○ Automatic energy-savings function enables highly effective driving
	FRENIC -Lift	3-phase 400 V	5.5 – (45)	120	Vector-control inverter for elevators ○ Overload capability: 200 %, 10 s ○ Special functions and control for elevators ○ Supports synchronous motors in elevator applications
High-frequency inverter	FRENIC 5000H11S	3-phase 200 V	0.75 – 18.5	1,667	Special high-frequency inverter that utilizes PWM control technology
High-performance vector-control inverter	FRENIC 5000VG7S	3-phase 200 V 3-phase 400 V	0.75 – 90 3.7 – 800	200 200	High-performance vector-control inverter for general industrial use ○ Highly responsive torque and speed control ○ Control options provide full system functionality
Thin inverter	FRENIC 5000VG7F	3-phase 200 V 3-phase 400 V	5.5 – 11 5.5 – 15	200 200	Special thin inverter having a depth of 90mm
Regenerative PWM converter	RHC-C	3-phase 200 V 3-phase 400 V	7.5 – 55 7.5 – 800	50 – 60 50 – 60	Regenerative converter ○ Regeneration with high efficiency ○ Reduced harmonic current input

(110), (500), (45): Under development

performance vector-control inverter series are used in general-purpose industrial applications that require high responsiveness and high-precision torque and speed control. They have also extended their range of applications to include machine-roomless elevators, and are often used in combination with synchronous motors. Meanwhile, the RHC-C series of regenerative PWM converters used in combination with these inverters is also provided with capacity ranging up to 800 kW single-unit capacity as same as inverters.

Table 2 Fuji Electric's servo system product lines

Series	Applicable motor	Capacity range (kW) 0.1 1 10 100	Rated/ max. speed (r/min) 1,000 3,000 5,000	Main specifications
FALDIC-α (1) V type (for pulse train, speed control) (2) L type (for linear positioning) (3) R type (for rotational indexing)	GYC motor (low inertia type)	0.1 – 2	3,000/5,000	(1) Same frequency response: 600 Hz (2) Vibration suppression control can be installed (3) 16-bit ABS/INC shared encoder (4) Serial connection between amp and encoder reduces wiring (5) High-speed serial bus (SX bus) and support of various other buses
	GYS motor (low inertia type)	0.05 – 5	3,000/5,000	
	GYA motor (low inertia type)	0.5 – 2.5	1,500/2,500	
	GYM motor (medium inertia type)	2.9 – 7.5	1,500/3,000	
		11 – 15	1,500/2,000	
FALDIC-β (for pulse train)	GYC motor (low inertia type)	0.1 – 0.75	3,000/5,000	(1) Industry's smallest amp (2) Command follow-up control and vibration suppression control provided as standard equipment (3) Notch filter, servo analysis function (4) 16-bit serial encoder
	GYS motor (low inertia type)	0.05 – 0.75	3,000/5,000	
FALDIC-W (for pulse train, speed control)	GYS motor (low inertia type)	0.05 – 0.75	3,000/5,000	(1) Vibration suppression control provided as standard equipment (2) Easy tuning, servo analysis function (3) Many varieties motors (4) 17-bit serial encoder (5) RS-485 (2 ports), control power supply input
	GYG motor (medium inertia type)	0.5 – 2.0	2,000/3,000	
		0.5 – 2.9	1,500/3,000	
Digital ES motor (for pulse train, speed control)	GRK motor (high inertia type)	0.05 – 3.7	2,000/2,500	(1) Suitable for machines have a large load moment of inertia (2) Motor can be replaced with general-purpose motor (3) Simple setup and operation

3.2 Servo system product lines

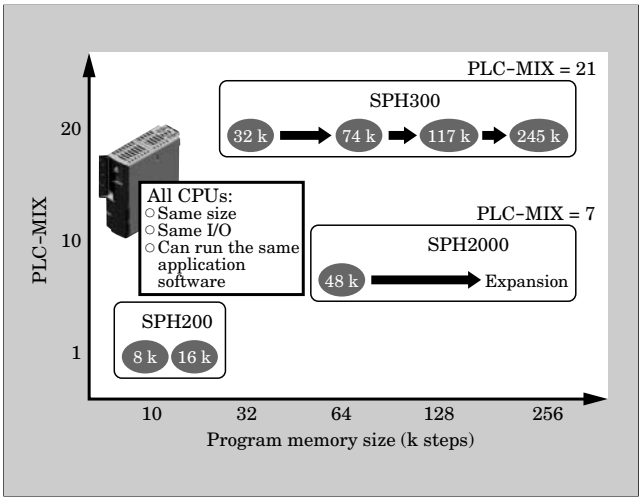
Table 2 lists Fuji Electric's servo system product lines. This product line consists of FALDIC-α series, equipped with a high-performance high-resolution serial encoder, the FALDIC-β series, provided with vibration suppression control as the industry's smallest amp, and the newest model, FALDIC-W series that supports global standards. Moreover, each of these series has been expanded in terms of capacity and rated speed of servomotor. FALDIC-α series has been expanded to maximum capacity of 15 kW, and FAL DIC-W series has added servomotors with rated speeds of 1,500 r/min and 2,000 r/min, to enable selection of optimal servomotor for each particular application.

For servomotor systems, in addition to the product lines listed in Table 2, Fuji Electric also provides the MC8 motion control module for MICREX-SX series. This module enables interpolative control or other high-level position control for up to 8 axes in a servo system.

3.3 Integrated controller product line

Figure 6 shows Fuji Electric's MICREX-SX CPU product line. SPH200, SPH300 and new SPH2000 series are provided to meet various requirements for memory capacity and performance. All CPUs have the same size dimensions, and have the advantageous ability of being able to inherit I/O and application programs completely. As a result, in cases where application capacity is insufficient or scan performance is not full accurate, user can simply upgrade the CPU to the next higher class, without having to modify the I/O or application programs.

Fig.6 MICREX-SX CPU product line



3.4 POD product line

Table 3 lists Fuji Electric's POD UG30 product line. This product line supplies a wide range of POD

Table 3 POD product line

Size	Model		Specifications
12 type	UG530H	V□	TFT 32,768 colors 800×600 dots
10 type	UG430H	V□	TFT 32,768 colors 800×600 dots
		T□	TFT 32,768 colors 640×480 dots
		S□	TFT 128 colors 640×480 dots
8 type	UG330H	V□	TFT 32,768 colors 800×600 dots
		S□	STN 128 colors 640×480 dots
6 type	UG230H	T□	TFT 32,768 colors 320×240 dots
		S□	STN 32,768 colors 320×240 dots
		L□	monochrome 320×240 dots
	UG221H	SR	STN 16 colors 320×240 dots
		LE,LR	monochrome 320×240 dots

Ethernet port and compact flash card interface are provided as standard equipment (except with the UG221).

sizes, from 6 inch type models for simple shop floor operation and to 12 inch type models that provide PC-level display capability.

4. Conclusion

The technical trends and product lines of Fuji Electric's system control components have been described above. In the future, to support system expansion in FA and shop floor applications, system control components are expected to advance toward higher levels of functionality, performance and capacity, and to become focused for particular applications. Moreover, applications are also predicted to expand into the field of information processing, which is replacing PCs, and to become increasingly integrated with management systems.

In the future, Fuji Electric intends to continue to assess these types of trends accurately, and to provide advanced components and tools as a good partner to our customers.