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e-Front runners

# FUJI ELECTRIC REVIEW

4

2003 VOL.49

Inverters, Servo Systems, Power Supplies and Distribution & Control Equipment


Fuji Electric Group

e-Front runners

Rich functionality to support a wide variety of applications

Compact new design

Simple operation


3-phase, 200 V, 0.75 kW, Actual size photo

Supports peripheral devices

Wide variety of models

Compatible with international standards

# The New Compact Inverter
# FRENIC-Mini Series

**FRENIC-Mini is a series of technology-intensive compact inverters developed by Fuji Electric, the global leader* for compact general-purpose inverters (3.7 kW and lower).**

The rich functionality, compact size, simple operation, wide variety of models and global compatibility of this inverter series are provided to meet customer needs for higher performance, system compatibility, energy savings, power savings and lower overall cost in machines and apparatus such as conveyance and transportation machinery, fan pumps, centrifuges, food machinery, etc.

*** Based on market share. Source: US-based ARC Advisory Group, "Low Power AC Drive Worldwide Outlook" (2001)**

**3-phase 200 V series: 0.1 to 3.7 kW, single-phase 200 V series: 0.1 to 2.2 kW**
**3-phase 400 V series: 0.4 to 3.7 kW, single-phase 100 V series: 0.1 to 0.75 kW**

# Fuji Electric Inverters

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# REVIEW

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## CONTENTS



**Cover photo:**

Fuji Electric has advanced new product development to provide the highest level of quality, performance and services in the world, focusing on power electronics equipment, power distribution & control equipment, and drive control equipment as basic components for FA systems. For wide product range of the system components, globalization, safety, practical usability, compactness, and environmental compatibility are commonly required.

The cover photo; Fuji Electric's latest manual motor starters and combination starters together with inverters and servo systems incorporating power electronics technology, arranged around a map of the world, symbolizes the global deployment of drive and control equipment.

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# FRENIC-Mini Series Compact Inverter

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**Takashi Nakanishi**

## 1. Introduction

General-purpose inverters are utilized in a wide range of applications for such uses as increasing the energy efficiency of fan pumps and increasing the labor saving and automation of industrial equipment. General-purpose inverters range from a series for simple variable-speed use to a series that utilizes sophisticated vector control, and are selected according to the required performance and functionality of the application.

The new developed FRENIC-Mini Series was designed to achieve compact size and low price, and has realized a level of performance and functionality at a low price, suitable not only for simple variable-speed use, but also for applications such as conveyance and transportation machinery which had formerly required top-tier models. Moreover, through environmental considerations such as the noise reduction and the partial adoption of lead-free solder as well as improved maintainability and longer life, this series was conceived to be a global product that can be used widely throughout the world.

Features of the FRENIC-Mini Series are introduced below.


Fig.1 External view of FRENIC-Mini Series

## 2. Wide Variety of Models

Figure 1 shows the external view of the FRENIC-Mini Series. The newly developed FRENIC-Mini Series is the successor to the former FVR-C11 Series and has kept the same external dimensions.

In consideration of suitability for global markets, a 3-phase 400 V series, which did not exist for former models, has been added.

Moreover, in order to cover various customer applications, a built-in EMC (electromagnetic compatibility) filter type, built-in braking resistor type, and a type compatible with RS485 communication have been

Fig.2 Built-in EMC filter type and built-in braking resistor type

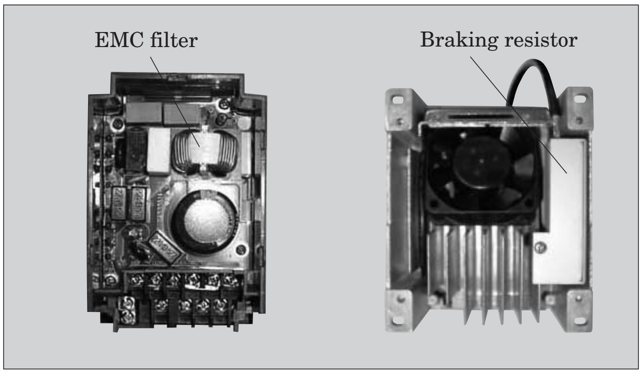



Table 1 Variety of FRENIC-Mini Series models

| Item | Varieties | | |
|---|---|---|---|
| Power supply voltage | 1 | Single-phase 100 V | 0.1/0.2/0.4/0.75 kW |
| | 2 | Single-phase 200 V | 0.1/0.2/0.4/0.75/1.5/2.2 kW |
| | 3 | 3-phase 200 V | 0.1/0.2/0.4/0.75/1.5/2.2/3.7 kW |
| | 4 | 3-phase 400 V | 0.4/0.75/1.5/2.2/3.7 kW |
| EMC filter | 1 | None | All models |
| | 2 | Built-in type | All models except single-phase 100 V |
| Built-in braking resistor | 1 | None | All models |
| | 2 | Built-in type | 1.5/2.2/3.7 kW (3-phase 200 V/400 V) |
| RS-485 compatible | 1 | None | All models |
| | 2 | Same package | 3-phase 200 V/400 V |

(shaded) : Additional models and functions developed as quasi-standard models in this series. (See Fig. 2.) In the past, these features had only been available as options.

Table 1 lists the model varieties.

In contrast to the former series which had 17 models, the FRENIC-Mini Series has been expanded greatly to 58 models to accept wide range of customer needs.

Just increasing the number of models would lead to a drastic increase in the types of component parts. However, because the FRENIC-Mini Series was designed to standardize the common components, and function allocation was optimized for structural units such as the control board and power supply board, this series was realized with almost no increase in the number of such units.

## 3. Technology for High Performance

Simple torque vector control was developed to enhance the torque characteristics of small-capacity general-purpose inverters, and to provide automatic energy-saving, stall prevention and other functions that are demanded by the market. As a result of the ratification of the Kyoto Protocol, an international accord to thwart global warming, the energy-saving effect of inverters has been attracting attention, and even small capacity inverters are being provided with energy-saving functions.

Simple torque vector control has enabled powerful operation to be realized at low-speed and made possible the application of inverters to conveyance and transport machinery and mixers. Moreover, the energy-saving function has made it possible for fan pump applications to achieve even higher efficiency. Figure 3 shows a control block diagram.

Fig.3 Control block diagram

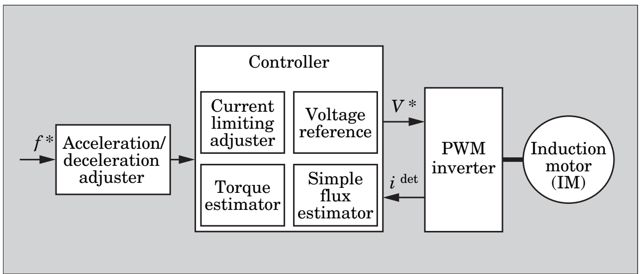
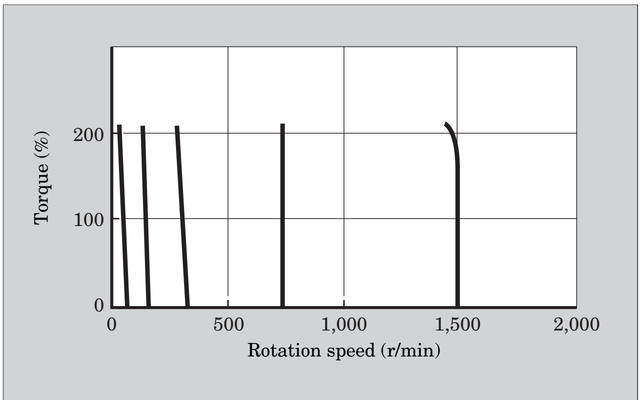



Fig.4 Speed vs. torque characteristics




### 3.1 Simple torque vector control

An induction motor flux estimator operating by means of *V/f* control enables the constant application of an appropriate voltage, regardless of the load, and the generation of smooth, large torque even at low-speed. Consequently, a starting torque of 150 % (at 5 Hz) was achieved.

Figure 4 illustrates the speed vs. torque characteristics. Slip compensation control enables highly responsive and stable operation to be achieved in response to load fluctuations (step loads).

Figure 5 illustrates the dynamic characteristics during slip compensation.

Moreover, voltage control performance was enhanced and motor instability at low speed was improved to approximately 1/2 compared to our former models. Figure 6 illustrates the dynamic characteristics of motor instability at low speed.

### 3.2 Automatic energy-saving function

Torque is calculated from estimated values of the flux estimator of Fig. 3 and from the induction motor current. Because an appropriate voltage can be applied to the induction motor in accordance with the

Fig.5 Dynamic characteristics during slip compensation

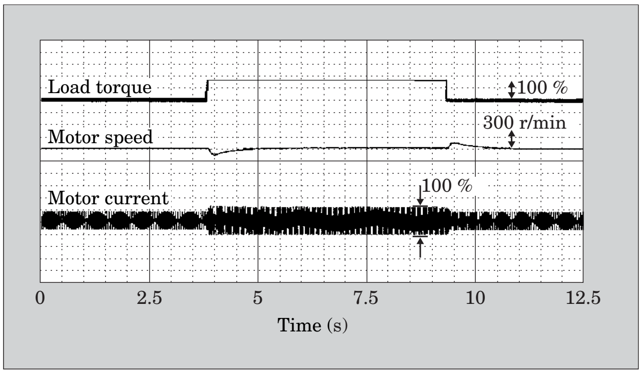



Fig.6 Dynamic characteristics of motor instability at low speed

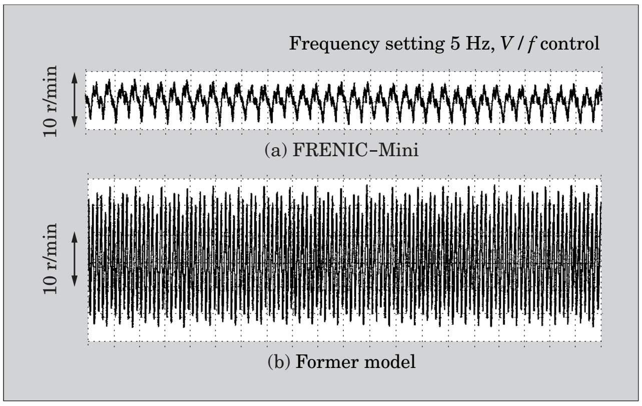


Fig.7 Energy-saving characteristics

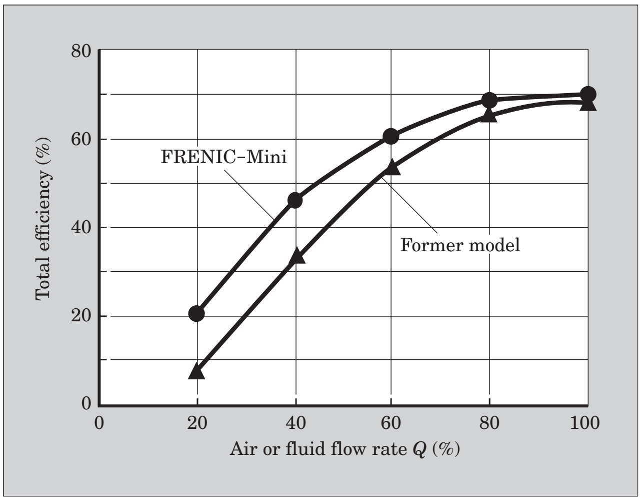
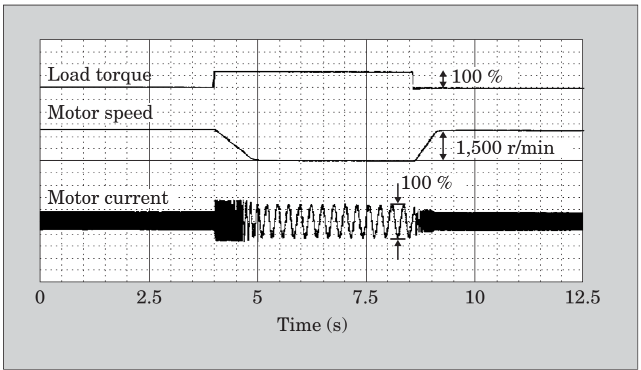



Fig.8 Dynamic characteristics of current limiting function




load, the induction motor efficiency can be kept at its optimal state. Figure 7 illustrates the energy-saving characteristics.

### 3.3 Highly responsive current limiting function

A highly responsive current limiting function is provided so that operation can continue at impact load torque without tripping. This function and the slip compensation control described in paragraph 3.1 have advanced the application of inverters to conveyance and transportation machinery.

Figure 8 illustrates the dynamic characteristics of the current limiting function.

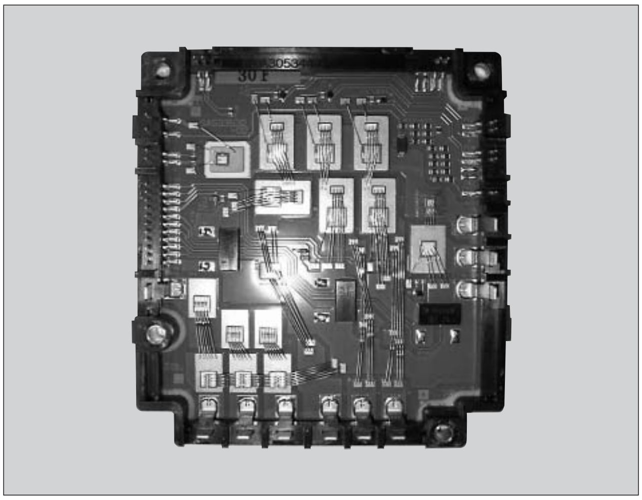
## 4. Environmental Considerations

### 4.1 Reduction of EMC noise

The noise generated by an inverter may cause other devices to malfunction in some cases, and for this reason, the reduction of generated noise is an important issue.

The main cause of inverter generated noise is the switching of the IGBT (insulated gate bipolar transistor) element and of the control power supply FET (field effect transistor) in the main circuit. Other types of noise include conductive noise that is transmit through

Fig.9 IGBT module using lead-free solder



the stray capacitance between modules and wiring and ground, and radiative noise generated by electromagnetic waves.

Former inverter models have implemented noise reduction measures, for example, by lowering the voltage change rate $dV/dt$ of the IGBT in the main circuit.

The FRENIC-Mini Series employs such noise-reducing schemes as a structure that cuts off the transmission path for the FET of the control power supply.

Moreover, in former models, a noise reducing EMC filter was an optional external attachment. But an internal EMC filter has been developed for the FRENIC-Mini Series in compliance with the European EMC standard (EN61800-3).

### 4.2 Use of lead-free solder

Lead is an environmentally harmful material and its use will be restricted in Europe beginning in 2006. Therefore, it will not be possible to use lead in the future.

An IGBT module that utilizes lead-free solder was developed for the new FRENIC-Mini Series. (See Fig. 9.)

The use of lead-free solder enables better thermal resistance and power cycle characteristics than in the past.

## 5. Enhanced Maintainability

### 5.1 Longer service life of cooling fan

The inverter contains internal parts which have finite service lives, such as a cooling fan, DC bus capacitor, electrolytic capacitor on the printed circuit board, etc. It is recommended that these parts be replaced periodically.

In former models, the recommended standard replacement interval was 3 years for the cooling fan, 5 years for the DC bus capacitor and 7 years for the

Table 2 Criteria for judging part replacement based on "maintenance information"

| Part to be replaced | Criteria |
|---|---|
| DC bus capacitor | Capacitance is 85 % or less of value when shipped |
| Electrolytic capacitor on printed circuit board | 61,000 or longer cumulative run time |
| Cooling fan (applicable motor rating : 1.5 to 3.7 kW) | 61,000 or longer cumulative run time |

electrolytic capacitor on the printed circuit board. The cooling fan had the shortest service life.

However, to use an inverter for 10 years, for example, would require that the cooling fan be replaced 3 times, resulting in an increase in the frequency of maintenance work.

