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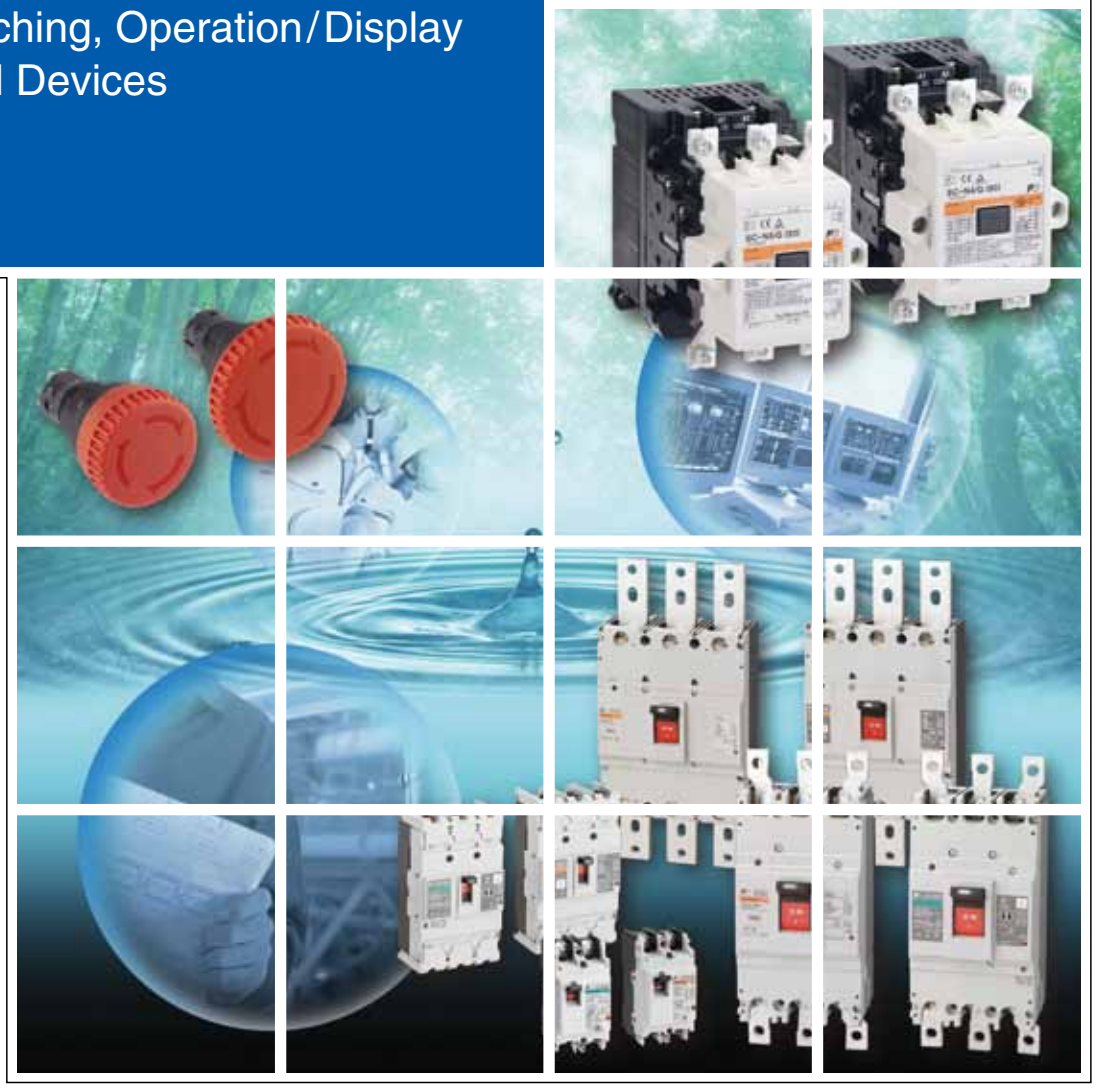
Issue: Switching, Operation/Display and Control Devices



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REVIEW

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Cover photo:

Fuji Electric's products, such as electrical power distribution equipment to utilize electricity more efficiently and safely as well as control equipment to optimally automate production facilities and various types of machines, support the foundation of industrial infrastructure in various places in society such as buildings and FA lines.

The realization of a low carbon society has become an urgent subject. As a result, in the field of industrial infrastructure, there is strong demand worldwide for using various types of renewable energies such as photovoltaic power generation and for improving the power usage efficiency of energy-hungry facilities at data centers. To respond to these requests, the adoption of a new power distribution method such as DC power distribution or high-voltage power distribution is needed.

To provide solutions for such globally shared challenges, Fuji Electric has broadened its lineup of products to include global low-voltage breakers, high efficiency electromagnetic switches, a 16 mm diameter and shallowest depth command switch, and so on, and has launched them in the marketplace.

The cover photo shows these devices and products that realize energy savings and comply with environment-related regulations.

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Current Status and Future Outlook for Switching, Operation/Display and Control Devices

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ABSTRACT

In order to achieve a low carbon society, systems for generating and supplying energy are becoming more diversified. As a result of this diversification, there is increasing demand for devices for the DC circuits in photovoltaic power generation facilities and data centers and for energy savings in electrical equipment. To meet this demand, Fuji Electric provides DC circuit breakers that expand the range of models in the "Compact NS Series" molded case circuit breakers and has commercialized "F-MPC" multiple function protection systems and devices that monitor the electricity, gas and water usage of a business or the like. Fuji Electric also contributes to the energy-saving initiatives of its customers. Furthermore, so as to support, on a product or system level, the trend toward safety standards and regulations of low-voltage equipment, Fuji Electric also contributes to the intrinsic safety of customers' equipment.

1. Introduction

To reduce the effects of global warming, the realization of a low carbon society has become an urgent issue in recent years. As an alternative to conventional power generation based on the combustion of fossil fuels, power generation from natural renewable energy sources is increasing at an accelerating rate.

This paper discusses the trends of switching, operation/display and control devices that support the fluctuating supply of such electric energy, trends of safety requirements for electrical equipment, and introduces features of the latest new products and describes Fuji Electric's planned future efforts.

2 Trends in renewable Energy Usage and Energy Savings

2.1 International and domestic trends

As a measure to mitigate global warming, a commitment period for implementing emission reductions in accordance with the Kyoto Protocol began in 2008 with the objective of reducing average annual greenhouse gas emissions by 6% compared to 1990 emission levels within the 5 years until 2012. To achieve the reduction target established by the Kyoto Protocol, the Japanese "Law Concerning the Rational Use of Energy" (Energy Conservation Law) was revised to strengthen regulations across a wider applicable range, and has been in force since April 1, 2010.

Former Japanese Prime Minister Hatoyama announced a medium-term target of achieving by 2020 a 25% reduction in greenhouse gas emissions from 1990 levels. At the Fifteenth Session of the Conference of Parties to the United Nations Framework Convention on Climate Change (COP15) held in the December 2009, developed nations entered agreement about further strengthen the emissions reductions initiated by the Kyoto Protocol. The issue of global warming is being approached on a global scale.

In Japan, the Ministry of Economy, Trade and Industry published in March 2008 a "Cool Earth Innovative Technology Plan" that summarizes 21 technologies for creating a low-carbon society.

Against the backdrop of these developments, companies are actively engaged in adopting energy saving measures, expanding power generation facilities for solar, wind and other forms of renewable energy, and developing electric cars and the like to reduce CO_2 emissions,

Electric power companies are advancing the concept of a Japanese-style smart grid (next-generation power distribution network) that supports the Japanese government's policy for improving the efficiency of power generation and power distribution and for significantly increasing photovoltaic power generation.

Photovoltaic power generation which is attracting attention as a renewable energy, and requirements and application examples of low voltage equipment used in DC circuits at environment-friendly data centers and elsewhere are discussed below.

2.2 Photovoltaic power generation system

Photovoltaic power generation and wind power generation are examples of the generation of power from natural sources of renewable energy. Because the energy output from these types of power generation varies significantly depending on the natural environment, the generated electric power is stored as DC power in batteries at an electric facility.

In AC circuits, switching devices ensure the insula-

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tion strength by interrupting at the current zero, but in DC circuits, there is no current zero. Therefore, interrupting the current is difficult. In accidents caused by broken wires or the like, there is concern that it will be impossible to extinguish arcs that may result in the occurrence of fire or shock hazards. As a result, demand is rapidly increasing for switching devices, control devices and protection devices that can be used in DC circuits.

Figure 1 shows an example configuration of a photovoltaic power generation system[1]. The portion extending from the photovoltaic cell array until the inverter input of the power conditioner is at a DC voltage. The rated input voltage of a power conditioner typically ranges from 200 V dc to 500 V dc. However, in consideration of voltage fluctuations and drop-outs, switching devices and breakers are required to support voltages up to 750 V dc.

Figure 2 shows an example of an internal circuit diagram and the component devices in a connection box[1]. A connection box is designed to minimize the range of effect of a failure of the photovoltaic cell array, and to simplify the task of isolating the circuit during maintenance or inspection, and is configured from a DC starter, arrester, reverse current protection diodes and the like. For the DC starter, a breaker such as a MCCB having suitable short-circuit current breaking capacity for the DC voltage and rated current of a photovoltaic cell, or for the photovoltaic cell array, is used. The arrester is installed to protect the photovoltaic cell array and the power conditioner from lightening surges, and is an important surge protective device that enhances the stability and reliability of the power supply.

