

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 difficulty 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
	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
	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
	Overload capacity	105%, 1 min at rated current																												
	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					
	Allowable power variation	Voltage: $\pm 10\%$ (Inter-phase unbalance within 2%), Frequency: $\pm 5\%$																												
Control power supply	Phase, Voltage, Frequency	3-phase, 200/220V, 50/60 Hz																												
	Allowable power variation	Voltage: $\pm 10\%$ Frequency: $\pm 5\%$																												
Control, structure	Control system	Constant V/f control with simple sensor-less vector control																												
	Output frequency range	0.2 Hz to 50/60 Hz (optionally up to 120 Hz)																												
	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, ob-

Fig.2 Plant drive application map

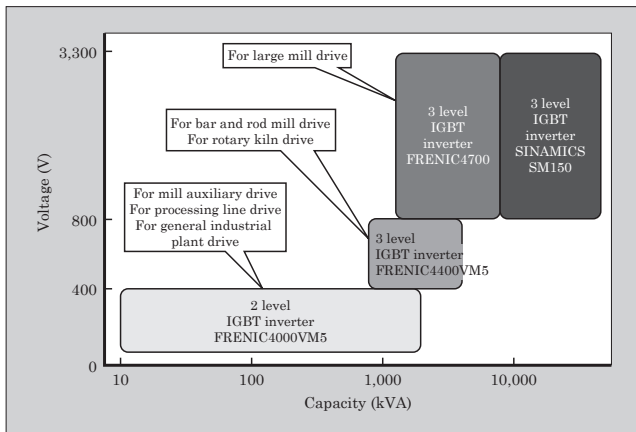


Table 2 Plant drive standard specifications

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 \pm 0.01%	Speed \pm 0.01%	Speed \pm 0.01%

server control function, etc.

- (d) Easy to maintain

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

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.

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 tachogenerator.

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.

Fig.3 Tuning-less control configuration

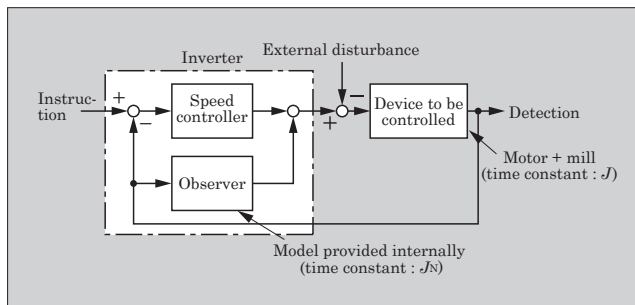
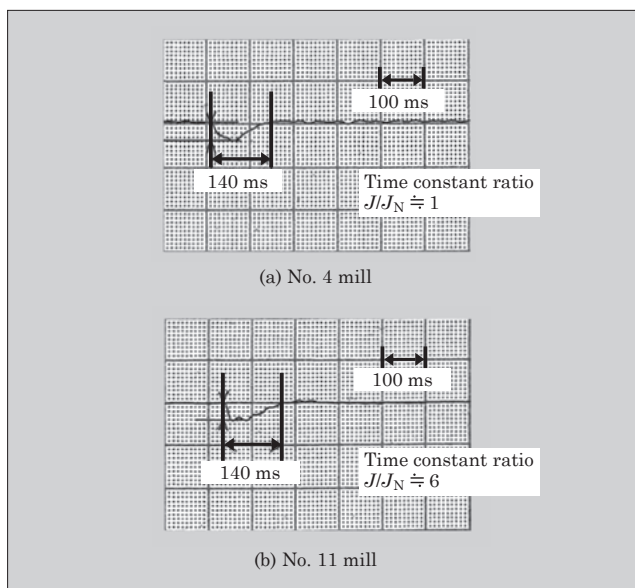