The FRENIC-Mini Series uses a long-life cooling fan (designed for a lifespan of 7 years at 40°C) having a standard replacement interval that is the same or longer than that of the DC bus capacitor. This reduces the amount of replacement work.

### 5.2 Service life diagnosis function

The DC bus capacitor has a finite service life, and its electrostatic capacity decreases as the remaining lifespan becomes shorter. This decrease in capacitance varies widely according to usage conditions such as the ambient temperature and load conditions and cannot be determined solely from the number of years of usage.

In order to judge when part replacement is necessary, the FRENIC-Mini Series automatically performs an internal computation of the discharge time of the DC bus capacitor when the power is turned off and displays the percentage decrease from the initial value.

Moreover, cumulative run time for each of the other finite service life components, the electrolytic capacitor of the control power supply and the cooling fan, may be referenced from the "maintenance information" via the keypad.

Table 2 shows the criteria for judging the part replacement of each finite service life component.

Further, when these finite service life components reach the criteria of Table 2, they are judged to have reached the end of their useful life and this decision may be output from a transistor as a lifespan forecast signal.

## 6. Advanced Functionality

### 6.1 Keypad function

The keypad of the former FVR-C11 series was chiefly for setting monitor functions such as frequency and functions that determined inverter operation, but the keypad of the FRENIC-Mini Series utilizes a menu mode to dramatically increase the quantity of displayable information, which includes maintenance and alarm information.

Table 3 Displayable information in the menu mode

| Menu No. | Menu | LED display | Description |
|---|---|---|---|
| 1 | Function code, Data setting | 1.F_ _ to 1.y_ _ | Sets function codes and data |
| 2 | Function code, Data verification | 2.rEF | Displays only function codes that have been changed from their factory defaults |
| 3 | Drive monitoring | 3.oPE | Displays operating information required for maintenance or testing |
| 4 | I/O checking | 4.i_o | Displays external interface information |
| 5 | Maintenance information | 5.CHE | Displays maintenance information including cumulative run times |
| 6 | Alarm information | 6.AL | Displays alarm history and the operation information at the time when the alarm occurred |
| 7 | Data copying (requires a remote keypad) | 7.CPy | Reads/writes/verifies function codes and data |

Table 3 lists the contents corresponding to each menu number in the menu mode.

In addition to the functionality of the FVR-C11 Series, the FRENIC-Mini Series has added individual menus for function code and data verification, drive monitoring, I/O checking, maintenance information, and alarm information.

The drive monitoring function allows the display of 10 types of data including output current, the maintenance function allows the display of 12 types of data such as cumulative run time, and the alarm information function allows the display of 19 types of data including the output frequency generated when an alarm occurs.

Moreover, in contrast to the former series, which was capable of storing only information from the prior alarm occurrence, the FRENIC-Mini Series is able to store information from the past four alarm occurrences. Such information is useful for analysis of the event when trouble occurs.

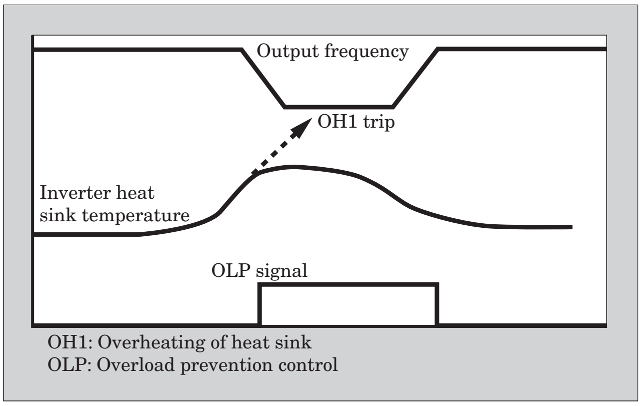
In addition to the standard keypad, a remote keypad is provided optionally. Also, LEDs (light emitting diodes) for unit display and to indicate the operating status, and a data copying function have been added to the standard keypad.

### 6.2 Overload prevention control function

In an application where operation is continuous, such as a fan pump, it may be undesirable in some cases to halt operation to protect the equipment, even when the inverter becomes overheated due to load and ambient temperature conditions.

The overload prevention control function is a newly

Fig.10 Overload prevention control function




developed function that, as shown in Fig. 10, operates before the inverter trips due to cooling fan heating or inverter overloading, to automatically lower the output frequency of the inverter in order to avoid tripping.

## 7. Conclusion

Features of the FRENIC-Mini Series of compact inverters have been presented above.

For the highly price-competitive inverter class of 3.7 kW and below, the development of the FRENIC-Mini Series has broadened the range of possible applications to include uses that require one-class higher performance, and global applications are anticipated.

Fuji Electric will continue to actively incorporate new technology and functions, and will strive to develop even better products for the future.

# Control Technology of FRENIC5000VG7S Vector-control Inverter

**Yoshikazu Ichinaka**
**Tatsuya Yamada**
**Tsutomu Miyashita**

## 1. Introduction

Fuji Electric's high-performance vector-control inverter "FRENIC5000VG7S" series (VG7S) is being used in many applications such as elevators, cranes and winding machines as a special specification product. Even in fields where dedicated controllers and variable speed drive devices have been used in the past, demands for price reduction are resulting in a yearly increase in the number of cases in which systems containing VG7S and other general-purpose inverters are customized and used.

This paper introduces the VG7S's characteristic control technology which is capable of driving induction machines, synchronous machines and DC machines. Also described are example applications that leverage the flexible technology of digital control systems and example applications that utilize the optional OPC-VG7-UPAC user programmable application card (UPAC).

## 2. Application to a Power Supply System

### 2.1 Power backup system with flywheel

Fuji Electric has delivered an inverter that has specifications suitable for use in a power backup system with a flywheel. This power backup system is configured as shown in Fig. 1 and has the following features:

(1) The speed of a flywheel whose inertia is more than 100 times greater than that of the motor is controlled to operate stably at high speed. Motor efficiency during standby is maximized in order to reduce power consumption.

(2) When a power failure is detected, the system switches to automatic voltage regulator (AVR) control, and commercial power is supplied to suppress excessive voltage drops even in the case of a power failure at 150 % load.

Use of this system together with an uninterruptible power supply (UPS) has the advantage of enabling the system to be configured without the use of lead batteries, thereby eliminating the necessity for the processing of specific hazardous wastes. Moreover, the cost of using a UPS is less expensive than batteries when capacity is being enlarged. For these reasons, an increase in demand for these types of systems is anticipated.

Figure 2 shows the backup response after a power failure in the case of 20 kW and a 150 % load. Figure 3 shows the response of load torque fluctuation (100 %

Fig.1 Block diagram of power backup system with flywheel

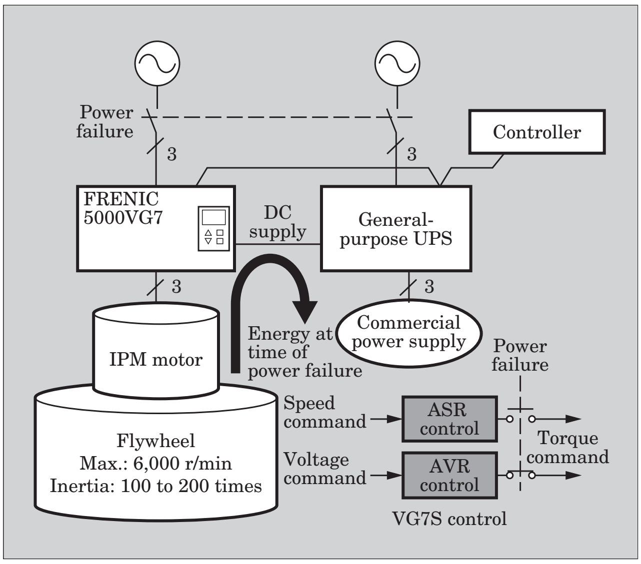
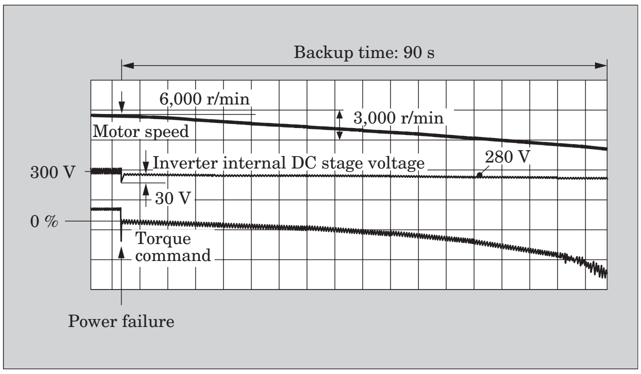



Fig.2 Response of power backup after power failure (20 kW, 150 % load)



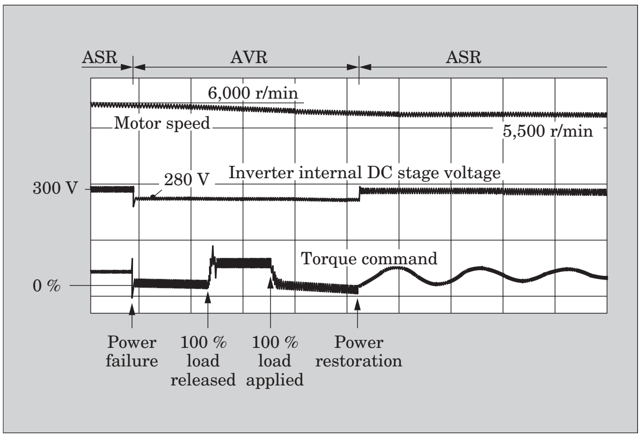


Fig.3 Response of load torque fluctuation during power failure and behavior at power restoration (20 kW, 100 % load)

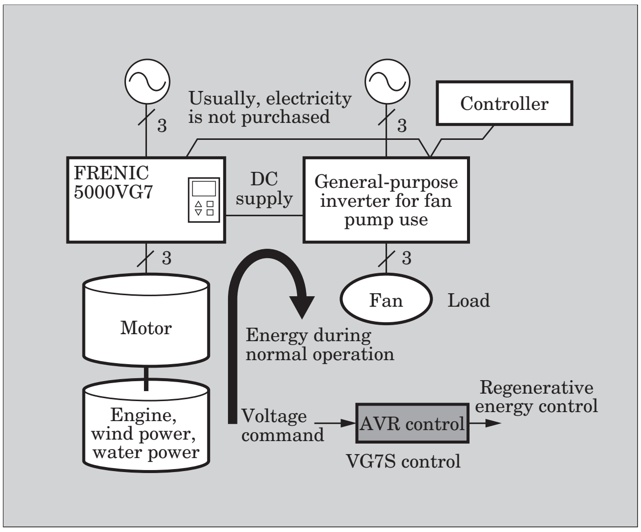


Fig.4 Machine energy regeneration system

load) during backup operation after a power failure and the behavior at power restoration. After power is restored and speed has been selected, the torque fluctuates due to the transition involved in bringing a large inertial body to a constant speed

### 2.2 Machine energy regeneration system

Figure 4 shows an example application to a system that effectively uses the machine energy.

This system converts surplus kinetic energy such as engine power, wind power or water power into electrical energy and supplies it to a fan or pump. Features of this system are as follows:

(1) Voltage is controlled so that energy is continuously regenerated via the motor.
(2) Controller is monitored to ensure that load does not exceed kinetic energy × total efficiency (machine, motor, inverter efficiency), in order to avoid having to purchase electric power for the system.

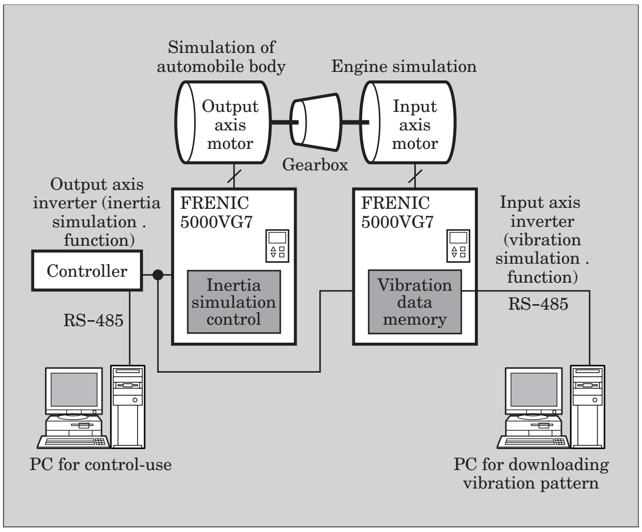


Fig.5 Block diagram of gearbox test equipment

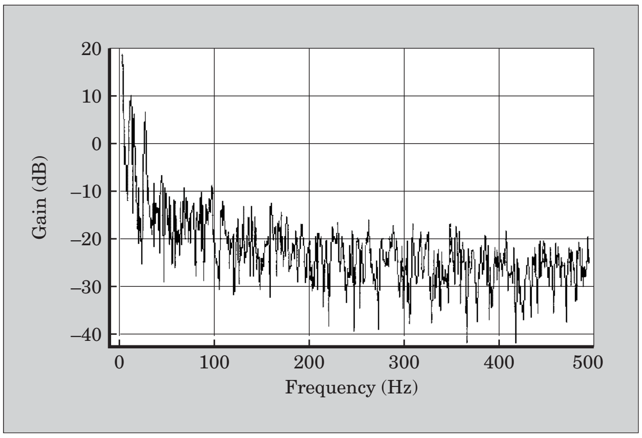


Fig.6 Frequency spectrum of engine driving

## 3. Application to Gearbox Test Equipment

### 3.1 Overview of test equipment

This system uses an electric motor to simulate the inertia of the automobile body and engine behavior. System features are as follows:

(1) Complex vibration patterns generated by the engine can be reproduced by means of a vibration simulation function. This enables testing in an environment that closely resembles actual conditions.
(2) Motor inertia can be changed electrically by means of an inertia simulation function. Compared to the conventional fixed-inertia flywheel (mechanical inertia) mechanism, this system allows for a greater variety of tests to be performed and requires less time for the acceleration and deceleration processes.

Figure 5 shows a block diagram of the gearbox test equipment that Fuji Electric recently delivered.

Fig.7 Vibration simulation results

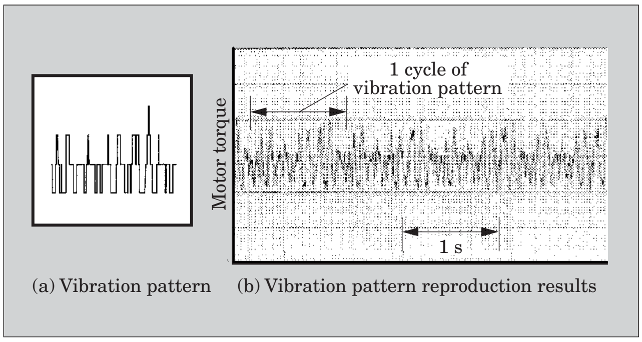



Fig.10 Example configuration of crane hoisting mechanism

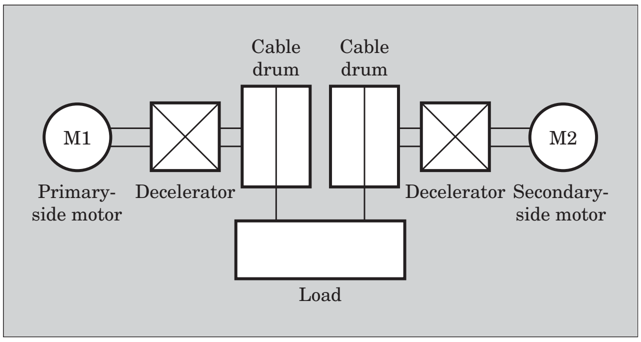



Fig.8 Block diagram of inertia simulation control

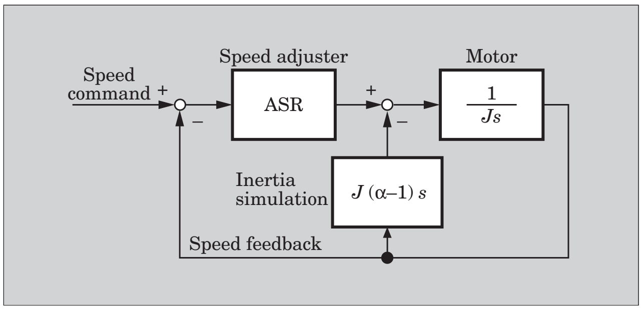
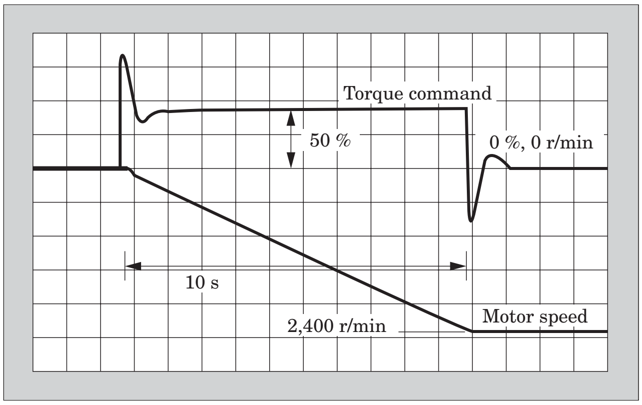



Fig.9 Inertia simulation results (**α** = 2)




In the system, the output axis motor simulates the automobile body inertia and the input axis motor simulates the engine.