Fig.1 Example configuration of photovoltaic power generation system

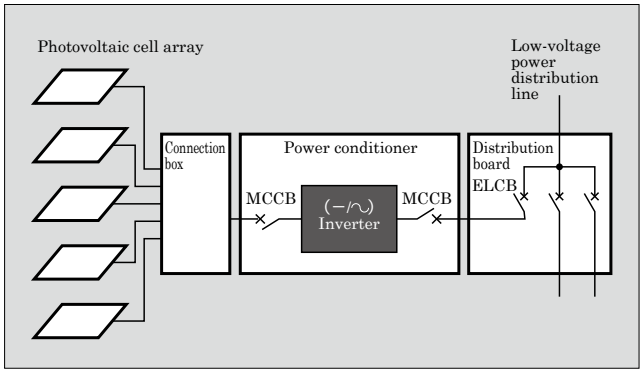
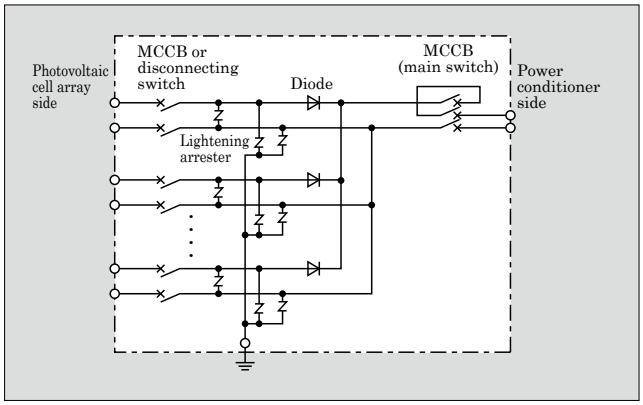


Fig.2 Example of internal circuit diagram and component devices in connection box



2.3 High-voltage DC power supply system for environment-friendly data center

As a way to save energy at data centers that consume large amounts of power due to a higher density of IT equipment, the use of a high-voltage DC power supply system is being considered. Use of a high-voltage DC power supply aims to improve the efficiency of substation equipment and decrease power consumption[2].

Figure 3 compares an AC power supply system and a DC power supply system. A high-voltage DC power supply system supplies a high DC voltage of approximately 400 V dc directly to server equipment, and by reducing the number of AC-DC conversions performed in UPS devices and IT equipment, increases the conversion efficiency of the entire power supply system. Moreover, cables can be made thinner to reduce equipment costs and also be made for longer distances, thereby improving installation flexibility.

Fig.3 Comparison of AC and DC power supply systems

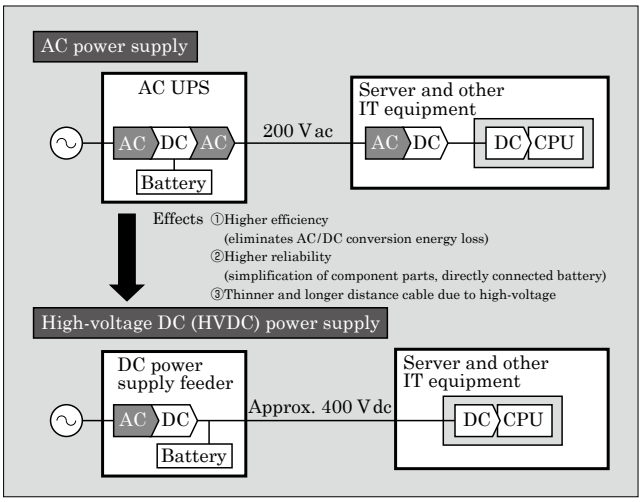


Fig.4 High-voltage DC (HVDC) power supply system diagram

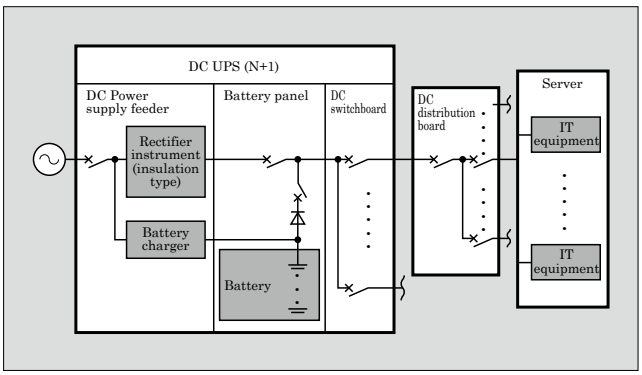


Figure 4 shows an example configuration of a high-voltage DC (HVDC) power supply system. The DC starter normally uses a breaker such as a molded case circuit breaker (MCCB) or miniature circuit breaker (MCB). When selecting equipment, in addition to considering the DC voltage and load current, the DC power supply feeder, backup battery, breaking capacity that reflects characteristics of the capacitor characteristics, and the protective coordination must also be considered.

The use of DC power supply systems is accelerating for a wide range of industries, including homes, offices, factories, stores and electric cars, and the selection of and technology for applying switching devices and protective devices to the DC circuits is becoming increasingly important.

3. Application of Low-Voltage Equipment to DC Circuits

3.1 Application of low-voltage breakers to DC circuits

(1) Application of the "Compact NS Series" to DC circuits

To safely switch and interrupt a DC distribution circuit in which there is no current zero, the Compact NS models of the MCCB series (Fig. 5) employ a rotary arc breaking method which revolve a moving contact with two contacts. Since this method has a larger opening distance per pole than MCCB with a single contact, it can break higher voltage. The Compact NS Series can apply to 100 kA at 250 V dc, 500 V dc circuit in series 2-pole and 750 V dc circuit in series 3-pole. And the Compact NS Series of 4-pole can break larger load current.

As can be seen in Fig. 6, the "Compact NS Series" can be applied to a wide range of circuits with voltages ranging from 24 V dc to 750 V dc and currents of up to 1,000 A.

(2) Application and precautions to high-voltage DC circuits

In AC electric equipment in Japan, the TT earth system is used most commonly. At data centers, hospitals and the like, however, ungrounded (IT) systems are also used in order to prevent a sudden power outage or electric shock hazard due to ground faults that may occur when insulation becomes degraded. As in the case of DC circuits, the earth system of TN, TT and IT are used. The connection method and general precautions for each earth system are discussed below.

Table 1 lists the connection methods and the voltage per pole at the accident point of a short-circuit or ground fault for the Compact NS Series to a high voltage DC circuit. Also, the bottom of the table shows the relationship between the accident point and the operational or non-operational status of the MCCB. In the case of a single line-to-ground fault with the IT earth system, the MCCB will not operate since there is no ground-fault current flow, but if the single line-to-ground fault is left unnoticed, there is the risk that a double ground fault may cause an electric shock hazard or breaking incident. Therefore, prevention monitoring using installed insulation monitoring devices and the like is considered to be necessary.

Furthermore, as can be seen in Table 1, in the case of a negative polarity installation or when using a DC breaker that has polarity, the connection method also requires careful attention.

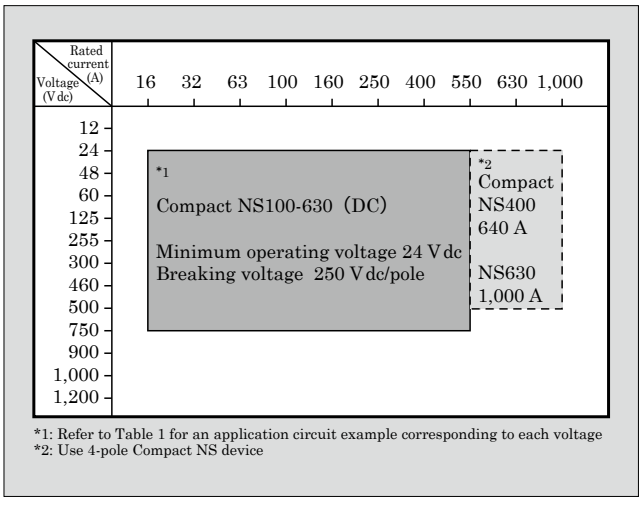
3.2 Application of low-voltage switching devices to DC circuits and DC control

Magnetic starters and other low-voltage switching devices have primarily been used in AC load switches for starting and stopping induction motors. However, as a consequence of the aforementioned trends of electric equipment, applications for DC load control, such as for DC circuit switching and disconnecting when trouble arises, are increasing. In addition, as a result of lower power loss and larger battery capacities, DC circuits are trending towards higher voltages and higher currents.

Figure 7 shows the DC circuit application range for low-voltage switches. Fuji Electric's product lineup

Fig.5 "Compact NS Series"

Fig.6 Applicability of "Compact NS Series" to DC circuits

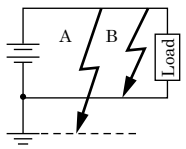
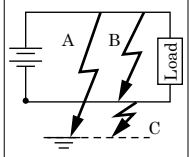
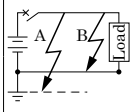
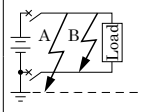
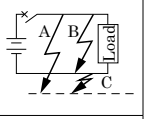
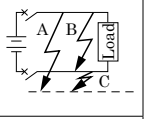
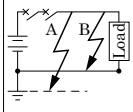
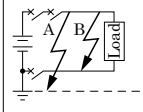
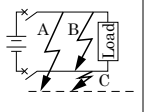
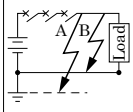
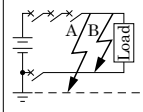
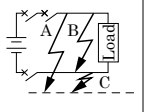
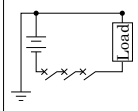
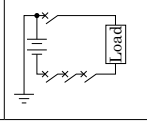


*1: Refer to Table 1 for an application circuit example corresponding to each voltage
*2: Use 4-pole Compact NS device

covers a wide range of voltages (from 24 to 1,500 V dc) and currents (1 to 1,000 A).

The use of PELV (protective extra-low voltage) circuits to prevent electrical shocks, the direct driving of control devices by programmable controllers (PLC), and the miniaturization of DC power supplies and the like are recent technical trends of the control panels in manufacturing equipment and electrical systems. Consequently, even lower operating voltages and lower power consumption is being required of DC-operated magnetic contactors. The power consumption of the "LC1-D Series" (contact rating: 9 to 38 A) and the "SC-N4 to N5/G Series" (contact rating: 80 to 93 A) has been reduced to 2.4 W and 20 W, respectively, which is the world's smallest class.