Fig.4 Results of application of tuning-less control to bar and rod mill



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 con-

struction 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

Fig.5 Large capacity servo system

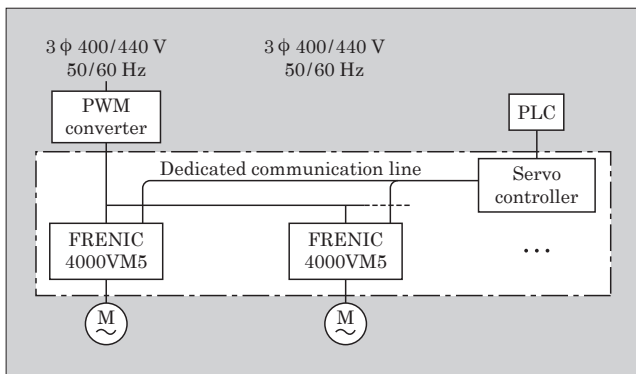
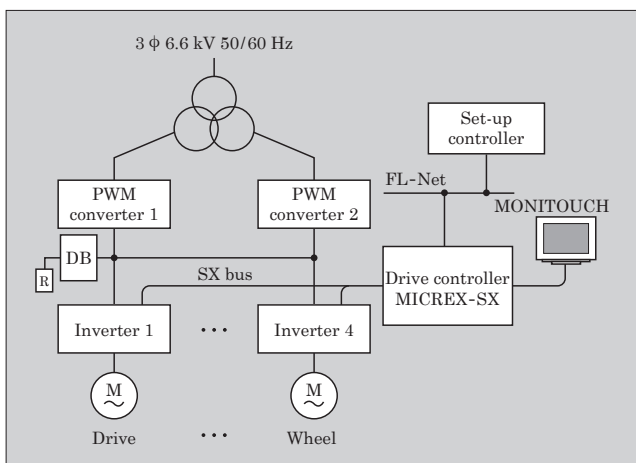


Fig.6 Single system diagram for drive system test equipment



- (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

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

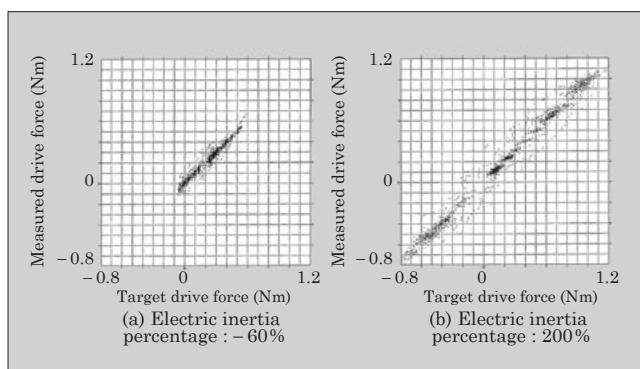
Table 3 Electric inertia-type chassis dynamometer requirements

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 momen-

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



tary 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.

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

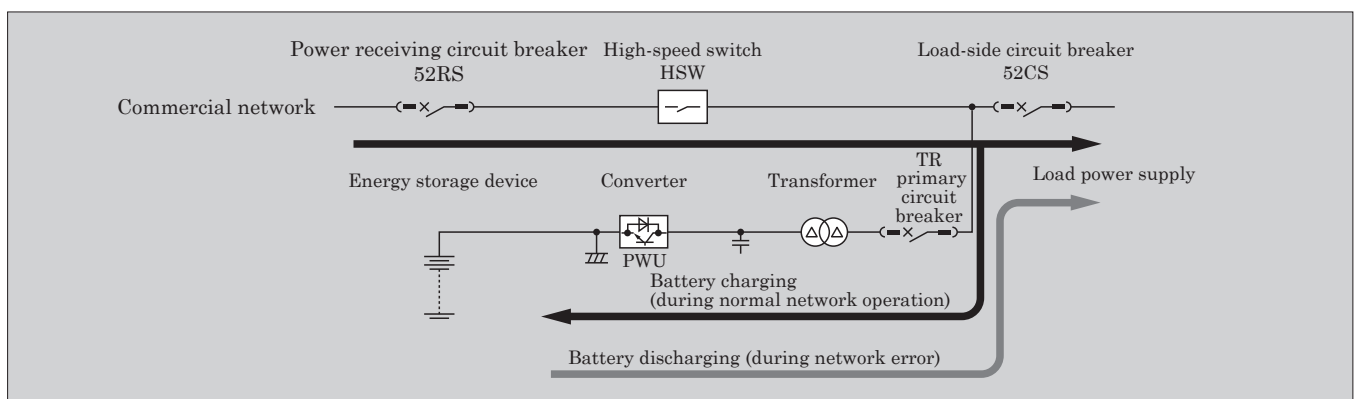
Figure 8 shows a photograph of the external appearance, Table 5 lists basic specifications, and Fig. 9 shows the configuration of this system.

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.





* All brand names and product names in this journal might be trademarks or registered trademarks of their respective companies.