### 3.2 Vibration simulation

Figure 6 shows the fast Fourier transform (FFT) results of data measured from an actual engine. The simulated frequency band had a maximum frequency of 500 Hz. The vibration pattern is prepared from this data.

Figure 7 shows the results of vibration simulation based on the downloaded data of the vibration pattern of the frequency spectrum of Fig. 6. In the figure, 7(a) is the downloaded vibration pattern for 1 second (engine measurement data), and 7(b) is the result of repeatedly reproducing that pattern.

### 3.3 Inertia simulation

Figure 8 shows a block diagram of the control system for inertia simulation.

In an inertia simulation, the speed response of a motor is made to correspond directly to the inertia to be simulated. The time-rate-of-change of the motor speed feedback is multiplied by $J$, the motor + mechanical inertia, and by a coefficient ($\alpha$–1) and the thus computed torque is added to (subtracted from) the output of the speed adjuster (ASR) to express the value of the simulated inertia. The setting operation is performed as follows:

- ○ $\alpha$ = 1: motor + mechanical inertia only
- ○ $\alpha$ < 1: simulates an inertia less than the value of motor + mechanical inertia
- ○ $\alpha$ > 1: simulates an inertia greater than the value of motor + mechanical inertia

Figure 9 shows the acceleration results in the case where inertia ratio $\alpha$ = 2. For 100 % torque and acceleration to 2,400 r/min, the acceleration required 5 s when $\alpha$ = 1, but nearly twice as long (10 s) was required in a simulation of twice the inertia.

## 4. Application to a Crane Mechanism

### 4.1 Synchronized position control

Fuji Electric has delivered an inverter for use in a crane hoisting mechanism. This system is a vertical transport system that consists of two hoisting mechanisms. Its features are as follows:

(1) In addition to the pulse train control of the two motors, in order to compensate for position shifting due to stretching of the hoist rope, the mechanical part of each hoisting mechanism is provided with a sensor and the positional relationship of the two hoisting mechanisms is automatically corrected in real time.

(2) The amount of position correction is stored even when power is off so that the synchronous positions can be kept.

Figure 10 shows an example configuration of the crane hoisting mechanism.

Fig.11  Block diagram of trace back system

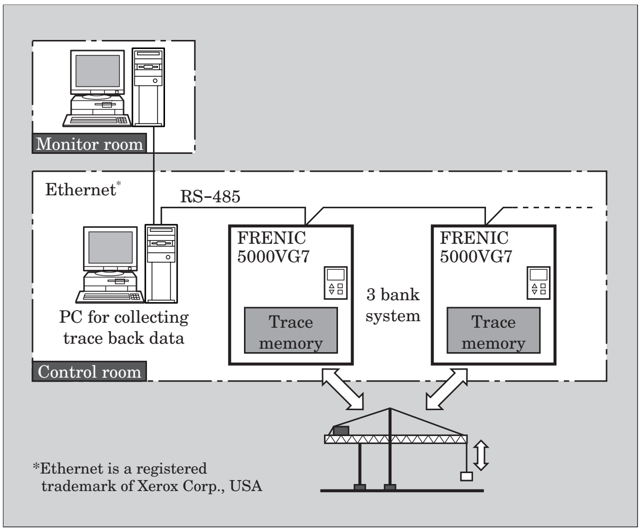



Fig.12  Example configuration of Ward-Leonard system

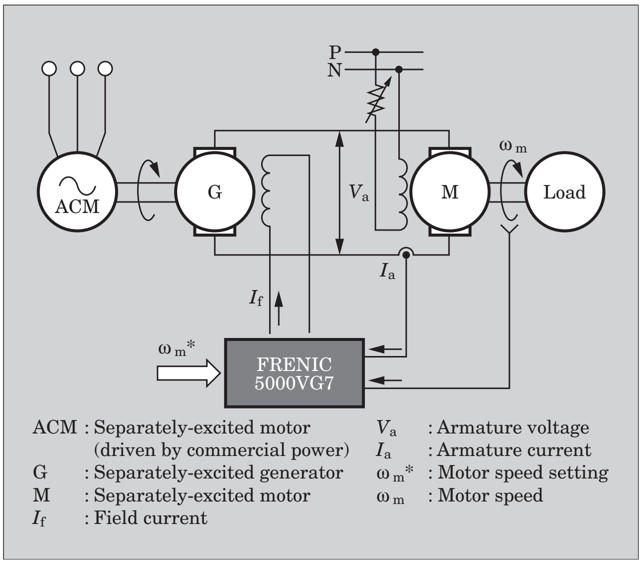
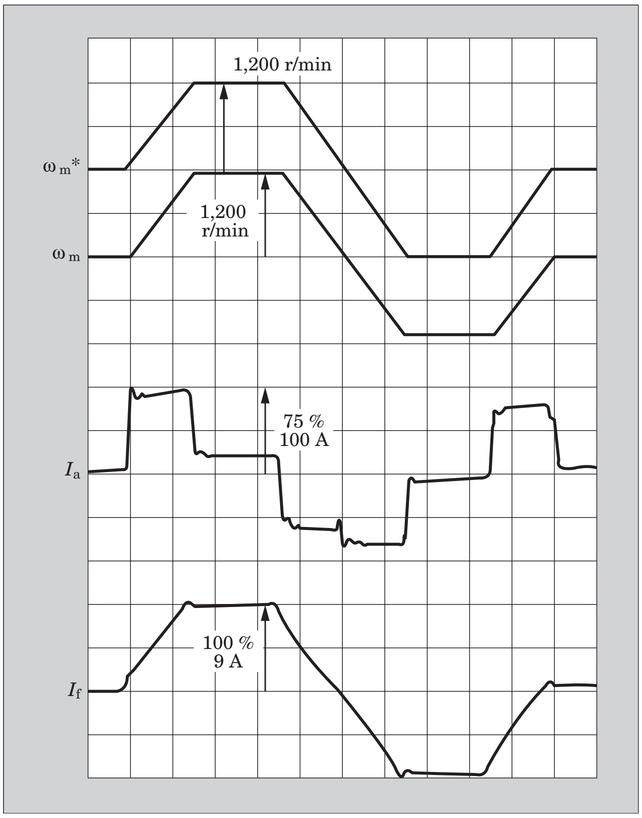



Table 1  Trace back conditions

| Item | Unit | Min. | Max. value |
|---|---|---|---|
| Number of banks | — | 1 | 3 |
| Sampling time | ms | 1 | 10 |
| Total measurement time | ms | 500 | 1,500 |
| Measurement time before trigger | ms | 0 | 1,500 |

Fig.13  Operating data




### 4.2 Trace back system

Fuji Electric has delivered a trace back system that monitors the operating status of a harbor crane and supports data analysis in the case of an abnormality. This system is configured from VG7S inverters, a UPS and a PC. System features are as follows:

(1) The system is comprised of a monitor room and a control room, such that the operating status of several VG7S inverters in the control room can be monitored all at once from a PC located in the monitor room.

(2) The occurrence of an abnormality triggers various types of data to be saved automatically. It is possible to connect the PC only in cases when an abnormality occurs.

Figure 11 shows an outline of the trace back system.

From a list of 20 items including speed setting, speed detection and motor output, data trace back is possible for a maximum of 8 selected items. Moreover, the trace back conditions of Table 1 may set to enable trace back to be realized according to various intended purposes.

## 5. Application to DC Machine Driving

The use of a Ward-Leonard system to control the voltage of a DC motor has long been established. Figure 12 shows an example system configuration. Here, separately-excited motor (M) is electrically connected to separately-excited generator (G). VG7S adjusts the field current ($I_f$) of G, which is direct-coupled to induction motor (ACM), to manipulate armature current ($I_a$) and control the motor torque. Additionally, speed control is performed by means of motor speed ($\omega_m$) feedback. This system was delivered to replace an older system.

Figure 13 shows the operation of an actual assembly for acceleration and deceleration up to the rated speed. $I_a$ and $I_f$ increase according to the motor speed setting ($\omega_m$*). $I_f$ is controlled to generated armature voltage ($V$a) in accordance with $\omega_m$, and $I_a$ is controlled according to the acceleration and deceleration pattern of the motor.

## 6. Conclusion

An overview of applied examples of the control technology of the high-performance vector-control inverter FRENIC5000VG7S has been presented above.

Hereafter, Fuji Electric will continue to leverage the flexible technology of digital control systems, and in addition to applications for driving induction machines, synchronous machines and DC machines, will strive to development applications that utilize the UPAC, to realize various types of functions and performance, and to develop inverters that meet user requirements.

Lastly, the authors wish to express their sincere gratitude to the users who graciously accommodated our requests during the write-up of system examples for this paper.

# Expansion of FALDIC-α Series AC Servo Systems


**Hiroaki Hayashi**
**Takumi Migaki**
**Isao Igarashi**


## 1. Introduction

With the aim of achieving a smaller size, higher precision, faster response and less wiring, it is recently popular for AC servo systems to be equipped with a serial encoder and to be connected to various interfaces to upper level systems. Moreover, by simplifying the adjustment work required for each installed machine, providing various control functions to suppress mechanical vibration while keeping high-speed response capability, and implementing full-closed control to achieve even higher precision, daily progress is being made toward the realization of high precision, easy to use equipment.

In consideration of these trends, Fuji Electric brought to market the FALDIC Series high-performance AC servo systems, and the marketplace reception has been favorable. In order to broaden the range of market applications and to address demands for applications such as printing machines, molding machines and large conveying equipment, Fuji Electric has newly introduced a medium capacity FALDIC-α Series (hereafter, the medium capacity series) that is provided with vibration suppressing control and a notch filter as standard functions, in addition to the various types of interfaces supported by prior models.

An overview, specifications and features of this medium capacity series are presented below.

## 2. Features of the Medium Capacity Series

Figure 1 shows a model map of the FALDIC Series and Fig. 2 shows an external view of the FALDIC-α Series.

Because the medium capacity series keeps the features of the FALDIC-α Series, it realizes a dramatic improvement in functionality and performance compared to the FALDIC-IM Series, the former medium capacity series.

Main features are described below.

### 2.1 Damping control function with a 2-mass model

The damping control function of the FALDIC-α Series and FALDIC-β Series has been well-accepted in the marketplace, and Fuji Electric also provides this independently developed technology as standard function for this medium capacity series. The damping control function achieves a dramatic reduction in

Fig.1 Map of FALDIC Series models

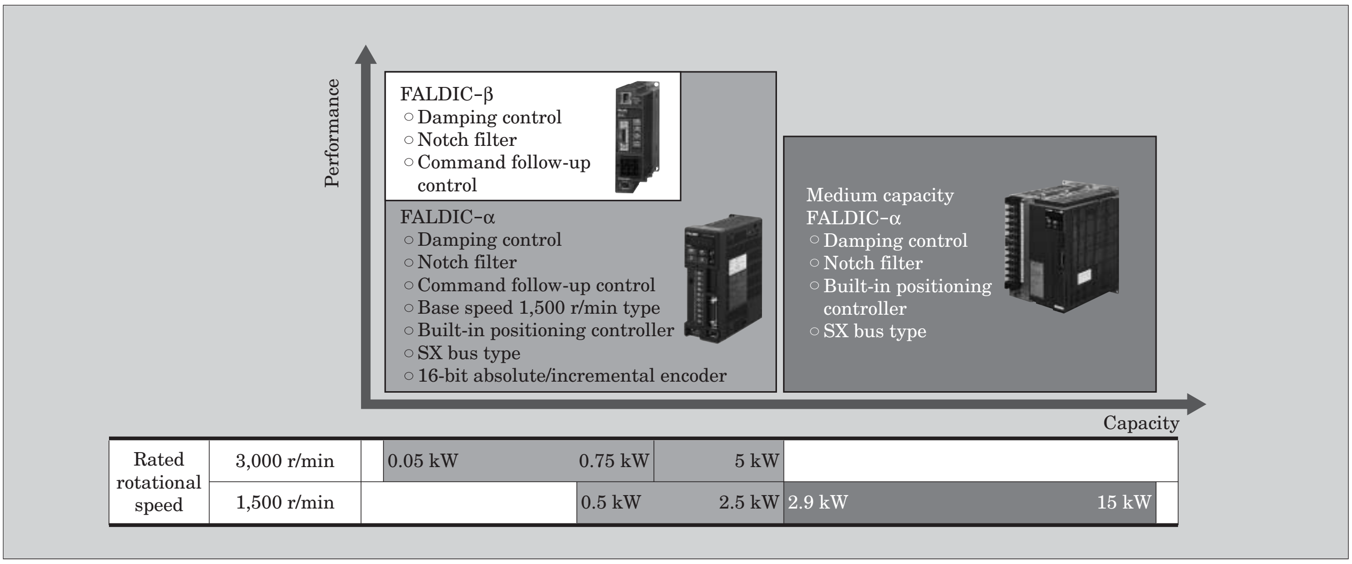


Fig.2 Appearance of FALDIC-α Series


position setting time and suppresses vibration of the mechanical system.

### 2.2 Notch filter function to suppress resonance of the machine

As in the case of the damping control function, a notch filter function that has been well-accepted with the FALDIC Series is also provided as a standard function. By presetting the servo amp with resonance point data as a parameter to prevent the inherent resonance of the machinery, the notch filter function can be used to decrease mechanical resonance.

### 2.3 Expanded user interface

This medium capacity series may be connected to the same PC loader (option) as for the FALDIC-α Series. This is useful in retaining the same ease of use, while reducing setup time and improving maintainability.

## 3. Product Specifications of Medium Capacity Series

### 3.1 Capacity range of the series

The series has capacities ranging from 2.9 to 15 kW (rated speed: 1,500 r/min) and may be applied to large torque loads.

### 3.2 Basic specifications of servo amp

Table 1 lists the basic specifications of the medium capacity series. There are four varieties of servo amp models according to their different control functions and interfaces to upper level systems.

(1) VVK type

The VVK servo amp is able to perform positioning control by means of pulse train input and can perform speed control and torque control by means of analog voltage input. The interface to an upper level controller is I/O based.