Table 1 The connection method and protective operation for high voltage DC circuit

Grounding method		Grounded DC electrical circuit			Ungrounded DC electrical circuit
Circuit diagram and site of ground fault/ short-circuit accident					
earth system / Applied voltage		Breaking performance: 250 V/pole breaker (Compact NS)			
	No. of poles	TN (grounded poles are not isolated)	No. of poles	TT (power supply and load are isolated)	No. of poles	IT (ungrounded)
250 V	1-pole		2-pole		1-pole	
					2-pole	
500 V	2 -pole		3-pole		2-pole	
750 V	3-pole		4-pole		3-pole	
750 V Grounded positive	3-pole		4-pole		3-pole	–
Voltage per pole at the accident point		A, B: 250 V		A: 250 V B: 125/167/188 V (Applied voltage: 250/500/750 V)		A, C: Ungrounded with no voltage load sharing B: 250 (1-pole)/ 125 (2-pole) (Applied voltage: 250 V) /250/250 V (Applied voltage: 500/750 V)
Operational/non-operational status of MCCB at time of ground fault or short-circuit*					
Accident point	A	○ Ground fault		△ Ground fault (changes according to resistance value)		× (single line-to-ground fault)
	B	○ Short-circuit		○ Short-circuit		○ Short-circuit
	C	–		–		× (single line-to-ground fault)

*○: Operational △: Indeterminate behavior ×: Non-operational

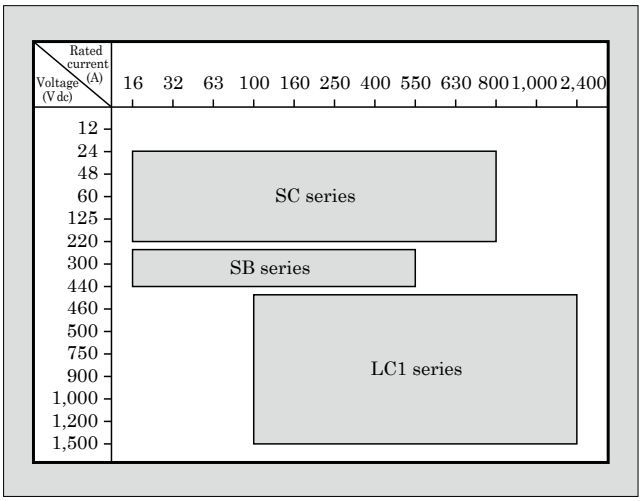
3.3 Revised Energy Conservation Law and power monitoring system trends

The monitoring of power consumption is important in renewable energy. With the enforcement of the revised Energy Conservation Law in 2010, energy management regulations will change from conventional energy management in factory and workplace units to management in company units (corporation units) that requires the planning and promotion of energy conservation from a managerial perspective. Regulations concerning building operators and the business sector for expanding franchise chains, such as convenience stores, will be strengthened. The regulation coverage rate is predicted to increase from approximately 10% to 50% after enforcement of the revised law.

Business offices and franchise member stores where the amount of contracted power and energy usage is not very large will also be covered by this law. Therefore, it is important that power monitoring can be performed by individuals not possessing specialized knowledge. In response to this need, Fuji Electric has developed the "F-MPC Web" unit that can be introduced as a small-scale system with a relatively low-cost initial investment.

Figure 8 shows an example of a system based on the F-MPC Web unit. Requiring only a general-purpose browser for a PC and without the need for specialized software, this system makes it easy to assess

Fig.7 DC circuit application ranges of low-voltage switching devices (electromagnetic switches)



energy consumption.

4. Trends in Electrical Equipment Standards and Fuji's Approach to Equipment

4.1 Trends in electrical equipment standards

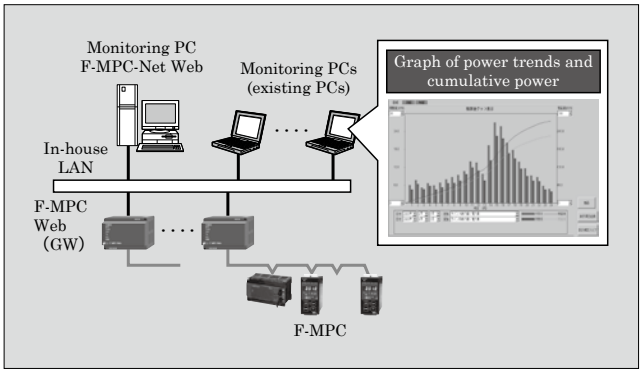
In Japan, conformance with the international standards for low-voltage electrical equipments and the components in use (IEC standards and ISO standards) is progressing rapidly. The "Interpretation of technical standards for electrical equipment" incorporates international standards (IEC 60364), and the construction of electrical equipment in Japan in accordance with IEC standards has been authorized. In addition, the JIS C 0364 series that conforms to IEC standards has also been issued.

As a safety standard for electrical equipment in industrial machinery, IEC60204-1 (JIS B 9960-1) has surely prevailed, and this standard has shaped the design guidelines for machinery control panels and the like.

As new safety standard trends, compliance with U.S. SEMI standards (S22) and IEC standards for semiconductor manufacturing equipment is actively being pursued, and IEC 60204-33, an international standard for semiconductor manufacturing equipment, has newly been issued. In addition, individual standards for interlocks, emergency stopping mechanisms, various sensors and other safety devices have been established, and there is strong demand for adherence to safety standards in the electrical devices used in machinery.

In the U.S., with the revision of the National Electrical Code (NEC: electrical equipment standards in the U.S.), in order to eliminate the risk of secondary disasters and fire incidents occurring at the time of short-circuit accidents and to realize the goal of ensuring onsite worker safety, short-circuit current rating (SCCR) values are required to be displayed on industrial control panels. The SCCR is the maximum level of short-circuit current that devices inside the panel can withstand, whereby even if these devices become damaged by the short-circuit current, there shall be no harm to people and peripheral equipment due to fire, explosion or loss of insulation function. Table 2 shows the trends of laws and standards concerning low-voltage devices.

Fig.8 Example configuration of power monitoring system



4.2 Compliance with SCCR requirements for low-voltage breakers

The OHSA (Occupational Safety and Health Administration) and the IAEI (International Association of Electrical Inspectors) are organizations that inspect whether risk-free products and equipment have been constructed in accordance with the NEC, and in some cases, forcibly implement improvements. The OHSA and IAEI examine also the coordination between the estimated short-circuit current value, supplied from the factory's power supply, and the control panel's SCCR value. If, for example, the control panel's SCCR is not larger than the estimated short-circuit current value at the location where the control panel is installed, the electricity cannot be provided to the equipment, and the SCCR value will have to be increased by changing the components and design.

Fuji Electric can provide suitable components for various SCCR requirements of control panels. The "G-TWIN" breaker series can be applied to satisfy 240 Vac/25 to 50 kA and 480 Vac/10 to 50 kA SCCR requirements.

When SCCR requirements exceed 240 Vac and 480 Vac/50 kA, the UL489-compatible "Power Pact Series" (Fig. 9) for the North American market can be used. This series can also be used in 600 V Δ circuits.

4.3 Machinery safety standard trends and Fuji's approach to equipment

With the prevalence of machinery safety and functional safety, safety measures for machinery and equipment are required to be implemented proactively in order to protect the safety of workers, and various

Table 2 Trends of laws and standards concerning low-voltage devices

Trends of laws and standards	Details
Inclusion of IEC standards in electrical installation technical standards, release of detailed regulations	Introduction of concepts relating to TN systems, protection against electric shock and overvoltage protection system
JIS for components used in low-voltage electrical equipment are unified with IEC standards	Western-style unified platform for design criteria for low-voltage electrical equipment
Dissemination of ISO 12100 and IEC 60204-1, and new issuance of IEC 60204-33	Enhancement and proliferation of safety standards for the electrical equipment for machines and semiconductor manufacturing equipment
Revised Energy Conservation Law, RoHS directive	Prevention of global warming and adoption of environmental regulations, prohibited usage of hazardous substances
Revision of NEC (National Electrical Code)	Control panels exported to the U.S. display their short-circuit current rating (SCCR) value

Fig.9 “Power Pact Series”

safety functions in manufacturing equipment and in machinery control devices and systems are required so that people will not be harmed in the case of failure or misuse. The main requirements include redundant design so that safety functionality will not be lost when a single component fails (safety categories 3 and 4), a self-detecting function for failures (safety categories 3 and 4), diversity in order to prevent the phenomenon in which electromagnetic interference or the like inhibits the redundancy (safety category 4), the prevention of inadvertent startup, improved visibility of the operator interface, etc. These safety functions for control equipment and systems can be realized by using and configuring suitable safety devices.

Fuji Electric has prepared a lineup of safety devices, including ϕ16 mm emergency stop button switches, trip wire switches, various sensors, safety door switches, safety relay units and safety controllers. By adding such safety devices to MCCBs and switching devices, the establishment of a lineup of safety devices contributes to the safe construction of highly reliable manufacturing equipment.

5. Postscript

In the future, measures to mitigate the effects of global warming will be advanced as global efforts. Power equipment utilizing renewable energy which is an effective measure against global warming is expected to become increasingly diverse and varied. The low-voltage distribution equipment, switching devices, safety control devices, preventative maintenance devices and the like that reliably protect, control and monitor these types of electrical equipment will become even more important. Fuji Electric will continue to incorporate global market requirements into its products and aims to supply products that will provide solutions to the challenges our customers face.

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(1) Japan Photovoltaic Energy Association. Photovoltaic Power Generation System Design and Enforcement. 3rd Edition. Ohmsha. 2006, p.245.

