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Drive and Power Supply Technology

Fuji Electric Group

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Cover photo:

Products incorporating power electronics technology are used at various public locations and in various market sectors. Fuji Electric has been providing power semiconductors, an important power electronics device, since the mid-1970s, and has provided products containing power electronics as the key technology to various market sectors.

Responding to major trends such as the support of energy and environmental issues in order to move closer toward a sustainable society, Fuji Electric is engaged in many efforts to apply power electronics technology to realize that goal.

On the cover, arranged at the center, are key components that use power electronics technology, these components are organically linked together by a plurality of rings and solutions developed in response to customer requests are depicted outside the rings.

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editor-in-chief and publisher Hisao Shigekane
Corporate R & D Headquarters
Fuji Electric Holdings Co., Ltd.
Gate City Ohsaki, East Tower,
11-2, Osaki 1-chome, Shinagawa-ku,
Tokyo 141-0032, Japan
http://www.fujielectric.co.jp/eng/index.html

editorial office Fuji Electric Journal Editorial Office
c/o Fuji Electric Information Service Co., Ltd.
9-4, Asahigaoka 1-chome, Hino-shi, Tokyo 191-0065, Japan

Increasing Expectation for Power Electrics Applied Technology

Yoshio Okuno
Fuji Electric Systems Co. , Ltd.

Inverters, uninterruptible power supplies and other products incorporating power electronics technology are currently used at various public locations and in various market sectors. For example, the trains you may ride during your morning commute and the elevator you may ride up to your office are driven by motors that are controlled by inverters. Also, the computers comprising the backbone of an IT system that provides work support are protected from power failure by uninterruptible power supplies, and power supplies, servo systems and the like are also used inside office automation equipment. Thus, power electronics technology, which is one of Fuji Electric's strengths, is indispensable to our daily lifestyle and production activities.

Recently, with efforts to limit global warming and reduce CO_2 emissions in order to realize a sustainable environment, there is a strong awareness of the urgent challenges presented by energy and environmental issues. At the July 2008 Hokkaido Toyako Summit, a proposal was made to cut global CO_2 emissions by 2050 to half the present amounts. According to the Japanese Ministry of the Environment, CO_2 emissions from factories and such in the industrial sector in 2007 were 1.3% less than in 1990, however emissions from offices and such in the business sector increased by 41.7% and emissions in the household sector increased by 41.1%. Under these circumstances, an amended "Law concerning the Rational Use of Energy" (Energy-saving Law) was announced on May 30, 2008 and is slated to be enforced on April 1, 2009. With this amendment, the energy management obligation of large factories greater than a certain size will instead become mandatory for each company (including franchise chains). Also, with the goal of reaching the Kyoto protocol targets and achieving further dissemination of these targets, a subsidy program for the cost of installing consumer-use photovoltaic power generation equipment, which had temporarily been suspended, will resume accepting applications as of January 2009.

Responding to major trends such as energy and environmental issues, Fuji Electric intends to use applied power electronics technology in response to expectations concerning these market demands.

As a leader in the power electronics sector, Fuji Electric has been providing power semiconductor devices, which is an important power electronics device, since the mid-1970s, and has provided products applied power electronics technology for various market sectors. When we integrated our businesses in July 2008, applied products were concentrated in Fuji Electric Systems Co., Ltd. and reorganized as our drive business, and we transformed from being a business with an awareness of conventional products to a business structure that provides solutions from customers' perspectives and provides products and systems that fulfill a wider range of society's needs.

For example, IDCs (Internet Data Centers) have expanded as the quantity of digital information has increased, but the accompanying increase in their electric power consumption has caused a noticeable problem. At an IDC, IT devices account for approximately 30% of the power consumption, while the majority of electric power is used for cooling, air venting, power supply equipment and the like. A green IDC concept, which promotes total power savings, is under consideration and efficiency improvements are sought for the entire system rather than for individual devices.

On the other hand, continuous economic growth on a worldwide scale is essential. With economic development, however, people and objects tend to move about with increased frequency, and consequently, demand for transportation infrastructure improvements will increase, especially in the BRIC nations. As a result of the recent global financial crisis, the world economy might decline temporarily. For an economic counter measure to it, railway transportation is being reconsidered as an eco-friendly transportation means and aggressive investment is planned, with investment in the transportation infrastructure being expected to rebound soon. A transportation system that limits CO_2 emissions during mass transit via railroads and ships, and to contribute to energy and environmental issues, is desired to be proposed as a benign to the global environmental and is highly efficient measure to the global environment.

Leveraging the Fuji Electric group synergy, proposals for this kind of green IDC concept and the highly efficient transportation system concept are being considered as proposals for a total system.

Moreover, for the individual devices required for solution proposals, we plan to implement further improvements in power electronics applied technology, to manufacture from a global perspective and to improve the service environment in order to provide optimal products and services for overseas countries as well.

Businesses contributing to protection of the global environment by providing, with an energy saving system utilizing a limited amount of energy efficiently as much as possible, a new electric drive system and a system utilizing natural energy such as solar power and wind power to the maximum extent as an economical efficiency could allow instead of fossil fuels are expected to expand continuously.

This special edition describes some of Fuji Electric's efforts involving drive and power source technology.

In response to public and market needs, Fuji Electric intends to make a positive contribution continuously to assisting to the global environment protection and support from the readers of this journal earnestly.

Drive and Power Supply Technology: Current Status and Future Outlook

Shinobu Hosaka †
Shinichi Itou †

1. Introduction

At present, expectations are increasing throughout the world for drive and power supply solutions to provide energy savings and meet environmental needs. For example, with the full-scale adoption of ICT (Information and Communication Technology), by 2025 the quantity of information in Japan is expected to become about 200 times as large as the present. Accordingly, the Green IT Promotion Council estimates that by 2025 the consumption of electric power by IT devices and systems will reach approximately 5.2 times the amount consumed in 2006. Factoring in the development of the BRIC countries and the like, the consumption of electric power worldwide in 2025 will increase to 9.4 times the amount consumed in 2006, and this worldwide rate of increase exceeds that of Japan. In order to limit this sudden increase in power consumption, green ICT solutions that utilize power electronics technology have been proposed. Moreover, regarding the battle against global warming, Japan's greenhouse

Fig.1 Drive device business concepts

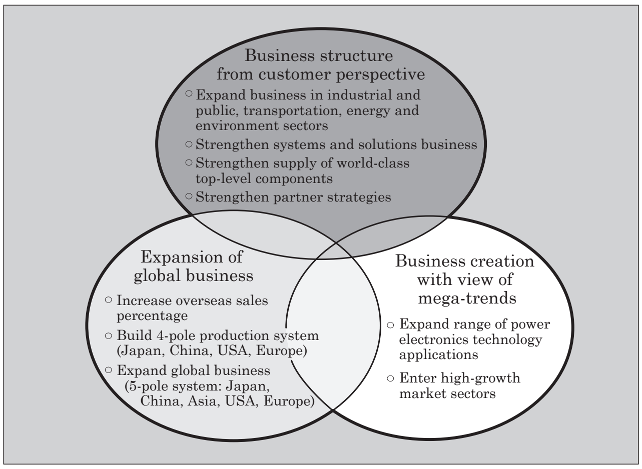


Table 1 Four sectors of the drive device business

Sub-unit	Main markets	Basic products	Solutions
Industrial systems and solutions	Domestic Japanese industrial plants Overseas steel rolling plants Overseas steel processing plants Automobile industry Petrochemistry	Inverters Servos PM motors PLCs	○ Drive solutions for plants ○ Energy saving drive solutions based on PM motors ○ Global deployment
Transportation systems and solutions	Electric devices for rolling stock Merchant marine electric ship propulsion Forklift market	Electric devices for rolling stock Electric devices for special machinery in Japan Inverters	○ Propulsion systems for Shinkansen trains and existing railways, door systems ○ Electric ship propulsion system having excellent environmental qualities ○ Solutions in new market sectors for rolling stock
Energy and environmental systems and solutions	IDC market Manufacturing industry New energy	Large UPSs Mini UPSs Solar PCSs	○ Green data center solutions (power supply / heat/ new energy) ○ Power supplies and ultra-high efficiency power supplies for Green IDCs ○ New energy sector (photovoltaic generation system)
Components and integrated solutions	Cranes Machine tools Printing machines Testing machines Semiconductor manufacturing equipment	Inverters Servos PLCs	○ Capability to provide products that satisfy market needs (faster, more affordably and with better service) ○ Expansion of integrated solution business (component and system solutions) ○ Energy saving solutions

UPS: Uninterruptible Power System
PCS: Power Converter System

† Fuji Electric Systems Co. , Ltd.

gas emissions will become apparent in 2009, the first year in the first commitment period under the Kyoto Protocol. To compensate for the divergence from the target value of emissions reduction, additional measures for energy savings and environment friendliness are likely to be requested.

On the other hand, as a result of advances in power electronics technology, products that satisfy market needs have also progressed.

Incorporating the strong market needs for energy savings and environmental friendliness, Fuji Electric has adopted an interim strategy of focusing on its drive business as a core business sector. In its drive business, Fuji Electric is targeting four sectors: industrial and public solutions, transportation solutions, energy and environmental solutions, and components. By rethinking the business structure from a customer's perspective, strengthening the system solutions business and providing world-class top-level components, Fuji Electric is attempting to expand its business. Business concepts are shown in Fig. 1, and products based on the markets of the four target sectors are listed in Table 1.

The chapter below describes the market trends and technology of drives, and Fuji Electric's product development strategy.

2. Market Trends

2.1 Industrial and public solutions

Variable speed driving of electric motors is used widely in energy saving applications to improve the operating efficiency of square-lowering load machines which consist mainly of fans and pumps. Consequently, general-purpose inverters and medium-voltage inverters are being used in practical applications, and motors are being replaced to permanent magnet type synchronous motors (PM motors). Furthermore, in systems that combine an inverter and an electric motor, not only is higher efficiency desired, but higher combined efficiency, including improvements in the operating method, is also requested.

At iron and steel, paper, cement, petrochemical and other industrial plants, there is healthy demand for aging renewal, to replace existing electric motors and drive equipment, and for facility renewal, to improve facility capacity and functionality. Good drive system performance and functionality contribute to efforts to increase the capacity of electric motors, increase the manufacturing capacity through higher speed operation, improve product dimensional accuracy, and to attain higher yields.

2.2 Transportation solutions

Although the size of the domestic Japanese market for rolling stock remains stable, as in the case of the N700 series Shinkansen train, development efforts for greater energy savings are actively being advanced. Overseas, mainly in emerging nations in Asia, investment in railroads is vigorously being promoted in order to improve the transportation infrastructure. Also in the shipping sector, environmental friendliness is being advanced through the use of electrical propulsion ships. Future market growth is expected for electric propulsion systems used in merchant vessels.

2.3 Energy and environmental solutions

Driven by needs for stronger internal controls and improved work efficiency, the trends toward a concentration of larger-scale IT devices and management outsourcing are increasing, and the IDC (Internet Data Center) market is growing. Reducing the consumption of energy in the information sector is an urgent task.

With the rapid expansion of new energy sources, such as solar power generation and wind power generation, the power conditioners, system coordination and electric power stabilization technology used in connecting generated electric power to a power distribution system have become crucial.

2.4 Components

In the industrial sector, electric motors, inverters and servo drive system components are requested to provide energy savings, reduced CO_2 emissions, improved safety of machinery and equipment, an expanded range of carriage applications and capacities, and so on.

To realize energy savings, higher device efficiency is requested of the general-purpose inverters and electric motors that operate fans and pumps at optimal output levels. Also, in addition to providing the previous level of high speed and high accuracy operation, the servo drive systems installed in machinery and equipment are also requested to have a simple system configuration, be easy to use, have a short setup time and a low price.

2.5 Services

After the abovementioned solutions and components have been delivered to customers, the provision of operational support for these solutions and components throughout their lifecycle, up to and including renewal and disposal, is highly expected.

Especially for components such as general-purpose inverters which have been delivered widely in Japan and overseas, greater readiness is requested worldwide for supplying the spare parts and finished spare parts needed for emergency maintenance, and for the related repair work and technical support.

Moreover, to improve planned facility maintenance, a data acquisition function for acquiring the data necessary to ascertain the operating condition, and also the enhancement and higher accuracy of predictive maintenance technology to avoid unexpected facility shutdowns and realize more stable operation, are indispensable.

Responding to the above-described expectations and requests, Fuji Electric is actively strengthening its worldwide network and developing predictive maintenance technology to enrich its lifecycle maintenance support (service) which is a critical element of operational support.

3. Trends of Fuji Electric's Drive and Power Supply Technology

3.1 Market trends

Energy and the environment are recent megatrends of the market, and based on the keywords of "low-loss" and "new energy", drives and power supplies are pursuing lower power consumption and higher efficiency through the use of low-loss devices and circuit technology, and machinery is beginning to transition to electric propulsion. Meanwhile, for the electric power generated by solar power, wind power and other types of new energy, conversion by a power conditioner, storage by an electric storage device, and stabilization by a bidirectional converter have become necessary. Moreover, products and technologies for the optimal usage of electric power with a smart grid have appeared in the marketplace. Thus, in today's market which emphasizes energy and the environment, the technology for drives and power supplies is extremely critical.

3.2 Direction of technical development

Fuji Electric's vision of its drive business is "to become the number-one provider of products, systems and services that maximally utilize power electronics technology and contribute to environmental friendliness." Thus, the basic objectives of technical development in the four target sectors are as follows.

In the energy and environment sector, Fuji Electric's power supply business has achieved the number one rank in Japan, and in the transportation sector, Fuji is expanding its business through partnership strategies. In both of these sectors, Fuji Electric is making significant inroads to overseas markets. In the industrial/public sector, Fuji Electric is focused on expanding its energy savings business consisting mainly of medium-voltage inverters and PM motors. In the component sector, Fuji Electric aims to change from a component business to an integrated solution business, and to expand its business that uses standard modules suitable for customization. For each of these four sectors, the development of technology and hit products that help expand Fuji Electric's solution business are key measures, and basic technology that is common to both drives and power supplies is strengthened for this purpose.

3.3 Features of technical development

Power electronics technology is a technical field that combines devices, circuits and control elements, and these closely correlated technologies can be combined to create competitive products. Power electronics technology is a strength of the Fuji Electric Group, which possesses synergy for the technology of these three elements. By leveraging this group synergy and pursuing higher efficiency, Fuji Electric creates overwhelmingly distinctive products that consume low amounts of power.

Fuji plans to introduce powerful products in the energy savings sector for power supply systems, variable speed control systems and electric propulsion systems for ships and rolling stock, and in the energy generation sector for solar power conditioners, wind power generation bidirectional converters, power supply stabilizers and electrical power storage. Specifically, Fuji Electric plans to combine the development of green power electronics, which uses new devices, with common basic technology for which development has traditionally been prioritized, and apply this combination to green IDC, solar power generation, power storage, global vehicle electric propulsion, ship propulsion and variable speed drive products.

3.4 Common basic technology

(1) Power electronics platform

In order to more efficiently utilize development resources through the design and restructuring of basic technologies common among power electronics, Fuji Electric is pushing to strengthen common technologies and establish a power electronics platform. Main tools for this platform are listed below.

(a) Magnetic component design tool for minimizing materials and downsizing components through optimized design and critical design of reactors and transformers, also for reducing product development time by enabling highly accurate performance measurements during the design phase

(b) Automatic design tool for built-in type switching power supplies capable of quickly supporting different customer specifications and realizing mistake-free designs, also for reducing the time needed for design changes and re-evaluation

(c) Cooling design tool capable of estimating with high accuracy, and within a short amount of time, the airflow distribution in a large power electronics panel and the distribution of temperature due to chip-level heat generated by a semiconductor module

(2) Power conversion technology

Drive technology is basically power device and power conversion circuit technology, and the control technology for these under optimal conditions. Fully utilizing its advantage of having an internal device department, Fuji Electric has traditionally applied thyristors, transistors, MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors), IGBTs (Insulated Gate Bipolar Transistors) and other conversion devices to various power electronics products. These power electronics products range from a several tens-of-

Watts-class switching power supply for IT equipment, to a ten to several hundred kVA-class general-purpose inverter, a several MVA-class inverter for rolling mills, and a several hundred MVA-class rectifier for aluminum electrolytic capacitors. Distinctive conversion circuit technology is applied to these products according to their application.

As an example of large-capacity converter technology, a 7.5 MVA industrial-use inverter (Fig. 2) with multi-level control has been commercialized by connecting 3.3 kV IGBT devices in series, and application to large-capacity frequency converters and flicker compensators is being considered. For uninterruptible power supplies (UPS), power units that are common among UPS models are connected in parallel to expand the UPS model product series and realize increased capacity.

To realize high power density in the switching power supplies for IT equipment with small-capacity converters, technology for configuring the windings of an insulated transformer using the wiring pattern of a multilayer printed circuit board and technology for discharging the heat generated by a semiconductor switching device and the like using the printed pattern of a printed circuit board are put into practical use.

(3) Control technology

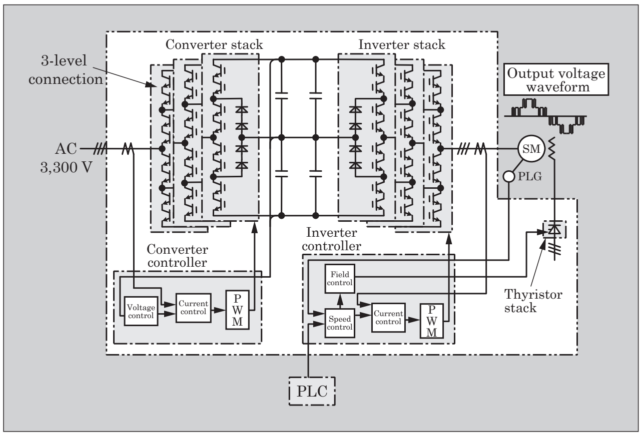
Magnetic pole location sensor-less control technology capable of driving a PM motor stably even at low speeds is applied to applications for rolling stock and the like. A magnetic flux observer control method capable of accurately estimating the location of magnetic poles without being limited by noise or motor type is applied to the above control technology.

Also, anti-sway control for the conveyor and machine tool sectors is realized by applying a multi-rate observer consisting of a high-rate sampling observer and a low-rate sampling observer. The use of this technology helps reduce the tact time involved in the automation of crane equipment.

(4) Motor technology

A PM motor is a product that has a permanent magnet positioned in its rotor, and the significant reduction in loss within a rotor enables the motor to realize higher efficiency and smaller size and to meet the needs for energy savings and environmental friendliness. Energy saving systems comprised of a PM motor and an inverter are core products of Fuji Electric's drive business, and Fuji Electric is advancing their technical development. A PM motor design platform has been constructed, and this key items enables the optimal design and performance estimation of a motor, minimization of the amount of magnetic material used, and design of the demagnetization withstand ability of a magnet to be implemented within a short time. This design platform is presently being used by Fuji Electric's design department.

Fig.2 3.3 kV IGBT series-connected inverters



(5) Service related technology

(a) Remote monitoring technology

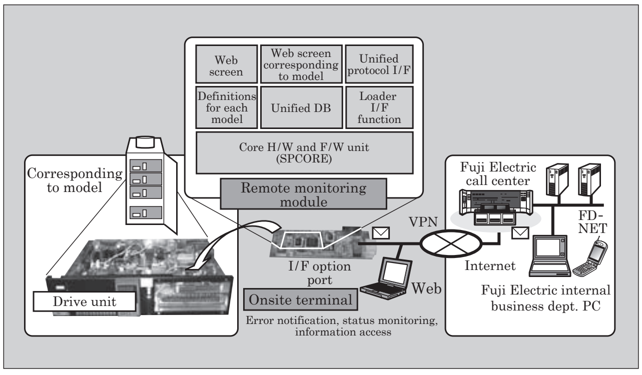
Fuji Electric began to develop a remote monitoring function in 1975 in order to supervise the operation of a control computer from remote overseas locations, and has expanded the applicable range of this technology to include DCS (Distribution Control Systems), UPS (Uninterrupted Power Systems), electric power generators, and some inverters and fuel cells.

Fuji Electric has newly developed a remote monitoring module that functions as a common foundation when providing plant devices with a remote monitoring function, and is promoting the use of this module with all products supplied by Fuji Electric. As the result, "plant (equipment) status ascertainment" function is added to the conventional "product status ascertainment" function, enabling acquisition of the operating data necessary for ascertaining the operating state. These functions enable improvement in the preventative maintenance for equipment, and contribute to more efficient delivery tests and post-delivery startup tests, after equipment has been shut down for maintenance. Figure 3 shows an overview of a remote monitoring module for inverters.

(b) Predictive maintenance technology

Predictive maintenance technology is status monitoring maintenance technology for predictive maintenance, and consists of degradation diagnostic

Fig.3 Remote monitoring module



technology and remaining life assessment technology. Fuji Electric has been performing degradation diagnoses and remaining life assessments for oil-filled transformers since 1980 and for electric motors since 2000. Recently, in addition to increasing the accuracy of remaining life assessment for oil-filled transformers, and systematizing the degradation diagnosis and remaining life assessment technology for molded transformers and inverters, Fuji Electric has developed a wireless vibration diagnostic system that uses RFID (Radio Frequency Identification) technology for diagnosing the vibration of rotary machines (electric motors and their load machines).

4. Direction of Product Development

4.1 Industrial and public solutions

Fuji Electric is engaged in the following development efforts in order to provide system and service solutions that combine strong components with an abundance of plant engineering know-how.

As an example of new product development linked to a power electronics platform, Fuji Electric is developing products to broaden its lineup of overseas production models of medium-voltage inverters, which have a successful track record in the energy savings sector, and to maintain and improve their competitive strength in Japan. Also, as an example of technical development of large drive devices, Fuji Electric has commercialized an IGBT module series-connected inverter.

On the other hand, to expand the existing equipment renewal business, Fuji Electric is pushing to expand the menu offerings of the FRENIC4000/4400 series of inverters for iron and steel, paper, petrochemical and other industrial plants, to enhance the thyristor Leonard control functions, and to achieve better reliability through theoretical explanations of the voltage surges and roller bearing electrolytic corrosion in an inverter drive motor system.

To further expand product menu offerings to the automobile and construction equipment sectors, Fuji Electric has developed a test equipment drive system and a large-capacity servo system.

4.2 Transportation solutions

As product development for the rolling stock sector, Fuji Electric is engaged in efforts to develop a propulsion system for Shinkansen trains, electrical equipment for electric multiple units (EMU) and diesel multiple units (DMU), and the next generation of linear door systems.

As a propulsion system for Shinkansen trains, a PM motor magnetic pole sensor-less drive system is under development. As electrical equipment for electric multiple units (EMU) and diesel multiple units (DMU), Fuji Electric is developing higher performance and higher functionality auxiliary power supplies having IGBT multi-serial connection technology at their core in order to advance the development of multifunctional auxiliary power supplies for overseas railroads. For door systems, the linear motor method has been highly evaluated.

In the shipping sector, to meet future market needs, technical development is advancing to develop a system structure that combines an electric propulsion system and an auxiliary power system.

4.3 Energy and environmental solutions

Fuji Electric is involved in the following development efforts in order to satisfy the strong needs of the market for energy savings, to move into the new energy market, and to improve power supply stability.

For medium and large capacity UPSs, Fuji Electric is expanding support of the parallel redundancy function of the UPS7000D Series of high efficiency UPS models for use at IDCs, advancing support of the standby redundancy function of the UPS8000D Series of UPS models, and will continue with development efforts in pursuit of lower loss so as to realize greater power supply stability and energy savings in the IDC sector.

For small-size power supplies, Fuji Electric is developing products to meet efficiency standards such as the international Energy Star program (Refer to the Glossary on page 172) and the CSCI (Climate Savers Computing Initiative) (Refer to the Glossary on page 172), and is also working to digitize control circuitry and apply new silicon carbide (SiC) MOSFET devices to power supplies.

In the new energy sector, Fuji Electric is advancing the development and commercialization of power conditioners for photovoltaic generation and power conditioners for power storage systems.

4.4 Components

Fuji Electric is engaged in development to provide world-class top-level components.

So that new products can be developed efficiently and speedily, the following items of basic technical development are being advanced as a part of our efforts to strengthen the power electronics platform.

(a) Improved simulation technology as a result of the creation of thermal analysis, transmission noise and strength analysis models for the inverter unit
(b) Advanced functional safety technology
(c) High-speed communications interface (Ethernet*1 application technology)
(d) Improved vibrational resistance and research of evaluation technology for PM motors
(e) Commonalization of the PM motor and servo motor technology (critical design technology for loss and cooling)

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*1: Ethernet is a registered trademark of Fuji Xerox Corp.

(f) Establishment of development process for next-generation general-purpose inverters

On the basis of these basic technical development works, we are working to develop such new components as next-generation inverters, custom inverters, servo drive systems, PM motors and custom controllers. To strengthen integrated solutions that feature combinations of components, we are also developing various types of software packages for controllers.

4.5 Services

Fuji Electric is strengthening a lifecycle maintenance support (service) function that provides maintenance support for solutions and components that have been delivered to customers.

Development for expanding call center functions to improve responsiveness to emergency maintenance requests, and for expanding the parts supply management system and remote monitoring system is being advanced from a global perspective.

Moreover, with the goal of improving planned facility maintenance, we are promoting expanded use of the remote monitoring module with other products. Additionally, to avoid unexpected facility shutdowns, we are working to establish new predictive maintenance technology and to increase the accuracy of existing predictive maintenance technology.

5. Inverter and Power Supply Product Series

As an example of our drive products, Fuji Electric's inverter product series is shown in Fig. 4. This product lineup supports a wide range of market needs, from low voltage and small capacity to medium voltage and large capacity models, and applications ranging from multipurpose to high precision and sophisticated plant applications.

Fig.4 Fuji Electric's inverter product series

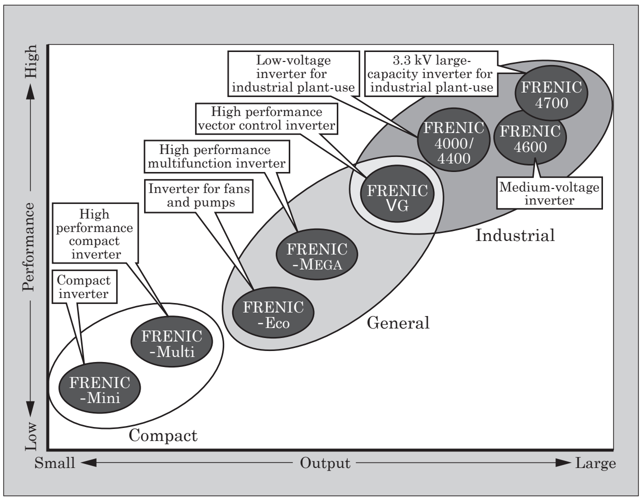


Fig.5 Fuji Electric's uninterruptible power supply product series

Model	Series name (product name)	Capacity of the series (kVA)	Main applications
Switching power supply for IT equipment	DC/DC converter	0.1 to 0.2	Installed on motherboard, etc.
	High density front-end power supply	1 to 3	Used on primary-side of motherboard, etc.
Mini UPS	NetpowerProtect (100 V)	0.5 to 3	Single-phase load for PC NetpowerProtect: Standby type UPS GX series: Dual-conversion method
	Global mini UPS GX200 series (200 V) GX100 series (100 V)	0.7 – 10 1 – 10	
	Intelligent UP RX series	7 – 21	Single-phase load for computer etc. (added internal units can increase capacity up to 21 kVA) Dual-conversion method
Large UPS	UPS6000D-1 series	20 – 100	Single-phase medium-capacity load for computer etc. (3-phase input), isolated type
	UPS6100D series	10 – 100	Three-phase medium-capacity load for computer etc., isolated type
	UPS6000D-3 series	100 – 1,500	Three-phase load for large capacity computer system and manufacturing facilities, isolated type
	High-efficiency UPS7000D series	500	High-efficiency (95%) large capacity system such as IDC, non-isolated type
	UPS7700 series	100 – 600	Overseas spec product (3-phase, 4-line) high-efficiency (94%), non-isolated type
	Dual processing type UPS8000D series	100 – 2,000	Super-high efficiency (98%) large capacity system for IDC and manufacturing facilities, non-isolated type, dual processing type
	Parallel processing type UPS8100D series	15 – 75	Super-high efficiency (98%) system for medium capacity manufacturing facilities, non-insulated type, parallel processing type

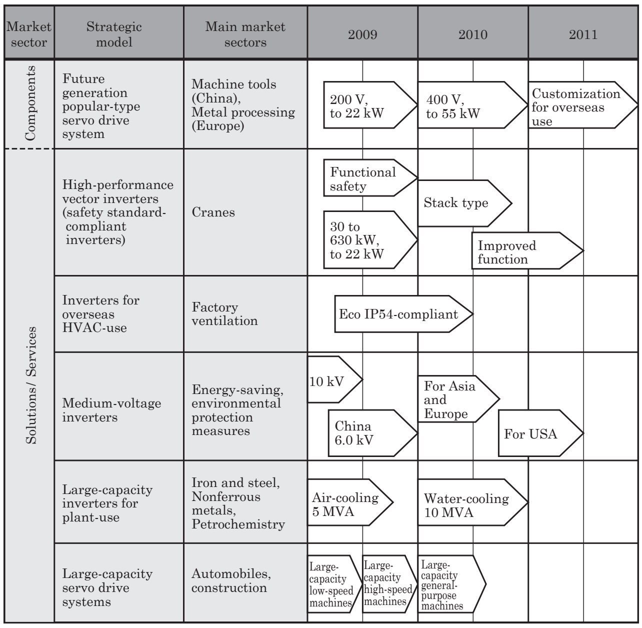
An energy-saving drive system that combines a high efficiency PM motor and a FRENIC-MEGA general-purpose inverter is able to realize the IE4 efficiency level stipulated by IEC 60034-30. Moreover, the medium-voltage inverter FRENIC4600 Series, suitable for realizing energy savings in large fans and pumps that are driven by 3.3 to 10 kV electric motors, has a successful track record as a product matched to the needs of the market. The platform technology for these inverters is also used with inverters for rolling stock.