(2) VSK type

Table 1 Servo amp specifications

| Servo amp model (RYS○○○M3-□□□) | | | VVK | VSK | LPK | LSK |
|---|---|---|---|---|---|---|
| Main uses | | | Speed control | | Linear positioning | |
| Input power supply | | Voltage | 200 to 230 V, +10 % / –15 % | | | |
| | | Frequency | 50 / 60 Hz | | | |
| Control specifications | | Control method | Sinusoidal wave PWM control (all digital) | | | |
| | | Carrier frequency | 5 kHz | | | |
| | | Feedback | 16-bit serial encoder | | | |
| | | Speed range | 1 : 3,000 | | | |
| | | Frequency response | 300 Hz | | | |
| | | Overload capability | 236 to 250 % / 3 s (according to capacity) | | | |
| | | Positioning resolution | 16-bit (16,384 pulse equiv.) / rev | | | |
| | | Position management | Absolute / incremental selectable | | | |
| Control function | | Speed control | ○ | ○ | – | – |
| | | Torque control | ○ | ○ | – | – |
| | | Pulse train | ○ | ○ | ○ | ○ |
| | | PTP positioning | – | – | ○ | ○ |
| | | Origin return | ○ | ○ | ○ | ○ |
| | | Interrupt positioning | ○ | ○ | ○ | ○ |
| Interface specifications | Input | Digital | 8 points | 5 points | 21 points | 5 points |
| | | Analog | 2 points | – | 1 point | – |
| | | Pulse | 1 channel (can be either open collector or differential input) | | | |
| | Output | Digital | 5 points | 2 points | 10 points | 2 points |
| | | Analog | 2 channels | | | |
| | | Pulse | 1 channel (differential output) | | | |
| Environment | | Temperature, humidity | –10 to +55°C, 10 to 90 %RH (no condensation) | | | |
| | | Usage site, elevation | Indoors, 1,000 m or below (no dust, corrosive gas, flammable gas or direct sunlight) | | | |

Similar to the VVK type, the VSK servo amp is able to perform positioning control by means of pulse train input and can perform speed control and torque control in accordance with commands received from an upper level controller. Fuji Electric's MICREX-SX programmable controller is used as the upper level controller to realize various types of motion control. Fuji Electric has prepared a large library of software function blocks (FBs) that are optimal for motion control use, making it easy to configure applications according to customer needs.

(3) LPK type

A positioning control function is built into the servo amp, and positioning can be implemented by receiving on and off signals from the upper level controller. The interface to the upper level controller

Table 2 Servo motor specifications

| Servo motor model (GYM□□□BC1-○C) | 292 | 402 | 552 | 752 | 113 | 153 |
|---|---|---|---|---|---|---|
| Rated output (kW) | 2.9 | 4.0 | 5.5 | 7.5 | 11 | 15 |
| Rated torque (Nm) | 18.6 | 25.5 | 35.0 | 48.0 | 70.0 | 95.4 |
| Rated rotational speed (r/min) | 1,500 | | | | | |
| Max. rotational speed (r/min) | 3,000 | | | | 2,000 | |
| Max. torque (Nm) | 45.1 | 63.4 | 87.6 | 119 | 175 | 221 |
| Moment of inertia ($kgm^2$) | 0.0046 | 0.0068 | 0.0089 | 0.0125 | 0.0281 | 0.0315 |
| Rated current (A) | 23.8 | 30.0 | 42.1 | 54.7 | 58.6 | 78.0 |
| Max. current (A) | 56.0 | 76.0 | 110.0 | 130.0 | 140.0 | 170.0 |
| Insulation class | F type | | | | | |
| Rating | Continuous rating | | | | | |
| Protection ventilation | Fully enclosed, self-cooling IP67 (except for penetrating portion of shaft) | | | | | |
| Terminal (motor) | Canon connector | | | | | |
| Terminal (detector) | Canon connector | | | | | |
| Overheat protection | None (electronic thermal detection by servo amp) | | | | | |
| Attachment method | Flange attachment | | | | | |
| Shaft extension | Cylindrical shaft, with key | | | | | |
| Color of coating | N1.5 (semi-gloss) | | | | | |
| Detector | 16-bit incremental serial encoder (standard)<br>16-bit absolute serial encoder (option) | | | | | |
| Vibration | V15 | | | | | |
| Site of usage, elevation | Indoors, 1,000 m or below | | | | | |
| Ambient temperature, humidity | 0 to 40°C, 20 to 90 % RH (no condensation) | | | | | |
| Vibration resistance | 24.5 $m/s^2$ | | | | | |
| Total mass (kg) | 18 | 23 | 30 | 40 | 57.5 | 86 |

is I/O based, and a system can be configured without requiring a motion control module in the upper level system.

(4) LSK type

Similar to the LPK type, a positioning control function is built into the servo amp. The upper level controller is the abovementioned MICREX-SX, and point-to-point (PTP) positioning can be performed via the SX bus without use of a motion control module,

### 3.3 Basic specifications of servo motor

Table 2 lists the basic specifications of the medium capacity servo motor. The medium capacity servo motor uses a synchronous motor and achieves a large reduction in size and inertia compared to the former FALDIC-IM Series.

The built-in encoder is a 16-bit serial encoder, similar to the FALDIC-α Series, and a reduction in wiring, higher response and higher precision are realized.

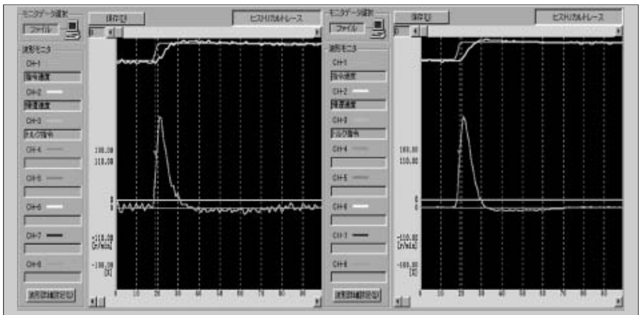
Moreover, requested features such as the provision of an absolute encoder, gears, brake, shaft key, etc. are available as options.

### 3.4 Main standard functions

(1) Damping control

The damping control function is a control technology developed independently by Fuji Electric to dramatically reduce both sustained vibration at the edges of mechanical parts, and vibration and shock to the machinery. In the implementation of this damping control function, a 2-mass mechanical model is provided within the control block, and the model is internally controlled so to eliminate vibration at its edges. By applying this control amount to compensate motor positioning and speed control, the vibration at the edges of mechanical parts can be suppressed

Fig.3 Effect of notch filter



Without filter With filter

This damping function enables faster operating speed of the machinery itself as well as a reduction in tact time and positioning stabilization time.

(2) Notch filter

The phenomenon of mechanical resonance occurs

Fig.4 Block diagram of full-closed control

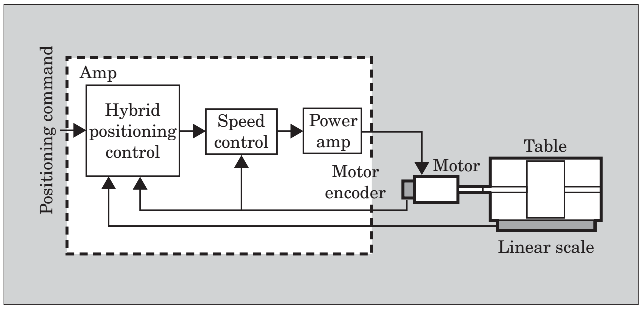
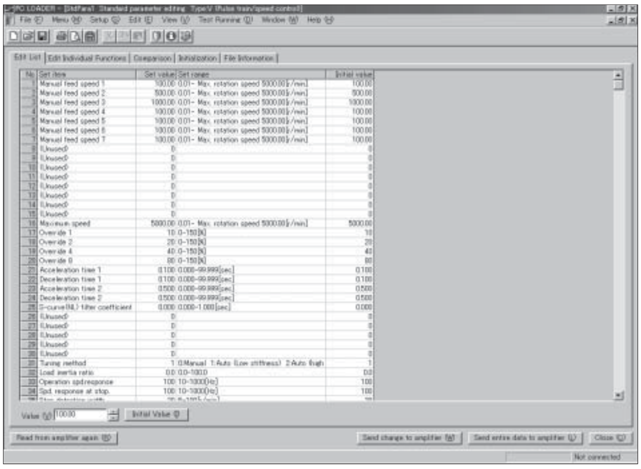



Fig.5 PC loader screenshot



at different points (frequencies) for each machine. The notch filter function acts to attenuate only the resonance frequency components of amp torque commands, and therefore the overall gain remains high. In other words, this function suppresses the phenomenon of mechanical resonance without degrading the overall response.

Figure 3 shows examples of torque command waveforms, both with and without using a notch filter. By presetting the servo amp with the parameters of resonance frequency and the amount of attenuation, the vibration-inducing components in a torque command can be suppressed to a large extent.

(3) Full-closed control

Full-closed control is a control method to achieve higher precision and is applied to systems in which positioning precision is affected by mechanical vibration. Full-closed control is available as an option with the medium capacity series. Figure 4 shows a block diagram of an implementation of the full-closed control method. Here, the position of a table or task to be controlled is detected as feedback from a linear scale (or external encoder), and hybrid position control is performed according to feedback from the servo motor's internal encoder (also known as the motor encoder). Since dynamic control is performed with feedback from the motor encoder and static control is performed with feedback from the linear scale, there is less positional deviation than in the case of conventional control methods, and the high-speed response performance is kept.

(4) PC loader

The same PC loader software of the FALDIC-α Series is also available with the medium capacity series as an option. The software is simple to operate and allows easy editing and copying of each parameter, real-time and historical tracing of various data, etc. Figure 3 shows example trace screenshots and Fig. 5 shows the parameter editing screen.

## 4. Conclusion

Features, specifications and an overview of the medium capacity FALDIC-α Series have been presented. This series was developed to provide a large improvement in control functionality and performance and to be applicable to a wide range of uses. We at Fuji Electric will continue our efforts to provide solutions that satisfy user needs.

# Expansion of Mini-UPS Series and Networked Operation Support

**Hiroshi Sandanbata**
**Nobuhisa Tanaka**
**Hideomi Naitou**

## 1. Introduction

In today's fast-paced information society, communication devices such as computers are required to be highly reliable, and accordingly, a stable power supply is an absolutely essential prerequisite. The use of an uninterruptible power supply (UPS) to protect critical devices from disturbances such as power failures, surges and noise, is already common knowledge among users. In addition to computer applications, UPSs have recently also been used in other various applications, and there is a growing diversity of specification requirements. Demands are emerging from new markets that had not existed before, including for example, demand for a capacitor-type UPS that does not require battery replacement and demand for a low-profile UPS that can be used with machine-room-less elevators. As for the management (chiefly, computer power management) of load devices that are backed-up by the UPS and the management of the UPS itself, UPS manufacturers are being requested to provide power management solutions suitable for different user environments.

In response to these demands from a diversifying market, Fuji Electric has developed the DipHunter, a maintenance-free instantaneous voltage drop protection device, a P-series UPS for use with elevators, a J-series UPS that supports foreign voltages, and the NetpowerProtect 200 V, 3,000 VA rack-type off-line UPS. To support networking, Fuji Electric has also developed the multi-server shutdown box and Web/SNMP (simple network management protocol) card UPS peripheral devices, and NetpowerView-F UPS management software. These products are introduced below.

## 2. Expanded Series with More Varieties of Models

### 2.1 DipHunter instantaneous voltage drop protection device

Nearly all power failures in Japan in recent years have been instantaneous voltage drop, with the majority lasting for no more than 200 ms and incurring a voltage dip of no more than 50 %.

Fig.1 External view of DipHunter instantaneous voltage drop protection device

Aiming to protect load devices from the instantaneous voltage dips that comprise nearly all power failures, the DipHunter (Fig. 1) is a power supply device designed to have the features of compact size, light weight and maintenance-free operation. The principle features of the DipHunter are described below:

(1) SEMI (semiconductor equipment and materials international) F47 standard compliant

The SEMI F47 standard (Fig. 2) defines the instantaneous voltage drop ride-through capability required for semiconductor manufacturing equipment. The DipHunter not only complies with the standards for the prescribed region, but additionally provides a wider area of support up to recommended values.

(2) Maintenance-free operation

The DipHunter is limited to protecting against instantaneous drop and utilizes a backup method based on stored capacitive energy. Consequently, use of the DipHunter will eliminate the troublesome and regular replacement of batteries, and enable operation to continue maintenance-free for 8 years (at an ambi-

Fig.2 SEMI F47 standard and DipHunter instantaneous voltage drop ride-through capability

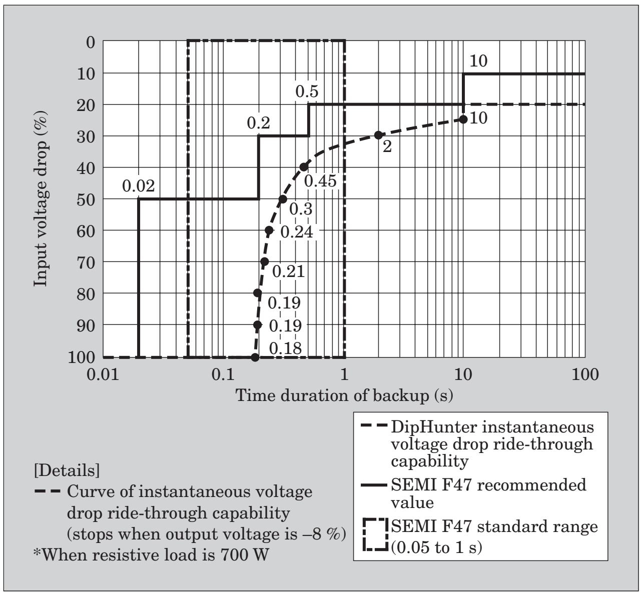
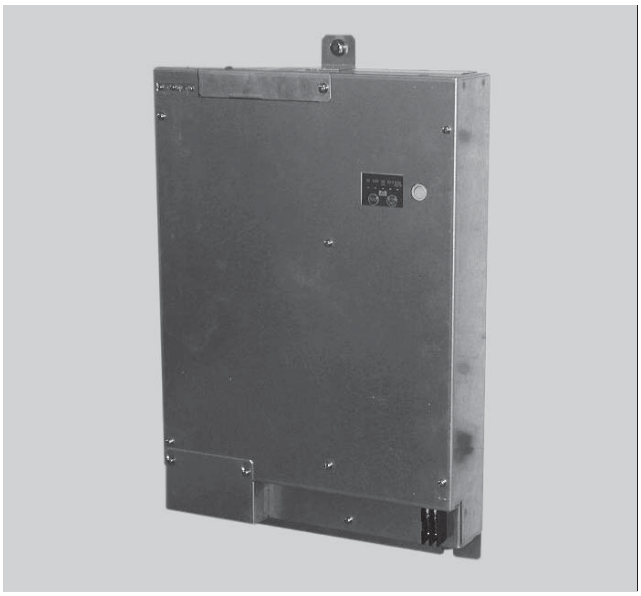



Fig.3 External view of P-series low-profile UPS



ent temperature of 25°C) until reaching the end of the useful life of the product.

(3) Compliant with overseas standards

To simplify the processing of devices for export overseas, the DipHunter has acquired UL1778 certification, an overseas safety standard, and also conforms to CE marking standards.

### 2.2 P-series UPS for use with elevators

This space-saving low-profile UPS can be installed in locations where the installation space is limited. Especially in building and train station elevators, where there has been a trend in recent years toward machine-room-less designs due to space constraints, there is growing demand for low-profile wall-mount type UPS devices capable of powering an elevator to the nearest floor during a power failure.

In response to these market demands, the low-profile P-series UPS (Fig. 3) has been developed and commercialized. Its main specifications are described below:

(1) Low-profile, wall-mount model having a thickness of 90 mm

(2) Two types of rated output capacities, 2 kVA and 3 kVA

(3) I/O is single-phase 200 V, with no step-up/step-down transformer

(4) The main body and battery unit are constructed separately, enabling installation and battery replacement to be performed simply

### 2.3 J-series UPS that supports foreign voltages

Demand for mini-UPSs has been growing in recent years, not only for use with server devices, but also for other applications. In particular, there is increasing demand for UPSs to be built-into electronic equipment, most notably semiconductor manufacturing equipment, as backup power supplies for the devices installed in that equipment. Since the equipment is intended for both domestic use in Japan and for overseas export, it is strongly required that the equipment be compatible with foreign voltages and foreign standards.