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Expanded Line-up of "NEO SC Series" Magnetic Contactors

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ABSTRACT

In response to market needs for magnetic contactors with smaller size and lighter weight, and a low-voltage DC control circuit with reduced inrush power consumption, Fuji Electric has developed the "SC-N5A" AC operated contactor that retains compatibility (external dimensions, mounting dimensions and terminal locations) with, but is lighter than, the previous model, and the "SC-N4/G" and "SC-N5/G" DC operated contactors which feature greatly reduced inrush power consumption of the DC control circuit, and these models, ranging from 5.5 kW to 22 kW, have been added to the "NEO SC Series." Using a multi-objective algorithm, the power consumption and electromagnet dimensions were optimized and electromagnetic field analysis of coupled motion, large deformation analysis and thermal-hydraulic analysis were performed to develop a new electromagnet structure.

1. Introduction

Magnetic contactors switch electric circuits on and off by manipulating an electromagnet and are used for automated load switching. A magnetic contactor combined with a thermal overload relay (thermal relay) is known as a magnetic starter, and magnetic starters are used primarily for the automated operation of electric motors and are equipped with a function for protecting the electric motor in an overload state due to damage from burnout.

For more than 50 years since being introduced to the market in 1954, Fuji Electric's magnetic contactors have continuously maintained the top market share in Japan, and a cumulative total of 270 million these devices have been manufactured. By consistently anticipating market demands and technical trends of the times, Fuji Electric has contributed to technical development through providing distinctive products to the market, and has maintained its position as a leading manufacturer in the field of electric motor control.

With the globalization of markets, internationally-compatible products and environmentally-friendly products are being requested, and in 1999 Fuji Electric rolled out the SC-N1 to SC-N16 models (motor capacity 200 Vac, 5.5 to 200 kW) of the NEO SC Series of magnetic contactors. These standard products conform to CE marking (EU standard) and UL/CSA (North American standards) standards, and with the resulting significant reduction in product power consumption, the products have been well received by customers as energy-saving global products.

Efforts to address environmental concerns, not only by improving the energy savings during product usage such as by reducing the power consumption during operation, but also efforts to minimize the total amount of energy consumption and environmental load throughout the product lifecycle, including production, transportation, usage and disposal, are attracting attention. Similarly, for the control panel, the following environmental measures are also being advanced.

- Resource conservation by reducing the part count and shrinking the installation space
- Reduction of transport energy by making the control panel lighter weight
- Reduction of the amount of power consumed during operation

Moreover, safety standards for machinery and equipment have been established. As an inherently safe design measure for protecting against electric shocks in the control panel, the use of lower voltage DC control circuits, such as typified by the use of 24 Vdc circuits, is being advanced. In response to requests for the abovementioned environmental and safety measures, the ability to realize smaller size and lower capacity DC power supplies has become an important topic in the development and design of control panels.

In implementing the abovementioned environmental and safety measures, requests have intensified for the magnetic contactors installed inside a control panel to be made more compact in size, lighter in weight so as to be less power consuming, and for the DC operating circuits it is required to reduce the inrush input consumption.

In response to these types of changing requests, Fuji Electric has developed the "SC-N5A" AC operated magnetic contactor and the "SC-N4/G" and "SC-N5/G" DC operated magnetic contactors (motor capacity SC-N4: 18.5 kW, SC-N5A: 22 kW, 200 Vac) to expand the line-up of the NEO SC Series (see Table 1). Figure 1 shows the external appearance of the SC-N5A and SC-N5/G. An overview of these newly developed products

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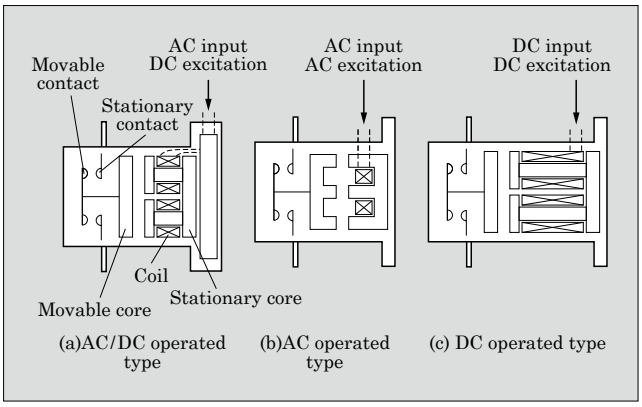
Table 1 "NEO SC Series" line-up (22 kW and smaller)

Frame		N1	N2	N2S	N3	N4	N5
Rating	Motor capacity 200 V ac	5.5 kW 26 A	7.5 kW 35 A	11 kW 50 A	15 kW 65 A	18.5 kW 80 A	22 kW 93 A
Operating method	AC/DC operated type (with super magnet attached)	N1/SE	N2/SE	N2S/SE	N3/SE	N4/SE	N5
	AC operated type	N1	N2	N2S	N3	N4	N5A
	DC operated type	N1/G	N2/G	N2S/G	N3/G	N4/G	N5/G

: New product

Fig.1 External appearance of "SC-N5A" and "SC-N5/G"

Fig.2 Methods for manipulating electromagnet of magnetic contactor



is presented below.

2. Development Goals

There are three ways in which the electromagnet of a magnetic contactor can be manipulated, AC/DC operation, AC operation or DC operation (see Fig. 2).

The SC-N5 to SC-N16 (motor capacity 55 to 200 kW, 200 V ac) large magnetic contactors of the NEO SC Series use an AC/DC operated "super magnet[(1)]." In the case of a super magnet, an AC input is rectified into a DC signal and the electromagnet is driven with DC excitation, and a characteristic feature is that the operating circuit is equipped with a voltage detection circuit and a power switching circuit. When the coil voltage is applied to the operating circuit of a super magnet, the voltage detection circuit verifies the magnitude of the applied voltage, and only if it has been determined that there are no obstructions to the closing operation, a closing signal is generated and the coil is excited. After completion of the closing operation, the signal changes to a sealing signal, and the power switching circuit suppresses the coil excitation current to reduce the power consumption. The magnet operation will remain in a sealed state even voltage fluctuations or the like cause the coil voltage drop to below a certain level. If the case of a significant drop in the coil voltage, before the voltage drops to a level at which chattering among the contacts would occur, the voltage detection circuit operates to determine the necessity for opening, and if necessary, terminates the sealing signal and opens the contacts. The voltage detection circuit constantly monitors the coil voltage, and in doing so, ensures stable operation without chattering even in the case of such conditions as voltage fluctuations, instantaneous sag or when the applied voltage is in the low voltage region, which would cause unstable voltage with other operating methods.

An AC/DC operated magnetic contactor having these types of characteristics is suitable for use in environments susceptible to large voltage fluctuations and in applications for which there is a desire to lower power costs.

On the other hand, the AC operated method is provided with an AC-input AC-excitation AC electromagnet. With an AC electromagnet, in the open state, the reluctance is small. Therefore, the inductance decreases, and when closing the contact, a large coil current flows. After application of the attractive force, the inductance increases and the coil current decreases. Therefore with a compact-size and simple electromagnetic structure, an AC operated electromagnet provides the advantage of a relatively large attractive force when closing.

The DC operated method is provided with a DC-input DC-excitation DC electromagnet. With a DC electromagnet, there is no change in the excitation current when opening or closing. Therefore, the number of ampere-turns must be increased in order to maintain a sufficient attractive force when closed. Although the volume of the coil windings will increase, the capability to reduce the inrush power consumption is an advantage of this method.

Table 2 Comparison of specifications of newly developed products (AC-operated and DC-operated types) to prior models

		AC/DC-operated type (with super magnet)		AC-operated type	DC-operated type	
Motor capacity 200 V		18.5 kW	22 kW	22 kW	18.5 kW	22 kW
Model		SC-N4/SE	SC-N5	SC-N5A	SC-N4/G	SC-N5/G
External appearance						
Coil power consumption 200 V, 50 Hz	Pick-up (VA)	100	80	250	20	
	Seal (VA)	2.8	4	18.4	20	
External dimensions (mm)	H×W×D	127×88×132		127×88×132	127×88×159	
Weight (kg)		1.8		1.5	2.3	

: New product

Table 3 Characteristics of each operating method

	AC/DC-operated type	AC-operated type	DC-operated type
Compact size	◎	◎	○
Light weight	○	◎	○
Energy savings (sealed power consumption)	◎	○	○
Smaller DC power supply (inrush power consumption)	△	–	◎
Voltage fluctuation immunity (SEMI sag immunity)	◎	×	◎

◎ : Optimal, ○ : Suitable, △ : Less suitable, × : Unsuitable, – : Not applicable
: New product

Considering the characteristics of each operating method and the needs of control panels, the SC-N5A AC-operated magnetic contactor is compact in size and light weight, and is well suited for use in a control panel environment. The SC-N4/G and SC-N5/G DC-operated magnetic controllers reduce the inrush power consumption, which helps to realize more compact and lower capacity DC power supplies, and are well suited for safety-related applications.

Accordingly, this enhanced line-up of the NEO SC Series enables Fuji Electric to provide various magnetic contactors well suited to a diversity of customer applications.

3. Characteristics

The main characteristics of Fuji Electric's newly developed AC-operated magnetic contactors and DC-operated magnetic contactors are described below.

3.1 AC-operated magnetic contactor

The specifications of the SC-N5A and the SC-N5 prior model (AC/DC operated type) are compared in Table 2. Utilizing a small and lightweight AC electromagnet, the SC-N5A maintains compatibility (in regard to external dimensions, installation dimensions and pin locations) with the prior model while realizing lighter weight, and as a result, helps to realize lighter weight and resource conservation in control panels.

3.2 DC-operated magnetic contactors

Specifications of the SC-N4/G and SC-N5/G are also compared with those of the SC-N5 prior model (AC/DC operated type) in Table 2. The SC-N4/G and SC-N5/G realize the world's lowest power consumption and smallest external dimensions. In particular, their inrush power consumption is reduced to 1/5th that of the AC/DC operated type, enabling the DC power supply installed in a control panel to be made smaller in size and capacity, and helping to realize smaller size, resource conservation and lower costs for control panels.