Fuji Electric's product lineup of power supplies, the key devices for uninterruptible power system solutions such as green IT, is shown in Fig. 5. The lineup includes an uninterruptible power supply for each type of application.

During the development and planning phases, products are formed according to a roadmap. In the energy and environmental solution sector, we aim to achieve a comprehensive optimization of heat and electric energy in order to realize a green IDC, and in the transportation sector, we are concentrating on systems that support our solution business in the global market for rolling stock.

As examples of product development, Fig. 6 shows the roadmap for the component and solution/service sectors. For applications to machines tools, Fuji Electric has commercialized a popular-type servo drive system and increased our competitiveness against foreign manufacturers, and for high-performance vector control inverters which have a successful record of production, Fuji is working to realize compatibility with safety standards that are requested mainly from overseas markets. Energy saving applications with factory ventilation equipment are highly anticipated for large overseas markets, and special-purpose machinery that improves the environmental resistance of low-voltage inverters is commercialized. For energy-savings applications such as plant fans and pumps, with which significant energy savings can be realized,

Fig.6 Roadmap of main products



medium-voltage inverters having the highest level of performance in Japan have been commercialized successively for overseas use.

6. Postscript

The present status and future direction of Fuji Electric's drive and power supply technology and products have been presented in part. In particular, "energy" and "environment" have become technical keywords for the 21st Century, and expectations for the evolution of power electronics technology are surely increasing. To meet these expectations, Fuji Electric intends to continue to increase its level of technology and to contribute positively to society by providing products that satisfy needs for energy savings and environmental friendliness.

Core Technology of Power Electronics Equipment

Kazuo Nakamura †
Kiyoaki Sasagawa †

1. Introduction

Power electronics equipment is used in a wide range of fields, ranging from consumer electronics device to industrial and public infrastructure applications, and contributes to the realization of greater energy savings, improved productivity, and the more efficient utilization of electric power energy.

Fuji Electric has a history of providing many families of products to the industrial, public infrastructure, transportation, energy and environmental fields, and has advanced the development of power electronics which is fundamental to these fields.

This paper describes Fuji Electric's efforts involving the core technology of power electronics equipment.

2. Efforts in Core Technology Development

The social environment is changing due to factors such as global environmental issues (global warming, environmental pollution, etc.), depletion of fossil fuels, decreasing birth rates and aging populations, shrinking labor forces, globalization, and the pursuit of security and safety. In the marketplace, there are strong demands for reduced CO_2 emissions, energy savings, utilization of natural energy, productivity enhancements, and better safety and reliability.

Accordingly, power electronics equipment is requested to facilitate the realization of further miniaturization and higher efficiency through the use of miniaturized and lower loss power semiconductor devices, the use of high frequency circuits and improved packaging technology, a greater sophistication of control functions, higher reliability for continuing stable operation at a production site, and reduced power source harmonics and lower electromagnetic noise for improved environmental harmony.

As shown in Fig. 1, Fuji Electric has provided distinctive power electronics products to the market for a wide range of applications, capacities and frequencies, including a DC/DC converter (50 watt class) for use in information-processing equipment, an uninterruptible power supply (UPS) (500 kVA), an inverter for rolling mills (5 MVA and greater), an aluminum electrolytic rectifier (800 MW class) and an induction heater (1 MHz, 1 MW class).

The basic types of power electronics technology can be broadly classified as: (1) power conversion circuit technology involving power semiconductor devices and their application technology, (2) control theory and control technology for the specific control for various power electronics devices and for network, and (3)

Fig.1 Power electronics products by Fuji Electric

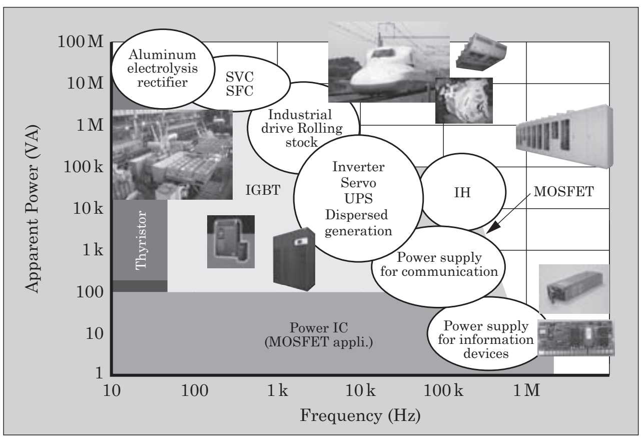
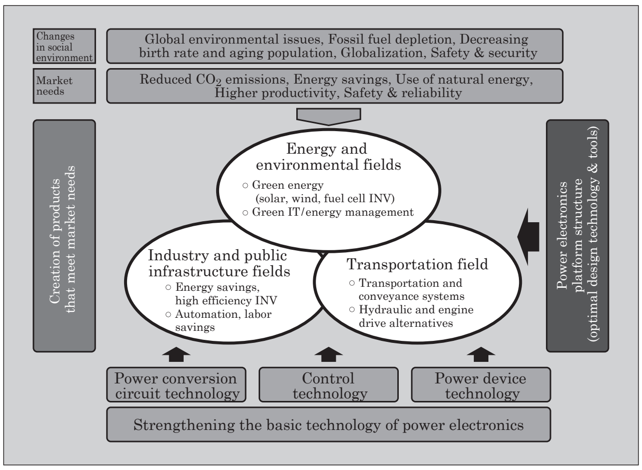


Fig.2 Market needs and power electronics equipment development efforts



† Fuji Electric Systems Co. , Ltd.

transformers, reactors, rotating machines and other hardware-related power equipment technology. In order to provide the abovementioned distinctive product families and to provide desirable next-generation products that satisfy market needs in such fields as industrial and public infrastructure, transportation, energy, and environmental regulatory compliance, Fuji Electric is advancing the development of core technologies to strengthen its basic power electronics technology and to establish a power electronics platform (to develop optimal design technology that can be shared among various devices). (See Fig. 2.)

This paper describes the relevant issues and Fuji Electric's recent efforts involving capacity-expanding technology for increasing the stand-alone capacity of equipment and high-power density technology for realizing miniaturization as power converter technology, drive control technology for realizing more sophisticated drive devices, motor design technology as power device technology, and power electronics platform technology.

3. Power Converter Technology

3.1 Capacity-expanding technology

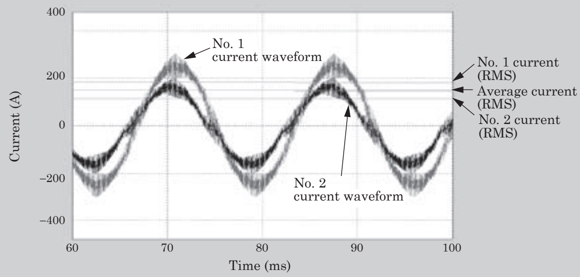
To expand the range of applications of products that use power electronics technology, Fuji Electric is working to develop capacity-expanding technologies for realizing serial-parallel connections of power semiconductors, parallel connections of power units, multi-converters and multi-level power converters. Serial-parallel connection technology and power unit parallel connection technology are described below.

As serial-parallel connection technology for power semiconductors, we developed a circuit method which has an extremely simple circuit configuration and is capable of balancing the voltage of a serially-connected IGBT even during transient operation. Features of this method are the capability to realize serial connections with almost no change in the device switching characteristics, and the ability to prevent an increase in switching losses. Fuji Electric realizes high-performance, high voltage and large capacity converters by using, instead of a high voltage IGBT, a 1 kV-class general-purpose IGBT, having good switching characteristics at high frequencies, applied to a multi-serial connection of this method to achieve higher blocking voltage.

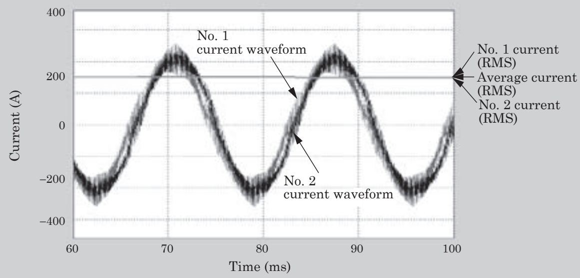
Moreover, as an application of power unit parallel connection technology, Fuji Electric's new large capacity UPS 7700F Series uses shared power units (100 kVA) and parallel connections to realize a wider lineup of models with expanded capacity from 100 kVA to 600 kVA (max.).

When connecting power units in a parallel configuration, limiting the current imbalance among outputs of the various units presents a challenge. Differences in the values of the filter inductor L_f, also used for parallel connections, and differences in the IGBT gate drive unit (GDU) delay times are the main factors responsible for the current imbalance among units operating in response to the same control signals within a device. Figure 3(a) shows simulated waveforms of two inverter power units connected in parallel in the case where differences exist in the L_f values and in the GDU delay times. According to the results of the simulation, when using standard-specification L_f and GDU values, current imbalances of approximately 20% and 40% occur when 2 units and 6 units, respectively, are connected in parallel configurations. Therefore, we added to the power unit's GDU a function for detecting the amount of current difference of the unit and for automatically adjusting the IGBT drive signal. Specifically, an adjustment function was added to increase the amount of dead time between a pair of IGBT arms only when the unit's output current difference is positive. This simulated waveform is shown in Fig. 3(b). As a result of the above-described method, even when there are differences among the L_f values and GDU delay times, the unit's current imbalance could be suppressed and a parallel connection of 6 power units (max.) was realized with a simple method.

Fig.3 Simulated waveforms of two inverter power units connected in parallel



(a) GDU without auto-adjustment



(b) GCU with auto-adjustment

3.2 High power density technology

Miniaturization is continuously sought in power supplies, and especially in the information and communications sectors in recent years, there are increasing requests for higher power density, i.e., a reduction in size while maintaining the same capacity or increased capacity while maintaining the same size.

A bus converter is an insulated DC/DC converter for converting the output voltage of a front-end power supply (AC input/DC output) in a communication device or the like to an intermediate bus voltage (such as 12 V), and the industry standard size is known as a "brick". In the 100 W class, the 1/4 brick size had been the mainstream size but the 1/8 brick size is gaining popularity. Fuji Electric has successfully downsized to the 1/8 brick size while boosting the output of that size from 100 W to 200 W. Figure 4 shows the external appearance of this 200 W bus converter. The external dimensions are 22.8 (W) × 57.8 (D) × 9.5 (H) (mm), and the rated input voltage is 48 V and the output voltage is 12 V. The following technologies where utilized to realize higher power density.

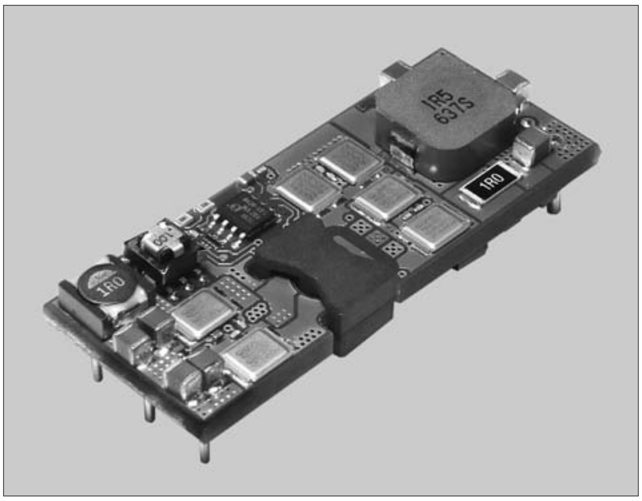
(a) The windings of the isolation transformer were constructed using the wiring pattern of a high-count multi-layer PCB to realize a thinner design. Additionally, the shape and arrangement of the wiring pattern were designed so as to minimize leakage inductance and winding resistance, and to reduce the amount of loss generated.

(b) A wiring pattern is used to disperse the heat emitted from heat-producing components such as semiconductor switching elements and the like. For this reason, the wiring pattern is provided with a shape and structure such that the heat transfer characteristic is extremely large in the horizontal (in-plane) and vertical (layer) directions.

(c) The bus converter is configured with a switching unit and a control unit for the main circuit current located in extremely close proximity to each other, and therefore the wiring pattern is shielded, or a through-hole connecting layers of the circuit board is grounded, in order to prevent mis-operation due to main circuit noise.

(d) The use of a new-type snubber circuit (voltage suppressor) in the rectifier circuit on the secondary-side of a transformer enables the use of low-loss, low-voltage semiconductor components.

Fig.4 200 W bus converter



Presently, Fuji Electric is working to deploy the abovementioned technology in other types of devices.

4. Control Technology

Fuji Electric is working to develop application techniques, such as vector control and observer theory, to improve the performance of drive systems with motors. Sensor-less magnetic position control technology for a permanent magnet synchronous motor to improve motor driving performance and anti-sway crane control technology to improve the drive system performance are introduced below.

4.1 Motor drive performance-enhancing technology

In applications for electrical rolling stock, fans, pumps and the like, the use of permanent magnet motors (PM motors) is increasing due to their smaller size and higher efficiency compared to induction motors. In response to needs for sensor-less and high-accuracy torque control similar to that of an induction motor, Fuji Electric is working to develop vector control technology that does not use a magnetic position sensor. Performance in the low-speed region, which has been a problem, is described below.

As a technique for improving stability in the low-speed region, inductance can be used as a function of the magnetic position. This method detects inductance fluctuations from the voltage and current values when a high-frequency component is applied, and then estimates the magnetic position. This method has the advantage of being capable of accurate estimation of the magnetic position even during low-speed operation, but also has the disadvantages of acoustic noise from the applied high-frequency component and of not being applicable to low saliency motors.

Fuji Electric is researching and developing a flux observer method capable of accurate estimation of the magnetic position even during low-speed operation,

Fig.5 Magnetic position and sensor-less vector control configuration

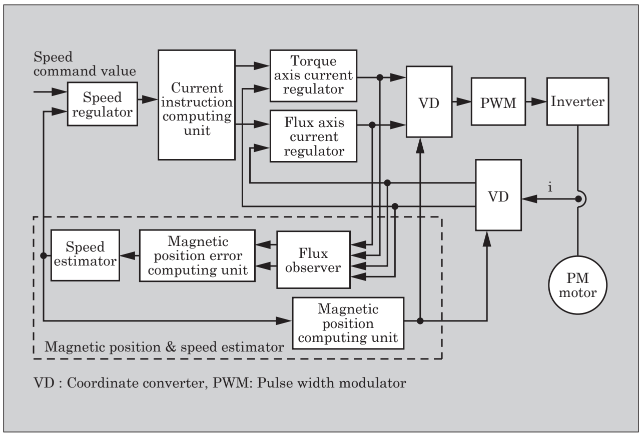
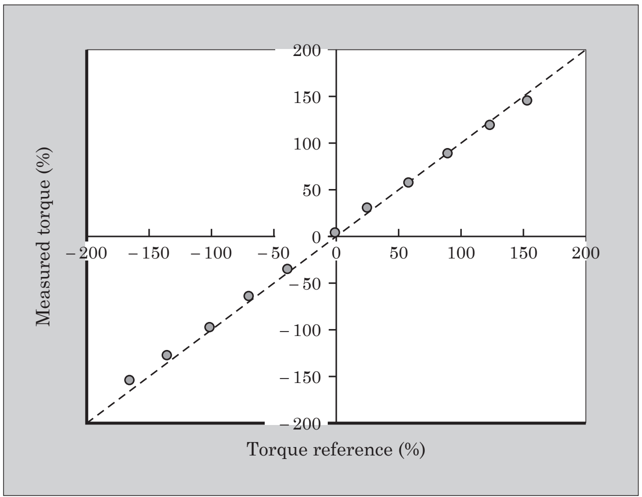


Fig.6 Torque performance (2% speed)



and that is not limited by noise or applicable types of motors. The flux observer method estimates the magnetic position and rotor speed from a value of magnetic flux that is computed based on a state equation of the motor. With the magnetic position and speed estimator configured as shown in Fig. 5, an adjusting operation is performed such that the magnetic position error becomes zero and the estimated magnetic position value matches the correct value. Figure 6 shows the torque performance at low speed (2% speed). Good performance can be ensured within the torque range from – 150% to + 150%.

4.2 Drive device performance-enhancing technology

In drive systems where the load is a conveyance machine, machine tool or other mechanical system, vibration suppression of the mechanical system is critical from the perspectives of both work efficiency and safety. The anti-sway control for a crane is described below.

Anti-sway control for a crane system is typically implemented by detecting the sway angle with a camera. Because image processing is implemented, however, the sway angle cannot be detected at the same rate of frequency as with which motor control computations are performed and detection delays also occur which inhibit performance improvement.

Fuji Electric is engaged in the research and development of sway angle estimation technology that uses a dual-rate observer and has high accuracy and minimal detection delays. The sway angle observer, as shown in the control system configuration of Fig. 7, is configured from a high-rate sampling observer that performs an estimate for each motor control computation, and a low-rate sampling observer that performs computational processing for each camera image processing interval. The low-rate sampling observer computes an amount of observer model compensation from the difference between the detected value of sway angle, which includes the computed time delay due to

Fig.7 Crane anti-sway system configuration

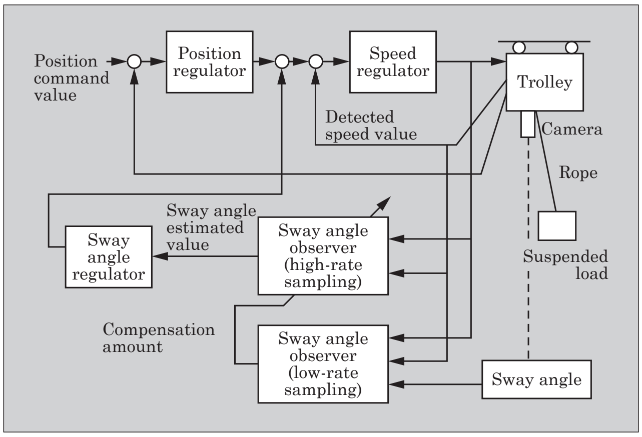
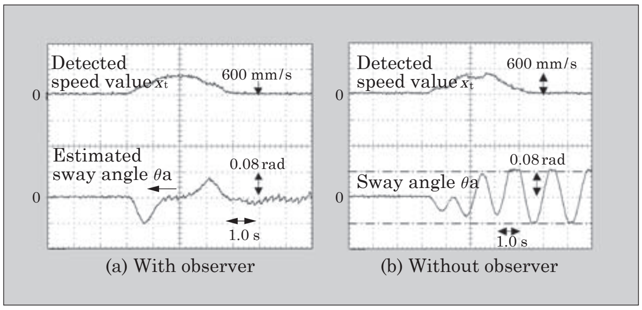


Fig.8 Crane anti-sway test results



the image processing, and an estimated value of the sway angle computed from an equation of up-motion for the crane. The high-rate sampling observer corrects the observer model, based on this compensation amount, to a suitable value and thereby increases the accuracy of the estimated sway angle used in the sway angle control. Figure 8 shows the results of the evaluation of sway angle control in an experimental setup in which the rope length was shortened by 15% and the equation of up-motion for the crane, i.e., the observer model, contains a certain amount of error. Even in this case, as long as the correction to the observer model by the low-rate sampling observer is effective, good results for the sway control could be verified.

5. Platform Technology for Power Electronics Design

Aiming to organize and restructure basic technologies common among power electronics, Fuji Electric is pushing to strengthen the design platform technology for electric circuits, control devices, software, cooling, construction, electromagnetic compatibility (EMC), and so on. Power electronics design technology has previously been applied to uninterruptible power systems (UPS), inverters, switching power supplies and driving units for train, achieving smaller size and lighter weight and helping to shorten the development time.

This chapter introduces a design tool for magnetic components which are indispensible in power electronics devices, a design tool for unit-type power supplies, such as switching power supplies, and capable of instantaneously supporting designs for customization, and a design tool for cooling which is a key technology for higher density equipment.

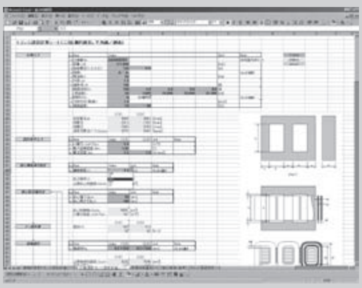
5.1 Magnetic component design tool

As a result of advances in semiconductor elements and with the continuing trend toward higher density power electronics devices, the percentage by volume and the generated loss of main magnetic components, such as transformers and inductors, has increased on a relative basis. On the other hand, with the sudden rise in materials prices in recent years, in order to meet the requested component performance with fewer materials, it has become more important than ever to pursue optimal design and limit design.

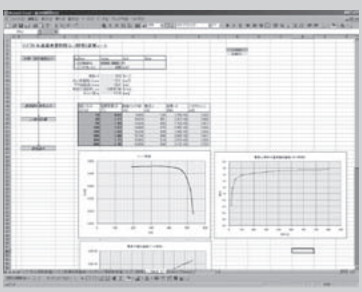
Fuji Electric has developed a magnetic component design tool, and is advancing the development of high-quality and highly cost-effective power electronics devices.

Figure 9 shows the configuration of Fuji Electric's magnetic component design tool. The tool consists of an input sheet for selecting the required electric specifications, the iron core material to be used, and the like from a data sheet, and a characteristic computation sheet that automatically computes the various characteristics. The design tool supports the design of DC/AC (single-phase and three-phase) inductors and single-phase/three-phase transformers used in inverters, and automatically computes such characteristics as the inductance, gap length and loss (core loss and copper loss). The design tool is additionally provided with a function for computing, according to the shapes of the core and coil and the amount of generated loss, the temperature rise of each component under actual usage conditions, thereby enabling a reduction in the amount of time required for determining the optimal design conditions for realizing the desired performance and reliability of the magnetic components with the minimum materials.

Fig.9 Configuration of magnetic component design tool



(a) Design tool (three-phase transformer) input sheet



(b) Characteristic computation sheet

As a result, not only could the performance expected in the design stage be realized with fewer prototypes and less verification testing, and the time required for product development be shortened, but the materials were also minimized and the components miniaturized.

5.2 Automatic design tool for unit-type switching power supplies

Unit-type switching power supplies are often custom products based on various specifications, and design, manufacturing and evaluation processes are implemented in each case according to the customer specifications. Fuji Electric has developed an automatic design tool for unit-type switching power supplies, and this tool is being used to provide products speedily in response to customer requests.

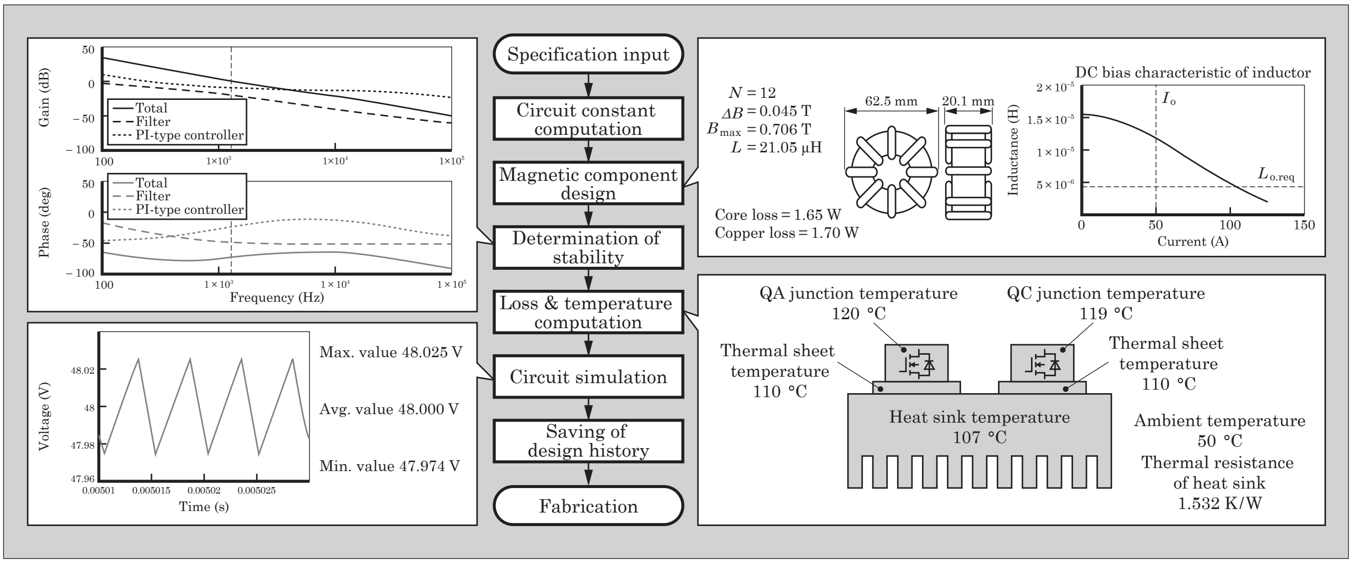
This tool is configured as shown in Fig. 10, and upon inputting the desired specifications, the tool is able to compute circuit parameters automatically. In the design of magnetic components, the number of turns, the core, wires and the like are computed and selected based on the circuit parameters obtained so as to minimize loss and size. The design algorithm incorporates Fuji Electric's proprietary know-how and leverages the ability of a computer to perform repetitive operations to realize an optimal design. The design results are reflected in Bode diagrams and circuit simulations, enabling immediate verification of the stability and circuit operation. Moreover, the loss and temperature for each component are computed automatically, and reflected in the thermal design. Lastly, a series of results for design, analysis and the like are saved as a single file, and traceability is ensured.

At present, circuits are becoming more diversified, and the automatic design tool can be used with various switching power supply products. Use of this tool not only shortens the design time, but also makes it possible to realize designs that contain few mistakes, reduces the amount of time required for design changes and reevaluation of prototypes, and strengthens the ability to handle customized designs. For example, use of this tool enables development times to be shortened by 20% on average compared to the case when conventional design techniques are used.

5.3 Tool for cooling design

In the conventional cooling design of power electronics equipment, the path from a heat emitting part

Fig.10 Overview of design tool for unit-type switching power supplies



to a cooling part was expressed as a thermal circuit, and the steady temperature rise and transient temperature rise were computed. With high-density large-scale products, however, the component layout and structures are complex and therefore significant differences between the design values and the actual device evaluation results may occur according to the level of modeling and the accuracy of such boundary condition settings as the heat transfer coefficient and so on. Additionally, since measurement of the temperature distribution of a semiconductor module junction and the wind speed distribution at small voids inside a cooling fin are difficult, three-dimensional computational thermo-fluid simulations must also be used.

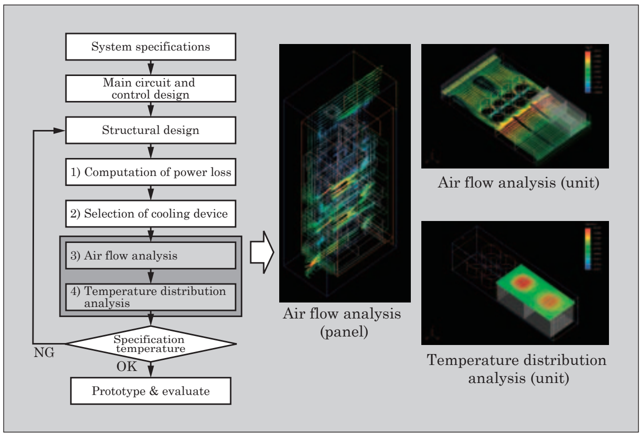
Thus, Fuji Electric developed techniques for analyzing airflow and temperature distributions in conjunction with three-dimensional CAD, and consolidated these techniques as a cooling design tool capable of quickly performing highly accurate computations of the airflow distribution within a large cubicle structure and of the temperature distribution corresponding to the chip-level heat generated by a semiconductor module.