In response to these market demands, Fuji Electric has developed and commercialized a foreign-voltage-compatible UPS that is based on its J-series UPS. Main features are listed below:

(1) I/O voltage

(a) 700 VA model
Three types: 110 V, 115 V, 120 V AC

(b) 5, 7.5, 10 kVA model
208 V AC

(2) Support of foreign standards

Acquired UL1778 certification, conforms to CE marking standards

(3) External dimensions and weight are the same as the standard J-series

### 2.4 NetpowerProtect 200 V, 3,000 VA (rack type) off-line UPS

Influenced by the recent trends toward smaller size and lower cost servers, backup power supplies for servers have accelerated the transition from use of on-line UPSs (UPS) to use of small, low-cost off-line UPSs (SPS).

Moreover, the power supplies for upper level systems are often 200 V, and to expand the application range so as to include those power supplies, a 200 V, 3,000 VA rack-mount type SPS has been developed and commercialized. Figure 4 shows an external view of the device, and its main features are listed below:

(1) High frequency conversion technology realizes compact size and light weight without use of

Fig.4 External view of NetpowerProtect 200 V, 3,000 VA rack-type UPS

commercial transformers

(2) Succeeds the high reliability and high quality of the NetpowerProtect series

(3) Can use the wide array of options (such as peripheral devices and UPS management software, to be described later) of the NetpowerProtect series

## 3. Expanded Line of Peripheral Devices, Support of Networked Operation

### 3.1 Multi-server shutdown box

The multi-server shutdown box (MSD box) uses standard UPS management functions of the OS and is an optional product for use with mini-UPSs having a function for safely shutting down servers by means of a contact signal. The contact signal (input power abnormality signal and battery voltage dip signal) from the mini-UPS branches to a maximum of 8 servers, and this signal can safely shutdown each server when a power supply abnormality occurs. Figure 5 shows the configuration of the connections.

The product (see Fig. 6) consists of an interface card installed in the mini-UPS, an expansion box (19-inch 1 U pich rack-mount type. See Fig. 7) that branches the signals, and connection cables that link the interface card with the expansion box. Additionally, a small-footprint desktop-type expansion box is also available. (Up to 4 servers can be connected to each unit. A maximum of 2 units enables connection of up to 8 servers. See Fig. 8.)

### 3.2 Web/SNMP card

Figure 9 shows the external view of the Web/SNMP card. The Web/SNMP card fits into the UPS's card slot and is a device that performs management and information transmission and reception functions for the UPS via a network, without relying on the server's OS. Functions of the Web/SNMP card are described below.

#### 3.2.1 Web functions

A UPS equipped with a Web/SNMP card can be remotely managed from a client (WWW client), in which general-purpose browser software is installed,

Fig.5 Schematic diagram of connections for 19-inch rack-type multi-server shutdown box

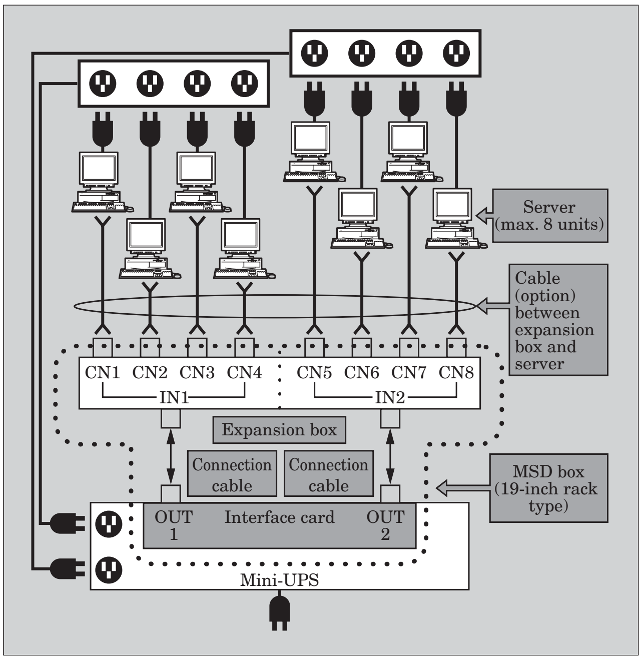



Fig.6 Component parts of multi-server shutdown box

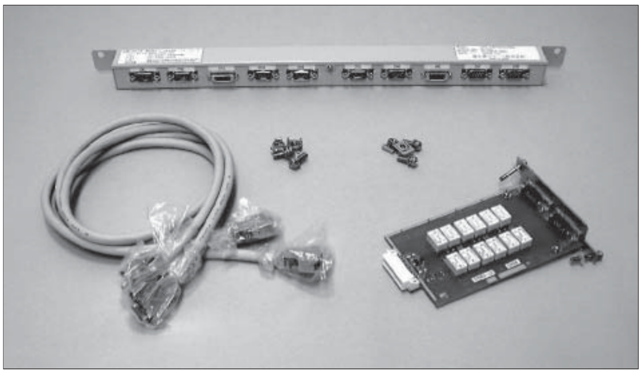
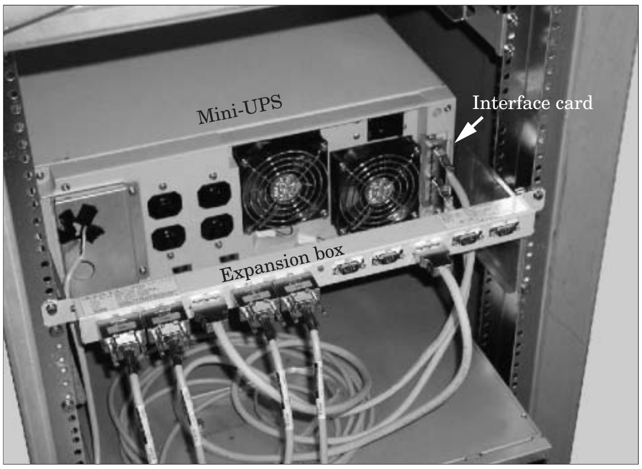


Fig.7 External view of installation of 19-inch rack-type multi-server shutdown box



via the network to which the Web/SNMP card is connected.

The following types of web screens are available. From the client, it is possible to monitor the status, retrieve information, and implement settings for e-mail transmission and scheduling of the UPS.

(1) UPS monitor screen: Real-time display of UPS operating status
(2) UPS management screen: Stop operation setting, network settings
(3) Event log: Display and saving of trigger event log
(4) Data log: Display and saving of input and output data
(5) UPS schedule setting: UPS output stop/start settings
(6) Extension command: UPS output handling and operation testing
(7) Firmware update (Web/SNMP card)

The UPS output stop and start time settings are entered from the schedule setting screen (Fig. 10) and can be specified as daily or weekly settings or set to occur on a specific date.

### 3.2.2 SNMP-based UPS management

The Web/SNMP card is provided with a SNMP agent function. Therefore, if a UPS equipped with a SNMP card is added to a PC network system in which SNMP management software is installed, UPS management can be performed without requiring any changes.

When a power failure or other event occurs, the SNMP manager (PC in which SNMP management software is installed) at the specified IP address can be notified of the occurrence of the abnormal event by using a SNMP trap.

### 3.2.3 Multi-server shutdown function

Multi-server shutdown is a function that shuts down a multiple number of servers residing on the same network (TCP/IP). Figure 11 shows an example configuration of a multi-server shutdown system that transmits remote console commands (RCCMD) from a Web/SNMP card equipped in a UPS.

When a power failure occurs, the Web/SNMP card transmits a shutdown command via a network (TCP/IP) to a multiple number of servers in which RCCMD software module has been installed.

In response to this shutdown command, each server that is powered by the UPS terminates its programs, enabling the OS to be shutdown safely.

Fig.8 External view of desktop type multi-server shutdown box

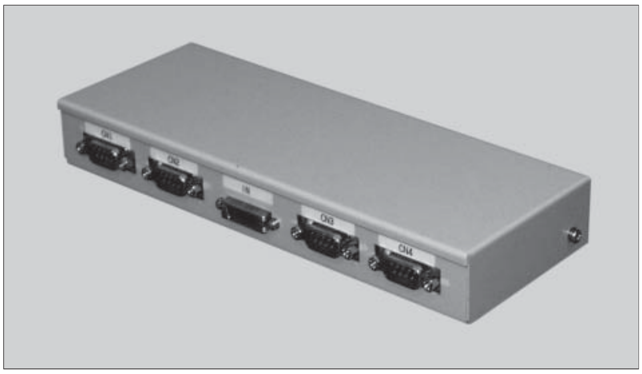


Fig.9 External view of Web/SNMP card

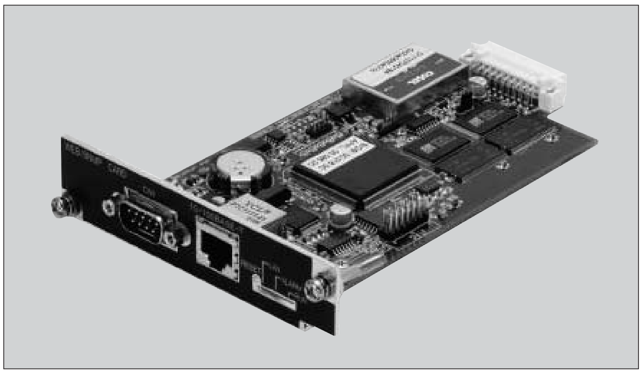


Fig.10 Example UPS schedule setting screen of Web/SNMP card

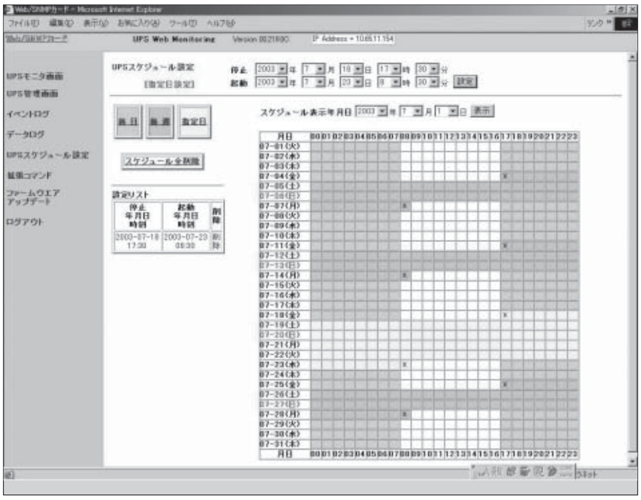



Fig.11 Example Web/SNMP card system configuration

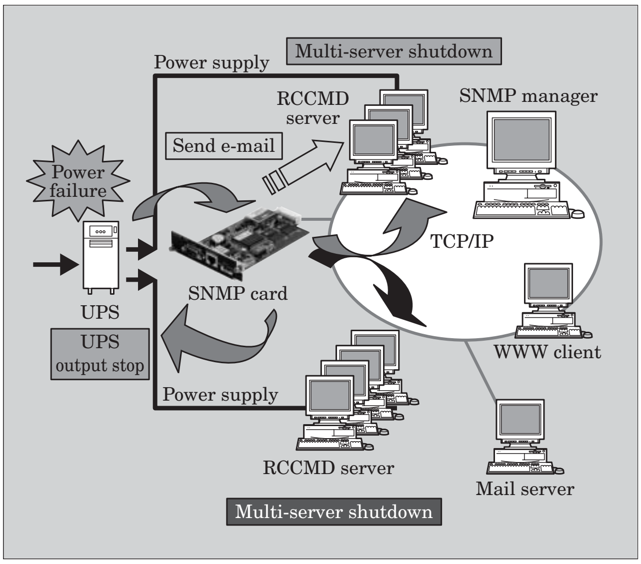


Fig.12 Example NetpowerView F system configuration

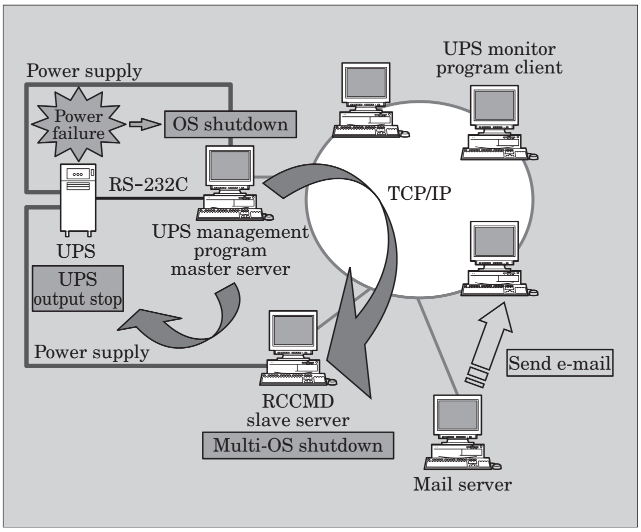



Fig.13 Example UPS monitor screen (X-window version)


### 3.3 NetpowerView F UPS management software

NetpowerView F is installed in the master server and is a program for UPS management via serial communication (RS-232C), which corresponds to NetpowerProtect series.

Figure 12 shows an example configuration of a system using NetpowerView F.

Recently, many servers are being configured with Linux*1 as the OS, and new distributions are being developed one after another. Accordingly, NetpowerView F, which is installed on a server machine to monitor and control a UPS, will phase in new distributions to support the operating environments of:

○ Windows XP/Server 2003
○ Red Hat Linux 7.3/8.0
○ Red Hat Enterprise Linux AS/ES
○ Turbolinux 8

in addition to the operating environments of Windows*2 95/98/NT4.0/2000 and Linux (Red Hat, Turbo, Open) which it already supports.

Moreover, the UPS monitor screens of the Linux version running in an X-window environment feature improved GUI (graphical user interface) display functions and have been designed to be easier to view and easier to navigate.

Figure 13 shows an example UPS monitor screen of the X-window version.

*1 : Linux is a registered trademark of Linus Torvalds in the US and other countries.

*2 : Windows is a registered trademark of Microsoft Corp. of the US.

## 4. Conclusion

The products introduced above are all highly refined products that have incorporated user requests for UPSs and been subject to repeated improvements, or are newly commercialized versions of prior products that have been customized to support the usage environments and required specifications of niche applications. It is the duty of the manufacturer to provide easy-to-use products to its customers, and Fuji Electric will continue its efforts to develop even better products for the future.

### Reference

(1) SEMI STANDARD. SEMI F47-0200, 2000.

# Manual Motor Starter Series for Motor Circuit Protection

**Katsunori Kuboyama**
**Hisao Kawata**
**Yoshinobu Hamada**

## 1. Introduction

In recent years, there have been two big changes that effect low-voltage switching devices such as circuit breakers and magnetic starters, one is the globalization of standards and the other is the globalization of customers.

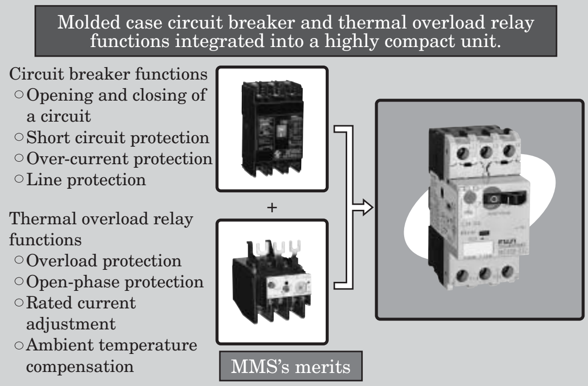
The former change involves the introduction of IEC standards for low-voltage switching devices into JIS standards. For example, IEC 60947-1 pertaining to general regulations for "low-voltage switchgears and control-gears", including regulations concerning the safety of electrical equipment and motor control panels to which industrial devices are applied, was standardized as JIS C 8201-1. Individual product standards such as IEC 60947-2 pertaining to circuit breakers or IEC 60947-4-1 pertaining to magnetic starters were also enacted as JIS C 8201-2 and 8201-4-1. Furthermore, IEC standards were also introduced into the technical standards for electrical equipment, and from these trends, we can say that the globalization of devices and electric equipment is advancing from the field of standards and regulations.