Characteristics of each operating method are shown in Table 3. The magnetic contactor best suited for a particular application can be selected.

4. Technology to Achieve Smaller Size and Lighter Weight

4.1 AC-operated magnetic contactor

The structure of the SC-N5A AC-operated magnetic contactor is shown in Fig. 3. The electromagnet consists of a movable core, a stationary core and a coil, and the movable core is coupled to a part that houses a movable contact known as a movable contact carrier. Also, a contact spring is attached to the movable contact so as to apply contact pressure toward the stationary contact when the contactor closes. When an excitation current flows in the coil, the movable core

Fig.3 Structure of "SC-N5A"

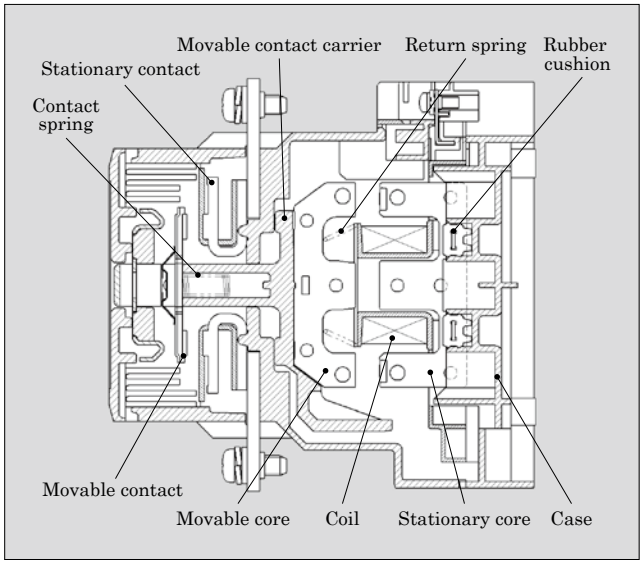
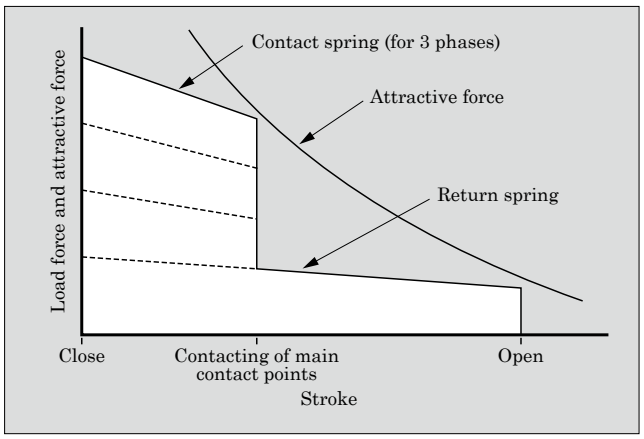


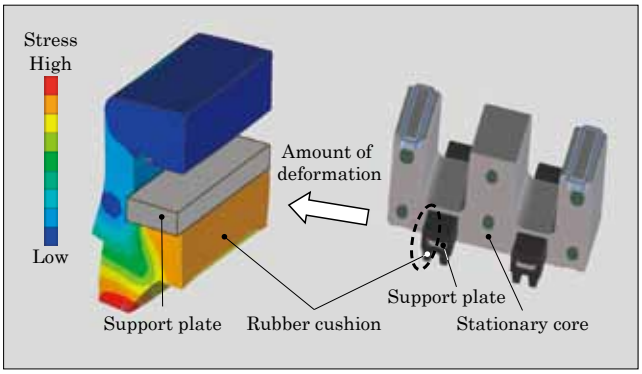
Fig.4 Load force of electromagnet and attractive force generated by electromagnet



is attracted toward the stationary core, the movable contact and movable core move toward the stationary core, and as a result of this series of actions the contact closes. When the contact closes, the movable core ultimately collides with the stationary core. To absorb the impact at the time of this collision, a rubber cushion is placed between the stationary core and the case.

For the SC-N5A to realize compact size and light weight, a small AC electromagnet having the same dimensions as that of the SC-N4 lower frame is used as the electromagnet load. As shown in Fig. 4, the load force becomes the combined total load force of the moving return spring and contact spring. Therefore, the electromagnet must generate an attractive force that is larger than this load force. Since the carrying capacity and the making capacity determine the load force of the contact spring (i.e., the contact force), a large spring load force is needed to ensure the carrying capacity and the making capacity of the SC-N5A. The higher the carrying current, the greater the heat generation and larger the electromagnetic repulsive force

Fig.5 Example analysis of stress distribution and deformation of rubber cushion (1/2 model)



of the contacts. As a reslut, a stronger spring load force is needed.

However, the kinetic energy of the moving parts increases when an attractive force comparable to the load force is applied. Therefore, ensuring the mechanical durability by cushioning the impact at the time of the collision of the electromagnet core presented a challenge during development of the SC-N5A.

To overcome this challenge, the design of the rubber cushion was optimized to realize a small and lightweight electromagnet structure that features a powerful attractive force and strong durability. At the time when the core collides, if the cushioning of the impact is inadequate, the core and the movable contact carrier will be damaged. To ensure sufficient mechanical durability, the rubber cushion must be designed with sufficient shock-absorbing functionality and a large compressive deformation capability. However, if the amount of compressive deformation capability is increased, the stress caused from repeated deformation will damage the rubber cushion, and the shock-absorbing functionality will deteriorate.

Therefore, large deformation analysis was carried out to analyze materials capable of large amounts of deformation. By computing the deformation amount and stress of the rubber cushion, and optimizing the materials, shape and support structure design, a cushion structure that combines both shock-cushioning functionality and strength was developed. Rubber cushions are positioned on both sides of the stationary core, support plates inserted through a hole formed in each part are coupled together and the assembly is housed inside the case. Figure 5 shows an example of this analysis.

4.2 DC-operated magnetic contactor

The structure of the SC-N5/G, a DC-operated magnetic contactor, is shown in Fig. 6. The structure of the arc extinguishing part and the contact part is the same as for the SC-N5 AC/DC-operated type. By increasing the efficiency of the electromagnet part, the world's smallest power consumption and external dimensions in a DC-operated magnetic contactor were realized.

Fig.6 Structure of “SC-N5/G”

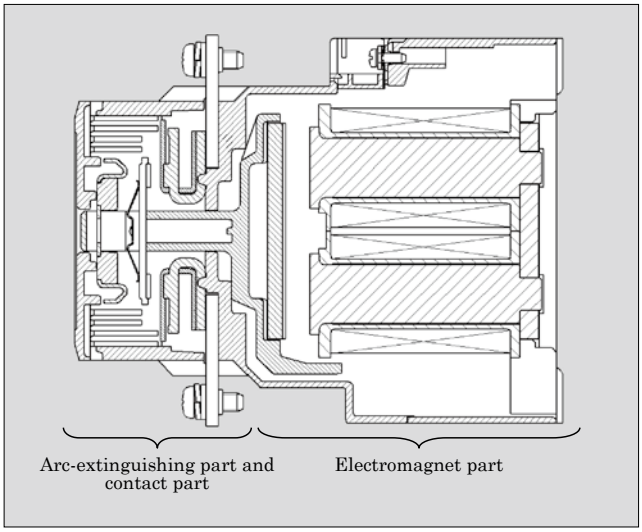
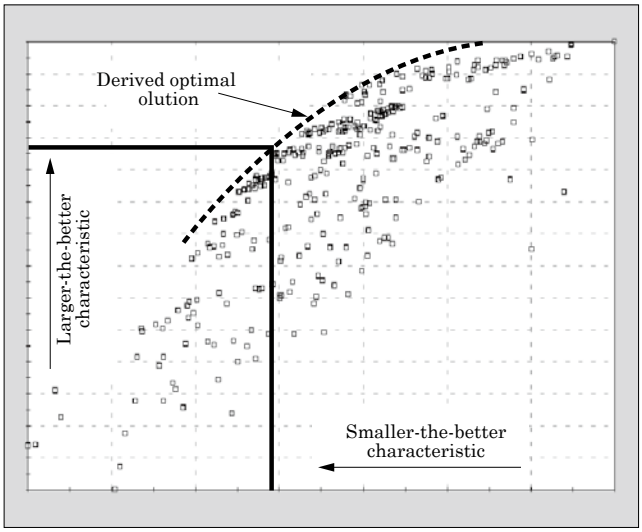


Fig.7 Results derived from optimal solution using “MOGA”



The basic structure of the SC-N4/G is the same as that of the SC-N5/G, only the contacts are different.

(1) Application of an optimization method

In a DC electromagnet, for a given number of ampere-turns, a so-called tradeoff relation exists between the power consumption and size of the coil windings (electromagnet dimensions). Attempting to reduce the power consumption will result in an increase in the number and size of the coil windings. On the other hand, attempting to reduce the size of the coil windings will result in an increase in current to compensate for fewer number of coil windings, and the power consumption will increase. In the development of the new DC electromagnet, an optimization method known as a multi-objective genetic algorithm (MOGA*1) was used to derive an optimal solution for the tradeoff relation between power consumption and electromagnet dimensions, and the designs of the electromagnet shape and winding specifications were optimized. Figure 7 shows an example of the optimal solution results derived from the MOGA.