Figure 11 shows an overview of the cooling design process flow for power electronics equipment; highly accurate power loss computations and steady and non-steady thermo-fluid analyses are performed. Thus, since the temperature distribution can be assessed accurately during the design stage, the number of prototype and evaluation iterations can be reduced and the development time shortened.

Moreover, the pursuit of smaller size, lighter weight and lower cost makes it possible to realize an optimized design with high reliability.

Using these design techniques, Fuji Electric intends to enrich the functionality of and to deploy this tool to implement cooling designs within a short time and with high reliability.

Fig.11 Overview of cooling design process flow



6. Motor Technology

6.1 Surrounding circumstances and technical issues

With the global needs for energy savings and reduced CO_2 emissions, there is an increased opportunity for improving the efficiency of all sorts of electrical products. Of the approximate 400 billion kWh of annual total electric power consumption by Japan's industrial sector, preliminary calculations show that the electric power consumption by motors accounts for approximately 70% of that figure, and increased efficiency will have a large effect. Also, for factories and other individual utility customers, improved motor efficiency will lead to a reduction in CO_2 emissions, lower electric power fees and lower capacity requirements at electric power utilities, and as a result, will contribute to reductions in cost.

In consideration of the abovementioned types of trends, motors, especially PM motors and their drive systems are positioned as strategically important items for Fuji Electric's drive business, and Fuji

Fig.12 PM motor structure

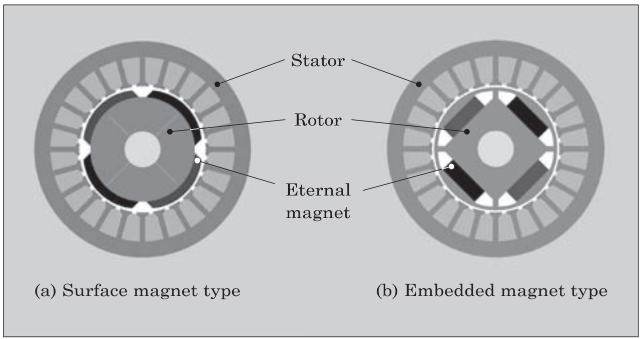
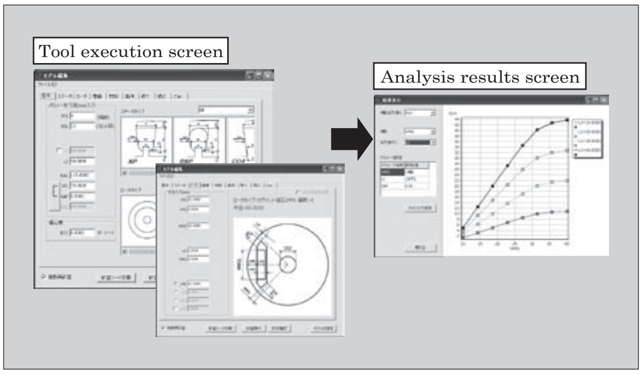


Fig.13 Example of operating screen of PM motor design platform



Electric is advancing their technical development. As shown in Fig. 12, PM motors are equipped with a permanent magnet inside the rotor part. Compared to induction motors which are widely used in industrial applications, the significant reduction in loss within a rotor enables PM motors to achieve higher efficiency, smaller size, and to be suitable for machine-embedded applications requiring a high degree of design freedom.

On the other hand, optimal design technology is needed to overcome the major technical challenges facing PM motors, i.e., achieving higher efficiency and the use of fewer materials. Particularly since customized design is often necessary to provide the required degree of freedom, the capability to implement a design and to estimate performance within a short time interval is critical. Moreover, neodymium magnets, often used as high-performance magnets, have low resistivity and as a result, changes in their flux density causes large eddy currents, and the resultant heating and temperature rise may lead to increased susceptibility to demagnetization. Accordingly, durability against demagnetization is a critical design item for a permanent magnet.

In response to these issues and in support of business expansion that promotes PM motors, Fuji Electric has developed the following design platform and is working to advance the application of this platform to design tasks.

6.2 PM motor design platform

In order to shorten the time required for PM motor design, Fuji Electric has constructed a design platform that incorporates simulations. Figure 13 shows examples of the operating screen. The main features are as follows.

(1) Design conditions input

The various motor parts and parameters can be set with this dialog-style input screen.

(2) Design computation

Fuji Electric's accumulated design guidelines and know-how are compiled into a database and referenced, and characteristics can be computed using the latest magnetic circuit analysis solver and numerical analysis solver technology. Parameter searches and highly accurate designs can be implemented efficiently.

(3) Design results output

Graphical displays of parameter search results and the seamless transition of design information to manufacturing documents are possible.

(4) Add-on function

The durability against demagnetization of a permanent magnet is evaluated, and assuming the most severe conditions, the extent to which the operating point of the permanent magnet approaches the demagnetization limit can be estimated by numerical analysis.

The accuracy of design computations is verified through multiple prototype tests.

Use of this platform enables the design time to be reduced to approximately one third of its prior value, and because the design can be optimized, estimates regarding the required specifications can be received in shorter times, and products that meet user needs can be provided.

7. Postscript

Fuji Electric's efforts in strengthening the core technology of power electronics equipment have been described.

The 21st century is being called the century of energy and the environment. As a basic technology for solving energy and environmental issues, expectations toward power electronics, which is indispensible for the effective utilization of clean and easily controllable electric energy, will increase further in conjunction with the progress of technical development of next-generation energy-saving power devices.

Fuji Electric will continue to develop power electronics technology so as to be able to provide products that are desirable and meet the needs of the market.

Drive and Power Supply Technology in the Industrial and Public Sectors

Kouji Saigou †
Takahiro Yamaemori †
Masayuki Nakagawa †

1. Introduction

In the industrial plant and public infrastructure sectors, which include the iron and steel, paper and petrochemical manufacturing industries, many drive devices and power supplies are being used. Drive devices and power supplies have evolved dramatically due to advances in the conversion elements they use and also due to the increased speed and functionality of microprocessors.

This paper introduces Fuji Electric's latest technology used in representative models of drive devices and power supplies, and describes application examples.

2. Trends of Recent Needs in Industrial and Public Sectors, and Fuji Electric's Approach

As an approach to climate change, an agreement was reached at the July 2008 Hokkaido Toyako Summit to share a vision of achieving at least a 50% reduction of global emissions by 2050.

In the industrial and public sectors, further energy savings, higher efficiency and space-savings are requested in order to reduce the emissions of greenhouse gases.

In the industrial plant sector, highly accurate speed control, higher dynamic response, improved speed matching and highly accurate torque control are requested to address demands for faster manufacturing processes, higher quality products and stable operation.

Meanwhile, with advances in ICT (Information and Communication Technology), progress is being made in the high-level information integration and networking of computer systems. So that large-scale systems which use many such computer systems in the industrial and public sectors will run stably, high quality power supply equipment that does not experience momentary voltage drops or outages is increasingly being requested. Previously, individual measures employing various methods, such as a low voltage UPS, were implemented. Due to various issues such as the high cost of equipment necessary for such countermeasures and the associated maintenance, and the difficultly in ascertaining the effect of a momentary voltage drop on a load system, large-scale measures to backup the power for an entire system are requested.

In response to these market needs, Fuji Electric has commercialized energy-saving drive devices that realize high efficiency, high reliability and space-savings, high-performance drive devices for use in industrial plants, and a high-efficiency medium voltage, large capacity uninterruptible power supply system. Technical details are presented below.

3. Drive Devices that Contribute to Energy-savings Solutions

Fuji Electric's FRENIC4600 Series of drive devices are suitable for driving medium-voltage motors directly, without having to provide a transformer on the output side of the inverter. The main uses for these drives are fans, pumps, blowers and the like where the objective is to realize energy savings through variable speed operation. In a continuation of the prior 3 kV and 6 kV product series, Fuji Electric expanded its product line with 10 kV and 11 kV output, IEC 61800-4 compatible products that enable a wider range of motors to be driven directly. Table 1 lists the standard specifications of the FRENIC4600FM5e medium-voltage inverters. Moreover, Fuji Electric's 6 kV-class of inverters was also made compliant with IEC standards. These inverters are manufactured in China, and since 2009 have been provided to users in China and throughout the world.

3.1 Example application to water-lifting pump

Figure 1 shows an example application to a water-lifting pump for agricultural irrigation use in Japan. Because water-lifting pumps are often installed at locations in which the power supply system is weak, the avoidance of voltage fluctuations when starting the motor was a challenge. Previously, voltage fluctuations were avoided by using rotor-resistance starting in a wound rotor motor, but slip ring maintenance was required. By using a medium-voltage inverter (560 kVA)

† Fuji Electric Systems Co. , Ltd.

Table 1 Standard specifications of the FRENIC4600FM5e medium voltage inverter

Product name		FRENIC4600FM5e																												
Voltage classes		3 kV									6 kV																	10 kV		
Output	Rated capacity (kVA)	350	500	700	1,050	1,350	1,600	2,350	3,200	4,750	420	500	600	700	860	1,000	1,200	1,400	1,600	1,800	2,100	2,360	2,700	3,200	4,700	6,400	9,500	1,200	1,700	2,300
Output	Applicable max. motor output (kW)	285	400	560	840	1,100	1,280	1,930	2,570	3,850	340	410	490	570	700	800	960	1,120	1,280	1,450	1,680	1,900	2,200	2,560	3,860	5,140	7,700	960	1,350	1,820
Output	Rated current (A)	68	98	134	202	262	306	459	612	918	41	50	59	68	84	98	115	134	153	173	202	227	262	306	459	612	918	68	98	134
Output	Overload capacity	105%, 1 min at rated current																												
Output	Rated frequency (Hz)	50, 60 Hz																												
Input (Main circuit)	Voltage, Frequency	3,000/3,300 V, 50/60 Hz									6,000/6,600 V, 50/60 Hz																	10,000 V, 50 Hz		
Input (Main circuit)	Allowable power variation	Voltage: ±10% (Inter-phase unbalance within 2%), Frequency: ± 5%																												
Control power supply	Phase, Voltage, Frequency	3-phase, 200/220V, 50/60 Hz																												
Control power supply	Allowable power variation	Voltage: ± 10% Frequency: ± 5%																												
Control, structure	Control system	Constant V/f control with simple sensor-less vector control																												
Control, structure	Output frequency range	0.2 Hz to 50/60 Hz (optionally up to 120 Hz)																												
Control, structure	Method of cooling	Air cooling (forced ventilation with ceiling fan)																												

Fig.1 Water-lifting pump for agricultural irrigation use in Japan

and soft-starting, the voltage fluctuation problem was solved and energy-saving operation was made possible.

3.2 Example application to cooling pump

An example application to a cooling pump for an overseas chemical manufacturing plant is described below. Previously, medium-voltage motors were run with commercial power supplies, and water quantities were controlled with valves. When driving a medium-voltage motor (360 kW) at a variable frequency according to the quantity of plant production, a reduction in the frequency from 50 Hz to 44 Hz results in energy-savings of 29% compared to ordinary models, and a reduction in the frequency from 50 Hz to 40 Hz results in energy savings of 50% compared to ordinary models.

4. Drive Devices for Production Solutions in Manufacturing Plants

The drive devices used in industrial plants are diverse, with output capacities ranging from several kVA to tens of MVA corresponding to the objective plant, and the required control method, i.e., speed control, speed control with droop, torque control or synchronous control of multiple drives, and the degree of accuracy required for speed matching and for speed and torque control, are also varied. Fuji Electric's product lineup consists of the 10 to 5,400 kVA output FRENIC4000 Series of 2-level IGBT inverters, the 1,200 to 16,000 kVA output FRENIC4400 Series of 800 V-class 3-level IGBT inverters, the 2,500 to 7,500 kVA output FRENIC4700 Series of 3.3 kV-class of 3-level IGBT inverters, and the SINAMICS SM150 10 MVA, 3.3 kV-class 3-level IGCT inverter for even higher output capacity.

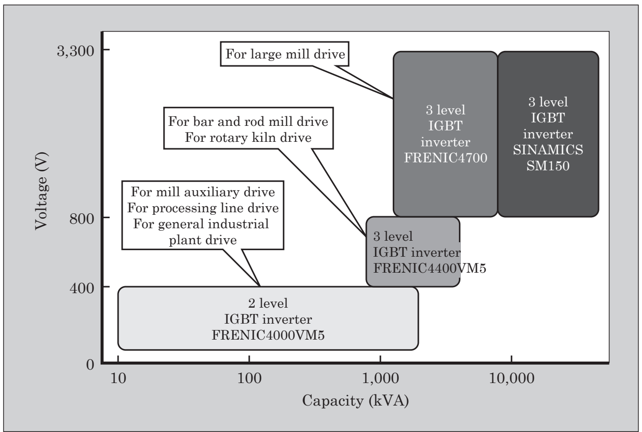
Figure 2 shows an application map of Fuji Electric's plant drives, and Table 2 lists the standard specifications of the plant drives.

4.1 Drive device for use in a processing line

The FRENIC4000 Series of inverters are AC400 V-class output, DC-link type inverters that support vector control, sensor-less control and V/f control. The inverters are interchangeable and use the same main circuit and control system regardless of the control method. In this series, the 10 to 300 kVA capacity models have a plug-in type unit structure and the 450 to 900 kVA models have a panel structure. Main characteristics are listed below.

(a) Can house up to 12 stages (max.) per side for space-saving, freely arrangeable
(b) Compatible with various field buses
(c) Standardly equipped with various plant control methods, i.e., highly accurate torque control, observer control function, etc.
(d) Easy to maintain

Fig.2 Plant drive application map



A processing line where coil-shaped steel strips are unwound, subjected to other consecutively implemented surface treatments such as pickling, annealing and plating, and then rewound into coil shapes is configured from helper rolls of several kW to reels of several-hundred kW, bridle rolls, mills and the like, and speed matching and tension control are critical when several hundred rolls are being used to convey the steel strips. The rolls are used either for pulling the steel strips or for being pulled by the steel strips, and because the DC-link makes it possible for drive and regenerative energy to be exchanged between motors, the capacity of the power supply can be reduced. In the case where one of the several hundred helper rolls should fail, the failed unit can be replaced while operation continues without stopping the line. The system is provided with a function for shock-free in-process startup that starts the roll operation to match the speed of the steel strips. Fuji Electric also provides small-capacity inverters for applications in medium and small plants.

4.2 Drive device for bar and rod mill

The FRENIC4400 Series of inverters are AC 800 V-class output, DC-link type, 3-level inverters that support vector control and V/f control. With a 3-level inverter, the output harmonics form a step-like shape and therefore the output harmonics, torque pulse, and micro surge voltage applied to the motor windings can be reduced compared to a 2-level inverter. The stand-alone capacities of models in this series are 1,200 kVA and 2,000 kVA, and large capacities of up to 16,000 kVA can be achieved by multiplexing.

A bar and rod mill is provided with several-tens of

Table 2 Plant drive standard specifications

Item \ Product name		FRENIC4000VM5	FRENIC4400VM5	FRENIC4700VM5
Input voltage		DC600 V	DC1,200 V	DC5,400 V
Output	Voltage	3-phase, AC400 V	3-phase, AC800 V	3-phase, AC3,300 V
	Frequency	200 Hz (max.)	120 Hz (max.)	100 Hz (max.)
Capacity of the series		10, 15, 25, 38, 50, 75, 100, 150, 225, 300, 450, 600, 900 kVA	1,200, 2,000 kVA	2,500 kVA
Inverter multiplexing		2 units multiplexed: 1,200, 1,800 kVA 6 units multiplexed (max.): 5,400 kVA	2 units multiplexed: 2,400, 4,000 kVA 8 units multiplexed (max.): 16,000 kVA	2 units multiplexed: 5,000 kVA 3 units multiplexed (max.): 7,500 kVA
Rated operation		100% continuous, 150% overload for 1 minute	100% continuous, 150% overload for 1 minute	100% continuous, 150% overload for 1 minute
Operating mode		4 quadrant	4 quadrant	4 quadrant
Host transmission		PROFIBUS-DP, D line, T link, SX bus	PROFIBUS-DP, D line, T link, SX bus	PROFIBUS-DP, D line, T link, SX bus
Control	Speed control range	1 : 1,000	1 : 1,000	1 : 1,000
	Field control range	1 : 4	1 : 4	1 : 4
	Accuracy	Speed ± 0.01%	Speed ± 0.01%	Speed ± 0.01%

several-hundred kW motors arranged consecutively, and a large-capacity common diode converter has a DC-link configuration for connecting the inverter of each stand. Since the regenerative capacity is less than the drive capacity, a small-capacity converter for regenerative substitution is provided, and energy savings is realized by implementing regeneration on the power supply-side during decreasing speed operation.

Both the FRENIC4000 Series and the FRENIC4400 Series are equipped with an observer control function as a standard feature that enables improved disturbance response and reduced shaft vibration. Moreover, even if the moment of inertia or other parameters of the controlled system are different, with an observer there is no need to tune an automatic speed controller, and tuning-less control that maintains a uniform speed control response is possible. Figure 3 shows the configuration of tuning-less control using an observer, and Fig. 4 shows the results when applied to the rolling mill speed control of a certain company's bar and rod mill recently. As can be seen in the two charts, the disturbance response when material is gripped is approximately the same (recovery time is 140 ms) even though the control time constants are different by about a factor of 6.

Fig.3 Tuning-less control configuration

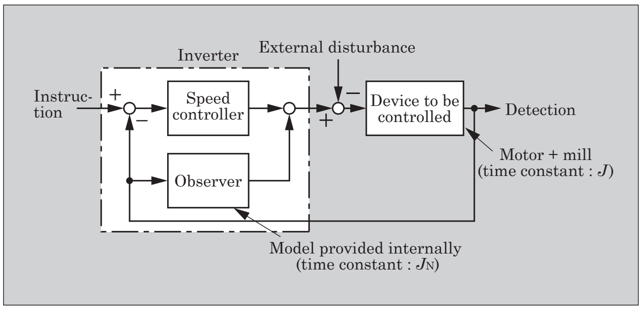
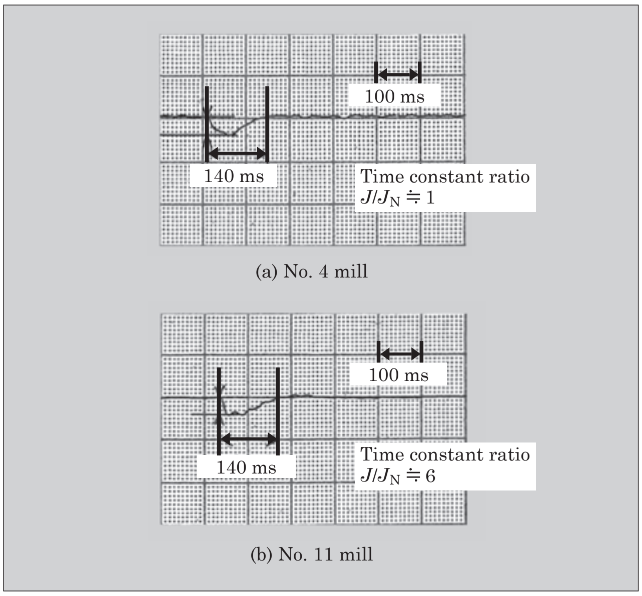


Fig.4 Results of application of tuning-less control to bar and rod mill



4.3 Drive device for large mill

The FRENIC4700 Series of inverters are AC 3.3 kV-class output, 3-level inverters that support vector control. With a system configuration in which PWM (Pulse Width Modulation) converters and inverters in provided a 1:1 ratio, linking the converter and inverters suppresses fluctuation of the DC intermediate voltage when switching from drive to regeneration. The stand-alone capacity of models in this series is 2,500 kVA, and large capacities of up to 7,500 kVA can be achieved by multiplexing.

For applications requiring capacities larger than above, the SINAMICS-SM150 10 MVA, 3.3 kV output IGCT 3-level inverter is used. This inverter is manufactured by Siemens Corp. of Germany and is sold in Japan by Fuji Electric.

4.4 Drive device for DC motors

Drive devices have most commonly been used with AC motors and inverters, but at present, they are also frequently used with DC motors. Fuji Electric has also commercialized the small capacity (DC 220 V 75 kW or less, DC 440 V 150 kW or less) LEONIC-M Compact that shares main components with the inverter. This product is considered to be a replacement for existing analog control thyristor converters (i.e., Fuji Electric's DSR series, LEONIC-U, and other company's thyristor converters), and supports various field buses, analog speed commands, and also high-speed feedback via a tacho generator.

For medium and large-capacity DC motor driving, the LEONIC-M700 is being developed and will use the same main control system as the LEONIC-M Compact.

The LEONIC-M Series is not just for DC motor driving and can also be used as a DC constant voltage power source.

5. Drive Devices for New Solutions

5.1 Development of a large capacity servo system

As a part of its drive business strategy, Fuji Electric has developed a large capacity servo system suitable for application to automotive equipment, construction equipment, and other manufacturing and test equipment. The servo system is capable of multi-axle control and is configured by adding a servo controller, which uses technology acquired with general-purpose servo systems and is dedicated for large capacity servo drives, to Fuji Electric's FRENIC4000VM5 inverter for plant drives. (See Fig. 5.) The FRENIC 4000VM5 capacity (stand alone: 900 kVA) can be used for each axle.

5.2 Development of drive system for construction machinery test equipment

Fuji Electric has developed a drive system for construction machinery test equipment. The test equipment for the construction machinery drive system is arranged in an inverted T-shape and is configured on the engine drive side and on the wheel side. The engine drive side is configured with a tandem motor and a reduction/step-up gear, the wheel side is configured with a motor and a step-up gear, and an axis torque detector is installed at each side. Figure 6 shows a single system diagram for the newly developed drive system test equipment.

The test equipment drive system for construction machinery evaluates the performance of the tested equipment under arbitrary conditions, and features of this system are described below.

(1) Motor
- (a) Complete dual axis connection of 840 kW 800/2,800 r/min × 4 units (including half-coupling of both axis ends)
- (b) High-strength axle materials and ball/roller bearings with oil bath used to support trial operation from zero speed to 2,800 r/min
- (c) Special rotating sensor allows use of both axis (axle diameter: 115 mm)
- (d) Grounding device for suppressing axis voltage, and capable of withstanding high-speed operation
- (e) Non-tilting, highly rigid, ordinary squirrel-cage structure

(2) Drive device
- (a) Highly accurate speed control and highly accurate torque control of FRENIC 4400VM5
- (b) Highly accurate axis torque detector (0.1%) based on axis torque control
- (c) Harmonic-free, redundant converter system
- (d) Various test conditions supported by regenerative power processing with PWM-converter and direct brake (DB) chopper

Fig.5 Large capacity servo system

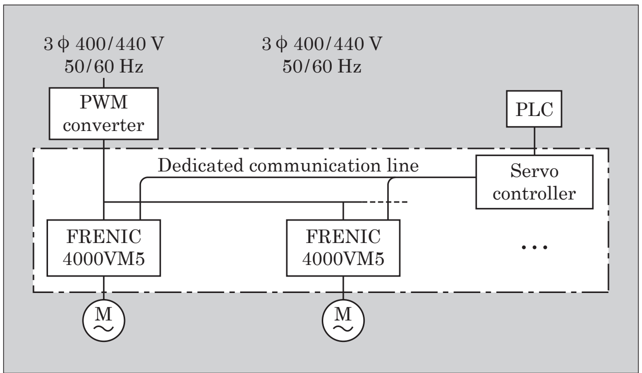
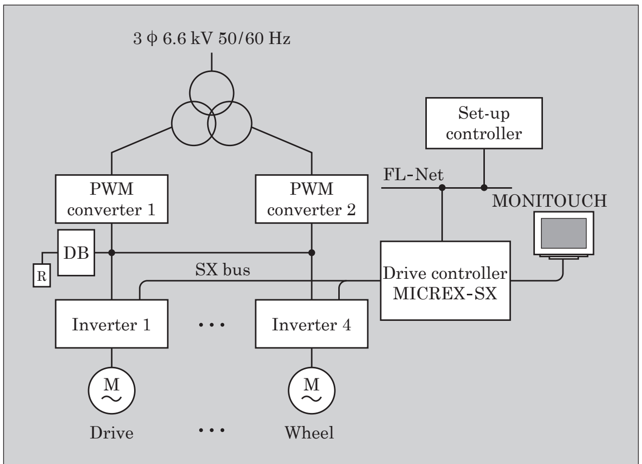


Fig.6 Single system diagram for drive system test equipment



5.3 Development of electric inertia system

In automotive chassis dynamometer and transmission test equipment, inertia mass corresponding to the tested object has been realized through recombination with a conventional flywheel (mechanical inertia), but with the recent application of inverter control, inertia is being modeled electrically (electric inertia). Electric inertia-type test equipment has many advantages, including the single-step implementation of inertia settings, a small equipment footprint, and inexpensive machinery cost. For this reason, the Society of Automotive Engineers of Japan published a JASO technical paper that tabulated the performance requirements for

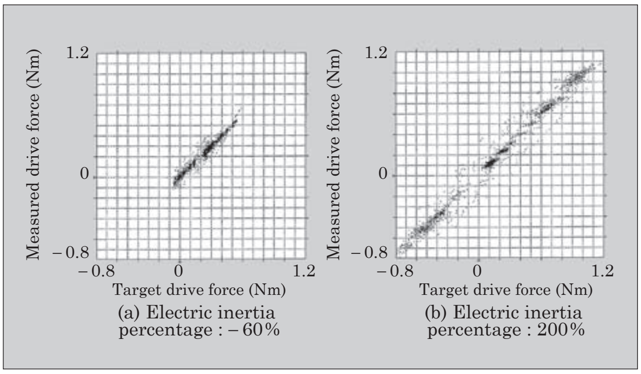
Table 3 Electric inertia-type chassis dynamometer requirements

Item	Specification	Comments
Electric inertia percentage	− 60 to + 200%	Electric inertia percentage = 100 × (equivalent inertia − mechanical fixed inertia)/ mechanical fixed inertia
Control response delay	Less than 0.1 s	90% response time

Table 4 Electric inertia-type chassis dynamometer evaluation items and criteria

Item	Range
Standard deviation	Within 5%
Interphase coefficient	0.98 or more
Regression line gradient	1 ± 0.02
Regression line intercept	± 20 N

Fig.7 Electric inertia verification results (10-15 mode operation) series



electric inertia-type chassis dynamometers to replace mechanical inertia-type chassis dynamometers. Thus, using the electric inertia functions of previously delivered transmission test equipment as its basis, Fuji Electric tackled the development of electric inertia in conformance with the requirements tabulated by the Society of Automotive Engineers of Japan.

Table 3 summarizes the requirements for electric inertia-type chassis dynamometers in accordance with the JASO technical paper. Moreover, the values of the target drive force and the measured drive force, as computed from the torque detection value, plotted at 50 ms intervals on an X-Y graph must satisfy the criteria listed in Table 4. Figure 7 shows the results of tests conducted with test equipment using Fuji Electric's inverters while performing the 10-15 mode operation prescribed in JIS D 1012 "Automobiles-Rate of Fuel Consumption Test Methods". The results were measured for electric inertia percentages of – 60% and 200%. In both cases, the criteria listed in Table 4 are satisfied.

6. Power-supply Unit to Contribute to Power Supply Quality Solution

To improve the quality of power against momentary voltage drops or power outages, low-voltage UPS and other various individual methods had been implemented in the past. In recent years, however, with the trend toward cogeneration and power diversification, the use of a single collective measure with high voltage circuit against momentary voltage drop has become common at manufacturing plants and the like.

Responding to these market needs, Fuji Electric has commercialized the UPS8000H Series of medium voltage, large capacity uninterruptible power supply systems that realizes high efficiency, high reliability and space savings and provides protection against short-duration momentary voltage drops and also against momentary voltage drops to long-duration power outages. This power supply system series has been successfully delivered to customers and is described below.