The latter change involves the globalization of customers and the unification of electrical equipment without differentiation between models for domestic and overseas use, leading to lower total cost. Low-voltage switching devices must be capable of being safely and economically installed in a panel in such a manner that reduces the wiring work and requires less mounting space within the panel.

To understand this situation, let us consider, for example, a motor protection circuit. Such circuits were formerly composed of three devices: a circuit breaker (MCCB) for short-circuit protection, a magnetic contactor (MC) for switching the circuit, and a thermal overload relay (TOR) for overload protection.

In this paper, we introduce the manual motor starter (hereafter, MMS) that compactly integrates the functions of a MCCB and TOR as shown in Fig. 1. This new product conforms to global specifications by satisfying IEC and UL standards, and has the potential to bring about great changes in the composition of devices for motor protection. An overview of the specifications, as well as the features and structure of the MMS are described below.

Fig.1 Features of MMS




| | |
|---|---|
| Compactness | 57 % reduction of required mounting space |
| High breaking capacity | 400 V AC 25, 50, 100 kA<br>50, 100 kA |
| Short-circuit protective coordination | IEC 60947-4-1 type1, 2 |
| Reduction in wiring work | 50 % reduction |
| Standards | Domestic standard : JIS C 8201-1, JIS C 8201-2, JIS C 8201-4-1, Electrical appliance and material safety law<br>Overseas standard : IEC 60947-1, IEC 60947-2, IEC 60947-4-1, UL 508, CSA C22.2 No.14 |

## 2. Aim and Features of MMS

### 2.1 Conformance with the globalization of motor protection circuits

The MMS is a motor circuit breaker applied to motor protection circuits. It is capable of switching the motor by manual operation according to IEC60947-4-1 as utilization category AC-3. Moreover, the MMS is equipped with functions such as overload and open-phase protection that differ significantly from the existing motor breaker. Furthermore, since the MMS has a high current-limiting ability to reduce the energy generated during a short-circuit interruption, its rated ultimate short-circuit breaking capacity, Icu, is much higher than that of the conventional motor breaker or MCCB.

In cases where the MMS needs to perform high frequency and remote-controlled switching of the motor, it is used together with a MC. One of the most important characteristics when used with a MC concerns short-circuit accidents that arise on the load side of a MC. The extent to which damage on the MC can be reduced or prevented by the protector is a big factor in determining the capability of the short-circuit protector. The IEC standard has two classifications, "type 1" and "type 2", according to the degree of damage. "Type 2" is defined as a level where the MC can be re-used. Due to the high current limiting capability of Fuji Electric's MMS, it can satisfy "type 2" combinations with a MC up to high breaking capacities.

Another important feature of the MMS is the reduction in size. Since the MMS compactly integrates the functions of a MCCB and a TOR, the mounting space required within the panel is 57 % less than that of existing devices. Other advantages, such as the reduction of wiring work, and the unified width of the MMS and magnetic contactor (types SC-M and SC-E) all contribute to the rationalization of device composition within the control panel.

### 2.2 Abundant rating

The external appearance of the MMS is shown in Fig. 2. In order to enhance the visibility of operating means or markings such as rated current scales, the surface of the MMS cover is colored in a uniform bright hue. The ratings and specifications of the MMS are shown in Table 1. The BM3R type has a maximum rated current up to 32 A (rated insulation voltage 690 V) and has a line-up of 15 current ratings. The larger BM3V type has a maximum rated current up to 63 A (rated insulation voltage 1,000 V) and has a line-up of 9 current ratings. The MMS is applicable to a wide range of motor capacities, from 200 V/7.5 kW AC to 400 V/15 kW AC for the BM3R type, and from 200 V/15 kW AC to 400 V/30 kW AC for the BM3V type. These MMSs are available in two series, according to their breaking capacity, the standard series rated up to 415 V/25 kA AC, and the high breaking capacity series rated up to 415 V/50 kA AC.

Fig.2 Appearance of MMS


### 2.3 Internationalization of products

The MMS conforms to the new JIS standards (JIS C 8201-2 and 8201-4-1), IEC standards (IEC 60947-2, 60947-4-1), and is categorized under "Group installation" and "Suitable for motor disconnect" for manual motor controllers according to Part Ⅲ of UL508. Since the MMS can be used as a control panel device in major world regions such as Japan, Europe and North America, it is a global product that can greatly contribute to the standardization of components and enable customers to carry less stock. Moreover, the MMS is also an eco-friendly product that utilizes cadmium-free contacts and recyclable thermoplastic resin.

### 2.4 Safety considerations

In order to avoid electric accidents such as electric shock, the terminal structure provides IP20-degree of protection to secure the operator's safety when the power is on. This mechanism is a finger protection structure that prevents the finger of an operator or maintenance inspector from directly touching a charged terminal. Moreover, the MMS complies with the isolation requirements prescribed by the IEC standard for MCCBs. This means that a fail-safe structure prevents the handle from being locked in the "off" position or indicating "off" when the main contacts have been welded. These safety mechanisms enable the MMS to be utilized as a "supply disconnected device" according to the international standard for safety of machinery EN 60204-1.

### 2.5 Operability

MMS has two types of handle structures, a rocker-type and a rotary-type. The rocker-type has different indications for on, off and trip conditions and displays a red color symbol in the off position to convey the meaning of "stop" in accordance with IEC standards. This helps to easily identify the off operation during an emergency stop situation. The rotary-type has a structure that stops the rotary handle in the trip state at an angle midway between the on and off positions. Furthermore, the MMS is equipped with a test trip function similar to the trip button of a circuit breaker, to check the function sequence and contact signal of the MMS and its accessories.

### 2.6 Accessories

Internal and external accessories are standardized for usage with all MMS models. The accessories have a structure that enables "one-touch" attachment by the customer. Since accessories can easily be installed from the outside without having to remove a screw or

Table 1 MMS specifications

<table>
<tr><td colspan="2">Item / Frame (A)</td><td colspan="8">32</td><td colspan="4">63</td></tr>
<tr><td colspan="2">Type</td><td colspan="4">BM3RSB</td><td colspan="4">BM3RHB</td><td colspan="4">BM3VHB</td></tr>
<tr><td colspan="2">Number of poles</td><td colspan="4">3</td><td colspan="4">3</td><td colspan="4">3</td></tr>
<tr><td colspan="2">Handle type</td><td colspan="4">Rocker</td><td colspan="4">Rotary</td><td colspan="4">Rotary</td></tr>
<tr><td colspan="2">Rated current (A)</td><td colspan="4">0.16 to 32</td><td colspan="4">0.16 to 32</td><td colspan="4">10 to 63</td></tr>
<tr><td colspan="2">Rated insulation voltage $U_i$ (V) /<br>Rated impulse withstand voltage $U_{imp}$ (kV)</td><td colspan="4">AC690/6</td><td colspan="4">AC690/6</td><td colspan="4">AC1,000/8</td></tr>
<tr><td rowspan="2">Utilization category</td><td>IEC60947-2,<br>JIS C 8201-2</td><td colspan="4">Category A</td><td colspan="4">Category A</td><td colspan="4">Category A</td></tr>
<tr><td>IEC60947-4-1,<br>JIS C 8201-4-1</td><td colspan="4">AC-3</td><td colspan="4">AC-3</td><td colspan="4">AC-3</td></tr>
<tr><td colspan="2">Overload protection, Open-phase protection</td><td colspan="4">Provided</td><td colspan="4">Provided</td><td colspan="4">Provided</td></tr>
<tr><td colspan="2">Instantaneous tripping characteristic</td><td colspan="4">13 × $I_e$ max.</td><td colspan="4">13 × $I_e$ max.</td><td colspan="4">13 × $I_e$ max.</td></tr>
<tr><td rowspan="2">Durability</td><td>Mechanical durability</td><td colspan="4">100,000 : $I_n$ = 0.16 to 25 A<br>70,000 : $I_n$ = 32 A</td><td colspan="4">100,000 : $I_n$ = 0.16 to 25 A<br>70,000 : $I_n$ = 32 A</td><td colspan="4">50,000</td></tr>
<tr><td>Electrical durability</td><td colspan="4">100,000 : $I_n$ = 0.16 to 25 A<br>70,000 : $I_n$ = 32 A</td><td colspan="4">100,000 : $I_n$ = 0.16 to 25 A<br>70,000 : $I_n$ = 32 A</td><td colspan="4">25,000</td></tr>
<tr><td rowspan="14">Rated breaking capacity<br>$I_{cu}$ (kA)<br>IEC60947-2<br>JIS C 8201-2</td><td>Rated current $I_e$ (A)</td><td>240 V</td><td>415 V</td><td>460 V</td><td>690 V</td><td>240 V</td><td>415 V</td><td>460 V</td><td>690 V</td><td>240 V</td><td>415 V</td><td>460 V</td><td>690 V</td></tr>
<tr><td>1.6 or less</td><td rowspan="7">100</td><td rowspan="5">100</td><td rowspan="3">100</td><td>100</td><td rowspan="10">100</td><td rowspan="6">100</td><td rowspan="4">100</td><td>100</td><td colspan="4" rowspan="4">—</td></tr>
<tr><td>1.6 to 2.5</td><td rowspan="9">3</td><td rowspan="2">8</td></tr>
<tr><td>2.5 to 4.0</td></tr>
<tr><td>4.0 to 6.3</td><td>50</td><td rowspan="3">6</td></tr>
<tr><td>6.3 to 10</td><td>15</td><td rowspan="2">50</td><td rowspan="9">100</td><td rowspan="2">100</td><td rowspan="4">50</td><td rowspan="2">6</td></tr>
<tr><td>9 to 13</td><td>50</td><td rowspan="5">10</td></tr>
<tr><td>11 to 16</td><td rowspan="4">25</td><td rowspan="4">50</td><td rowspan="4">35</td><td rowspan="4">4</td><td rowspan="7">50</td><td rowspan="7">5</td></tr>
<tr><td>14 to 20</td><td rowspan="3">50</td></tr>
<tr><td>19 to 25</td><td rowspan="5">35</td></tr>
<tr><td>24 to 32</td></tr>
<tr><td>28 to 40</td><td colspan="4" rowspan="3">—</td><td colspan="4" rowspan="3">—</td></tr>
<tr><td>35 to 50</td></tr>
<tr><td>45 to 63</td></tr>
<tr><td colspan="2">Dimensions W × H × D (mm)</td><td colspan="4">45 × 90 × 68</td><td colspan="4">45 × 90 × 79</td><td colspan="4">55 × 110 × 96</td></tr>
</table>

cover, the MMS can be quickly reconfigured within the control panel to conform to various specification changes. Moreover, a wide variety of wiring components are provided to reduce the amount of wiring and to reduce the occupied floor space for the customer.

## 3. Structure and Performance

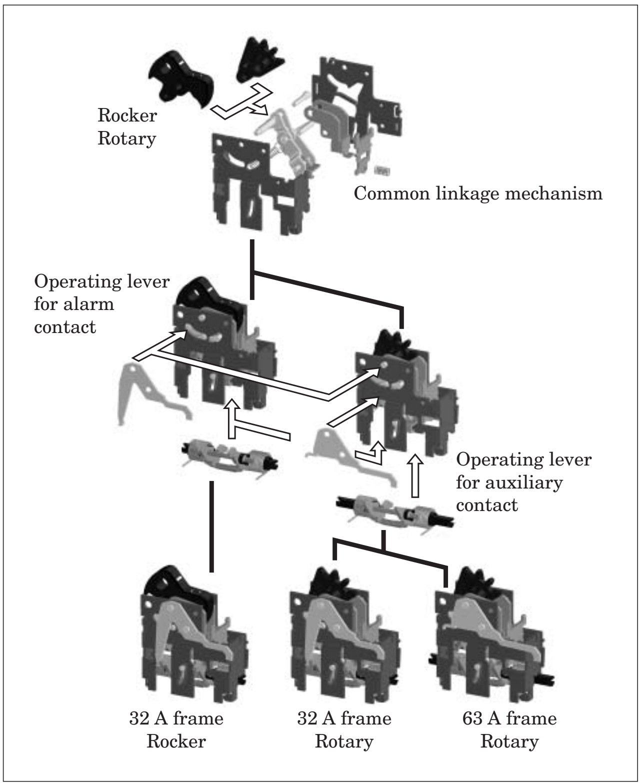
### 3.1 Composition

The main functional parts have single-unit structures, and are comprised in the most optimal arrangement. The operating mechanism, which utilizes the same basic parts even for different frames, has been arranged in the center of the main body. Other parts such as the line-side terminal and internal accessory insertion slots are provided on the line side, while the over-current release (OCR) unit and load side terminal are provided on the load side. The arc extinguishing chamber, which contains a moving conductor and arc extinguisher is located under the insulated wall and opposite the operating mechanism. All these units are inserted into the middle case of the MMS, and to miniaturize the 32 A frame, the design features efficient assembly structures having screw-less and snap-fit assembly systems that are applied to the three main parts, the cover, middle case, and case.

### 3.2 Operating mechanism

Figure 3 shows the internal structure and the combinations for different frames of the operating mechanism. The main parts are miniaturized to unify the mechanism for the 32 A frame (width 45 mm) and 63 A frame (width 55 mm). Furthermore, the linkage mechanisms are all common for each series, which raises the productivity. Consequently, the operating mechanism can easily be produced in the production line by changing the operating handle part to either the rocker or rotary handle type. Moreover, in order to correspond to the different phase pitches for each frame, an operating lever system is utilized to transfer the force of the operating mechanism to the moving conductor. Furthermore, in order to provide a common

Fig.3 Composition of operating mechanism




method of accessory attachment for the entire MMS series, the accessory output transfer parts have been separated from the common linkage mechanism. The connecting functions mentioned above such as the operating lever and the alarm contact block are also specifically shown in Fig. 3.

### 3.3 Short-circuit interrupting

The main feature of the short-circuit interrupting part is the 2-point contact opening structure (for each phase), as shown in Fig. 4, to reduce the amount of let-through energy during the breaking of a short-circuit current. When a short-circuit occurs, the contacts will open an instant before the operating mechanism has functioned. This is because the moving conductor will receive a repulsion force from the electromagnetic force generated between the parallel parts of the fixed conductor and will be further accelerated by the magnetic yoke of the arc moving plate. Moreover, directly above the moving conductor, there is a push bar that is pushed by the plunger of the instantaneous tripping coil, to forcibly open the contacts during instantaneous tripping currents and to prevent the contacts from closing during the short-circuit current. Furthermore, as shown in Fig. 5, the arc moving plate will increase the electromagnetic force to drive the arc from the contacts to the arc plate and will extend the arc so that it can be extinguished immediately.

Figures 6 and 7 show a continuous photograph of the arc and an oscillograph of the voltage and current during the breaking of the arc. From Fig. 7, you can see that it only takes 2.5 ms for the 400 V/50 kA arc to be extinguished. The arcing voltage ($V_p$) is higher than the supply voltage of 600 V and the short-circuit current is limited to only 12 kA. The overall breaking time is only 1/4 of that of an ordinary MCCB (normally 10 ms), which leads to a very low short-circuit let-through $I^2t$ of 1/5 (Fig. 8) that of our conventional MCCB.