*1: MOGA: Multi-objective genetic algorithm that uses stochastic search techniques (genetic algorithms) that model genetics and biological evolution to calculate by simulation an optimal solution (multi-objective optimization) for multiple functions that involve trade-off relations

Fig.8 Example of coil excitation current based on electromagnetic field analysis of coupled motion

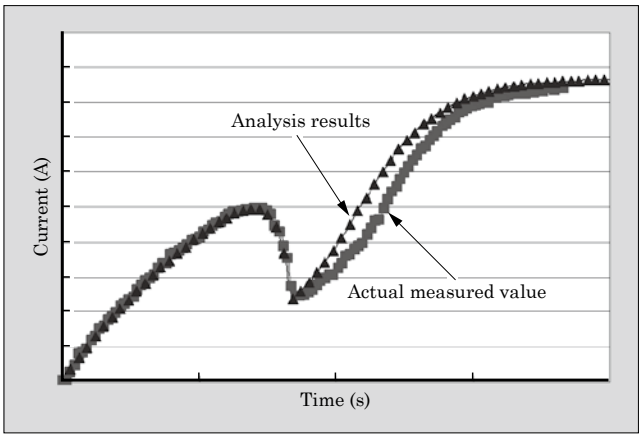
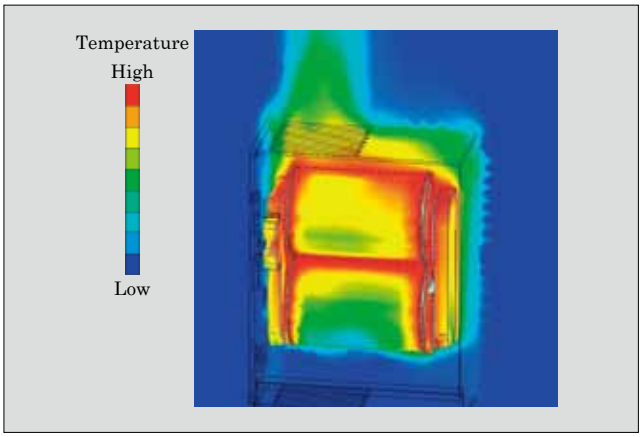


Fig.9 Example of thermal-hydraulic analysis inside DC electromagnet and case



(2) Detailed development of DC electromagnet

So that the magnetic contactor can perform a closing operation, an attractive force sufficient to drive the movable core must be ensured. Because the attractive force is generated according to the number of ampere-turns, i.e., the product of the number of coil windings and the amount of the coil excitation current, the coil excitation current must be calculated with a high level of accuracy in order to implement a detailed design of a DC electromagnet. When the movable core is displaced, the magnetic flux fluctuates and the inductance increases. Therefore the coil excitation current decreases temporarily at the time of a closing operation. This transient phenomenon cannot be calculated using static electromagnetic analysis techniques. Coupled analysis of the electromagnetic field and motion was

performed to calculate the transient coil excitation current and attractive force, and a high precision design of a new DC electromagnet was implemented. Figure 8 shows an example of the coil excitation waveform at the time of a closing operation according to an electromagnetic field analysis of coupled motion.

When designing an electromagnet, in order to ensure the thermal endurance of the coil windings, it is essential that any rise in coil temperature remains within the specifications. Thermal-hydraulic analysis that considers the flow of air was used to optimize the location and size of heat dissipation holes and to optimize the coil temperature rise. An example of thermal-hydraulic analysis is shown in Fig. 9. As a result, in conformance with the external dimension and power consumption constraints, a case was designed that efficiently disperses heat generated in the coils so that the rise in coil temperature can be minimized.

5. Postscript

Fuji Electric has expanded its lineup of models in the NEO SC Series which are capable of quickly responding to market needs such as for environmental and safety measures. Fuji Electric intends actively to continue to improve products so as provide precise support for the changing market needs of the future.

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New Technology of the Global Twin Breaker "G-TWIN Series"

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ABSTRACT

Against the backdrop of market globalization, Fuji Electric has developed and commercialized the "G-TWIN" global breaker, and upon completing the 32 to 800 AF series in January 2009, launched a full-scale effort to expand the market. Because of the relationship of protective coordination with lower devices, a fork-type dual-contact breaking method was adopted as new technology for compact high performance current-limiting breaking. Moreover, to ensure the stability and reliability of the supply of electric power, Fuji Electric has expanded its lineup of plug-in circuit breaker models, and demand for these models is expected to increase in recent years. Fuji Electric has also developed a proprietary arc extinguishing function and expanded its lineup of breaker models for use in photovoltaic cells and the DC circuits in data centers.

1. Introduction

Molded case circuit breakers (MCCB) and earth leakage circuit breakers (ELCB) function to protect wiring, equipment and human body from electrical accidents, such as the application of an overcurrent to distribution lines and loads, or the occurrence of a short circuit, ground fault or earth leakage in a distribution circuit. These circuit breakers are installed in all types of devices, machinery and buildings that use electricity.

In 1990, Fuji Electric released its "Twin Breaker Series" that featured MCCBs and ELCBs with common external dimensions for the first time in the world, and as a result of the improved convenience due to installation interchangeability and the ability to share accessories, as well as contributions to the standardization and miniaturization of switch board equipment and systems, this series has received the support of many customers. Meanwhile, in response to recent requests from customers who are expanding their global businesses, rather than the previous implementation in which successive variations of products were certified to meet individual standards, a single series of global MCCBs/ELCBs capable of satisfying all standards is believed to be necessary, and for this purpose Fuji Electric has developed and released the "G-TWIN" breaker series that combines the concepts of "global" products with that of "twin" breakers. In January 2009, the entire series, ranging from 32 to 800 AF, was completed (see Tables 1, 2 and 3) and a full-scale marketing campaign was conducted.

The basic development concept of combining compatibility with the new JIS/IEC standard and the UL489 standard, and the development of the elemental technology have already been described in other papers[1),2)].

Using the example of the 125 AF, this paper describes high performance current-limiting breaker technology for low-rated-current products, as innovative technology for enhancing the current-limiting performance of branch circuit breakers in order to coordinate tripping with devices connected in lower level. Also introduced are products that support plug-in circuit breakers and their expanded application to DC circuits, for which demand is expected to grow in the near future from the perspective of power supply stability and reliability.

2. High Performance Current Limiting Breaker Technology for Low-Rated 125 AF Products

The breaking capacity of low voltage circuit breakers that use a molded case is primarily determined according to the tolerable limit of stress that is created by arc energy generated during a breaking operation. If the stress cannot be controlled, the sudden increase in internal pressure will damage the molded case, the dielectric strength will deteriorate due to the melting and scattering of conductive materials and insulation materials at high temperature, the operation of the switching mechanism will malfunction, and so on.

The prior series of UL-standard products were intended for the North American market, and as such, were separate from the Twin Breaker Series. Compared to the Twin Breaker Series, this prior series featured larger external dimensions and also a larger-sized breaking mechanism and main contact separating distance, and had ample tolerance against stress.

In the course of developing the G-TWIN breaker which, within the same external dimensions, satisfies both the new JIS/IEC standard and the UL standard,

† Fuji Electric FA Components & Systems Co., Ltd.

Table 1 "G-TWIN Standard Series" (wiring-use)

Frame (A)	Rated breaking capacity *I*cu (kA)		MCCB	ELCB
	230 Vac	440 Vac		
32	2.5	–		EW32AAG
	2.5	1.5	BW32AAG	EW32EAG
	5	2.5	BW32SAG	EW32SAG
50	2.5	1.5	BW50AAG	EW50AAG
	5	2.5	BW50EAG	EW50EAG
	10	7.5	BW50SAG	EW50SAG
	25	10	BW50RAG	EW50RAG
	125	65	BW50HAG	EW50HAG
63	5	2.5	BW63EAG	EW63EAG
	10	7.5	BW63SAG	EW63SAG
	25	10	BW63RAG	EW63RAG
100	5	1.5	BW100AAG	EW100AAG
	25	10	BW100EAG	EW100EAG
125	50	30	BW125JAG	EW125JAG
	100	50	BW125RAG	EW125RAG
	125	65	BW125HAG	EW125HAG
250	36	18	BW250EAG	EW250EAG
	50	30	BW250JAG	EW250JAG
	100	50	BW250RAG	EW250RAG
	125	65	BW250HAG	EW250HAG
400	50	30	BW400EAG	EW400EAG
	85	36	BW400SAG	EW400SAG
	100	50	BW400RAG	EW400RAG
	125	70	BW400HAG	EW400HAG
630	50	36	BW630EAG	EW630EAG
	100	50	BW630RAG	EW630RAG
	125	70	BW630HAG	EW630HAG
800	50	36	BW800EAG	EW800EAG
	100	50	BW800RAG	EW800RAG
	125	70	BW800HAG	EW800HAG

Table 2 "G-TWIN Global Series" (wiring-use)

Frame (A)	Rated breaking capacity *I*cu (kA)		MCCB	ELCB
	230 Vac	440 Vac		
50	25	10	BW50RAGU	EW50RAGU
100	25	10	BW100EAGU	EW100EAGU
125	50	30	BW125JAGU	EW125JAGU
	100	50	BW125RAGU	EW125RAGU
250	36	18	BW250EAGU	
	50	30	BW250JAGU	EW250JAGU
	100	50	BW250RAGU	EW250RAGU
400	50	30	BW400EAGU	
	85	36	BW400SAGU	EW400SAGU
	100	50	BW400RAGU	EW400RAGU
	125	70	BW400HAGU	EW400HAGU
630	50	36	BW630EAGU	
	100	50	BW630RAGU	EW630RAGU
	125	70	BW630HAGU	
800	50	36	BW800EAGU	
	100	50	BW800RAGU	
	125	70	BW800HAGU	

Table 3 Variant usage of the "G-TWIN Standard Series"

Frame (A)	For electric motor protection	For use with primary-side of transformer	Instantaneous tripping	Non-auto switch	With leakage alarm	For use with resistance welder	4-pole product	DC-only product
32	○	○	○	○				○
50	○	○	○	○	○			○
63	○		○	○				○
100	○	○		○	○			○
125	○	○	○	○	○		○	○
250	○	○	○	○	○	○	○	○
400		○	○	○	○	○	○	○
630		○	○	○	○		○	○
800			○	○	○		○	○

the development of a new breaking mechanism with increased current-limiting effect was needed.