Fig.8 Overview of the 6.6 kV-2,000 kVA UPS (8,000H)

6.1 Overview of Fuji Electric's medium voltage and large capacity uninterruptible power supply system

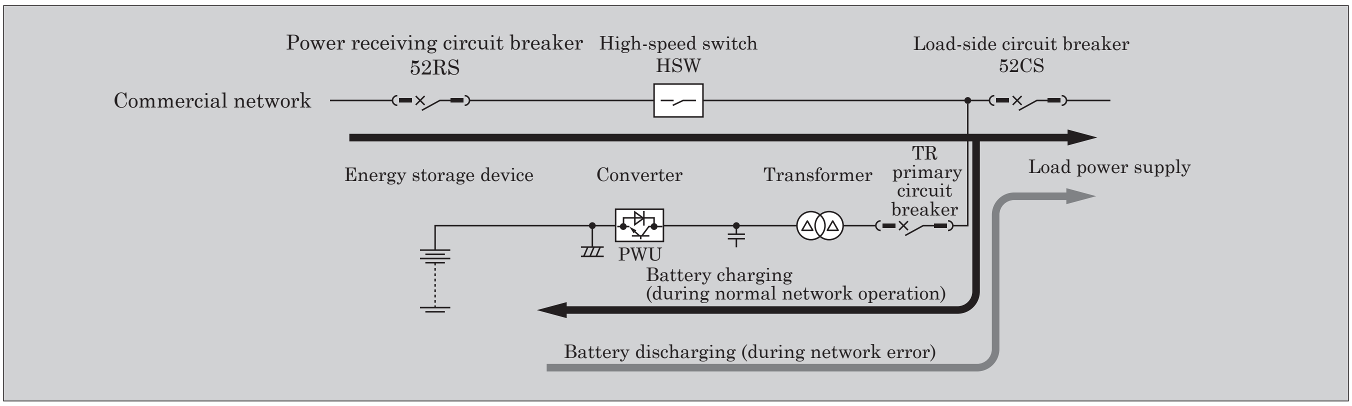
Figure 8 shows a photograph of the external appearance, Table 5 lists basic specifications, and Fig. 9 shows the configuration of this system.

The system, a medium voltage and large capacity uninterruptible power supply having a rated voltage of 6.6 kV and a rated capacity of 2,000 kVA, normally uses a commercial power supply, but when a momentary voltage drop occurs, high-speed switching operates to cutoff the load from the commercial network, and backup operation is implemented with an energy storage device.

Table 5 Specifications of the 8000H 2MVA UPS

Item	Specification
Rated capacity	2,000 kVA/1,600 kVA
Cooling method	Forced air cooling
Transfer time	Less than 2 ms
Input rated voltage	6,600 V/3,300 V
Frequency	50/60 Hz
Output voltage accuracy	± 3% (during power outage)
Rated load power factor	0.8 (during power outage)

Fig.9 System configuration of medium voltage and large capacity uninterruptible power supply



6.2 Features

(1) High-speed switch

A semiconductor switch enables uninterrupted (less than 2 ms) high-speed transfers, with performance that satisfies the JEC-2433 classⅡ requirements and also satisfies the power supply requirements (SEMI-F47) for semiconductor manufacturing equipment.

With a mechanical switch and adopting a method that uses Fuji Electric's proprietary resonant circuit for extinguishing arc current when open, and also adopting, in combination with a storage cell, the use of a high efficiency charging control system for a converter having almost no conductor heat loss, equipment efficiency is increased to at least 99.6% (during rated operation). Moreover, since the equipment is inherently power efficient, there is a significant reduction in the amount of power consumed by HVAC equipment to process the heat generated by power loss in the equipment.

(2) Uninterruptible during power outage

When there is a problem with the grid and a power outage or voltage drop occurs, a controller in the UPS system detects the voltage drop within 0.5 ms, the SWAC opens, and excessive voltage fluctuations can be reduced significantly when used in combination with the high-speed switch. Moreover, the load inrush current generated due to a momentary voltage drop is subjected to instantaneous inhibitory control, thereby achieving reliable control and a stable power supply.

(3) Parallel operation, high reliability

The stand-alone capacity is 2,000 kVA, but up to six units may be connected in parallel to increase the capacity according to the load. Also, the system can be built with redundancy to achieve extremely high reliability.

(4) Compatibility with a wide range of power outage compensation times

As energy storage devices, a short-duration charging, high-output, long-life capacitor is used for short-duration compensation on the order of 1 second, and a lead storage battery that supports high rates is used for long-duration compensation not only during momentary voltage drops but also during power outages lasting up to 5 minutes (max.). Moreover, compensation can also be used in the case of a 100% complete voltage outage, and may also be used reliably for repeated momentary voltage drops, automatic forced line charging by electric power companies, and the like.

The control system used with a medium voltage and large capacity uninterruptible power supply system may conceivably be applied to stabilization equipment for distributed power supplies and systems that use various energy storing elements.

In the future, Fuji Electric will develop products having the added functionality of the voltage compensation and reactive component power compensation, such as harmonic absorption, that was commercialized with the UPS8000D Series of low voltage uninterruptible power supplies.

7. Postscript

Representative models of Fuji Electric's industrial drive devices and power supplies have been presented. With our drive devices and power supplies, Fuji Electric intends to continue to provide solutions that benefit society.

Drive and Power Supply Technology for Solutions in the Transportation Sector

Ryoji Inoue †
Satoru Ozaki †
Masanori Fujita †

1. Introduction

Various efforts to reduce the emissions of greenhouse gases are underway worldwide to prevent global warming. The transportation sector accounts for approximately 20% of the total CO_2 emissions for Japan, and of that portion, 90% comes from automobiles. On the other hand, railways and ships are highly energy-efficient, environmentally friendly, large-scale, high-speed, safe and economical modes of transportation. The modal shift toward the use of low-environmental-impact railways and shipping for freight transport is also based upon environmental concerns. As keywords often mentioned in relation to the global environment, “railroads” and “ships” will play even more important roles in the future, and these modes of transportation will develop in a sustainable way.

In response to the strong market needs for energy savings and low environmental impact, Fuji Electric supplies power electronic products and services as drive and power supply technology for use in the rolling stock and ships that provide transportation solutions to customers, and in doing so, benefits the global environment. This paper describes Fuji Electric’s drive and power supply technology for rolling stock and ships.

2. Trends of Recent Needs in Transportation Solution Sectors, and Fuji Electric’s Approach

2.1 Rolling stock

Responding not only to requests for safety, reliability and economy, but also addressing the demands of the times such as requests for higher speed, greater energy savings, smaller size, lighter weight, easier maintenance, better ride quality and comfort, and harmony with the environment, Fuji Electric has achieved technical innovation in the power electronics used for rolling stock.

In developing products for the rolling stock sector, Fuji Electric is engaged in next-generation technical development for Shinkansen propulsion systems, electrical equipment for electric multiple units (EMU) and diesel multiple units (DMU) and door systems. In particular, Fuji Electric’s door systems, having a track record of high reliability and a high level of safety based on international standards, are highly regarded in Japan and overseas.

2.2 Marine

A modal shift is underway from land transportation, which has a high environmental load, to ocean transportation, and in the marine sector, the development of a next-generation coastal ship known as the “Super Eco Ship” having high energy efficiency and low environmental impact is being advanced and promoted as a project of the Japanese Ministry of Land, Infrastructure, Transport and Tourism.

Environmental friendliness has been advanced by equipping ships with electric propulsion systems, which compared to the conventional diesel propulsion systems, are superior with regards to environmental load, economy, operability, maintainability, vibration and noise.

Fuji Electric has delivered ship electric propulsion systems for use in the “Fuji” and “Shirase (1st generation)” ice breakers, and for use in submarines operated by the Japanese Ministry of Defense. In order be able to satisfy future market needs, Fuji Electric is utilizing the technology acquired from these power electronics products to advance technical development aimed at creating an integrated power system that combines an electric propulsion system and an auxiliary machine driving.

3. Rolling Stock

In the transportation sector, which accounts for 20% of the total CO_2 emissions in Japan, railroad transportation systems have large capacity, the highest energy efficiency, safety and stability. Fuji Electric provides transportation solutions that are comfortable, environmentally-friendly and human-friendly, which are based on an electric control system that uses the latest power electronics technologies.

† Fuji Electric Systems Co. , Ltd.

3.1 Shinkansen propulsion

As a symbol of Japan's advanced railway system, Shinkansen railcars have continuously incorporated state of art technology of the times. Fuji Electric has been delivering propulsion systems (including traction transformers, traction converters and traction motors) for successive generations of Shinkansen trains, from the first-generation series-0 Shinkansen train through the latest series-N700 Shinkansen train (shown in Fig. 1). As a representative example, this chapter describes the traction converter for the series-N700 for the Central Japan Railway Company (JR Tokai).

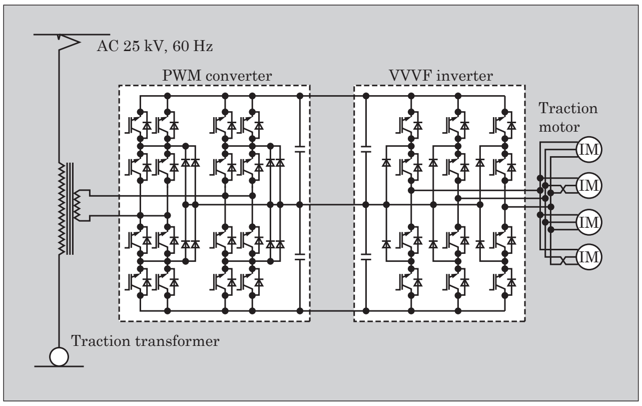
(1) Propulsion system for series-N700 Shinkansen train

(a) Traction converter

The traction converter, as can be seen in Fig. 2, is configured from a PWM (Pulse Width Modulation) converter and a VVVF (Variable Voltage Variable Frequency) inverter, and a single VVVF inverter collectively drives 4 traction motors connected in parallel. Two types of traction converters using different methods for cooling power devices have been delivered, a TCI3-model traction converter that uses a combination of boiling cooling (with a coolant) and forced cooling with a blower, and as shown in Fig. 3, a blower-less TCI100-model traction converter that uses a simple aluminum radiating fin and a natural ventilation method of self-cooling without the use of a blower or coolant.

Fig.1 Series-N700 Shinkansen train (photo courtesy of Central Japan Railway Co.)

Fig.2 Configuration of traction converter for series-N700 cars



The main circuit of a traction converter is configured from a converter unit, a filter capacitor unit and an inverter unit. Three-level converters and inverters are used. High efficiency and light weight are achieved by utilizing a low-loss snuberless circuit that includes a high-voltage, high-power, low-loss IGBT (Insulated Gate Bipolar Transistor) module (3,300 V, 1,200 A).

(b) Small size and light weight

The TCI3-model traction converter eliminates the snubber circuit and has an optimized structure to realize approximately 3% smaller volume and approximately 15% less mass than the previous TCI2-model while increasing the output by approximately 10%.

Moreover, the blower-less TCI100-model traction converter is 12% lighter than the TCI3-model.

(2) Control unit for traction converter

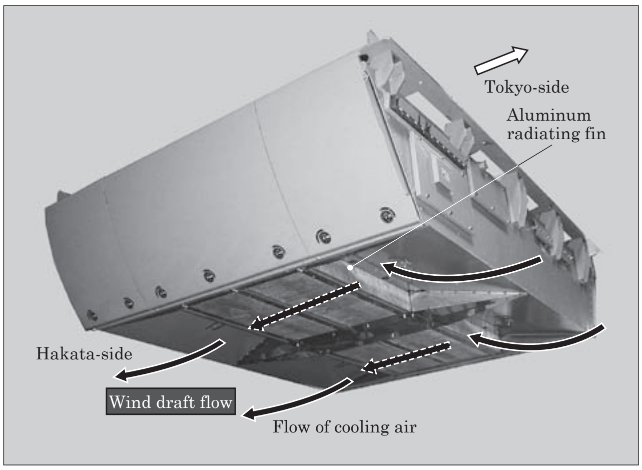
(a) Control unit for traction converter

The controller has a multi-processor configuration based on a 64-bit CPU core. The controller performs diverse control computations at high speed and with high accuracy, and for the purpose of advanced train control, also exchanges operating commands and transmits operating status monitor data. The latest microelectronics technology, data communications technology and the like are used to realize multi-functionality and high reliability while reducing the part count.

(b) Converter and inverter control

Depending on the operating condition, a 3-level converter may cause a voltage imbalance at the positive and negative sides of the filter capacitor with respect to the DC neutral point, and there is a risk that an excessive voltage may be applied to certain power devices. Focusing on the behavior of the potential voltage of the neutral point during periods in which power device switching is idle in a traction

Fig.3 Appearance of blower-less traction converter and cooling mechanism (wind draft flow)



converter, Fuji Electric developed neutral point potential control that does not depend on the polarity of power or current, and has applied this control to practical applications.

(c) Motor control

In the control of a rolling stock propulsion system, the acceleration and braking torque of the traction motor control must be highly responsive and highly accurate.

In the industrial sector, vector control is typically employed as a means to realize this type of control, but the vector control of a single inverter connected to a parallel configuration of 4 motors, as in the case of Shinkansen trains, is difficult to implement in principle. However, by using the phase angle of primary flux, which is considered to be a common state variable unrelated to the number of motors connected in parallel, as a basis for the vector control, Fuji Electric has used vector control in practical applications and has achieved good results.

3.2 Auxiliary power unit

An essential device for modern rolling stock, the auxiliary power unit, not only supplies stable power to the air-conditioning and lighting equipment necessary for maintaining comfortable conditions inside a railcar, but also functions to supply control power for devices such as the traction converter, and as a power supply for various IT devices such as the train control unit, display indicators inside a railcar, and the like.

The configuration of the auxiliary power unit will vary greatly according to the type of power source installed in the rolling stock.

(1) Auxiliary power unit for DC EMU

Feeding voltages in DC feeding systems are DC 1,500 V, DC 750 V or DC 600 V, and according to the output capacity and specifications required of the feeding voltage and equipment, an optimal voltage and current of IGBT are selected for configuring the circuitry or for application to the power circuit.

Usually, an IGBT having a withstand voltage capability that corresponds to the feeding voltage is used to configure a 2-level inverter, thereby simplifying the circuit, reducing the part count and increasing the reliability. On the other hand, for DC 1,500 V feeding, a product is commercialized in which the DC input sides of 2 inverter units that use 1,700 V-class IGBTs are connected in series, and the output of each inverter unit is combined with an output transformer, so as to increase the carrier frequency of the inverter and reduce noise. Figure 4 shows the configuration of the power unit for a DC electric railcar in a DC feeding system.

(2) Auxiliary power unit for AC EMU

In an AC electric railcar, power to large loads such as the cooling system is typically supplied directly from the traction transformer. The auxiliary power unit is limited to relatively small capacity loads such as indicator lamps, interior lights, control power, etc. These are critically important loads, and a high level of reliability is required of the auxiliary power unit.

As an example of an auxiliary power unit for an AC EMU, Fig. 5 shows the power unit configuration in the case where the single-phase AC power of the tertiary winding of the traction transformer is rectified using a diode rectifier and an IGBT chopper, and then is supplied as DC power to a DC load, and for an AC load, that DC power is converted by an IGBT inverter unit and an output transformer into single-phase AC power and then supplied to the AC load.

(3) Auxiliary power unit for diesel multiple unit (DMU)

A DMU is unable to receive power externally and so the installed diesel engine drives a generator that produces electric power. Fuji Electric has a history of numerous successes in manufacturing and delivering auxiliary power units for DMUs to various Japan Railway companies.

Figure 6 shows an example configuration of the main circuit of an auxiliary power unit for a DMU. The rotational speed of the diesel engine for driving the main shaft, which is the power source of the auxiliary power unit, will vary according to the operating conditions. Constant-frequency AC power obtained by a 3-phase AC power generator with the constant speed shaft by a constant speed unit is supplied directly to a load such as the air-conditioning system. The power control unit controls the excitation of the generator so

Fig.4 Example configuration of main circuit of auxiliary power unit for DC EMU

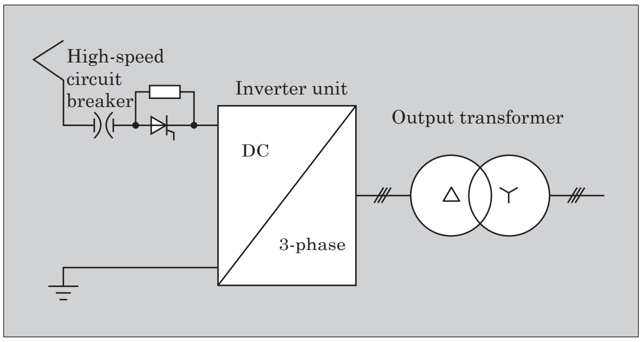


Fig.5 Example configuration of main circuit of auxiliary power unit for AC EMU

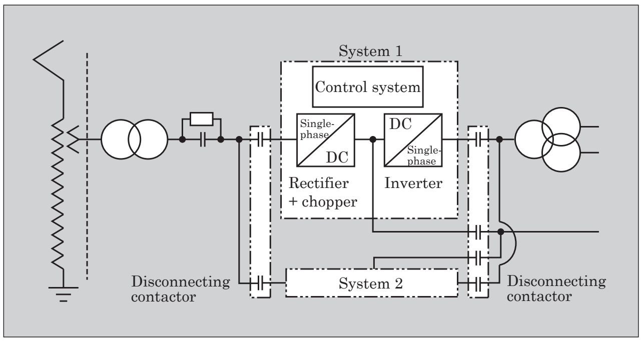
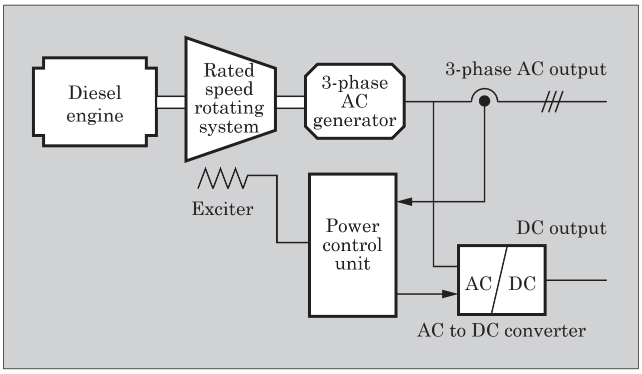


Fig.6 Example configuration of the main circuit of an auxiliary power unit for DMU



that the generator output voltage is maintained at a constant level, and AC to DC conversion is performed to supply DC power to the controller and the like.

(4) Features of Fuji Electric's auxiliary power unit

(a) High-performing control

The auxiliary power unit is required to provide a stable supply of electric power with little waveform distortion or voltage fluctuation even in the case of sudden changes in the feeding voltage, in the load current when a compressor or the like is turned-on or shut-off, or in an unbalanced 3-phase load such as a single-phase load. Responding to this requirement, Fuji Electric uses individual 3-phase waveform control, as shown in the control block diagram of Fig. 7, in the output voltage control. Individual 3-phase RMS value control is implemented, based on detected values of the 3-phase output voltages, so that the RMS voltage value of each phase becomes constant, and by combining with individual 3-phase instantaneous control, transient fluctuations in the output voltage due to load changes and so on can be suppressed. As a result, even in the case of sudden changes in the feeding voltage or load, stable voltage control performance is realized with a high-accuracy sinusoidal voltage having an output voltage deviation of ±1% or less and waveform distortion of approximately 1%.

(b) Higher reliability

Generally, a long rake of rolling stock is equipped with 2 to 3 auxiliary power supply units, while a short rake is often only provided with a single unit. Consequently, failure of the auxiliary power supply directly leads to a deterioration in service, and may result in a suspension of the rolling stock operation.

Fuji Electric has commercialized an auxiliary power unit equipped with dual-redundant inverters and controllers, and the unit itself has a standby redundancy system configuration for improved redundancy. When a failure occurs, the site of the failure and the site of suspended operation are switched over so that operation will continue. During the system design phase, sites for redundancy are selected based upon computed values of the failure rate and upon historical data to create the most appropriate system from rolling stock-use electric products for which small size and light weight are strongly requested. This method is being used in the general-type AC EMU series E721 trains operated by the East Japan Railway Company (JR East).

Fig.7 Control block diagram of Fuji Electric's high performance auxiliary power supply

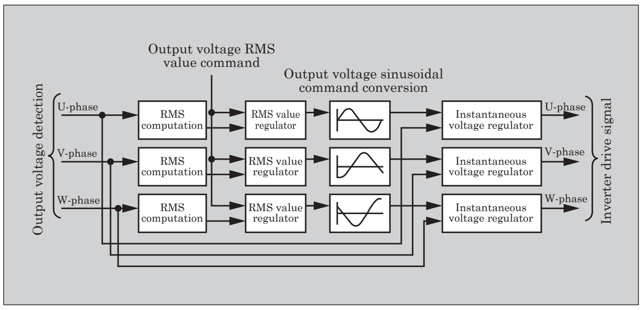
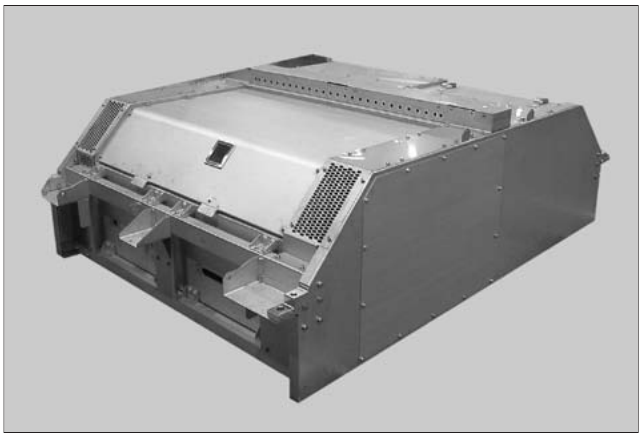


Fig.8 Roof-mount type auxiliary power system



(c) Enhanced functionality

IT is being incorporated into equipment for rolling stock to achieve advanced rolling stock operation and to improve the ease of maintenance. The auxiliary power unit usually employs a data transmission system with an RS485 for physical layer and a transmission procedure based on polling/selecting for the necessary data transmission function of IT equipment. To further advance the functionality of a data transmission system for rolling stock, Fuji Electric was early to commercialize a transmission system for rolling stock based on the highly-versatile MODBUS on TCP/IP protocol, and has shipped an auxiliary power unit for double-decker rolling stock to Australia. Figure 8 shows the appearance of the roof-mount model of the power supply unit.

3.3 Side door system for rolling stock

Among the types of equipment used in rolling stock, a side door system is the most familiar to passengers. During rush-hour, the failure of even a single door among the many installed on a commuter train may immediately cause a serious effect on the operation of the train. Therefore, among the many electric products used in rolling stock, train doors have particularly strong requirements for safety and reliability. Electrically-driven doors are able to achieve higher-speed control response and higher functionality than pneumatic doors, and are rapidly achieving popularity primarily in the Tokyo metropolitan area and in overseas markets.

(1) Features of electrically-driven doors and linear doors

(a) Advantages of electrically-driven doors

An electrically-driven door not only eliminates the air piping that had been required with a pneumatic door, but also has the advantages of being less susceptible to the effects of aging and of providing highly reproducible electric control, and consequently, results in lower initial costs and maintenance costs of the rolling stock system. Additionally, the flexibility of the controller has been leveraged and data transmission technology applied to simplify the pre-operation inspection work, increase the level of intelligence, and enhance the door self-diagnosis function.

(b) Power transmission mechanism

With conventional electrically-driven doors, a ball screw has been widely used as a mechanism for converting the torque of the rotating motor into linear operation of the door. This method, however, has the problems of requiring frequent lubrication of the sliding part, a decreased sensitivity to door obstruction (to be described later), and difficulty in ensuring the reproducibility of the preset detection sensitivity.

By employing a linear motor to directly drive a linear motion door, Fuji Electric has simplified the door driving mechanism and commercialized a linear door that uses servo technology to realize high-performing control.

(c) Locking/unlocking mechanism

In order to assure the door closed position and secure the safety, a locking mechanism with a lock pin is used. An unlocking mechanism is also provided for releasing the locked state when the door is about to open.

(d) Safety function

In recent years, accidents in which a passenger gets caught in a closing door of a building or train have occurred frequently, and door safety has become an important issue. Fuji Electric's linear door uses microprocessor-based electronic control to implement highly sensitive door obstruction sensing based on the door speed and other control information. Additionally, after sensing a door obstruction, the safety operation is implemented with detailed control based upon various different requirements according to the railway company.

(2) Example of linear door product

(a) One motor per door opening type

A biparting type or single-leaf type train door is driven by a single linear motor. This implementation is used in JR East's series E231, E233 and E531, and Seibu Railway's series 30000, and a total of approximately 14,000 of these doors were being used in commercial operations at the end of 2008.

One door leaf of a biparting type door is driven directly by the mover of a linear motor via a universal joint that isolates the motor from mechani-

Fig.9 Configuration of side door system

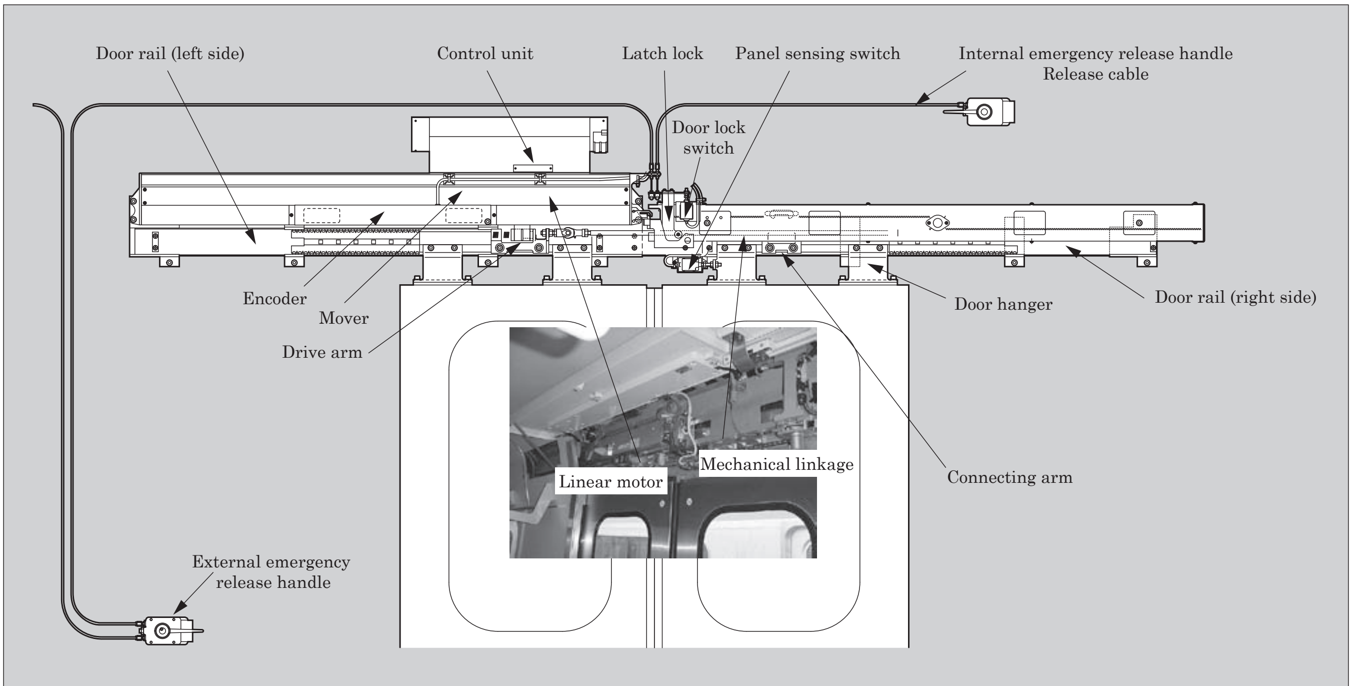


Fig.10 NYCT R160 train and door system

cal shocks from the door, and the other door leaf is driven in the opposite direction by a mover via a rack-and-pinion mechanism (mechanical linkage). When a door is about to open, an unlocking operation is performed using a self-unlocking mechanism of which drive force is supplied by the linear motor. Figure 9 shows the door system configuration.

The series E231 and subsequent models of rolling stock of the Tokaido Line use a standby redundancy system that features dual-redundant signal I/O interface circuits, control circuits and VVVF inverters. Even if a failure were to occur, operation is able to continue without any decrease in functionality.

(b) 2 motors per door opening type

In this implementation, each door leaf is driven by a linear motor. This implementation is used in the R160 subway cars operated by the New York City Transit (NYCT) Authority. By the end of 2008, 4,320 of these doors had been delivered and more than 2,000 were in operation. Figure 10 shows the external appearance of the NYCT R160 car and door system. To ensure stable operation despite voltage fluctuations in the DC37.5 V power supply, the supplied power is boosted to a constant voltage and stabilized by a chopper circuit, and then input to an inverter.

Also, an unlocking mechanism that uses a solenoid is applied to support customer specifications based on a safety concept that emphasizes functional independence.

4. Marine

In the domestic transportation sector, coastal shipping ranks second, after railways, as a highly energy efficient, environmentally friendly, large-scale, safe and economical mode of transportation. The volume of cargo transported via coastal shipping (in terms of ton-miles) accounts for approximately 40% of Japanese domestic cargo transport.

On the other hand, the shipping industry faces various challenges, such as the aging of seafaring workers, difficulty of securing young seafarers, a harsh work environment, delayed implementation of energy-saving measures, and so on. With the goals of conserving the global environment, increasing the efficiency of distribution and increasing the vitality of the marine transportation business, the Japanese Ministry of Land, Infrastructure, Transport and Tourism has, since 2005, been promoting coastal ships that use an electric propulsion system.