IEC60947-4-1 “type 2” is a classification that defines the short-circuit protective co-ordination between MCCB and MC. The regulation stipulates that the combination must remain usable without requiring replacement or sustaining damages except slight weld-

Fig.4 Internal structure of MMS, and motion of breaking arc

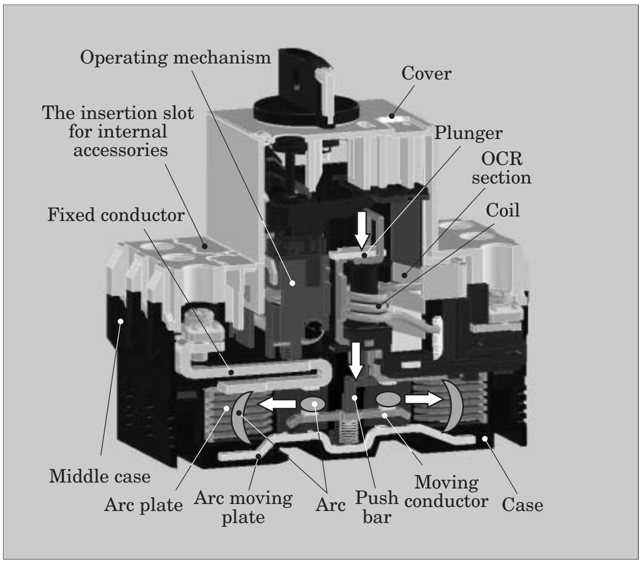



Fig.5 Short circuit breaking principle

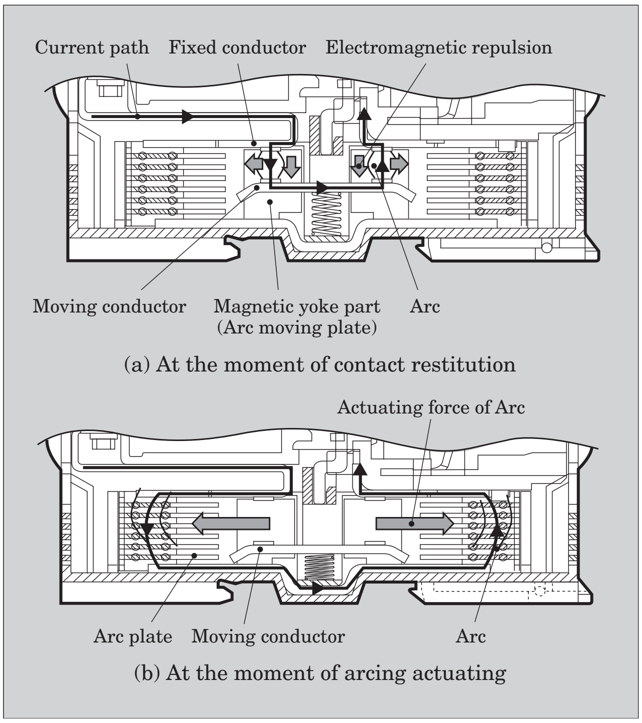


Fig.6  Continuous photograph of Arc

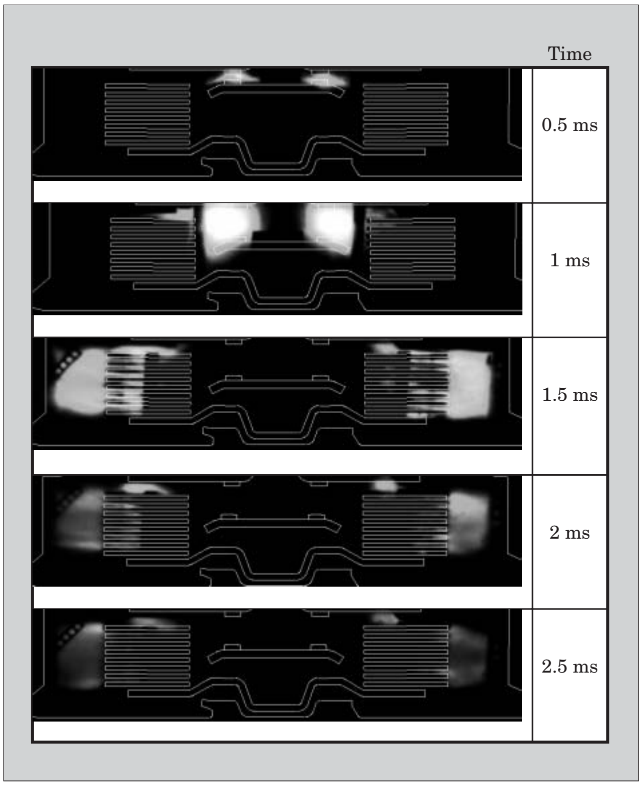
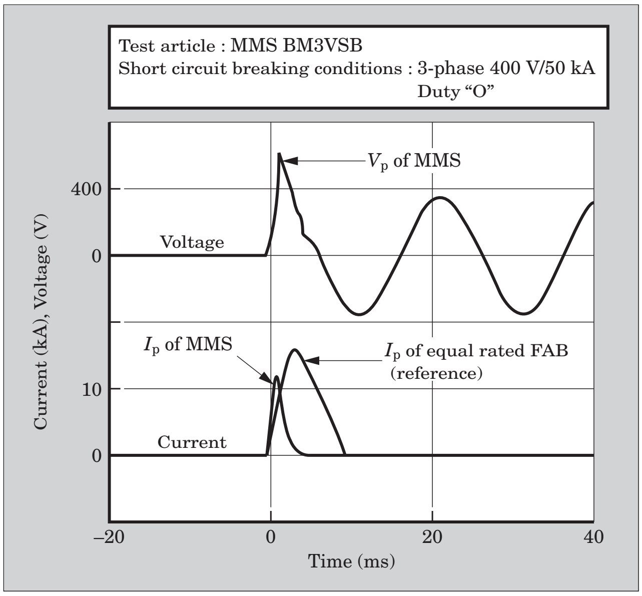



Fig.7  Short circuit breaking oscillogram




ing of the contacts of the MC. In order to prevent the contacts from welding, it is important to reduce the short-circuit let-through $I^2t$ value. For example, in Fig. 9 the contacts of the SC-E series MC will weld when the $I^2t$ value exceeds 90 kA²s. If we look at the MMS, the $I^2t$ of MMS:32 A at 400 V/50 kA is about 80 kA²s, and is less than the value at which the MC contacts will weld. Accordingly, the MMS is a short-circuit protective device that conforms to “type 2” regulations. For details please refer to another article

Fig.8  Short circuit let-through $I^2t$ (Comparison with breaker)

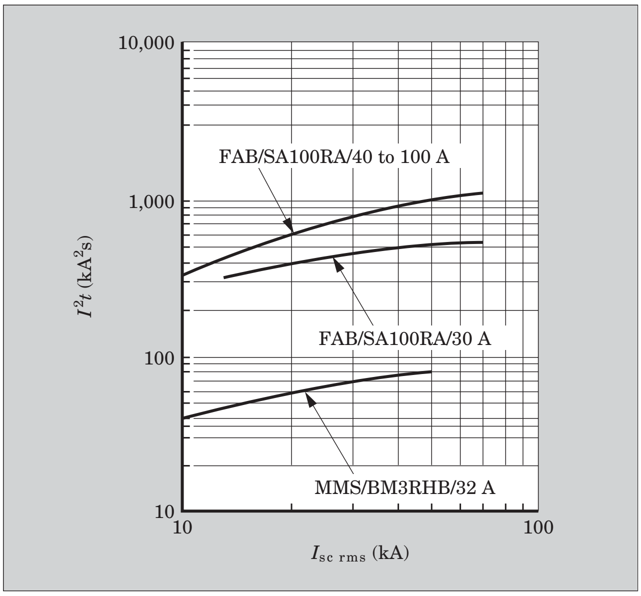
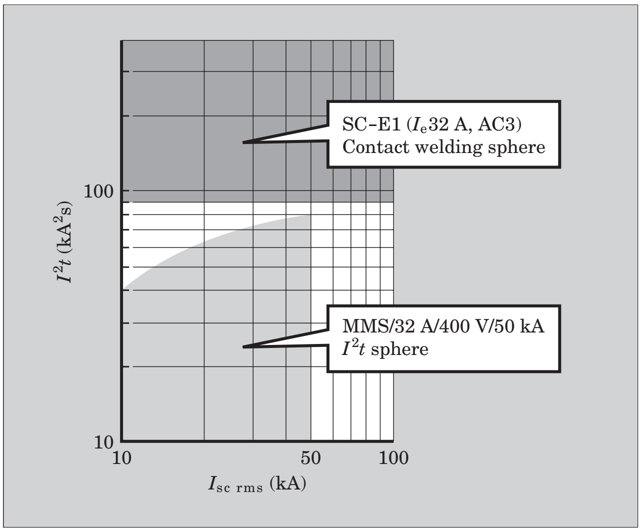



Fig.9  Contact welding sphere for a contactor




“Development of Compact Combination Starter Series” in this journal.

### 3.4 Screw-less molded case

As prescribed in clause 3.1, the 32A frame is a screw-less assembly. In order to achieve this construction without affecting performance and assembly, stress analyses have been performed for the snap fit parts under the gas pressure exerted during the breaking of a short-circuit and for the parts assembly as shown in Fig. 10. The most optimal conditions, such as material type, thickness and form, were verified to achieve this compact and high current breaking MMS.

### 3.5 Over-current release (OCR)

The overload and open-phase protection of the MMS conforms to IEC60947-4-1. Table 2 shows the required value for each standard concerning overload

Fig.10 Stress analysis of the snap-fit during short-circuit breaking impact

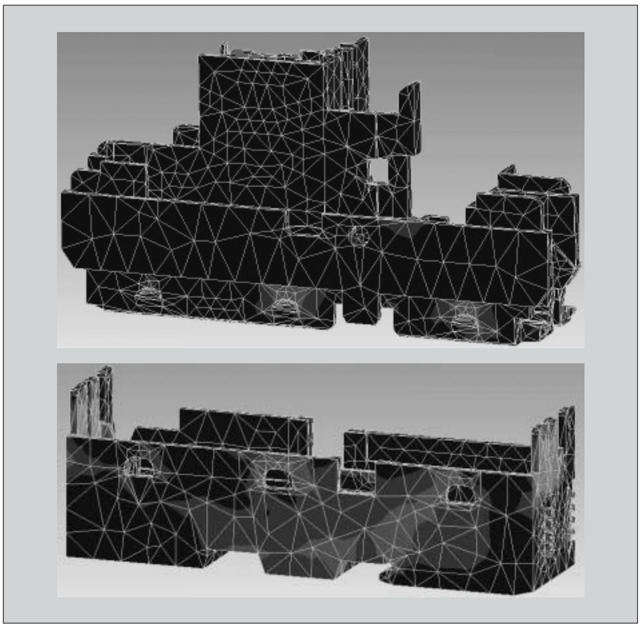


Table 2 Tripping regulations of standards

| Item \ Classification | Molded case circuit breaker | | Thermal overload relay |
|---|---|---|---|
| | JIS C 8370 | IEC60947-2 | IEC60947-4-1 |
| Overload tripping characteristic | 100 % non-trip | 105 % non-trip | 105 % non-trip |
| | 125 % trip | 130 % trip | 120 % trip |
| Open-phase characteristic | Non-required | Non-required | Required |

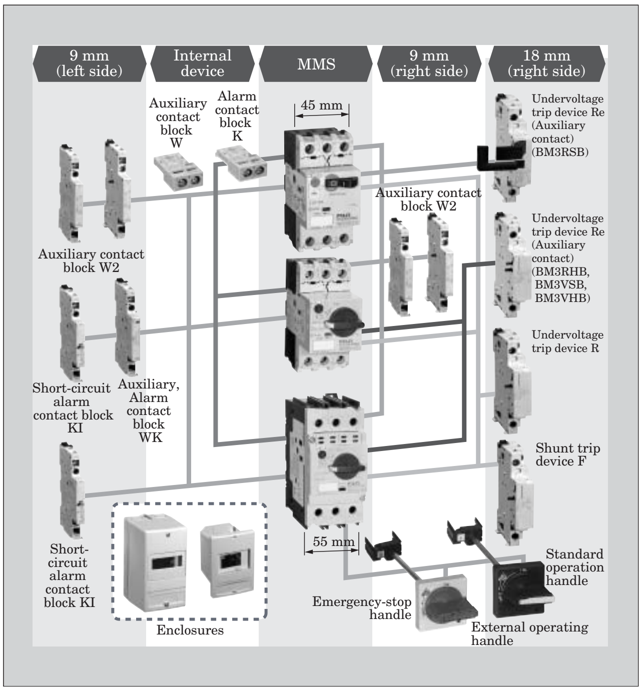
protection. IEC60947-4-1 prescribes the operating current of the OCR to be 120 % of the rated current, in consideration of co-ordination with an MCCB. Furthermore, the regulation requires the normal 3-phase 3-elemental open-phase protection that is common in the European market. By adopting the "differential lever mechanism" of our TOR, the required performance including the open-phase protection of IEC has been attained.

## 4. Structures and Features of Accessories

### 4.1 Internal and external accessories

The variety of accessories is shown in Fig. 11. All accessories (internal and external) are easily attachable with "one-touch" and are common to all models. Since internal accessories can be attached inside the MMS, they may be installed even after completion of the internal wiring of the control panel. External accessories, can be mounted on the left or the right sides, or piled up on one side. A maximum of 6 contacts may be mounted, enabling a flexible response to compositional changes in the control panel. The external alarm contact blocks are equipped with a

Fig.11 Composition of accessories




mechanical display that indicates the trip state. These indicating means are colored to enhance the visibility of the status of the MMS.

In addition to the contact blocks mentioned above, we have prepared plastic enclosures for the rocker-type MMS. These enclosures are available in two types of protection grades, IP 41 and IP55, and are utilized according to the environment at the installation site.

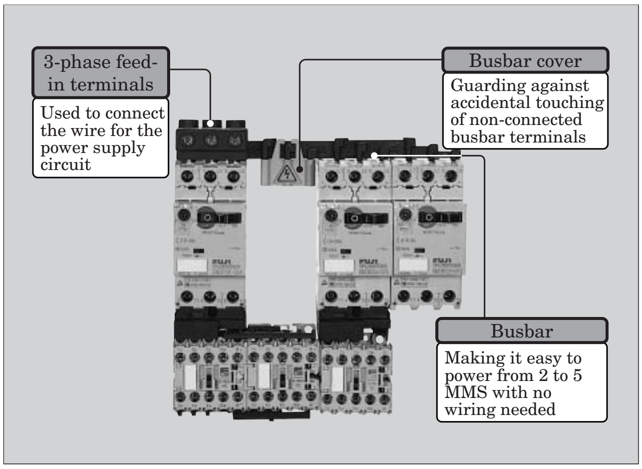
For the rotary type MMS, we have prepared an operation handle, similar to the V-type of Fuji Electric's MCCB, to enable switching of the MMS from the outside door of the control panel.

Based on the above, we can say that the MMS has an abundant array of accessories for both the interior and exterior, which meet various demands of the control panel.

### 4.2 The busbar system

The busbar system, as shown in Fig. 12, is a convenient wiring method for constructing branch circuits. The system consists of 3-phase feed-in terminal used to connect the power supply wire, a busbar to connect the line side of the MMS to make the circuit parallel and to simplify wiring work, and a busbar cover to prevent contact with charged parts when a portion of the busbar is not connected to the MMS. All these accessories also have a structure that prevents contact to charged terminal parts. Accordingly, the busbar system is a safe and simple way for complicated wiring work in the control panel. Use of the busbar will result in a reduction of the amount of wire used and will simplify the work involved in the installation of the control panel.

Fig.12 Busbar system




## 5. Conclusion

As has been described, Fuji Electric's MMS is a completely new product for motor control and protection. This new product conforms to Japanese demands for the globalization of control panels, and customer-driven demands for international specifications for control and protective devices. MMSs will bring about an enormous change in the component apparatuses of the conventional electric motor circuit. Because the aim was not only the pursuit of high product performance, but also to provide an abundant variety of accessories to reduce wiring, the MMS is sure to satisfy our customers' demands. Fuji Electric will continue to develop and supply high performance, low-cost and efficient products to provide convenience to our customers.

# Development of Compact Combination Starter Series

**Shinobu Takeuchi**
**Isamu Nagahiro**
**Hideki Daijima**

## 1. Introduction

Fuji Electric's low voltage switchgear devices such as magnetic contactors (MC) and circuit breakers (MCCB) have excellent characteristics in regards to internationalization, safety, miniaturization, usefulness, and environmental preservation, and as a result, have been well-accepted in various fields and broadly applied to a wide range of load types.