To increase the breaking capacity, the most effective method is to increase the arc voltage by separating the contacts at high-speed beginning at the time when a short circuit occurs, and to limit the current to a coolable current value. With the G-TWIN Breaker, to improve the current-limiting performance of the low-rated-current region, in addition to techniques used with high-rated-current products, a forked dual-contact breaking method was newly developed to realize technology for further improving the current-limiting effect. Such techniques were utilized from high-rated-current products as enhancing the ablation effect with the narrow slit resin, optimally arranging the magnetic yoke for promoting arc driving, and reducing the emission of ionized gas on the load side by adopting an isolated construction of the molded casing.

Characteristics of the breaking mechanisms of high-rated-current products and low-rated-current products are shown in Figs. 1 and 2, and a sketch of the breaking mechanism for low-rated-current products is shown in Fig. 3.

The principles of electromotive force generation with the forked dual-contact breaking method are shown in Fig. 4. The primary-side fixed contact connected to the line-side terminal is folded into a U-shape, and joined to a contact tip. The opposed movable contact is folded into a C-shape in the width direction of the breaker, and via a secondary-side contact,

Fig.1 Features of large current rated (40 to 125 A) breaker structures

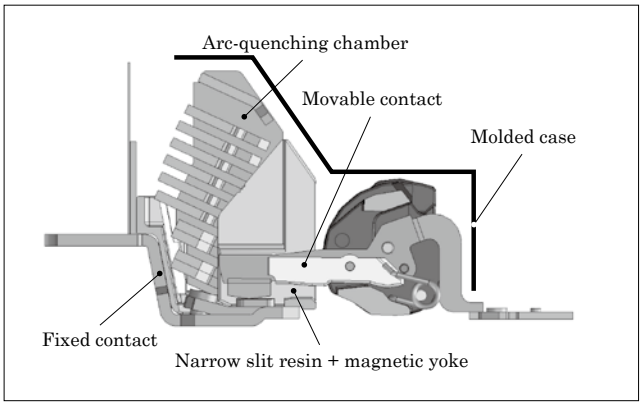


Fig.2 Features of small current rated (15 to 30 A) breaker structures

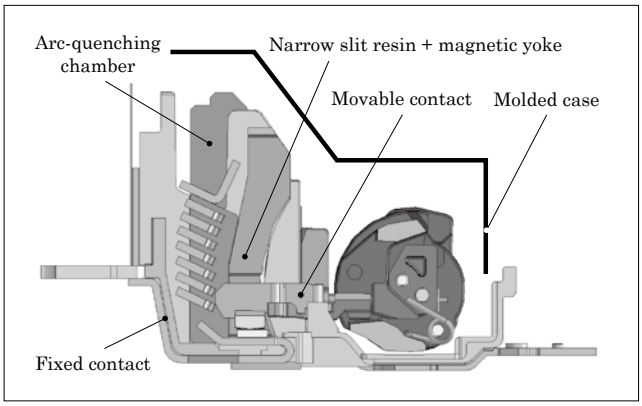
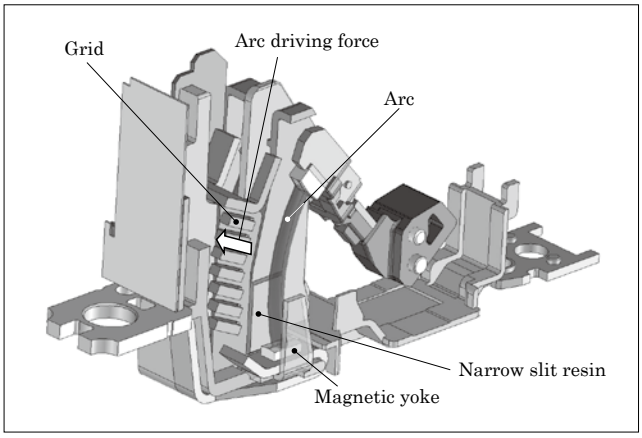


Fig.3 Breaker structure of small current rated device



opposes the fixed contact. The secondary-side fixed contact extends outward in a straight line and is connected to an overcurrent release. When a short-circuit current occurs, an electromotive force is generated between each of the respective primary-side and secondary-side fixed and movable contacts, and with the added effect of a magnetic yoke, the two contacts separate simultaneously at high-speed. The arc generated between the contacts is generated in series at the primary and secondary sides. Therefore, the rate of rise

Fig.4 Principle of electromotive force generation according to contact shape

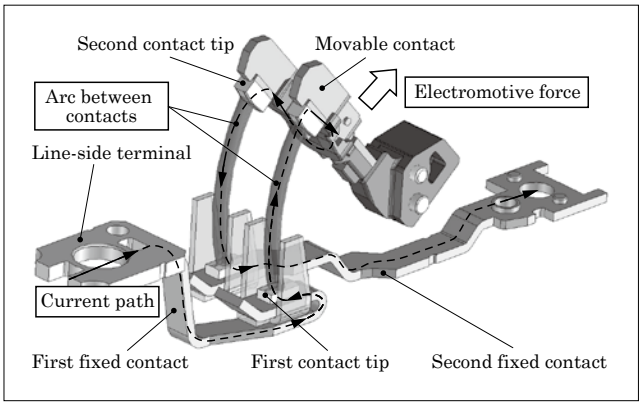
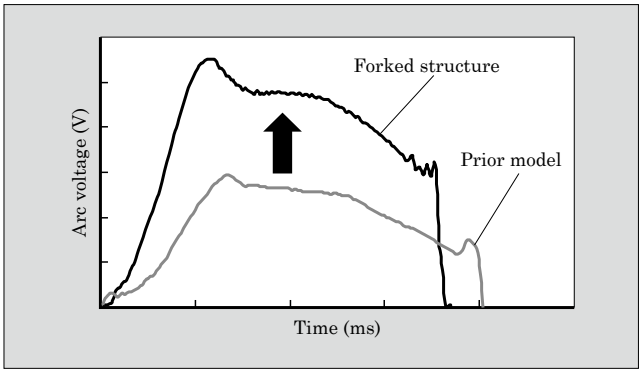


Fig.5 Comparison of arc voltages



of the arc voltage (dV/dt) is approximately twice that of a single contact. Moreover, by ensuring twice the contact separation distance with the same arc-quenching chamber space as for a single contact, a peak value of arc voltage that is approximately twice as large can be realized, and the current-limiting effect is enhanced significantly. The arc voltages for the forked structure and prior structure are compared in Fig. 5.

By applying these techniques, an approximate 15 % reduction in I^2t was realized in comparison to the prior series of breakers, and at the same time, performance that satisfies the UL489 standard was realized in a Japanese standard-size breaker shape. Moreover, the Twin Breaker concept of uniform dimensions for the MCCB and ELCB is maintained and parts for the make-and-break mechanisms in 40 A and higher rated products can also be shared.

3. High Reliability and High Efficiency Power Supply system technology

3.1 Plug-in type circuit breakers

In recent years, from the perspective of simplifying and reducing the amount of labor involved in the installation of equipment, improving the stability and maintainability of the electric power supply, and reducing the environmental load, plug-in type circuit breakers have attracted attention and have begun to

Table 4 Variations of “G-TWIN” plug-in circuit breakers

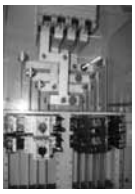
Name	Plug-in circuit breakers			
Main use	Switch board	Distribution board		
Applicable AF	125, 250, 400, 630	32, 50, 100, 125, 250	32 (MMS)	50 (MCCB-2P)
			Branched breaking capacity 200V/100 kA 	Branched breaking capacity 200V/2.5 to 25 kA
Mounting pitch	15 mm	15 mm	50 mm	
Installation height	125 mm	91 mm	94 mm	
Busbar layout	Vertical	Vertical	Vertical	
Busbar thickness	10 mm	4 mm	3 mm	
Busbar pitch	70 mm	45 mm	30 mm	
Features	○ Plug-in verification indicator ○ Can be equipped with power monitoring breaker, leakage alarm, etc. ○ High breaking capacity	○ Shutter mechanism for energized parts ○ Plug-in verification indicator ○ High and medium breaking capacity	○ Super-high breaking capacity ○ Selective trip coordination ○ Space-saving	○ Medium breaking capacity ○ Space-saving

Fig.6 External view of plug-in type circuit breaker

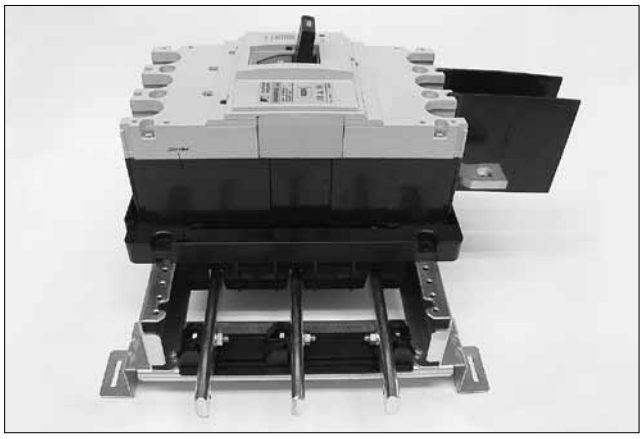


Fig.7 Structure of plug-in part connecting busbar

be used widely in facilities such as data centers and public utilities where a highly reliable supply of electric power is required.

Instead of using stud-type terminals such as in the previous insertion-type configuration, a plug-in circuit breaker (Fig. 6) is provided with clip-shaped contacts at the power supply-side terminal, and these contacts directly connect to and hold copper busbars provided at the board-side (Fig. 7). Since the wiring on the power-supply side of this structure can be realized without using electrical cable, the following benefits are provided.

(a) Space savings and resource savings of the switch board and distribution board
(b) Shorter assembly and delivery times
(c) Easier to change capacity, and shorter time required for replacement tasks
(d) Prevents work omissions and misconnections

Fuji Electric has prepared a wide variety of products that can be selected according to the usage and protection goals (Table 4).