In addition, the Japanese "Law Concerning the Rational Use of Energy" (abbreviated as the Energy Saving Law), revised in 2008 and put into force on April 2009, obliges shipping service operators with a transport capacity exceeding 20,000 gross tons to report their status of compliance with criteria based upon this law. These criteria include the "Super Eco Ship" (electrical propulsion ship) and "inverter controlled electrical equipment" as examples of the "use of superior transportation machinery and tools."

According to Lloyd's statistics for overseas electrical propulsion ships in 2007, European ship builders have a considerable backlog of orders for global cruise ships, and similar backlogs exist for LNG carriers in Korea and for offshore supply vessels in China, suggesting a growing trend of applying electrical propulsion to ship types that effectively utilize the features of electrical propulsion systems, i.e., operational flexibility, increased maneuverability, high efficiency, flexibility of installation, and so on.

Fuji Electric has delivered various systems such as electric propulsion systems, shaft generator and booster systems, various types of hoists, and data acquisition and analysis equipment for use in the "Fuji" and "Shirase (1st generation)" ice breakers and for use in submarines operated by the Japanese Ministry of Defense, and also has delivered various component devices such as inverters for variable-speed driving, electric motors, high-voltage molded transformers, vacuum circuit breakers, electromagnetic contactors and programmable controllers.

4.1 Simulation of electrical propulsion ship

Recently, there is a high state of anticipation regarding the application of various types of electrical propulsion systems to the aforementioned coastal ships and to other types of ships. Effective simulation techniques when planning to design a ship with an electric propulsion system are described below.

Figures 11 to 13 show example simulations of an electric propulsion ship that comprehensively model the power generating equipment including the prime motor, generator, electrical propulsion system, onboard load, propeller and hull. Data, such as the ship stopping distance, time, power supply voltage, frequency fluctuation, and back power for braking of the propeller, at the time of a crash-astern maneuver can be

Fig.11 Example of electric propulsion ship simulation model

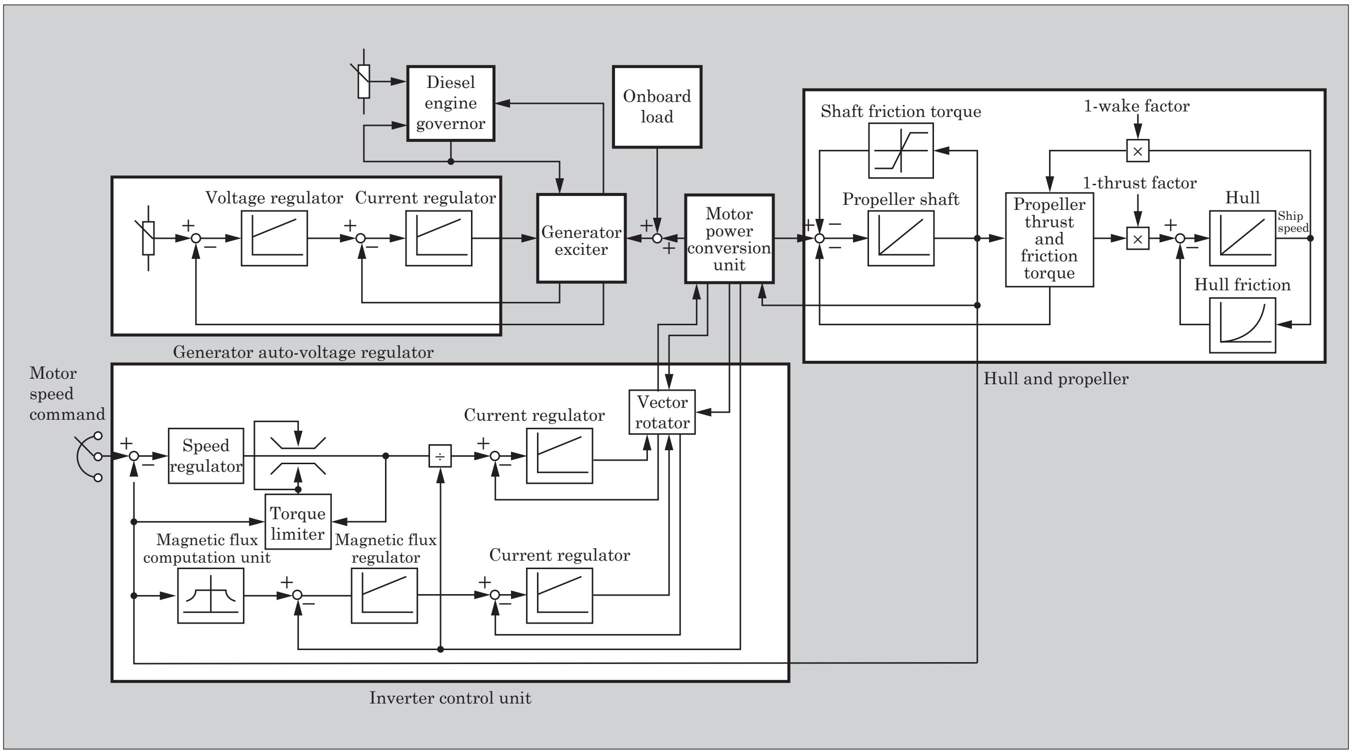


Fig.12 Simulation results (crash-astern) *1

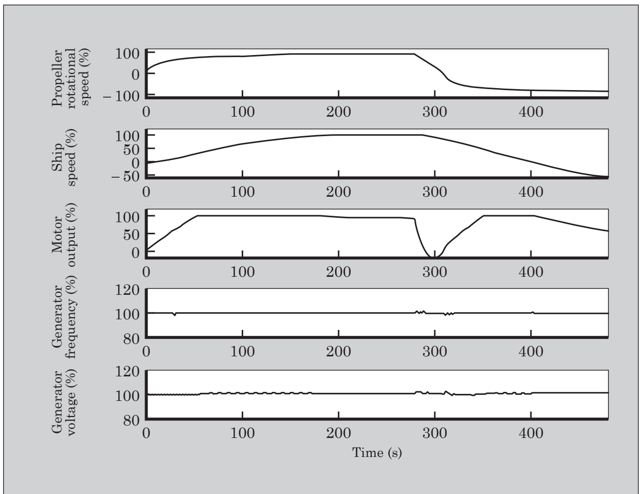
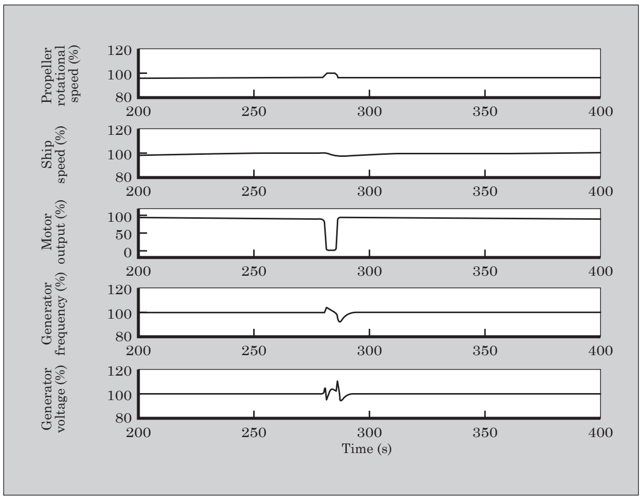


Fig.13 Simulation results (propeller racing) *1



obtained. An optimal system can be constructed for an entire ship in which the hull, propeller and electrical propulsion system including the power supply have matched characteristics. An electrical propulsion ship supplies both the propulsion power source, required for driving the propeller and propelling the hull, and the onboard power source required for using various devices and electric products onboard, from the same power generating equipment. For this reason, in addition to ensuring the required ship maneuverability, the maintenance of a certain level of power source quality (i.e., frequency, voltage, and the like) is also required. The performance of an electrical propulsion ship cannot be evaluated adequately from a simulation of only the hull and propeller system by themselves (i.e., a simulation of the changes in ship speed, propeller rotational speed and the like without consideration of the power source) or from a simulation of the electrical system by itself (i.e., a simulation of changes in the electric power, voltage and current with respect to simple load fluctuations). Simulations must be performed using a comprehensive model of the ship, from the power generating equipment to the propeller and hull.

Consequently, evaluating the relevance of analytical data obtained from a simulation becomes an issue. The relevance of simulations of the harmonics and

*1: See the "Glossary" on page 172.

short-circuit failure is already acknowledged. A simulation of the total system, including the hull, is evaluated for relevance based on comparisons with data acquired from an actual ship or with data acquired experimentally using a reduced-scale model. The popularization of electrical propulsion ships in the future will result in an accumulation of measured data from actual ships, and Fuji Electric plans to use this data to improve the accuracy of the simulation models.

4.2 Example of maritime solution

Figure 14 shows the "f(s) NISDAS" as an example of a data acquisition system for ships. The system is configured from an electric propulsion system, an onboard load, a PLC for acquiring GPS and other data, and a personal computer. The sampling time is 1ms at the fastest. The number of inputs is limited by the storage capacity and the sampling time. Figure 15 shows examples of the acquired data. The ship operation, from the stopped state to the accelerating state, can be verified. The capability to observe the energy flow is said to be important for realizing energy savings, and detailed data acquisition facilitates the planning of energy saving measures.

In the future, Fuji Electric intends to propose additional solutions based on such needs as "smoke and soot countermeasures for engines and boilers", "motorization of the hydraulic system to improve maintainability" and so on, and to apply new technologies and products, such as electric dust collecting technology, IH (induction heating) boilers and small-size large-performance inverters, to ships. While receiving guidance from ship owners, ship builders and manufacturers of marine equipment, Fuji Electric plans to continue to commercialize new products in the future.

Fig.14 Example of data acquisition system for ships

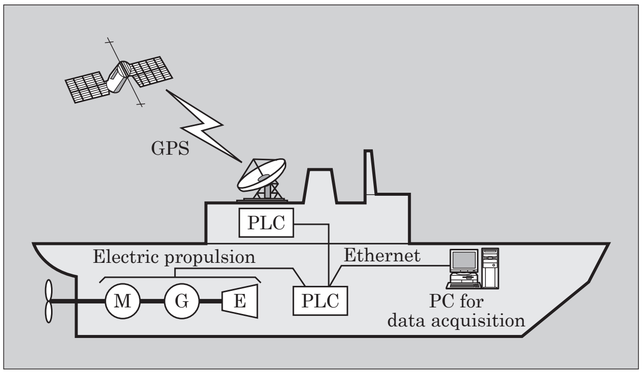
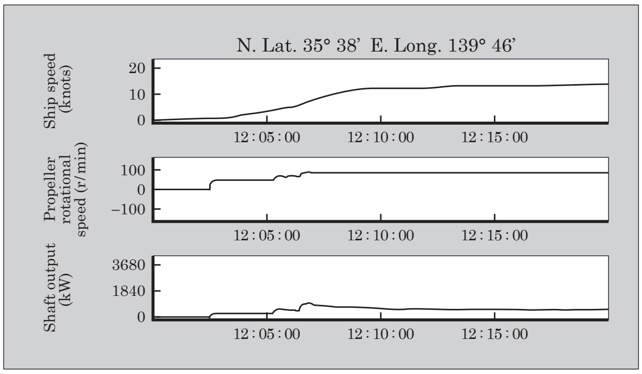


Fig.15 Examples of acquired data



5. Postscript

Power electronics technology for rolling stock and ships has been presented as a transportation solution. In these market sectors, requests for smaller size and lighter weight, higher performance, higher functionality, reduced maintenance, greater comfort and environmental friendliness are expected to continue to be driven by advances in power electronics technology and microelectronics technology. Fuji Electric is actively advancing research and development that anticipates market needs for energy savings and environmental friendliness, and intends to continue to provide products that benefit society.

Power Supply Technology for Energy and Environmental Solutions

Keiji Andou †
Masataka Matsubara †
Kunihiko Karube †

1. Introduction

The Kyoto Protocol, adopted in 1997 and enacted in 2005, aims to achieve a 6% reduction in greenhouse gas emissions (compared to 1990 levels) by 2012.

The emission of greenhouse gas that accompanies fossil-fuel energy consumption must be reduced significantly, and the amount of emissions worldwide must be reduced to the same level as is absorbed by nature. Thus, there is a global trend toward recognition of the importance of a sustainable lifestyle, i.e., toward a low carbon society.

As our information-intensive society has evolved, there has been an explosive increase in the amount of information that is processed. The Internet can be considered a representative example of such, and more information has been stored in the three years since 2003 than in the previous 300,000 year history of mankind. The computing resources needed to processes such vast quantities of information have lead to a rapid increase in electric power consumption.

With the enactment of the Sarbanes-Oxley Act (SOX Act) in the US and amendments to the Commercial Law in Japan, and with advances in internal control systems (prescribed partly by the Japanese version of the SOX Act, i.e., the “Financial Instruments and Exchange Law”) for companies, and information security promotion, there has been an increase in the number of large companies that outsource to IDCs (Internet Data Centers). The size of the IDC market is estimated to reach 3.3 trillion yen in 2012 and to grow at an annual rate of 6%.

In the US, in the five years from 2006 to 2011, the total power consumption by IDCs is expected to double, and may require the new construction of 10 nuclear power plants. Also in Japan, by 2025, it is estimated that there will be approximately 200 times as much information circulating on the Internet as now and that the power consumption by IDCs will grow to about 2.5 times as large as now. The total power consumed by IT equipment in Japan accounted for about 5% of the total amount of Japanese power consumption in 2006, but is predicted to account for approximately 20% of the total by 2025.

To help prevent global warming, it is important that energy conservation measures be implemented in the high-growth IDC sector, and IT equipment and facility equipment are requested to provide greater energy savings and higher efficiency.

From the perspectives of energy and the environment, this paper introduces Fuji Electric’s efforts, mainly in the IDC sector, for realizing energy savings, and also describes our efforts involving low-carbon energy using natural forms of energy such as solar power and efforts to realize energy savings in the industrial sector.

2. Fuji Electric’s Efforts to Realize Energy Savings at IDCs

Of the total power consumption at IDCs, 30% is attributable to IT devices, 25% to power supply equipment, and the remaining 45% to air conditioning equipment. To advance energy savings in the IDC sector, efforts must be made to reduce the energy consumption of each device and type of equipment.

As a measure of the efficiency of power usage at an IDC, the PUE (Power Usage Effectiveness) value is used. (Refer to the Glossary on page 172.) In a typical IDC, the PUE value is approximately 2.5, but aiming for higher efficiency, a PUE value of less than 2 is desired.

In the IDC sector, Fuji Electric’s approach to energy savings for air conditioning-related equipment which consumes a large amount of power is to propose not only an optimal design of the air conditioning system, but also to propose that the motor in such a system be a super high-efficiency permanent magnet synchronous motor (PM motor) so that the efficiency with an inverter and the PM motor reaches 94% and energy saving is advanced.

Moreover, to realize energy savings with power supply equipment, it is only natural that “Top Runner” super high-efficiency devices be used to increase the equipment efficiency, but Fuji Electric also seeks to increase the efficiency of the UPS itself, which is the

† Fuji Electric Systems Co. , Ltd.

source of power to the IT devices, so as approach the "Top Runner" super high-efficiency level and realize energy savings in the power supply equipment itself.

Additionally, Fuji Electric is working to realize energy saving solutions in the air conditioning equipment, power supply equipment and IT equipment in an IDC system by increasing the efficiency and reducing the consumption of power by the power circuitry inside servo equipment and other IT devices operated at an IDC.

This chapter describes Fuji Electric's approach, through leveraging its power electronics technology, to realize energy savings in the power supply and IT equipment sectors.

2.1 Fuji Electric's efforts in the IDC power supply sector

The conventional type of uninterruptible power system (UPS) used at an IDC has an efficiency of approximately 91%, which is much lower than that of a transformer or the like. Thus, Fuji Electric developed the UPS7000D Series, the UPS8000D Series and the UPS8100D Series of high efficiency UPSs that approach the efficiency of a transformer and are mainly intended for use at an IDC.

(1) UPS7000D Series features

The elimination of the insulated transformer in this series results in higher efficiency than in a conventional UPS. The 500 kVA model of this series achieves a high efficiency of 95% and 45% lower loss than the conventional type.

The footprint of the 400 V model, the device capacity used most commonly at an IDC, is approximately 70% that of a conventional model, and thereby enables a more efficient use of space. Supporting the parallel redundancy systems and the recently popular standby redundancy systems that are used at IDCs, separate input and separate battery systems are employed.

On the other hand, since the insulated transformer has been eliminated, the front and rear of the UPS are not insulated and earth leakage must be considered. Moreover, in the case where the bypass input and AC input are different, the operation will switch between different ground systems, and this switching will be implemented via the UPS battery power source.

(2) UPS8000D Series/UPS8100D Series features

The loss is large in a conventional UPS since the AC input is first converted to a DC voltage, and then that DC voltage is reconverted to an AC voltage and output. Moreover, even if the insulated transformer is eliminated, the lost efficiency of the portion involved in the conversion cannot be ignored.

In order to avoid the decrease in efficiency resulting from the conversion of the power supply voltage, Fuji Electric employs a method wherein a input power source is controlled directly so as to supply power according to the needs of the load device, thereby realizing a high efficiency of 98% (500 kVA model, ECO mode operation) and loss that is reduced by 78% compared to a conventional UPS.

In normal operation, AVR (automatic voltage regulation) compensation and active filter compensation are implemented so that a stable supply of power is provided to the load (Fig. 1). If a power outage or momentary voltage drop occurs in the commercial power supply, the power feed is switched to battery power so that a stable supply of power can be provided without interruption.

As shown in Fig. 2, the transient voltage characteristics of the UPS8000D Series at the time of switching satisfy the class 1 requirements, which are the strictest requirements specified by JEC-2433, and characteristics equivalent to those of a normal inverter feeding system are maintained.

The relevant series are the UPS8000D Series of 100 kVA or larger capacity UPSs, and the AVR function-constrained UPS8100D Series of 75 kVA or smaller capacity UPSs.

The power feed is usually from a commercial power source, and therefore at the time of a UPS failure or the like, the standard operation was to switch the power feed to the same commercial power source. This did not pose a problem with a parallel redundancy sys-

Fig.1 Operating principle of the UPS8000D Series

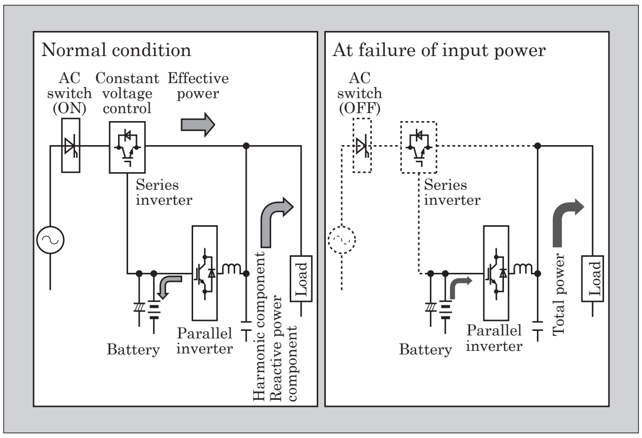


Fig.2 Switching characteristics of the UPS8000D Series

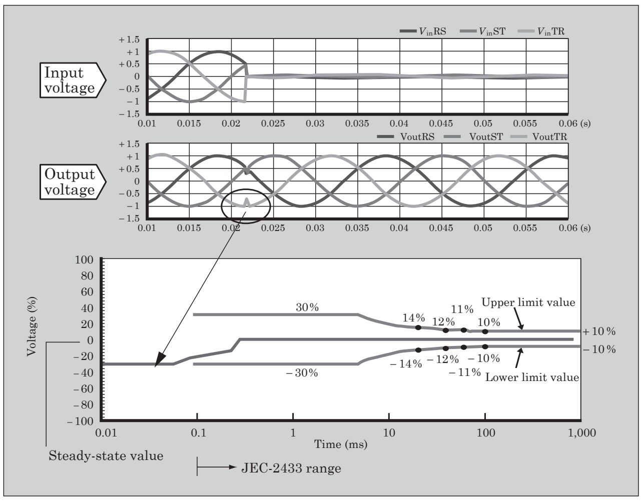
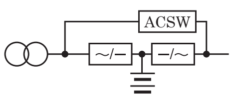
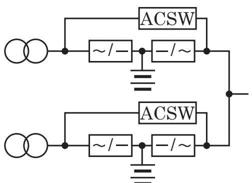
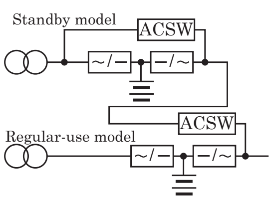


Table 1 Functional comparison of each UPS Series

(See Note 1)	UPS6000D Series (previous model)	UPS7000D Series	UPS8000D Series
Efficiency	91%	95%	98% (during Eco mode)
Setting area (see Note 2)	100	70	60 (see note 2)
No. of phases and wires	3-phase, 3-wire	3-phase, 3-wire	3-phase, 3-wire
Output voltage	415 V	415 V	415 V
Voltage tolerance (steady state)	± 1.0% or less	± 1.0% or less	During AVR mode: ± 2% or less During ECO mode: According to set value (± 1 to ± 5%)
Output frequency	50 Hz ± 1% During battery-powered operation: ± 0.01%	50 Hz ± 1% or ± 2% During battery-powered operation: ± 0.01%	Same frequency as input During battery-powered operation: ± 0.01%
Load power factor	0.7 (delay) to 1.0 Rated 0.8 or 0.9 (delay)	0.7 (delay) to 1.0 Rated 0.9 (delay)	0.7 (delay) to 1.0 Rated 1.0
Transient voltage regulation (see Note 4)	± 5% or less	± 5% or less	± 5% or less
Voltage waveform distortion	2.5% (RMS value of total harmonics at 100% linear load) 5% or less (RMS value of total harmonics at 100% rectifier load)	2.5% (RMS value of total harmonics at 100% linear load) 5% or less (RMS value of total harmonics at 100% rectifier load)	5% or less
Overload capability	125%: 10 min 150%: 1 min	125%: 10 min 150%: 1 min 200%: 2 s	125%: 10 min 200%: 1 min 800%: 1 cycle (at failure of input power) 150%: 10 s
DC circuit rated voltage	360 V	528 V	384 V
Switching time at failure of input power	JEC-2433 class 1 compliant	JEC-2433 class 1 compliant	JEC-2433 class 1 compliant

Note 1: 500 kVA, 415 V, 50 Hz models are compared
Note 2: In the case where the 6000 Series is 100
Note 3: Comparison includes protection device. When standby redundancy is supported, it will be same as 7000 Series without protection device.
Note 4: In the case where the load changes from 0 to 100%

Table 2 Comparison of system compatibility of each USP series

	Item (conceptual diagram) (See Note 1)	UPS6000D Series (previous model)	UPS7000D Series	UPS8000D Series
Single		○	○	○
Parallel redundant		○	○	○
Standby redundant		○	○	○ (See Note 2)

Note 1: 500 kVA, 415 V, 50 Hz models are compared
Note 2: To be compatible as of FY2009

tem, but was incompatible with a standby redundancy system or a system in which the input and the bypass power supply were different. In 2009, the expansion of this function to ensure compatibility with standby redundancy systems, which are becoming the mainstream systems in the IDC sector, is expected to lead to a broader range of applications.

Table 1 compares the functions of the previous UPS6000D Series with the new UPS7000D and UPS8000D Series introduced above, and Table 2 shows that the system compatibility is the same as that of the previous series.

2.2 Fuji Electric's efforts in the IT equipment sector

In computers, servers and other hardware, commercial power of AC100 V or AC200 V is first converted to DC power and then supplied to the CPU, memory and the like.

As is shown in Fig. 3, when the operating voltage of the CPU, memory and the like was 3.3 V or 5 V, a centralized power system was employed and the power supply and the device mother board were connected by wiring.

Recently, operating voltages have dropped to within the 1-to-2 V range, and wiring inductance between

Fig.3 Conventional centralized power system

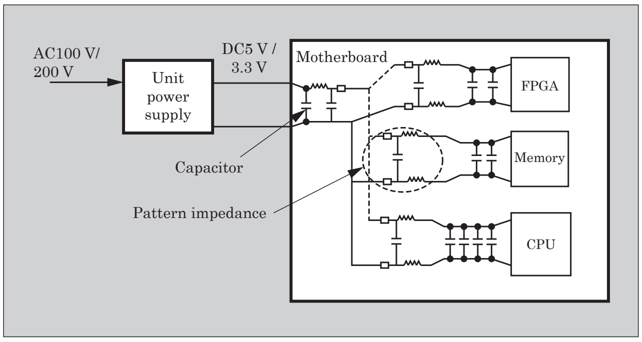
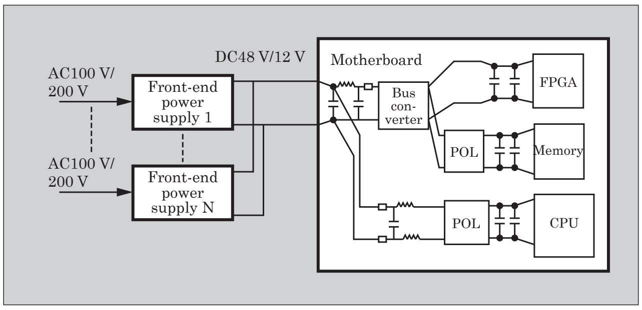


Fig.4 Example of distributed power system



the power supply and mother board and pattern inductance in the motherboard adversely affect the operation of the load. To inhibit such adverse affects, by providing, as shown in Fig. 4, a front-end power supply that converts the AC input to 12 V or 48 V DC and also positioning, in a later stage, a DC/DC converter as close as possible to the load, a distributed power system that reduces the abovementioned inductance effect can be realized.

Compared to a centralized power system, a distributed power system uses more converters arranged in series, and therefore has poorer conversion efficiency, which is disadvantageous for energy saving. Our customers, however, request power supply efficiency equal to or greater than that of a centralized power system, and therefore, as a benchmark, the capability to satisfy efficiency regulations such as Energy Star (Refer to the Glossary on page 172), CSCI (Climate Savers Computing Initiative) (Refer to the Glossary on page 172) and the like is necessary.

In order to satisfy these regulations, Fuji Electric is engaged in product development by applying leading-edge technology to the conversion circuit, switching element, wiring structure and the like. Examples of a front-end power supply and a bus converter are described below.

(1) Front-end power supply

Figure 5 shows a 12 V and 2 kW output front-end power supply product.

This power supply satisfies the requested 92% efficiency at a load factor of 50%, which is the strictest efficiency regulation of Energy Star and CSCI. The external dimensions of this power supply are 100 (W) × 375 (D) × 41 (H) (mm).

Fig.5 FH2000U1

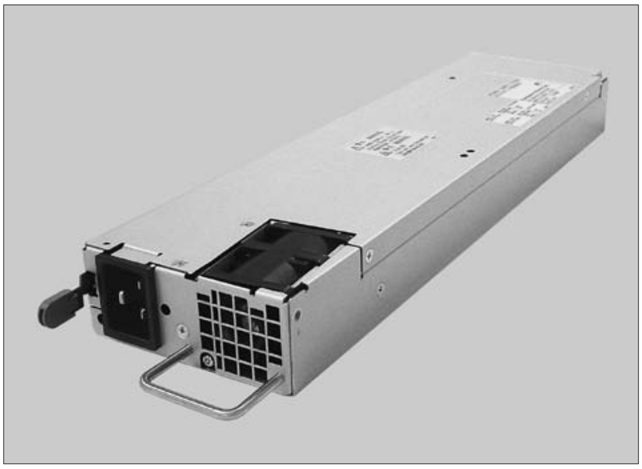
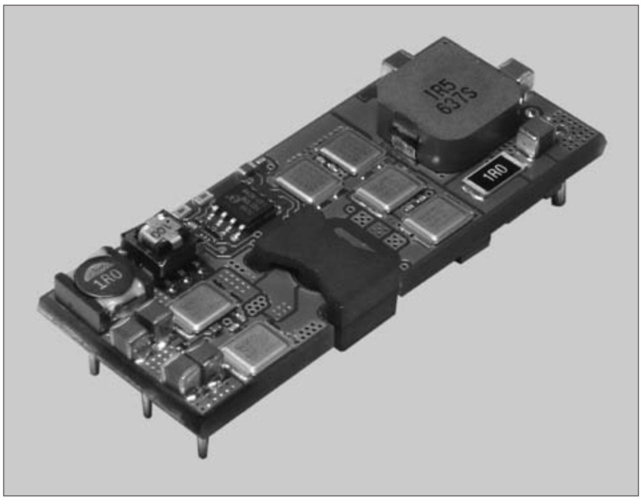


Fig.6 200W bus converter



(2) Bus converter

Figure 6 shows a DC48 V input, 12 V and 200 W output bus converter.