In recent years, with the progress toward internationalization of standards for low-voltage switchgears, higher levels of safety have been required for the power supply equipment of machines. Furthermore, in modern factory automation, besides the need for operational reliability, electric components are required to have a construction that enables not only safe breaking in the event of an accidental short-circuit, but also quick operation restorage.

In this article, we introduce Fuji Electric's combination starter series for electric motors up to 22 kW at 400 V that fulfill the above requirements. The external appearance of this series is shown in Fig. 1.

## 2. Development Aims and Features

The conventional combination starter consisted of a circuit breaker (MCCB) for short-circuit protection, a magnetic contactor (MC) for motor control, and an overload relay for overload protection.

New style combination starters are configured from a manual motor starter (MMS, introduced by another article in this journal) and the SC-M or SC-E series magnetic contactors (MC) newly put on the market. These combination starters use custom wiring components to achieve compact integration into a single unit. The aim of the starter is not only to realize space and wire savings, but also to conform to both UL and IEC standards concerning short-circuit protective co-ordination, thereby achieving broad correspondence to the world market.

### 2.1 Construction

(1) Configuration

As shown in Fig. 2, the combination starter consists of an MMS, MC, link module and base plate. Compared to the conventional motor control circuit as in Fig. 3, the new type of combination starter achieves a 50 % decrease in required mounting space and a 90 % decrease in wiring work by combining the short-circuit protection function of an MCCB and the overload and open phase functions of an overload relay into one component. Figure 4 shows an example of the space savings compared with the conventional style.

(2) Unified dimensions

Fig.1 Combination starter

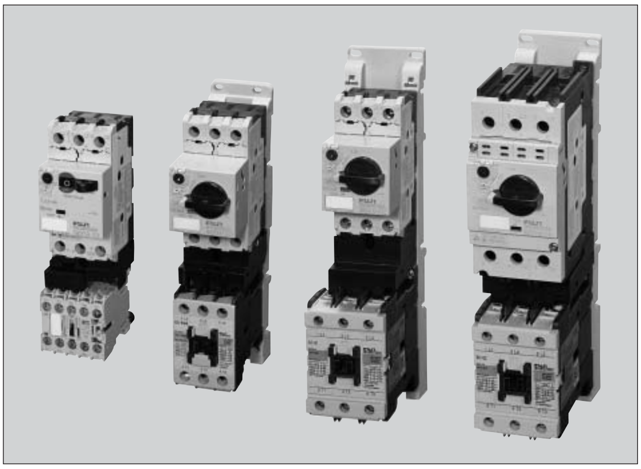


Fig.2 Combination starter composition

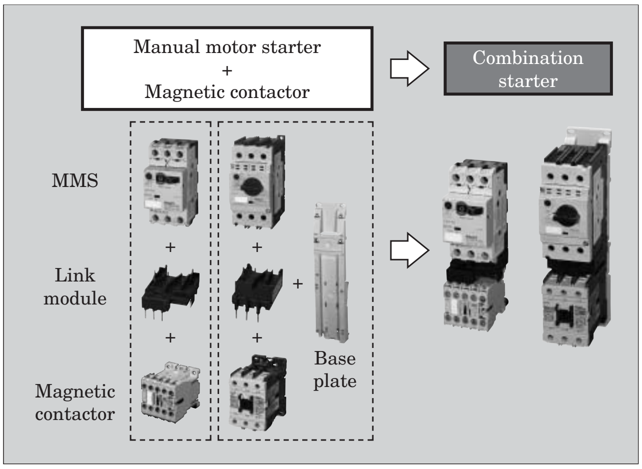


Fig.3 Conventional and new systems for motor control

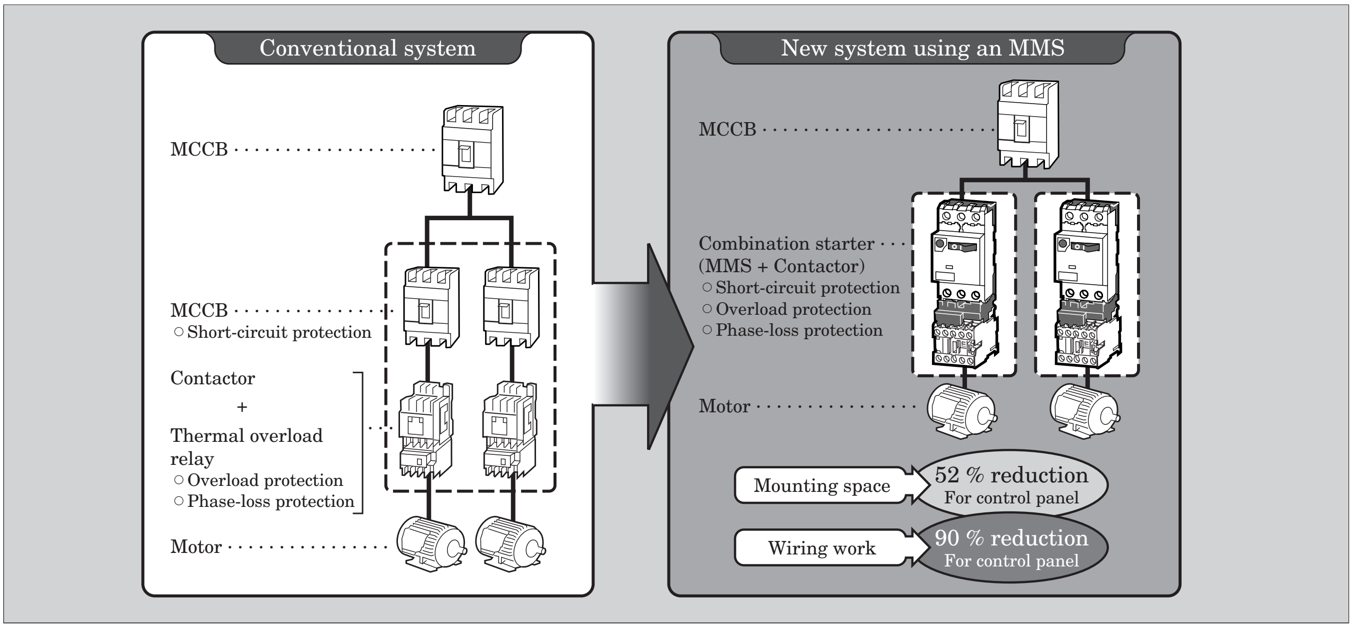
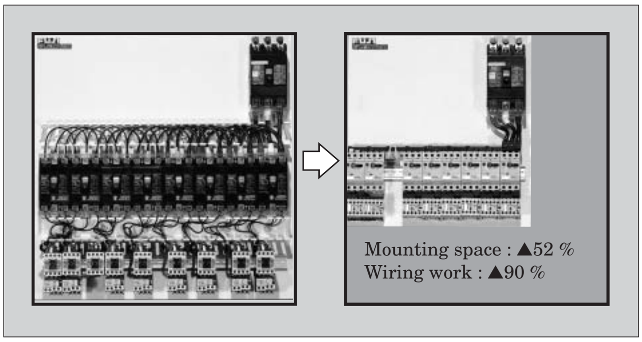



Fig.4 Space savings




The MC width of 43, 45, 54 or 67 mm is unified with the MMS width of 45 or 55 mm in order to attain a slim and unified appearance and also to promote an industrial standard form factor.

(3) Modularizing and block assembly system

Accessories for the MC and MMS are constructed as modularized blocks, and can be attached later according to the customers needs.

### 2.2 Conformity to global standards

(1) Trend for short-circuit protective co-ordination

In the conventional JIS and JEM standards for MCs, there was no regulation of short-circuit protective co-ordination, and generally an MC would be replaced after the occurrence of a short-circuit accident. The only regulation prescribed was by JEM1195, and this concerned the damage level of the MC after a short-circuit in a combined MCCB and MC apparatus. But this regulation was limited in scope to specific fields, such as motor control centers, and a general customer could not use it as a standard for apparatus selection.

On the other hand, IEC and UL had regulations such as “co-ordination with short-circuit protective device” for MCs (IEC60947-4-1) and “combination motor controllers” (UL508) to identify and rank the short-circuit protective co-ordination for component combinations. Both regulations clarify the combination performance level of the MCCB and MC and assess damage and reusability after breaking the short-circuit current for the MCCB, overload relay and MC apparatuses. This has enabled the general user to select protective devices having higher levels of safety and reliability.

(2) Conformance to IEC standard

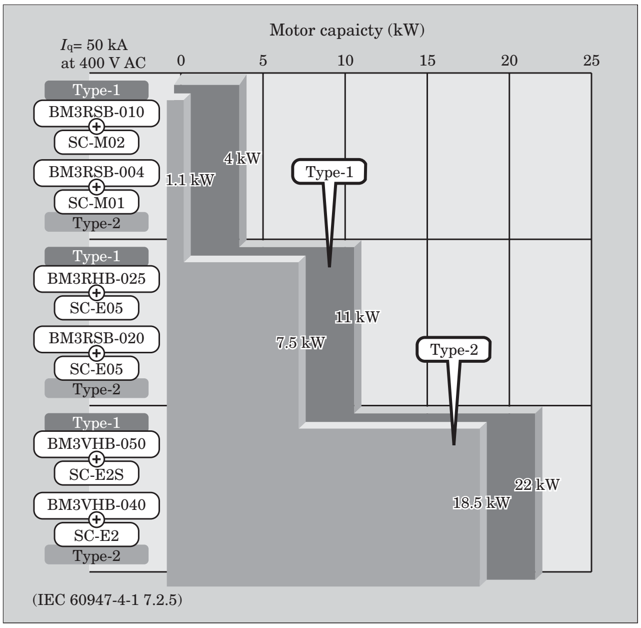
In the “co-ordination with short-circuit protective device” for MCs of the IEC60947-4-1 standard, there are two types of ratings for breaking a short-circuit, “r”, which is specified by the standard and “Iq”, which the manufacture will assure. Also, there are two types of protection levels defined as “type 1” and “type 2”. A “type 1” combination accepts that, under short-circuit conditions, the MC may sustain damage and require partial or complete replacement for further service. The contacts of a “type 1” MC are permitted to be welded. On the other hand, a “type 2” combination must be capable of continuous service, without requiring replacement or sustaining damage except light welding of the contacts of the MC. Conventionally, “type 2” short-circuit protective co-ordination had been attained only by the combination of an MC and a fuse. But now, Fuji Electric’s new combination starter (consisting of an MMS and MC) has achieved “type 2” protection at 400 V for a 50 kA short-circuit current.

The reasons why these combination starters achieved such high performance are because: (1), the MMS is developed with excellent breaking performance so that arc energy is minimized during the short-circuit and (2), return spring force, contact pressure and the

Table 1 UL508 Part 4 - Construction type of combination motor controllers

| Type | Device | Corresponding standard | Component function: Disconnect | Branch circuit protection | Motor control | Motor overload |
|---|---|---|---|---|---|---|
| A | Manual disconnect | UL98 or UL1087 | ○ | | | |
| | Fuse | UL248 series | | ○ | | |
| | Magnetic contactor or solid state contactor | UL508 | | | ○ | |
| | Overload relay | UL508 | | | | ○ |
| B | Manual disconnect | UL98 or UL1087 | ○ | | | |
| | Fuse | UL508 | | ○ | | |
| | Magnetic contactor or solid state contactor | UL508 | | | ○ | |
| | Overload relay | UL508 | | | | ○ |
| C | Inverse-time circuit breaker | UL489 | ○ | ○ | | |
| | Magnetic contactor or solid state contactor | UL508 | | | ○ | |
| | Overload relay | UL508 | | | | ○ |
| D | Instantaneous-trip circuit breaker | UL489 | ○ | ○ | | |
| | Magnetic contactor or solid state contactor | UL508 | | | ○ | |
| | Overload relay | UL508 | | | | ○ |
| E | Self-protected control device | UL508 | ○ | ○ | ○ | ○ |
| F | Manual self-protected combination controller | UL508 | ○ | ○ | | ○ |
| | Magnetic contactor or solid state contactor | UL508 | | | ○ | |

Fig.5 Short-circuit protective co-ordination types and the component combinations of combination starters, for the corresponding motor capacity




contact material of the MC are designed in accordance with the short-circuit breaking performance of the MMS. This means that characteristics such as "short-circuit breaking time", "short-circuit let through $I^2t$" and "contact bounce time of the MC" are considered in the design to achieve the total performance. See Fig. 5 for a summary of co-ordination type and the combination of components for the corresponding motor capacity.

(3) UL standard

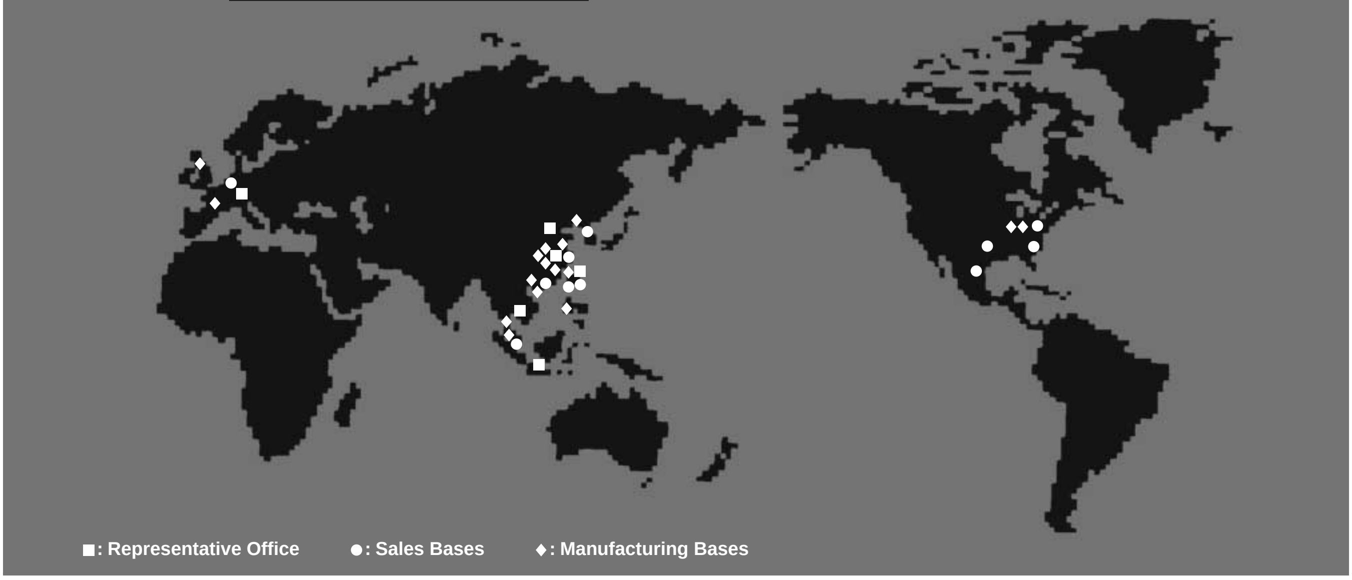
Formerly, in North America, there were regulations (defined as type A to type D) for the conventional apparatuses of fuses, MCCBs and MCs in motor protection circuits. In recent years, new types of combination apparatuses, "type E" and "type F", were established based on the national electric code (NEC). Table 1 lists the construction type of the components for the motor control and protection apparatus according to UL508. As indicated in Table 1, "type F" enables the use of UL508 components, which have satisfied additional structural and short-circuit protection requirements, to completely configure the apparatus. Since the UL489 MCCB can be omitted as branch circuit protection in the motor control circuit, the range of MMS application to motor control and protection can be expanded. (Note: This omission is only applicable to motor circuits.)

Fuji Electric's combination starter has been developed based on these trends, and accordingly, the combination of MC and MMS conforms to IEC and UL standard regulations.

## 3. Conclusion

In this article, we have presented an overview of Fuji Electric's combination starter that consists of an MC and MMS. The combination starter is a product that incorporates many years of Fuji Electric's diverse experiences and accumulated technology in the development of MCs and MCCBs. We intend to continue to strive for further improvement, to endeavor to meet the demands of the market, and to continue supplying high quality and high technology products.

# Global Network

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