This high-efficiency and high-density power supply has the industry-standard 1/8 brick size (22.8 (W) × 57.8 (D) × 8.8 (H) (mm)), an efficiency of 92.5%, and output power per unit volume of 16 W/cc.

Fuji Electric is presently working to digitize the control circuit. Development is being advanced not only to improve the control performance, but also to reduce the man-hours required for delivery inspection, and to enable hardware to be deployed horizontally across many different models. Moreover, in cooperation with the Device Technology Dept. of the Fuji Electric Group, we also plan to focus on the application of a new device [silicon carbide (SiC) MOSFET] to power supplies.

3. Fuji Electric's Efforts to Realize Energy Savings in the Industrial Sector

A composite power supply for use in the elevator industry is an example of Fuji Electric's efforts to realize energy savings in the industrial sector. In the elevator industry, the system configuration of a product and the required devices and functions differ for each customer. Product proposals must be presented as a product plan that incorporates the needs of the customer and maximizes the value provided to the customer.

There is a high degree of awareness of safety in the elevator industry, and approximately 70% of new construction is for the installation of automatic landing devices that operate during power outages.

In the conventional method, separate batteries were installed in the inverter unit, control unit and brake control to configure individual backup systems. Consequently, many power supply units existed, the circuitry was complex and maintenance was difficult to implement. Moreover, the regenerated energy created when the elevator slowed or stopped was dissipated as heat by resistors.

Fuji Electric comprehensively reassessed and consolidated the design of emergency power supplies for elevator-use. A new simplified and high-efficiency power supply system, shown in Fig. 7 and Table 3, that meets customer needs has been built and is being offered by Fuji Electric. Adopting a backup method in which the backup system abuts the AC power supply, the new system provides a backup power supply for each control unit.

In this method, the power supply unit is shared so as to simplify the circuitry and to configure an optimal evacuation system that is linked to the control units. Fuji Electric is also working to realize energy savings such as by absorbing the regenerative energy created when an elevator ascends or descends.

This system is compatible with conventional elevator equipment design and uses high-density mounting technology so that it can be installed in the control panel of an elevator building.

Fig.7 Example of emergency-use power supply for elevator

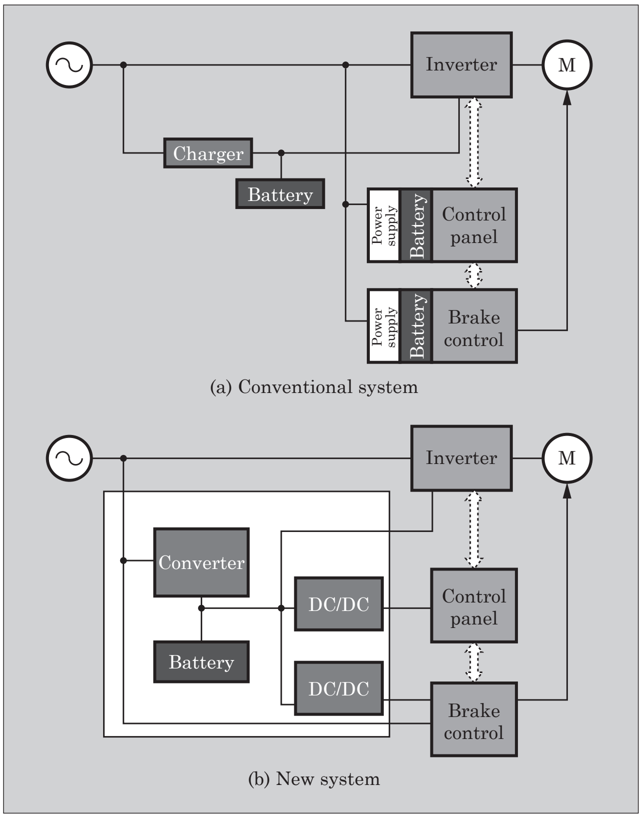


Table 3 Comparison of elevator emergency power supplies

Item	Conventional system	Fuji Electric's proposed new system
Battery power supply	Must be provided at each unit (elevator main unit, control unit, brake control unit)	Centralized at one location in emergency-use power supply unit
Regenerative energy at time of power outage	Heat dissipated by resistors and the like	Used for charging the battery

4. Fuji Electric's Efforts in the Natural Energy Sector

Power conditioners that use natural energy such as photovoltaic power and wind power are representative products of the new energy sector.

In Japan, as can be seen in Fig. 8, photovoltaic power generation is commonly used in homes and the home-use market is expected to increase significantly in the future.

Power companies are announcing plans one-after-another for large-scale photovoltaic power generation, "mega solar" plants. In September 2008, The Federation of Electric Power Companies of Japan announced plans by 10 power companies to build "mega solar" power generation plants with a total capacity of approximately 140,000 kW at about 30 sites by 2020.

In this manner, efforts to address global warming and to reduce CO_2 emissions are spreading from small-scale home-use photovoltaic power generation equipment to large-scale "mega solar" power genera-

Fig.8 Domestic Japanese market for photovoltaic power generation by usage

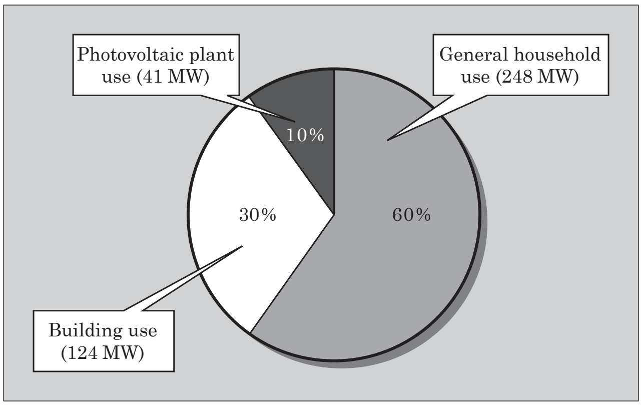
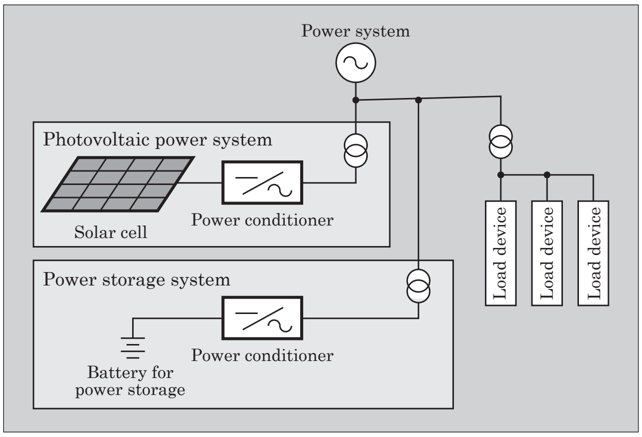


Fig.9 Example configuration of photovoltaic system



tion plants.

As shown in Fig. 9, in a photovoltaic power generation system, a power conditioner that converts the DC power generated by a solar cell into AC power is a key device that enables the DC power generated by a solar cell to be fed into the power system.

A power conditioner not only has an inverter function to convert the DC power generated by a photovoltaic cell into AC power, but also has a function for adjusting the load impedance seen from the photovoltaic cell and a maximum power tracking control function for extracting the maximum power. Moreover, so as not to adversely affect the AC power of the system, a power conditioner is also provided with a system protection function and an independent operation prevention function, both of which enable the power conditioner to be shut down safely in the case of system power outage.

Fuji Electric's power conditioner product lineup ranges from the medium-capacity to large-capacity devices listed in Table 4. These power conditioner products form the nucleus of a photovoltaic power generation system together with the "FWAVE", a film-type amorphous photovoltaic cell, and Fuji Electric plans to expand sales of these product both in Japan and internationally through direct marketing and OEM sales.

Particularly in the case of a "mega solar" system, unlike photovoltaic power generation equipment for home-use and the like, the power system will be affected significantly. When using natural energy in which the generated power fluctuates dramatically, power smoothing technology linked to a power storage system is absolutely essential. Even with a large power storage system such as a NAS battery, a power conditioner for converting AC power and DC power is a critical device.

Fuji Electric will continue to leverage its power electronics technology to develop its line of power conditioner products, and to leverage its power system linkage technology, to continue to propose new solar power systems.

Table 4 Fuji Electric's power conditioner product line up

	Specification							Comments
Output apparent power (kW)	50	100	200	300	400	500	600	
Rated output voltage	AC 380 V/400 V/415 V							
Rated frequency	50/60 Hz							
No. of phases and wires	3-phase 3-wire, or 3-phase 4-wire system							
Insulation method	Commercial frequency insulated transformer							
Output load power factor	0.95 or greater							At rated operation
Output current harmonic distortion	5% or less (total), 3% or less (each phase)							At rated operation
Rated input voltage	DC500 V							
Input voltage range	DC0 to 700 V							
Input voltage (operating range)	DC250 to 600 V							
Input voltage (MPPT range)	DC250 to 600 V							
Installation	Indoor, free-standing							
Cable feed	Top-fed							Bottom-fed is available as an option
Cooling method	Forced cooling							
Panel width (mm)	500		1,000	1,500	2,000	2,500	3,000	Not including transformer
Panel height (mm)	1,950							
Panel depth (mm)	800							
Mass (kg)	400		800	1,200	1,600	2,000	2,400	Not including transformer
Ambient temperature	Indoor: − 5 to + 40 °C							
Relative humidity	30 to 90%							No freezing or condensation
Elevation	1,000 m or less							

5. Postscript

This paper has discussed UPSs, power supplies for IT devices, and energy saving measures using power conditioners as examples of Fuji Electric's efforts to realize energy savings in the energy and environmental sectors using Fuji Electric's expertise in power electronics technology.

In the future, Fuji Electric intends to continue to work to realize energy savings in each of the air-conditioning systems, power supplies and IT devices used at IDCs, and to strive to establish system-wide energy saving solutions for the entire IDC sector.

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(1) Solarbuzz. http://www.solarbuzz.com/

Latest Technology for General-purpose Inverters and Servo Systems

Toshiaki Sakai [†]
Yoshihisa Okuda [†]
Hiroshi Tetsutani [†]

1. Introduction

In the industrial sector, the range of applications for general-purpose inverters and servo systems is expanding, and equipment and machinery trends are toward miniaturization, energy savings, labor savings, higher speed and higher accuracy. In recent years, in response to efforts to design safety systems that use risk assessment, not only is good performance required, but a simple configuration and ease-of-use that will lead to lower total costs for system development and maintenance are also requested.

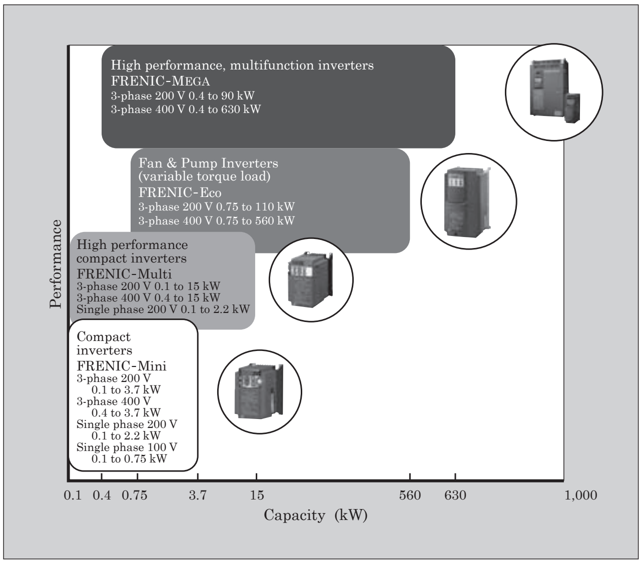
Responding to these requests and trends, the latest technologies have been incorporated into these general-purpose inverters and servo drive systems, and application examples thereof, are introduced herein.

2. Fuji Electric's Product Lineup

2.1 General-purpose inverters

Figure 1 shows Fuji Electric's product lineup of general-purpose inverters.

Fig.1 Fuji Electric's product lineup of general-purpose inverters



Fuji Electric provides four series of general-purpose inverters: FRENIC-Mini, FRENIC-Multi, FRENIC-Eco and FRENIC-MEGA.

The product lineup is described briefly below.

(1) FRENIC-Mini Series

Compact-type inverter series for the simple variable speed control of small capacity motors of 3.7 kW or less

(2) FRENIC-Multi Series

High-performance, compact-type inverter series for the general variable speed control of small and medium capacity motors of 15 kW or less

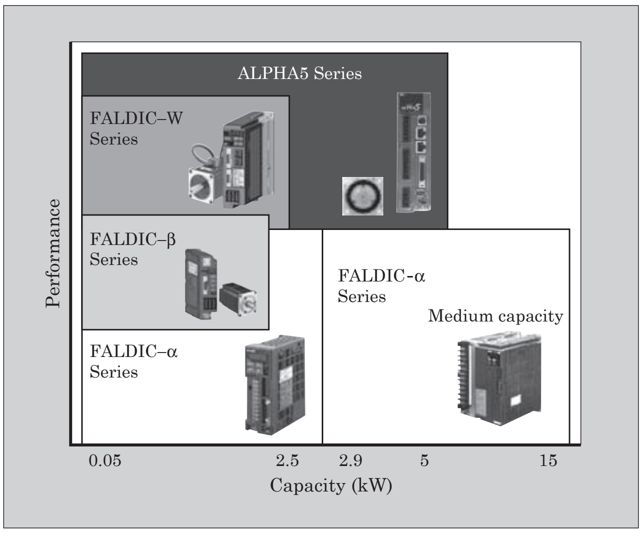
(3) FRENIC-Eco Series

Application specific inverter series with enhanced functions for air-conditioning applications that use fans, pumps and HVAC (Heating Ventilation and Air Conditioning) equipment for applications that target control of variable torque load of 560 kW or less

(4) FRENIC-MEGA Series

General-purpose inverter series provided with highest-class of vector control, and high performance and multi-functionality that support various applications of 630 kW or less

Fig.2 Fuji Electric's product lineup of servo systems



† Fuji Electric Systems Co. , Ltd.

2.2 Servo systems

Figure 2 shows Fuji Electric's product lineup of servo systems.

The FALDIC-α Series, FALDIC-β Series, FALDIC-W Series, and the ALPHA5 Series which is presently the main model, are available.

With capacities of 0.05 to 5 kW, a frequency response of 1,500 Hz, and the industry's highest level of performance, the ALPHA5 Series is suitable for a wide range of applications.

3. Latest Technology and Application Example

3.1 General-purpose inverters

(1) Synchronous motor drive system

A high efficiency synchronous motor drive system that combines a permanent magnet type synchronous motor (PM motor), and a dedicated inverter for PM motor driving is described below. A PM motor has a higher efficiency and contributes more to reducing CO_2 emissions and increasing energy savings than an induction motor.

(a) FRENIC-MEGA Series for PM motor driving

This series of dedicated inverters for PM motor driving utilizes sensor-less vector control, which has a track record of success, and realizes highly accurate torque control and speed control, as well as highly efficient operation, without the use of sensors for the PM motor.

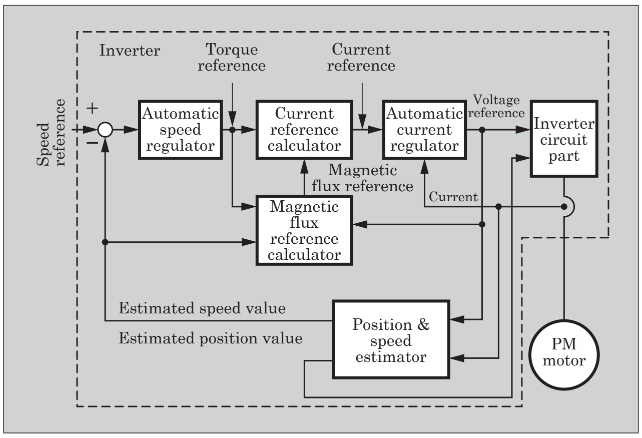
Figure 3 is a block diagram of the sensor-less vector control system.

Features of sensor-less vector control are described below.

(i) Highly accurate torque control and speed control

A position and speed estimator that uses a voltage equation model of the PM motor estimates the rotor speed and magnetic pole position from a voltage reference value and a current detection value. The torque is calculated from precise estimates of the rotor speed and magnetic pole position, and highly accurate torque control and speed control is realized.

Fig.3 Block diagram of PM motor sensor-less vector control



(ii) Highly efficient operation

Highly efficient operation is realized by using a magnetic flux reference calculator and a current reference calculator to control the torque with respect to the current so that the magnetic flux is always at its maximum value.

At speeds greater than the base speed, the terminal voltage (induced electromotive voltage proportional to the speed) of the PM motor becomes larger than the maximum output voltage of the inverter, and the terminal voltage cannot be controlled to the desired value. As a result, the current cannot be controlled properly and stable operation of the motor is difficult to achieve. With the FRENIC-MEGA Series, magnetic flux is controlled such that the terminal voltage of the PM motor does not exceed the maximum output voltage of the inverter, and therefore higher efficiency and greater stability can be realized than with the conventional control method.

(iii) Auto-tuning (offline)

To realize sensor-less vector control and high efficiency operation, the electric constants of the PM motor (armature resistance, inductance and induced electromotive voltage) must be known. The FRENIC-MEGA Series has a function for measuring these electric constants automatically.

For each regulator, an offline auto-tuning function automatically sets control parameters to optimal values based on measured values of the electric constants. The user is no longer required to perform the troublesome task of setting parameters, and a system having maximum efficiency can be realized easily.

Moreover, this offline auto-tuning function also enables the sensor-less driving of special PM motors, such as those having high-speed specifications.

(b) PM motors

(i) Standard PM motor

PM motors have no field loss and therefore generate a low amount of heat. For this reason, PM motors can realize less total loss than an induction motor, and the volume of the stator core can be reduced, the required cooling capability can be decreased, and the frame size can be made smaller than a standard induction motor. Fuji Electric's standard PM motors use a frame that is 1 to 2 sizes smaller than that of a standard induction motor, and realize a significantly smaller size and lighter weight with a 35% reduction in volume on average and a 40% reduction in mass on average. Accordingly, a machine in which a standard PM motor is installed is also able to realize smaller size and lighter weight.

Moreover, a standard PM motor by itself has an efficiency corresponding to the 1E3-level prescribed by IEC 60034-30 and is able to contribute more than an IE1-level standard induction motor to the reduction of CO_2 emissions and to the realization of greater energy savings.

The product lineup extends across a wide range, from 0 to 90 kW for the 3-phase 200 V series, and 11 to 300 kW for the 3-phase 400 V Series, and Fuji Electric sells two product lines, one without a sensor and one with a sensor.

Figure 4 shows the external appearances of the FRENIC-MEGA Series and a standard PM motor,

(ii) High efficiency PM motors

Seeking to maximize the low-loss advantage of PM motors, high efficiency PM motors that achieve IE4-level efficiency values are introduced below. Another advantage of this product is that it has the same frame size as a standard induction motor. In the case where a standard induction motor used in an existing plant facility or machine is to be replaced with a PM motor, the smaller frame size of the aforementioned PM motor requires that the installation base for the motor must be modified or the design of the machinery changed, and therefore the motor cannot be replaced easily. This extra work can be eliminated by using the same size frame as the standard induction motor. The high efficiency PM motor realizes a greater reduction in CO_2 emissions and greater energy savings than a standard PM motor, and can easily replace a standard induction motor.

These advantages have been well received, and about 30 standard induction motors of 75 kW and 22 kW capacities in existing pump and existing air-conditioning equipment at a certain customer's plant were updated with a combination of a high-efficiency PM motors and the FRENIC-MEGA series of inverters for PM motor driving. As a result, electric utility fees were reduced by more than 30 million yen annually and CO_2 emissions were reduced by more than 1,000 tons, and the sequential planned replacement of equipment is progressing.

Fig.4 Appearance of FRENIC-MEGA Series for PM motor driving, and a standard PM motor

Fuji Electric's product line of high efficiency PM motors consists of a 3-phase 200 V series of 11 to 90 kW capacity and a 3-phase 400 V series of 11 to 160 kW capacity, and these products are sold without a speed sensor.

(2) Inverter that satisfies category 3 of the safety standard EN 954-1

In Japan, there is a history of providing users with thorough safety training, and of isolating hazards and pursuing intrinsic safety at each plant to ensure safety and prevent accidents. A recent international trend, as prescribed in the international safety standard ISO 12100 (Safety of machinery -- Basic concepts, general principles for design) and the like, is to take into account risk probability and the impact thereof, and designs that limit risk up to an allowable range are a rapidly growing trend.

Inverters for driving machinery and equipment are no exception. It is strongly request that the main inverter unit be provided with functions adapted to the relevant safety standards, and safety standard compliance is particularly strict in Europe. Inverters that satisfy EN 954-1 are introduced below.

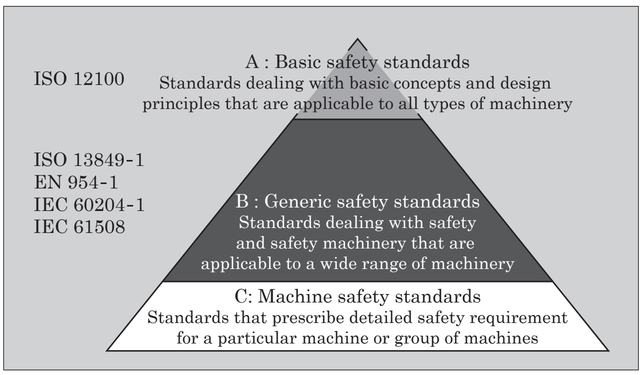
(a) Safety standard system

As shown in Fig. 5, the safety standards for machines are organized into three categories: (A) Basic safety standards, (B) Generic safety standards, and (C) Machine safety standards.

The "Safety of machinery -- Basic concepts, general principles for design" (ISO 12100/JIS B 9700) and other affiliated safety standards are known as "Basic safety standards" (category A standards) and deal with basic concepts and design principles that may be used commonly among all types of machinery.

EN 954-1 (Safety of machinery - Safety related parts of control systems, general principles for design), IEC 61508 (Functional safety of electrical/

Fig.5 Safety standard categories



electronic/programmable electronic safety-related systems) and the like are known as "Generic safety standards" (category B standards) and pertain to safety regulations applicable to all machinery in a specific field and to safety equipment. The generic safety standards are referenced from "Machine safety standards" (category C standards) which are detailed safety standards for specific machines.

(b) Applicable safety standards

EN 954-1 category 3 and IEC 60204-1 (Safety of machinery, Electrical equipment of machines, General requirements) stop category 0 are applied as safety standards to the FRENIC-Multi and the FRENIC-MEGA series.

When a safety signal is input to the dedicated safety terminal, the inverter turns off the torque (removes power) and conforms to stop category 0 (uncontrolled stop), i.e., "Stopping by immediate removal of power to the machine actuators."

In order to apply these safety standards, the following features are provided.

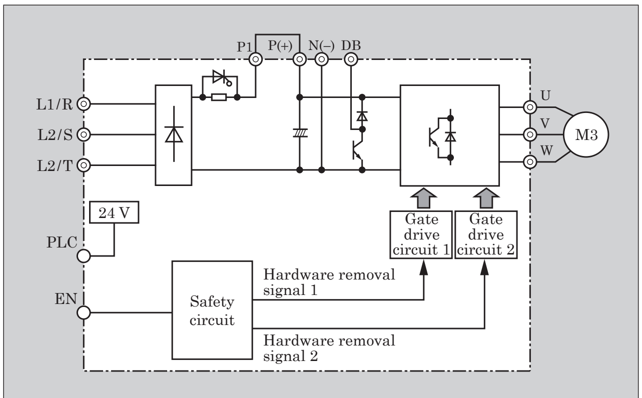
- ○ Removal of power can be implemented with hardware only, without using software
- ○ The hardware removal circuit has a dual-system redundant design

Figure 6 shows schematic drawing of the safety circuit configuration.

(c) User benefits from the use of safety standard-compliant inverters

As shown in Fig. 7, if an inverter does not support the safety standards, then in order to realize machinery that complies with EN 954-1 category 3, redundant contactors must be provided at the output of the inverter so that the safety function will not be compromised even if one of the contactors is contact welded. On the other hand, by using a safety standard-compliant inverter provided with redundancy functions for the hardware implementation of the power removal function and the removal circuit, the output-side contactor and the redundant safety circuit become unnecessary, and a safety circuit can be realized with a configuration that is essentially the same as that of a conventional circuit.

Fig.6 Schematic drawing of the safety circuit configuration



Furthermore, EN 954-1 will expire at the end of 2009 and will be replaced with ISO 13849-1 as a harmonized standard. ISO 13849-1-compliant products are planned to be sold during 2009.

(3) FRENIC-MEGA inverter series with built-in positioning control and vibration suppressing control

Inverters used in conveyor and transportation machinery and provided with positioning control and vibration suppressing control functions that are based on full-closed control are introduced below.

As shown in Fig. 8, in the case where an inverter is used in a conveyor requiring positioning control, semi-closed control is generally implemented. A position signal from an encoder attached to the motor shaft is input to a PLC of the upper level system or to a user-developed controller board, and position detection is performed and a frequency reference signal is sent to the inverter. If error due to wheel slippage of the moving object or the like cannot be ignored, a measure to improve the positional accuracy is employed wherein a laser distance sensor is used concurrently and a distance signal is input to the upper level system. The upper level circuit must contain a counter unit and a read circuit for receiving two detection signals, and as a result, such a system becomes more expensive. Moreover, the system cost increase further in the case where a servo is used, an encoder is provided on the

Fig.7 Examples of machines equipped with safety functions

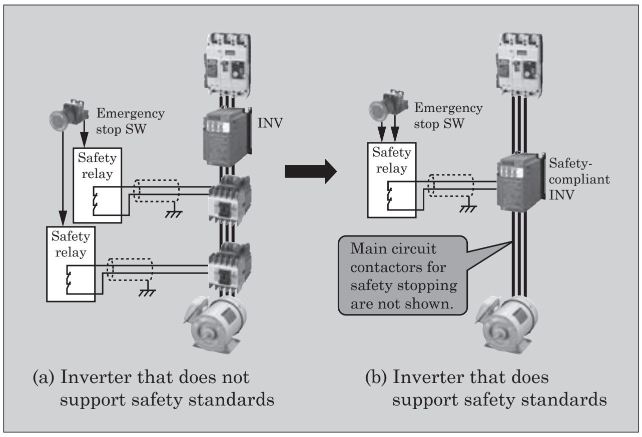


Fig.8 Example of conventional positioning control system (Semi-closed control)

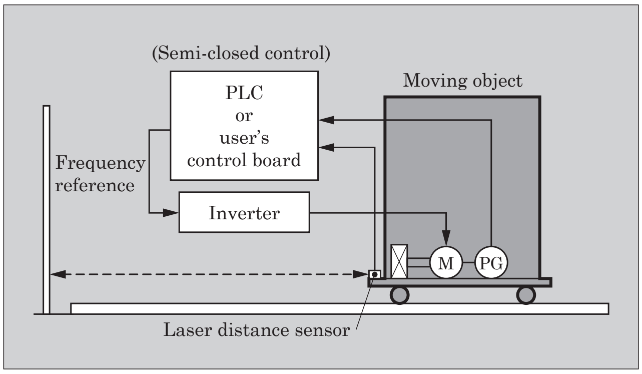


Fig.9 Example of positioning control system based on FRENIC-MEGA (full-closed control)

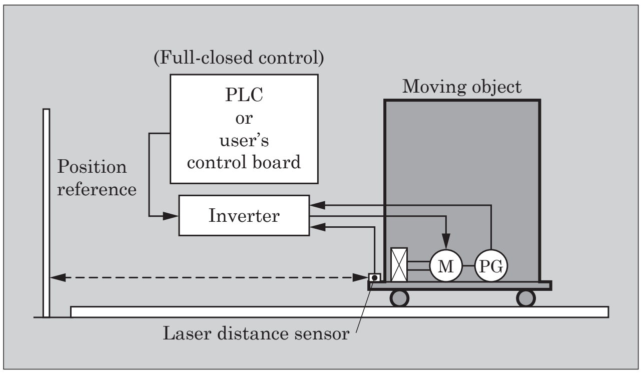
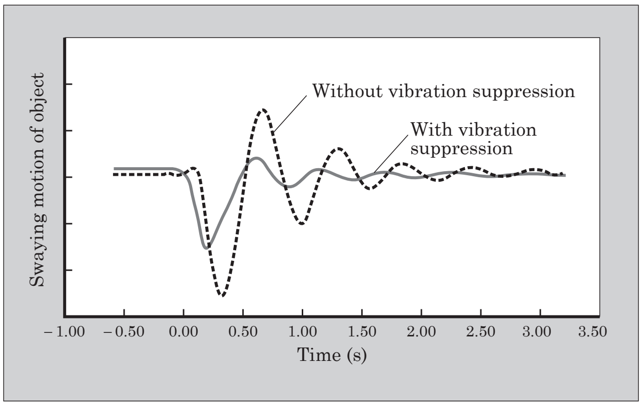


Fig.10 Comparison of results of vibration suppression measurement data



conveyor side and full-closed control is utilized.

In order to resolve these issues, as shown in Fig. 9, some of the conventional servo technology is incorporated into the inverter to provide the following control methods.

(a) Incorporating the servo's positioning control function

A positioning control function, which has been used successfully with servo equipment, is partially incorporated in an inverter to realize extremely low-cost positioning control. Basic functions are described below.

(i) Positioning control is implemented based on the target position setting data (number of pulses) and the deviation of the detected position signal

(ii) Equipped with a return to origin function, over-travel processing, position preset function and the like

(iii) Equipped with various I/O signals such as an enable/disable positioning control input, a position data selection input, a positioning completed output, over-travel detection, etc.

(b) Full-closed control based on laser distance sensor

In a system that improves positioning accuracy through the concurrent use of a laser distance sensor, full-closed control can be realized in an inverter by inputting the laser distance sensor signal directly to the inverter without passing through the upper level system, enabling the configuration of a low-cost and accurate system. This application is promising for devices for which, until now, an inverter provided insufficient performance and a servo provided excessive performance.

Figure 9 shows an example positioning control system based on a FRENIC-MEGA series inverter.

(c) Vibration suppression control

Because of shorter takt times, large-scale conveyors and the like must be able to start and stop with quick acceleration and deceleration, and be capable of high-speed operation. When stopped, operation of the next process starts after waiting for convergence of the vibration generated in a moving body, and therefore takt time increases. As a means for reducing this vibration, vibration suppression control that devises a speed pattern with the PLC of the upper level system is being developed by users. However, parameters such as the size, height and hardness of a moving object, and the height and weight of a load have a large effect but have been difficult to adjust.

Based on the successful track record of vibration suppression control in servo equipment, vibration suppression control that is effective even for the vibration of a moving object has been developed. The result leads to reduction in conveyor takt time and enables some users to slow the pace of their plans for developing vibration suppression control.

Figure 10 compares the results of measured data of the vibration suppression control.

Thus, by providing inverters with a positioning control function and implementing full-closed control and vibration suppressing control, the range of applications for inverters in conveyors is expected to expand further.

3.2 Servo systems

Application examples of servo systems having a simple configuration and that have achieved a total cost reduction are introduced in paragraphs (1) and (2) below. Then, in paragraph (3), the positioning function of a control system that uses the ALPHA5 to meet customer specification requirements is introduced.

(1) Application to blanking machine for paper aprons

A simple control system that combines an @E.Terminal and a servo system is introduced below.

(a) Overview of the conventional system

A paper apron-type blanking machine is used to produce the paper aprons often worn to protect one's clothes from becoming soiled by grease or food while dining at a Japanese yakiniku (barbecue-style) restaurant or the like. Figure 11 shows a sketch of the configuration of this system. In each machine, a two-axis servo system is used to drive a feed roll and a cutter roll. The feed roll driving causes material to be delivered at a constant speed, and synchronized to this speed, the cutter roll operates a cutter part synchronously to perform the predetermined blanking operation. Because aprons for adults and children have different cutting dimensions, the system has been generally configured with a control system that employs motion control capable of adapting to changes in only the settings. Figure 12 shows the configuration of a conventional control system.

The system is configured from Fuji Electric's MONITOUCH panel, a motion controller and a servo system (two axes).

In a conventional system, before the machinery can be setup, the software program for the positioning control module has to be generated with a custom loader, and other tasks, such as the adjustment of servo system parameters, also has to be implemented with the custom loader. Consequently, due to program development and debugging constraints, a significant amount of time was required for startup.

(b) Configuration of system using an @E.Terminal

Figure 13 shows the configuration of a control system using an @E.Terminal.

As can be seen in the figure, the system can be constructed with a simple configuration since motion control can be realized with simple settings without the need for software program development.

Figure 14 shows the work flow – from meetings about the specifications through the completion of combination testing. By using the @E.Terminal and its built-in motion contents function, there is no need to master the use of a motion-related loader or to create motion programs. In this case, significant time savings was realized compared to a conventional control system.

(c) Features of a system that uses am @E.Terminal

(i) Realization of wire savings and space savings

Four functions, i.e., the motion function, operation and display function, sequence function, and networking function, are integrated, and excellent wire-savings and space savings are realized so as to enable "one-touch" wired connection to a control device.

(ii) Realization of motion control with simple settings

Motion operations such as complex synchro-

Fig.11 Block diagram of blanking machine for paper aprons

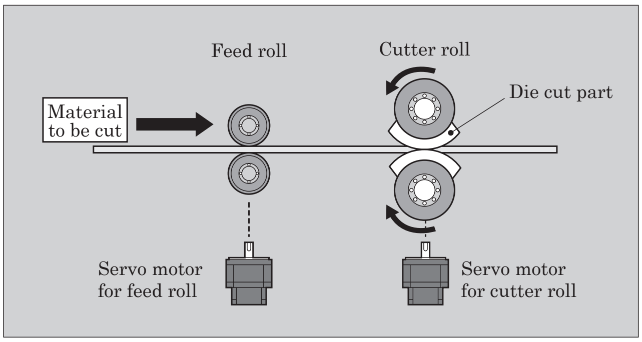


Fig.12 Configuration of conventional control system for blanking machine

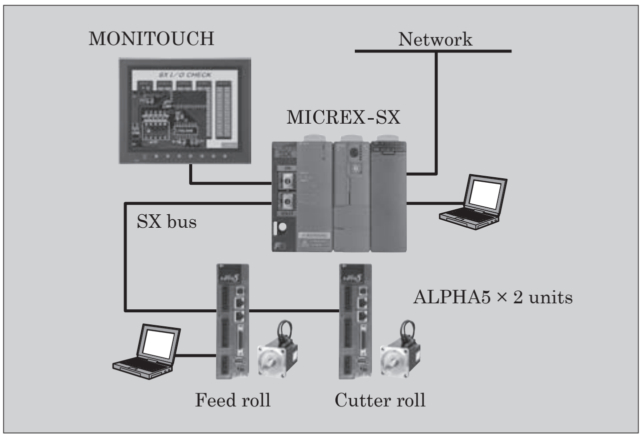


Fig.13 Configuration of new control system for blanking machine

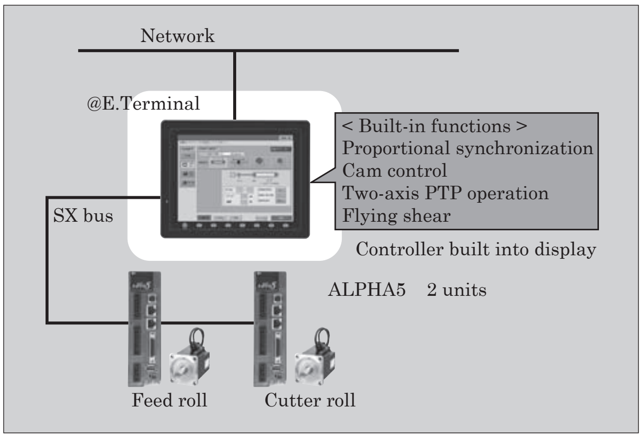
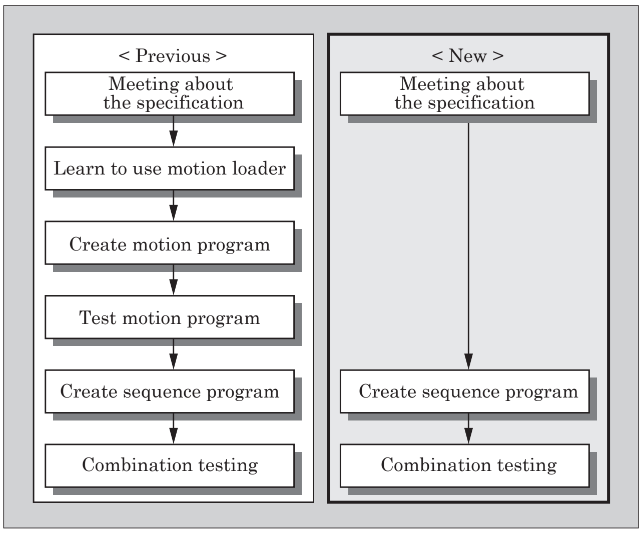


Fig.14 Work flow through the completion of combination testing



nous control can be realized easily, simply by setting the @E.Terminal screen with the motion operation for each axis.

(Example: PTP, proportional synchronization, flying shear, rotary shear, etc.)

(iii) Easy adjustment and maintenance

The @E.Terminal is provided with the required screens for servo parameter changes, waveform sampling, failure diagnosis, error history and the like so that adjustment and maintenance can be performed onsite without having to use a servo loader.

(2) Application to sizing and cutting machine

An example application of a servo system having a built-in positioning control function that leads to lower total costs is introduced below.

(a) Overview of the conventional system

A sizing and cutting machine cuts material (steel, fabric, paper, film, etc.) in units of a preset length. Ordinarily, a single-axis servo system is applied to a single machine, and used to drive the delivery of materials. Various machines, from small-scale to large-scale, are available according to the type of material.

Figure 15 shows the system configuration for a conventional sizing and cutting machine.

When the PLC receives a start signal, in accordance with the cut length and other data set by the MONITOUCH, and as a result of the pulse signal from the positioning control module, control is implemented such that the servo system operates in proportion to the preset values.

(b) Configuration of system using ALPHA5 Series with built-in positioning control function

Figure 16 shows the configuration of a system using Fuji Electric's ALPHA5 Series.

The ALPHA5 servo system series is equipped with a positioning control function. Since the MONITOUCH and servo amp are linked via the Modbus RTU (RS-485) communications function, there is no longer a need for the positioning control module. This implementation results in wire-savings and an extremely simple and low-cost configuration.

(c) Features of system using ALPHA5 with built-in positioning control function

(i) Positioning control function according to the application

The positioning control function provided as a standard feature of the ALPHA5 allows 15 points of positioning data to be registered internally. Furthermore, acceleration and deceleration times can be set separately for each type of data, thereby enabling usage in various ways according to the application.

(ii) Equipped with Modbus RTU (RS-485) communications function

The Modbus RTU (RS-485) communications function is provided to enable the external setting of positioning control data and modification of parameters. This communications function is an open network, and therefore various upper level devices such as PCs, PLCs, touch panels and the like can be connected easily.

(iii) Fuji Electric's positioning of a control system that uses the ALPHA5 to meet customer specification requirements

The two application examples described above both had new system configurations. In conventional implementations, all motion controls have

Fig.15 Conventional configuration of system for sizing and cutting machine

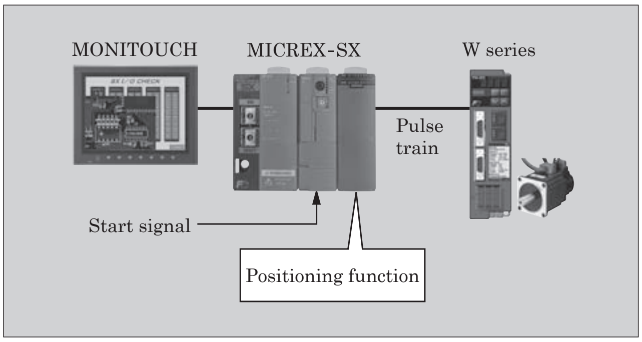


Fig.16 New configuration of system for sizing and cutting machine

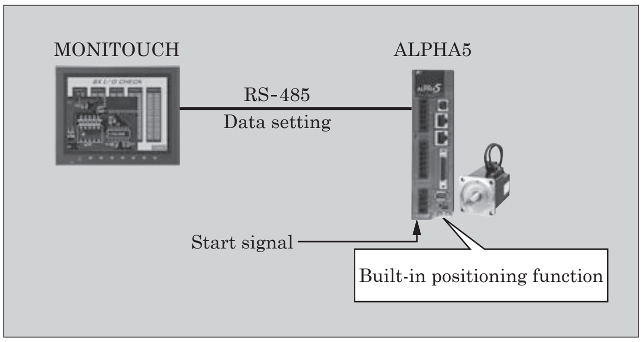
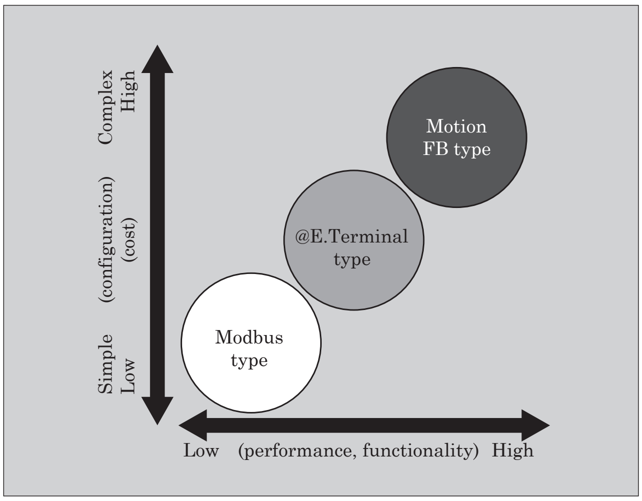


Fig.17 Fuji Electric's positioning of control systems to meet customer specification requirements



been implemented using motion function blocks in motion controllers, but each control function can be separated according to customer specification requirements by using ALPHA5.

Figure 17 shows Fuji Electric's positioning of control systems to meet customer specification requirements.

4. Postscript

The latest technology and application examples of general-purpose inverters and servo systems have been discussed. Fuji Electric intends to continue to accurately assess the latest needs and to manufacture products that incorporate technology to meet those needs.

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Worldwide Service Development for Drive Systems and Predictive Maintenance

Yasuo Nakahara †
Hirofumi Tsuchihira †
Tetsuyuki Iwasaki †

1. Introduction

Fuji Electric's drive systems play an important role among electric machinery systems and have been delivered to a wide range of locations both in Japan and overseas locations. Technical innovation for these drive systems occurs at a swift rate, and new products rapidly become available. The service infrastructure, which consists of an after-sales service system and a parts supply system, must respond quickly and globally to rapid product changes.

Drive systems are configured in various combinations that range from high-voltage electrical equipment to electronic equipment, such as inverters and other driving devices, PLCs and rotary machines and have relatively long service lives. Accordingly, it is desired that the component parts in a drive system use the latest suitable predictive maintenance technology to help achieve stable operation.

This paper describes the latest trends and future outlook for service networks and predictive maintenance technology that address and support the needs and challenges, from a service perspective, of the global deployment of drive systems.

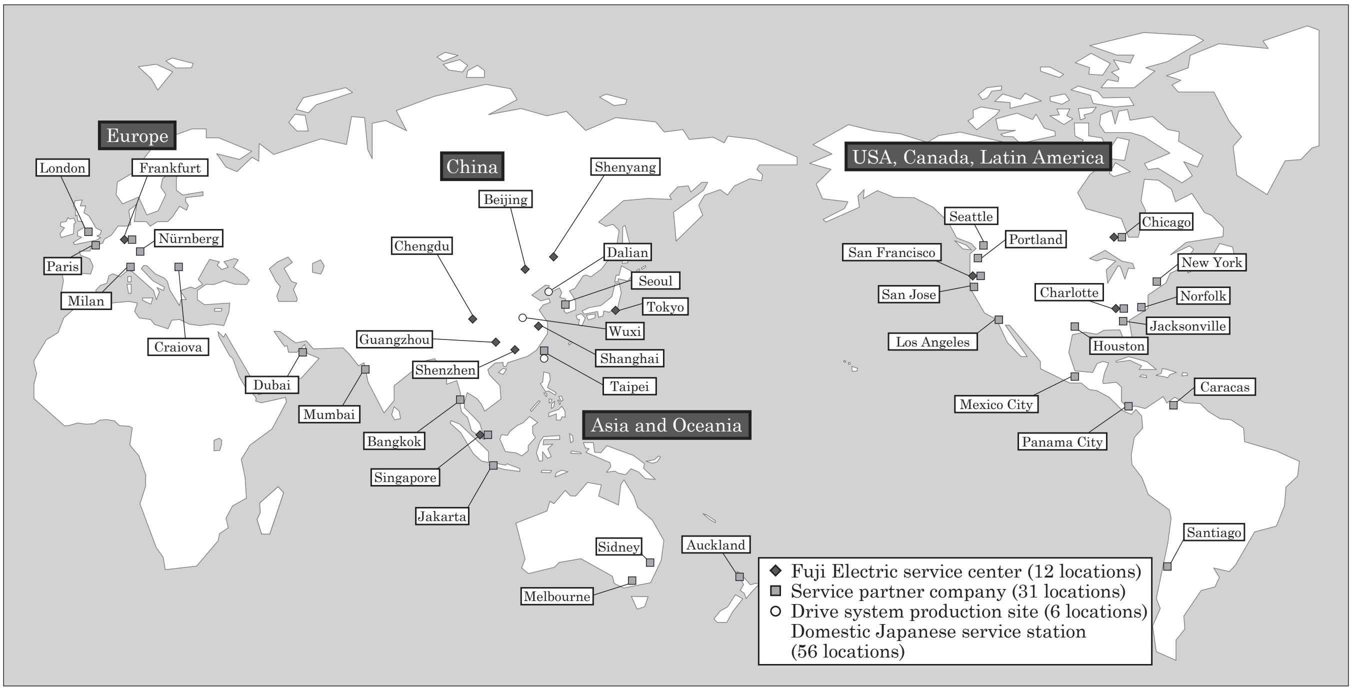
2. Worldwide Service Network

Drive systems play a crucial role at industrial facilities. In support of stable maintenance and management throughout the life cycle of a drive system, Fuji Electric has built a global service network for drive systems and provides detailed after-sales service. Figure 1 shows the main service network.

2.1 Overview of service network

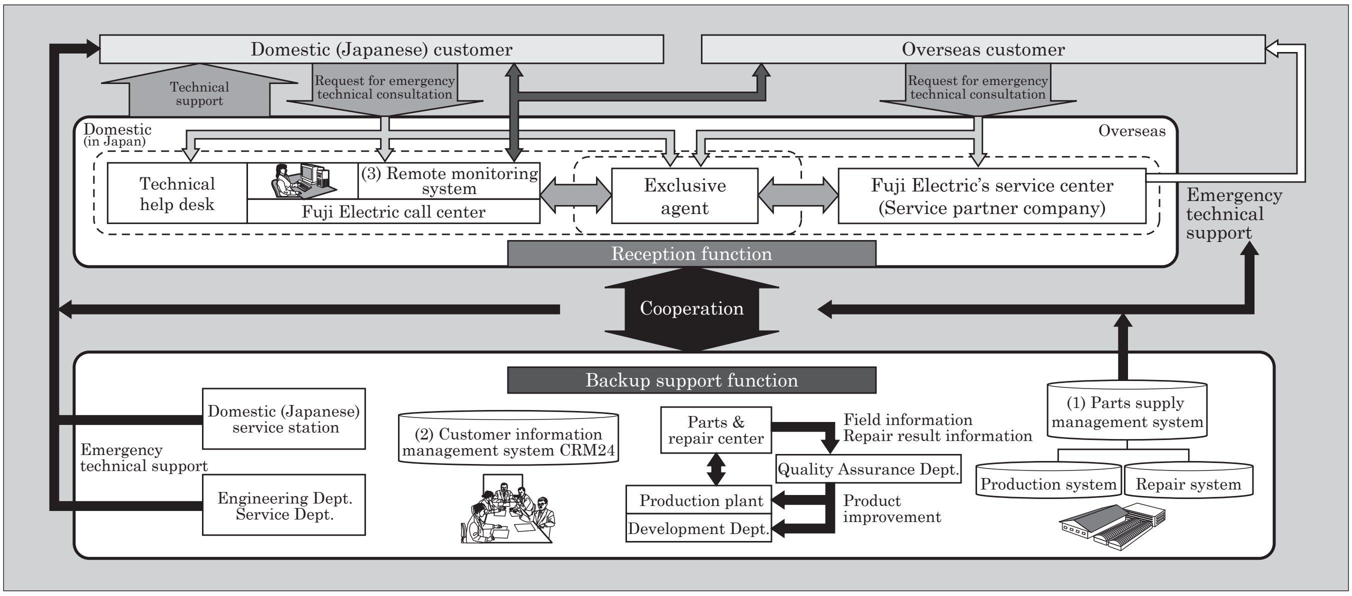
The service system has a reception function for

Fig.1 Worldwide service network for drive systems



† Fuji Electric Systems Co. , Ltd.

Fig.2 Functions and configuration of service system



handling emergency requests and technical consultations and a support function for supplying parts, performing repairs and providing technical support to customers and service personnel in order to facilitate a rapid recovery when a failure has occurred. Effective cooperation between the departments in charge of these functions enables the service system to respond quickly. Figure 2 shows the functions and configuration of the service system. These functions are supported by the following three service support systems, and a mechanism that enables the relevant departments to share information is configured.

(a) A "Parts supply management system" that is directly linked to a production plant and that supplies parts accurately
(b) A "Customer information management system (CRM24)" that implements centralized management of customer facility information
(c) A "Remote monitoring system" that realizes highly efficient maintenance and responds rapidly to failures

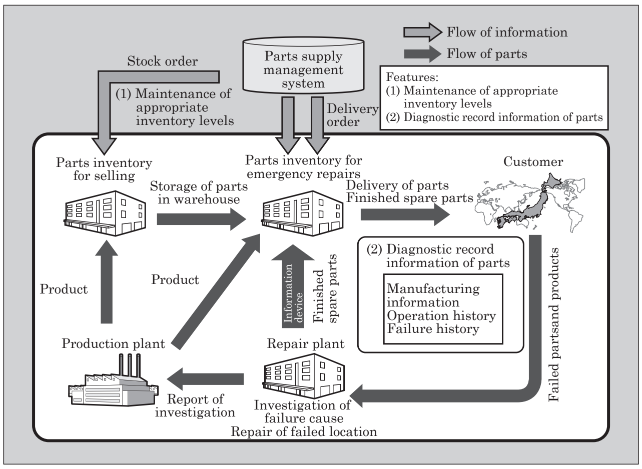
These three support systems are described in detail below.

2.2 Parts supply management system

When an emergency situation occurs at a customer's production facility, replacement parts and finished spare parts must be supplied rapidly. Fuji Electric deploys the parts supply management system shown in Fig. 3 as an infrastructure for managing the flow of parts from the stocking of inventory to the completion of repairs. As a result, parts can be supplied quickly when required, helping to maintain the stable operation of customers' facilities. Features of this system are described below.

(1) Rapid parts supply enabled by appropriate inventory levels

Fig.3 Parts supply management system and parts flow



The parts supply management system has a function for continuously maintaining an appropriate level of inventory. For example, if there is a shortage of inverter parts in the "inventory of parts for emergency repairs" unit, a delivery order is issued immediately to the "inventory of parts for sale" unit so that an appropriate level of inventory is maintained continuously. Thus, if a failure were to occur at a customer facility, parts can be supplied rapidly at all times.

(2) Utilization of diagnostic record information of parts

A function exists for reporting to customers the results of an investigation of the cause of failure and the repair status of failed inverter parts that have been collected, and for managing the diagnostic record information of each part. This information is feed-back via the quality department to the production plant and development department, and is reflected in product improvements and in successive products.

2.3 Customer information management system (CRM24)

(1) Call center reception function

To support the stable operation of equipment, a reception function capable of receiving calls at any time about the failure of customers' equipment or handling technical inquiries is needed. Fuji Electric has established a reliable reception system by operating a 24-hour 365-day per year call center and a specialized technical help desk service for inverters.

(2) CRM24 (Customer Relationship Management 24) basic functions

The CRM24 shown in Fig. 4, the backbone system of the call center, performs detailed management of information concerning customers' facilities and equipment, provides the information necessary for facility operations and maintenance to Fuji Electric and to the customer, and provides rapid recovery support when a failure occurs.

(a) Customer information/equipment information management function

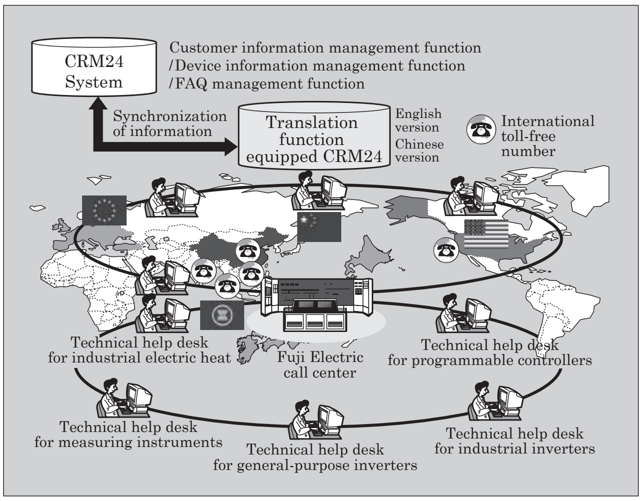
To support the stable operation of customers' equipment, this function is provided with a data structure capable of storing a list of delivered equipment, maintenance/failure information, drawings data, and emergency and maintenance support information, such as information about Fuji Electric's liaison structure. These information management functions enable equipment and facility information to be managed centrally, and are used for the stable operation of customers' facilities.

Moreover, precise support is provided through coordination with a specialized technical help desk.

(b) FAQ (Frequently Asked Questions) function

The FAQ function enables an operator to respond quickly to customer inquiries about the drive system, and a troubleshooting function and statistical function, based on incidents of failure and maintenance information, are also provided. Also, various statistical graphs can be generated easily and used as technical reference materials when responding to a received call, and at the same time, failure information and the like can be forwarded to the product development department.

Fig.4 Customer information management system (CRM24)



(3) CRM24 with translation function

Fuji Electric has constructed a CRM system equipped with a translation function for Chinese and English that uses template-formatted input to realize a 97% recognition rate of translated documents. Information can be shared between onsite Japanese engineers and foreign staff, as well as among staff in Japan, and Fuji Electric aims to provide support that is equivalent to onsite support in Japan for responding to various requests from overseas customers.

2.4 Remote monitoring system

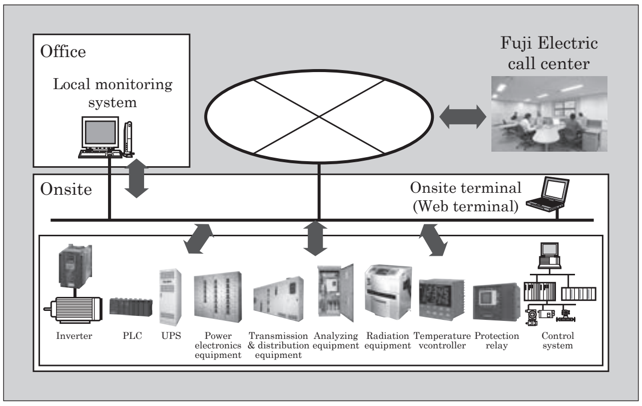
(1) Overview of the remote monitoring system

Fuji Electric supports remote monitoring throughout the entire equipment lifecycle, from delivery at a plant until renewal. In addition to enhanced abnormality identification and preventative maintenance functions based on device status assessment, a high-speed and real-time plant data acquisition function and a startup support function were developed as new functions. These functions contribute to improving the stability of plant abnormality identification and plant operation and help reduce the amount of time needed

Table 1 Main functions and effects of remote monitoring

	Function	Target	Description	Effect
Basic functions	Identification of device abnormality	Ascertainment of device status	○ Remote acquisition of data from which abnormal locations and causes of abnormalities of devices that configure a plant can be determined	○ Remote specialist provides detailed support and instructions for early recovery from abnormal states ○ Promotes higher efficiency since a specialist needs not always be present onsite
	Preventive maintenance		○ Acquisition and storage of data for detecting signs of abnormalities and for diagnosing degradation	○ Continuous stable operation as a result of being able to prevent failures ○ Diagnosis can be made without shutting down facility ○ Identification of plant trouble
New functions	Plant data acquisition	Ascertainment of plant status	○ Data acquisition and storage while plant is operating ○ Data acquisition during startup adjustment, and storage and adjustment of setting parameters	○ Reconsideration of settings and improvement of operation method for stable plant operation
	Startup support			○ Reduction of plant startup time

Fig.5 Configuration of remote monitoring system



for plant startup. Table 1 lists the main functions and effects of remote monitoring.

Fuji Electric's remote monitoring system configuration is compatible with the entire electrical equipment system, which extends from inverters and PLCs up to the control system, and enables information concerning electrical equipment and plants to be shared with call centers, local monitoring systems and onsite terminals (Web terminals). Moreover, in accordance with the communications environment and the security level, the method of communications between the onsite location and the call center can be freely selected as a VPN (Virtual Private Network), dial-up or Internet connection, or the like. Figure 5 shows the configuration of the remote monitoring system.

(2) Remote monitoring module functions

Fuji Electric has newly developed a remote monitoring module that functions to connect plant devices with a system for monitoring those devices, and is promoting the use of this module with all products supplied by Fuji Electric. This module is available in two varieties, a device-embedded type and an externally attached type. When installed on the various devices, the remote monitoring function acts as a platform and helps to achieve device miniaturization and higher quality of the monitoring function. Features of the remote monitoring module are described below. Also, Fig. 6 shows the structure of a remote monitoring module for inverters.

(a) Unified database (DB) and protocol

Device data is acquired and stored with tags in the unified DB of the remote monitoring module. Moreover, communication between the remote monitoring function and the exterior is implemented with a unified protocol that does not depend on a particular device.

(b) e-mail issuing function

If a device abnormality is detected, e-mail notification can be easily sent via the remote monitoring module to the related parties, enabling the rapid recognition of an abnormal state and sharing of relevant information.

(c) Web monitoring function

Fig.6 Structure of a remote monitoring module for inverters

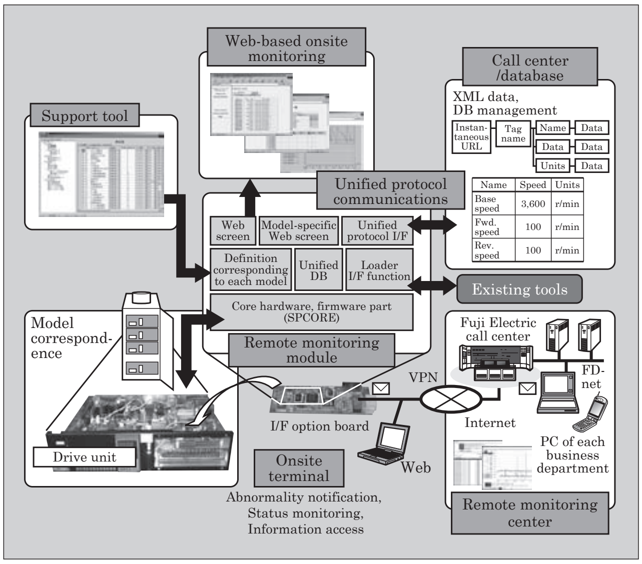
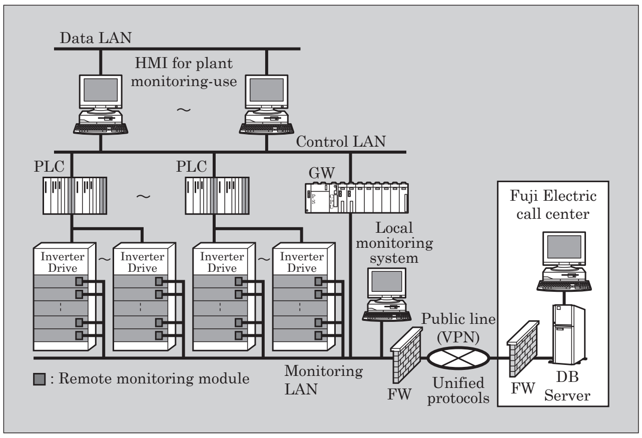


Fig.7 Example of a system that uses a remote monitoring module for an inverter



The remote monitoring module is provided with a Web server function. Devices can be monitored and adjusted remotely by connecting a Web browser-equipped PC to the network.

(3) Remote monitoring in a drive system

Figure 7 shows an example of a system for a plant that uses a remote monitoring module for an inverter.

Using a unified protocol, the inverter data acquired by the remote monitoring module is collected at a Fuji Electric call center and monitored. The inverter status can be checked from the Web screen of local monitoring equipment, and the provision of Fuji Electric's data acquisition and analysis support software package "f(s) NISDAS-x" enables high-speed real-time data acquisition and analysis.

2.5 Future efforts

In order to improve service capabilities not only in Japan, but also in China, North America, Europe and Southeast Asia, the parts supply system for emergency repairs and the centralized information management system (one stop channel) capable of responding to one-time inquiries from customers will be strengthened. Moreover, to further expand the application range for remote monitoring modules, Fuji Electric is planning to produce a series of remote monitoring modules equipped with an I/O function.

3. Predictive Maintenance Technology that Supports Drive Systems

3.1 Efforts involving predictive maintenance technology

The majority of equipment installed during the period of high economic growth of the 1970s is due for extensive renewal or replacement, and expectations are increasing for degradation diagnostic technology and remaining life assessment technology, which are crucial for equipment renewal and determining the renewal sequence. On the other hand, as it is becoming increasing difficult to shut down equipment in order to perform an inspection or diagnosis, expectations for live-line diagnostic technology are also increasing.

Therefore, with the goal of enabling electric equipment and facilities to operate smoothly throughout their entire lifecycle, Fuji Electric has continued to accumulate field data and pursue technical development, and has established many types of degradation diagnostic technologies, remaining life assessment technologies and live-line diagnostic technologies.

In the drive system sector, Fuji Electric is particularly involved in establishing predictive maintenance technology for drive systems and rotary machines, in which inverters are the component.

Representative examples of preventative maintenance technology for drive systems are listed in Table 2. To diagnose the degradation of electronic parts used in a drive system, tests such as opened testing of IC devices and sealed testing of thyristor devices have been performed. In recent years, diagnostic technologies that quantify the equipment environmental assessment have been developed. For general-purpose inverters that have been operating for a long time, Fuji Electric has developed a remaining life estimation system for parts needing regular replacement and this system does not require shutting down the facility or equipment.

As insulation degradation diagnostic technologies for rotary machines, remaining life estimation based on electric insulation diagnostic data and physicochemical degradation diagnosis of insulation material based on micro-sample collecting have been performed. As mechanical vibration diagnostic technologies for rotary machines, a vibration diagnostic system that uses wireless sensors has been newly developed and convenient, easy-to-use systems have begun to be provided.

3.2 Diagnostic technology for inverters

In addition to inverters for plant drives, general-purpose inverters are also key components used for driving equipment. These inverters are installed in relatively harsh environments, and a shift from breakdown maintenance to enhanced predictive maintenance based on degradation diagnostic technologies is highly anticipated.

(1) Overview of diagnostic technologies

Fuji Electric has developed various inverter diagnostic technologies as listed in Table 3.

Table 2 Drive system component devices and predictive maintenance technology

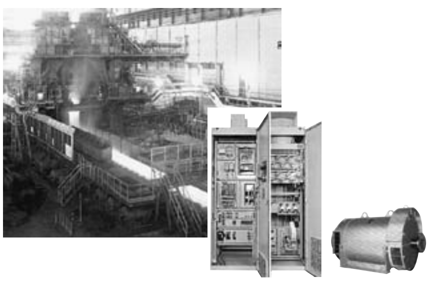
		Drive systems & rotary machines	Electronic control systems	Power supply equipment
Targeted equipment				
Typical degradation diagnosis/ remaining life assessment		Drive systems ○ Degradation diagnosis of power semiconductors ○ Degradation diagnosis of inverters Rotary machines ○ Remaining life assessment based on electric insulation data ○ Physicochemical degradation diagnosis ○ Mechanical vibration diagnosis	DCS, PLC ○ RAS analysis Battery ○ Short-duration discharge method	Oil-filled transformer ○ Gas-in-oil analysis ○ Structured neural remaining life assessment Molded transformer ○ Diagnosis of degradation due to reflected light High voltage switchboard ○ Infrared thermography ○ IV rays degradation diagnosis Breaker ○ Open/close characteristics ○ Degree of vacuum
	Common	Printed circuit board ○ Installation environment diagnosis ○ Parts analysis and diagnosis	Common for all equipment ○ Insulation resistance ○ Partial discharge	

Table 3 List of inverter diagnostic technologies

Step	Diagnostic level	Diagnostic technology	Target of diagnosis	Main parts for diagnosis	Summary of diagnosis
1	Primary diagnosis	Degradation diagnosis by diagnostic specialist	General-purpose inverter Industrial-use inverter*	Rusting, discoloration, vibration of component devices and parts, status of discontinued and maintenance parts	A diagnostic specialist determines the degree of degradation based on a diagnostic evaluation chart. Also, the supply availability is adjusted for discontinued and maintenance parts.
		Simple diagnostic system for remaining life assessment	General-purpose inverter	Degradation diagnosis of parts needing regular replacement: main circuit electric capacitors, printed circuit board electrolytic capacitors, cooling fan etc.	Using a simple inverter diagnostic system, diagnosis is made based on usage status (operating time, temperature conditions) of parts needing regular replacement
2	Secondary diagnosis	Environment diagnosis	General-purpose inverter Industrial-use inverter*	Temperature, humidity, gas, dust, corrosion and the like of component devices and parts	Environmental measurements, dust adherence and corrosion on electric and electronic devices, rusting and the like are investigated, a determination of whether to implement preventative measures is made, and improvements are proposed. For further detail, a pull-up diagnosis is also performed.
		Diagnostic technology for degradation caused by environment	General-purpose inverter Industrial-use inverter*	Degradation of printed circuit board due to temperature, humidity, gas and dust	The degree of printed circuit board degradation due to operating conditions (temperature, humidity, gas and dust) and the remaining life are calculated.
		Device degradation diagnosis	Industrial-use inverter*	Sealed characteristics of power device based on leakage current	From the device leakage current value, degraded devices are identified and replaced with devices having matching characteristics to maintain the quality of the entire system.
3	Exact diagnosis	Electronic parts degradation diagnosis	Industrial-use inverter*	Characteristics of transistor, capacitor and IC	Using an electronic parts tester and electronic microscope, the amplification and abnormal indications such as internal corrosion, electrolytic corrosion and the like are detected early, and countermeasures are proposed.

* : Industrial-use inverters include Scherbius systems and Leonard systems.

Diagnostic technologies are categorized according to the diagnostic level as a primary diagnosis based on device observation and a diagnostic evaluation chart, a secondary diagnosis that involves measurement instruments and testing, and a detailed exact diagnosis. After a diagnosis has been made, an optimal maintenance plan incorporating a parts replacement period or renewal period is presented based on the findings of the diagnosis.

(2) Recent diagnostic technologies

Diagnostic technologies recently developed by Fuji Electric are introduced below.

(a) Simple remaining life assessment system for general-purpose inverters

This system uses a PC to assess the remaining life of electrolytic capacitors and cooling fans used in general-purpose inverters. The remaining life of electrolytic capacitors is calculated according to Arrhenius' law (which states that the life expectancy decreases by half when the temperature increases by 10 °C), and the remaining life for cooling fans is calculated according to a life curve based on wear of the bearings. The accuracy of both calculations has been improved by maintaining databases of test data and device data for each model type. The inverter models diagnosed are Fuji Electric general-purpose inverters that have been delivered more than 10 years ago.

Features of this remaining life assessment system are described below.

(i) A live-wire diagnosis can be performed onsite while the inverter is operating.

(ii) The diagnostic system stores prior model data and is able to make diagnoses instantaneously simply by inputting the inverter intake temperature, the utilization rate, the load rate, and the like.

(iii) Approximately 20 inverters can be diagnosed per day.

(b) Environmental degradation diagnostic technology

This system quantitatively evaluates degradation due to the installation environment and diagnoses the degradation and remaining life of printed circuit boards, which are a component of inverters. The diagnosis consists of a corrosion degradation diagnosis and a dust accumulation degradation diagnosis.

(i) Corrosion degradation diagnosis

Corrosive gas causes the wiring patterns (copper foil) on printed circuit boards, which are a component of inverters, to become thinner, and

Fig.8 Cross-section of corrosion in a copper fragment

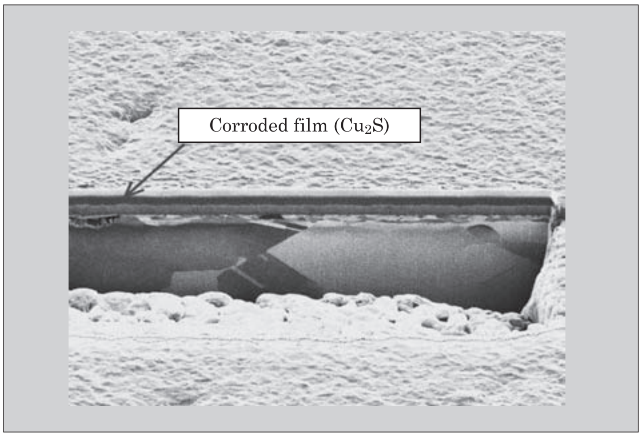
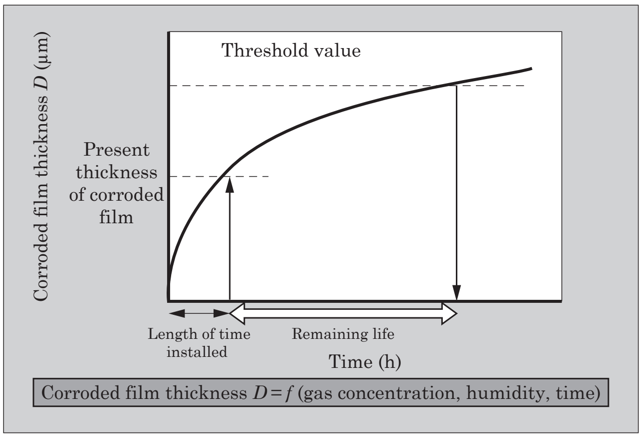


Fig.9 Example master curve of corrosion degradation diagnosis



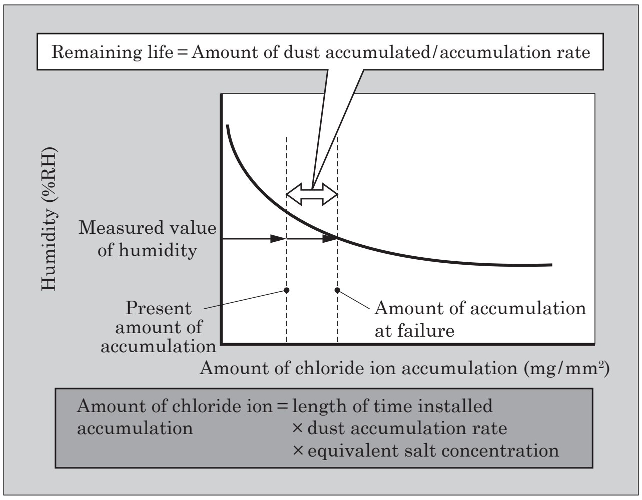
consequently the wire impedance increases and may result in electrical failure. To predict such problems, Fuji Electric has developed technology which, based on an assessment of the gas concentration, humidity, operating conditions and so on in the installation environment, estimates the time until the end of the lifespan is reached. Based on corrosion testing and evaluation of the corrosion film thickness, a master curve has been obtained for corrosion degradation diagnosis.

Figure 8 shows a cross-section of corrosion in a copper fragment, and Fig. 9 shows an example master curve of the corrosion degradation diagnosis.

(ii) Dust accumulation degradation diagnosis

Dust, including sea-salt particles and the like, accumulates on a printed circuit board, depending on the humidity and other conditions, may cause a decrease in the impedance between wires and lead to electrical malfunctions. In order to predict when such a problem might occur, Fuji Electric has developed technology for estimating the time until failure using operating condition data such as the equivalent salt concentration and humidity of the installation environment. A master curve for dust accumulation degradation diagnosis was obtained based on the relation between dust accumulation and humidity levels that lead to malfunction. Figure 10 shows an example master curve for the dust degradation diagnosis.

Fig.10 Example master curve of dust degradation diagnosis



3.3 Rotary machine insulation diagnostic technology

Utilizing degradation diagnostic and remaining life assessment technology developed over many years for rotary machines, Fuji Electric has provided data for determining the timing of equipment overhaul or renewal.

Figure 11 shows a general association chart of the rotary machine diagnostic methods. Of the factors affecting degradation of a rotary machine, degradation of the winding insulation is the primary factor that determines the service life.

Two representative methods of winding insulation diagnosis are described below.

(1) Remaining life assessment using electrical diagnosis of insulation

This diagnosis targets the winding insulation of high-voltage rotary machines, and many successful diagnoses have been performed in the past. A degradation master curve was created based upon electrical insulation testing (DC absorption, AC absorption, tan δ, partial discharge) and disassembling investigation data of an aged rotary machine, and the remaining life was calculated with high accuracy (within approximately ± 10%). Figure 12 shows the configuration of a remaining life assessment system using electrical insulation diagnosis.

(2) Physicochemical diagnosis of insulation degradation by heat

Physicochemical diagnosis is a diagnostic technique for quantifying property changes due to decreased mechanical strength, wear or excessive heat at winding locations that cannot be evaluated by the

Fig.11 General association chart of rotary machine diagnostic methods

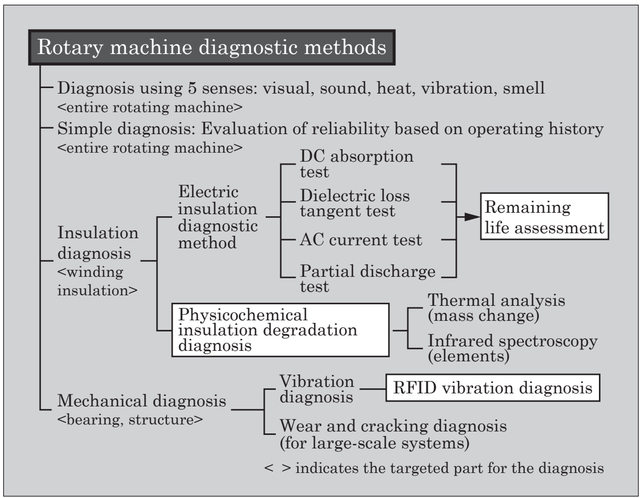


Fig.12 Configuration of remaining life assessment system using electrical insulation diagnosis

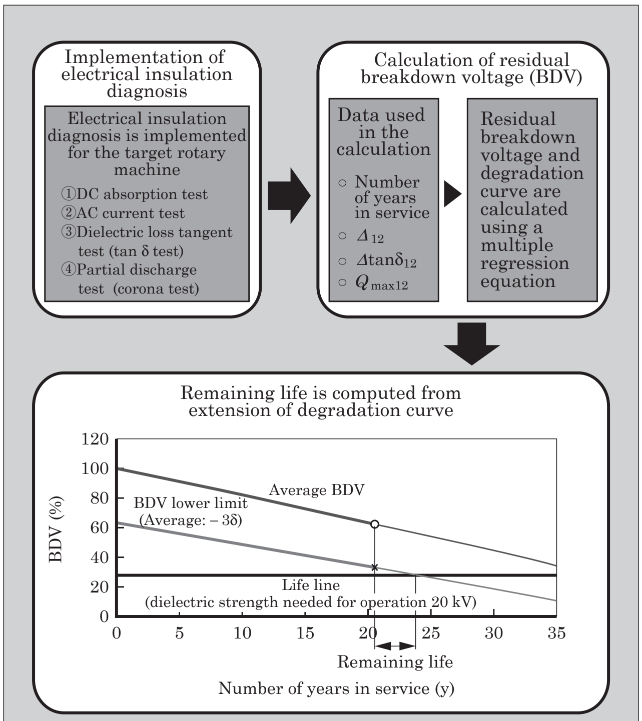
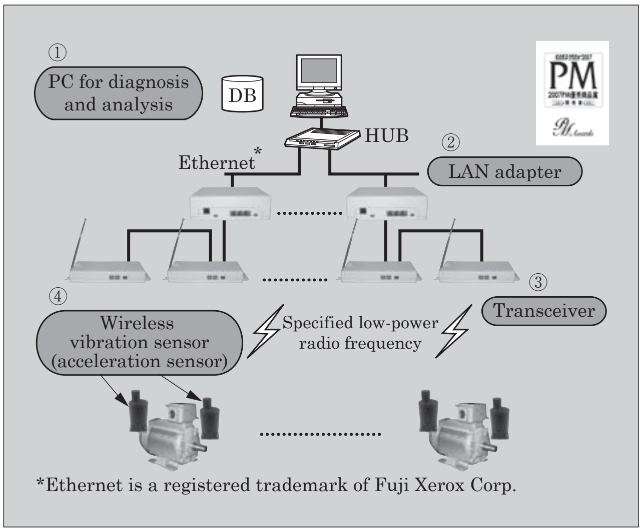


Fig.13 Overall configuration of RFID rotary machine vibration diagnosis system



electrical insulation diagnostic method, and performs physicochemical analyses such as thermal analysis and infrared spectroscopy on minute samples taken from insulation materials such as reinforced members. The mechanical strength and heating loss of the insulation material are evaluated based on the analysis results, and the amount of remaining life can be determined incrementally.

3.4 RFID rotary machine vibration diagnostic system

(1) Present status of rotary machine vibration diagnostic technology

The rotary machines of a drive system are used at many critical locations in a facility, and it is extremely important that abnormal conditions be ascertained, and that the facility operation be shut down according to plan before an abnormal condition occurs.

Vibration diagnosis is a typical mechanical diagnostic method for rotary machines. A portable-type manual diagnosis and an online diagnosis are performed. Issues with a manual diagnosis include the fact that measurements by maintenance personnel will depend upon an individual's skill level, the diagnostic work may be in a dangerous environment, and so on. At present, the online vibration diagnostic system is a wired system. Consequently, this system is expensive and its installation is limited to large-scale rotary machines. Because the system is wired, installation at an existing facility is expensive and the system has been limited in popularity.

To resolve these issues, Fuji Electric has combined its rotary machine diagnostic technology, wireless communications technology and MEMS (Micro Electro Mechanical Systems) technology to realize a rotary machine vibration diagnostic system that uses RFID (Radio Frequency Identification).

(2) System overview

With this system, an ultra low-power frequency is used to transmit vibration information from a wireless vibration sensor equipped with a built-in bidirectional acceleration sensor to a diagnostic analysis PC, and mechanical abnormalities due to low-frequency vibration and rolling bearing abnormalities due to high-frequency abnormalities are managed. The overall configuration of this system is shown in Fig. 13, and the diagnostic targets and system specifications are listed in Table 4. Furthermore, Fuji Electric received a PM Excellent Product Award (development award) for fiscal year 2007 from the Japan Plant Maintenance Institute.

Table 4 Diagnostic target and system specifications

	Frequency	Vibration measurement	Criteria for determination	Basis for determination
Diagnosis target	Low frequency (10 to 1,000 Hz)	VEL (velocity)	RMS value	Absolute value criterion based on vibration condition (ISO 10816)
		DISP (displacement)	Peak O/A (overall)	Relative value criterion based on time trends
			N/2N component (rotational speed component)	Relative value criterion based on time trends
			2f component (magnetic component)	Relative value criterion based on time trends
	High frequency (1 to 5 kHz)	ACC (acceleration)	RMS value	Relative value criterion based on time trends
			Q value (bearing diagnostic evaluation value)	Rolling bearing absolute value criterion based on Fuji Electric's own standards

	Item	Specification
System specifications	Diagnostic application range	Electric motor and generator (general rotary machine), rotational speed (600 to 3,600 r/min) Constant speed rotating device (partial determination not possible when changing speeds)
	Communication distance	20 m (max.) (depending upon installation environment)
	Frequency	314.88 MHz (Specified low power radio frequency (ARIB STD-T93)
	Measurement target	Low frequency (vertical/horizontal direction), high frequency
	Sensor/low frequency	10 to 1,000 Hz/No of sampling points: 4,096 points
	Sensor/high frequency	1 to 5 kHz/Number of sampling points: 4,096 points
	Dust-proof/waterproof structure	IP53 (outdoor simple countermeasure level)
	Method of attachment	Attached by screws (M5 screw holes)
	Battery life	Approximately 2 years (when sampling is performed once weekly)

(a) System configuration

The system is configured from a PC for diagnostic analysis and three other components.

(i) PC for diagnostic analysis

The PC transmits commands to acquire vibration data, and manages the collection and analysis of the vibration data. Up to 2,000 wireless sensors can be registered with the PC.

(ii) LAN adapter

Up to 30 transceivers can be connected.

(iii) Transceiver

A transceiver can communicate with up to 20 sensors.

(iv) Wireless vibration sensor

Equipped with a bidirectional (vertical, horizontal) acceleration sensor, the wireless vibration sensor measure vibrations and transmits the vibration data.

(b) Main functions

(i) Low frequency vibration diagnosis

Low frequency vibrations are diagnosed with a function for judging, based on ISO regulations (although individual user judgment criteria may also be set), mechanical abnormalities resulting from vibration conditions and a function capable of displaying measured information (peak value of displacement, frequency components, magnetic components, etc.) as a time series, performing trend control and providing a spectral display.

(ii) High frequency vibration diagnosis

High frequency vibrations are diagnosed with a function for judging abnormalities in rolling bearings as determined from the crest value and the RMS value of vibration acceleration, and a function capable of displaying RMS acceleration values as a time series, performing trend control and providing a spectral display.

(c) Features and effects of deployment

As a wireless small-size system, there is no need for wiring around devices as in a wired system, and the following effects are realized.

(i) Significant reduction in equipment cost and duration of construction

Cost can be reduced to one-third to one-half that of a conventional system.

(ii) Application to existing facilities, and changes and expansions are easy to realize.

(iii) Instead of periodic measurements by maintenance personnel, a facility or equipment can be diagnosed continuously online, thereby increasing the safety of the diagnosis, achieving further labor savings and improving the diagnostic accuracy.

3.5 Future efforts

For the remaining life assessment of a general-purpose inverter, Fuji Electric plans to expand the range of applicable models and to improve performance based on field results of corrosion degradation and dust accumulation degradation. For rotary machine vibration diagnosis, functional enhancements such as separating the sensor and antenna are planned.

4. Postscript

The deployment of a worldwide support service for drive systems and recent predictive maintenance technology have been described. After-sales service is a critical support operation for delivered products, and Fuji Electric intends to continue to expand its service network, to develop predictive maintenance technology, and to improve lifecycle service functions.

Glossary 1 Crash-astern, propeller racing

• Crash-astern

A crash-astern maneuver causes the ship to stop suddenly by changing the propeller rotation from full-speed ahead to stop and then to full-speed astern. “Astern” means going backwards, and the given name “crash” assumes that the hull must be stopped suddenly even when realizing that the propulsion system may be damaged by doing so.

• Propeller racing

Propeller racing occurs while the ship is sailing during stormy weather conditions and the like which cause the propeller to become exposed from the water and to spin idly. When propeller racing occurs, the load on the propulsion system suddenly decreases and increases.

Glossary 2 PUE, International Energy Star program (Energy Star), CSCI

• PUE (Power Usage Effectiveness)

PUE = (Total amount of power used at IDC facility)/(Power delivered to IT equipment)

Smaller values of PUE indicate less power consumption by devices other than the IT equipment at an IDC (Internet data center).

• International Energy Star program (Energy Star)

The International Energy Star program is an international environment labeling program for energy-saving electrical equipment that operates under a mutual recognition agreement between MITI (Japanese Ministry of Economy, Trade and Industry) and the EPA (United States Environmental Protection Agency). Targeted products range from household-use products to industrial equipment and computers. Power supplies are categorized into 4 ranks according to their efficiency. The strictest requirement for a front-end power supply is to provide an efficiency of 92% at a load factor of 50%.

• CSCI (Climate Savers Computing Initiative)

The Climate Savers Computing Initiative (CSCI) founded by Google Corporation and Intel in 2007 is a non-profit organization in which general consumers, companies and environmental protection organizations having high eco-awareness participate. The goal of this initiative is to promote the development, introduction and utilization of technology for improving the power efficiency of computers and of smart technology for reducing the consumption of power by computers during emergency operation. As of July 2009, application of the International Energy Star Program’s required efficiency of front-end power supplies will also be requested.

Overseas Subsidiaries

North America

Fuji Electric Corp. of America

Sales and marketing of inverters, power distributors & control equipment, power supplies, and ring blowers

Headquarters Office
Phone +1-510-440-1060 Fax +1-510-440-1063

New Jersey Office
Phone +1-201-712-0555 Fax +1-201-368-8258

Ohio Office
Phone +1-513-326-1280 Fax +1-513-326-1288

Illinois Office
Phone +1-847-397-8030 Fax +1-847-925-9632

Virginia Office
Phone +1-540-491-9625 Fax +1-540-491-9629

Texas Office
Phone +1-713-789-8322 Fax +1-713-789-8358

Los Angeles Office
Phone +1-714-540-3854 Fax +1-714-540-5731

Marketing of semiconductor devices and photoconductive drums
Phone +1-732-560-9410 Fax +1-732-457-0042

EU

Fuji Electric Europe GmbH

Marketing of Drive & Automation equipment, semi-conductors, photoconductive drums for copiers and printers

Head Office
Phone +49-69-6690290 Fax +49-69-6661020

Erlangen Office
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Marketing of semiconductor devices
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Marketing of semiconductors
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Marketing of power distributors, control equipment and drive system products in Taiwan
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