For switch board applications, the circuit breakers used for branched circuits can be equipped with MCCBs and ELCBs ranging from 125 to 630 AF, and the maximum value of the busbar conduction current is 2,100 A. Moreover, in addition to MCCBs and ELCBs for general wiring applications, a breaker equipped with a leakage alarm, the “FePSU Breaker” equipped with a power monitoring function and the like are provided, and breakers can be freely selected for a particular application.

For power distribution board and lighting distribution board applications, plug-in circuit breakers have

Fig.8 Current waveforms of AC and DC circuits

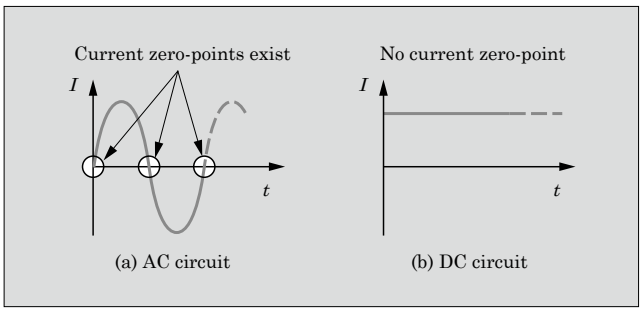
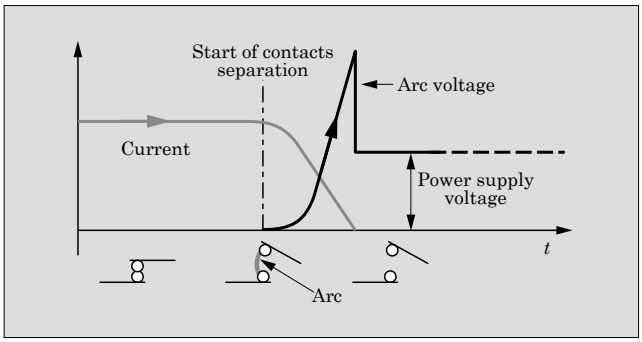


Fig.9 DC circuit current breaking waveform



been prepared in two varieties, with 32 to 250 AF or 32 to 50 AF, which enable further reductions in the size of switch boards. Also, "manual motor starter (MMS)" installation is also possible, and as a result of the super-high current-limiting breaking performance of an MMS, selective trip coordination with an upper-level circuit breaker can be implemented, thereby contributing to the realization of a reliable supply of electric power. Moreover, except for a few models, safety-related options, such as a safety shutter function that closes off the busbar when the breaker has been removed or a gauge function that verifies the plug-in status are also available.

3.2 "G-TWIN" DC breaker series

In recent years, with the increased popularity of green energy such as solar power and also with the widespread prevalence of data centers, requests for a more highly reliable and efficient supply of power have intensified, and there is growing demand to changeover from conventional AC power transmission and distribution to DC power transmission and distribution. Especially for data centers, decreasing the amount of AC-DC conversion is said to enable a reduction in power transmission loss of up to 10 or 20%, and the energy saving effect would be large. Additionally, higher voltage transmission and distribution technology has also been requested in recent years in order to reduce transmission loss.

In an AC circuit, a current zero-point generally occurs periodically, and at a zero-point, if the insulation can be maintained, the current can easily be interrupted (see Fig. 8). But in a DC circuit, because there is no zero point, a technique for boosting the arc voltage generated between contacts to a level greater than the power supply voltage is needed in the breaker to interrupted the current (create a zero point) (see Fig. 9). Additionally, as the power supply voltage increases,

Table 5 "G-TWIN DC Series" lineup

Rated DC voltage (V)	Basic model	No. of poles	Rated current (A)	Breaking capacity *I*cu (kA)				
				EAG	JAG	SAG	RAG	HAG
250	BW32 □*	2-pole	3 to 32	–	–	2.5	–	–
	BW50 □ BW63 □		5 to 63	2.5	–	5	5	–
	BW100 □		50 to 100	5	–	–	–	–
	BW125 □		15 to 125	–	15	–	40	–
	BW250 □		125 to 250	10	20	–	30	–
	BW400 □		250 to 400	20	–	20	40	40
	BW630 □ BW800 □		500 to 800	20	–	–	40	40
400	BW32 □	3-pole	3 to 32	–	–	2.5	–	–
	BW50 □ BW63 □		5 to 63	–	–	5	–	–
	BW100 □		50 to 100	5	–	–	–	–
500	BW50 □	3-pole	5 to 50	–	–	2.5	–	–
	BW100 □		50 to 100	2.5	–	–	–	–
	BW125 □		15 to 125	–	10	–	20	–
	BW250 □		125 to 250	–	10	–	20	–
	BW400 □		250 to 400	20	–	20	40	40
	BW630 □ BW800 □		500 to 800	20	–	–	40	40
600	BW125 □	4-pole	15 to 125	–	–	–	25	–
	BW250 □		125 to 250	–	25	–	40	–
	BW400 □		250 to 400	–	–	–	40	40
	BW630 □ BW800 □		500 to 800	–	–	–	40	40

∗ : □ indicates the breaker capacity type

Table 6 "G-TWIN" specifications of 2 or 3 parallel phases energizing breakers

Model	AF	No. of poles	Rated current (max.)	Rated breaking capacity (Icu)	
				60 V dc	125 V dc
BW32	32	2P	40 A	7.5 kA	5 kA
		3P	60 A		
BW50	50	2P	75 A	20 kA	10 kA
		3P	100 A		
BW63	63	2P	90 A	20 kA	10 kA
		3P	125 A		
BW100	100	2P	150 A	15 kA	10 kA
		3P	225 A		
BW125	125	2P	175 A	30 kA	20 kA
		3P	250 A	60 kA	40 kA
BW250	250	3P	550 A	60 kA	40 kA
BW400	400	3P	950 A	80 kA	60 kA
BW630	630	3P	1,400 A	80 kA	60 kA
BW800	800	3P	1,900 A	80 kA	60 kA

device miniaturization becomes more difficult as the arc-quenching mechanism must be made larger in size and the distance between contacts increased.

By developing a proprietary arc-quenching mechanism for DC applications, Fuji Electric has established efficient breaking technology. Further, by wiring 3-pole or 4-pole circuit breakers in series and maintaining the contact separation distance, these circuit breakers can be applied to block even higher voltages. As a result, compared to the applicable range of up to DC250 V with a standard breaker, the "G-TWIN DC Series" can be applied to voltage circuits of 400 to 500 V for 3-pole circuit breaker or up to 600 V for 4-pole breakers (125 to 800 AF), and with its wide range of AF specifications, the G-TWIN Series offers a product lineup suitable for a wide range of needs (see Table 5). Additionally, switches (non-auto SW) that do not contain overcurrent protection elements have also been developed into a product series, and the selectable range of models is expanding.

3.3 DC breakers variations

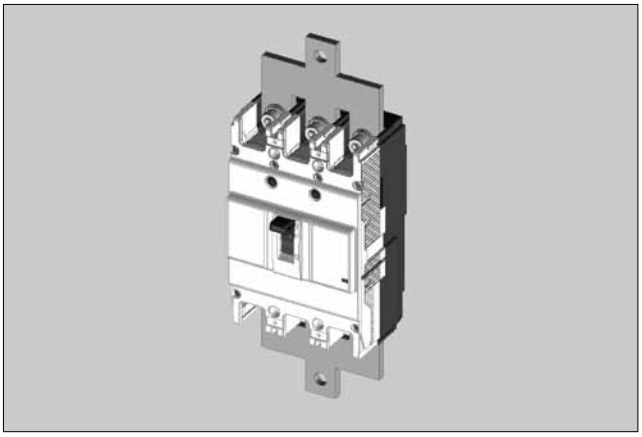
(1) 2 or 3 parallel phase energizing breakers

Specifications for parallel phase energizing breakers for low-voltage DC circuit applications have recently been added to the lineup of the G-TWIN DC Series (see Table 6).

These breakers are mainly used in applications involving DC power supply equipment for mobile base stations and the like (see Fig. 10), and since the current flow is divided into 2 or 3 phases, the current flow per phase is small, and the ability to realize conduction in excess of the previous maximum rating for each AF contributes to the miniaturization of devices and switch boards.

(2) Compact disconnecting switch for solar power applications

Fig.10 2 or 3 parallel phases energizing breaker



In the field of solar power, which has become widely popular, the installation of a disconnecting switch is required by the JIS C60364-5-55 standard in order to permit the maintenance and inspection of solar inverters. Also, aiming to raise the power generating efficiency of solar cells, the trend towards higher voltages is being advanced. In response, Fuji Electric has developed a compact arc-quenching mechanism that adds a permanent magnet to the conventional arc-quenching mechanism, and has also developed a compact disconnecting switch that is optimally suited for solar power generation. Designed to have the same size as an AC output-side ELCB, this breaker model contributes to the standardization of switch board design and the miniaturization of solar cell equipment.

4. Postscript

The elemental technologies of the G-TWIN Breaker Series and the various models introduced to the market have been described above. In the future, with advances in the reliability, safety and efficiency of electrical equipment both in Japan and overseas, a product lineup suited to the market needs, such as for selective trip coordination and DC distribution, and the improvement of product quality are expected to become increasingly important. By accurately assessing the requirements of its customers, Fuji Electric intends to continue to expand its offering of products, such as the G-TWIN Breakers, that are responsive to the needs of the market, and to broaden the lineup of its product series.

References

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Safety Devices that Support the Reliability of Machinery and Equipment

Kimitada Ishikawa † **Takao Yamasaki** † **Satoshi Sugawara** †

ABSTRACT

Against a backdrop of frequently occurring accidents at factories, railways and the like, interest in the safety of machinery and equipment is increasing. A newly developed short interruption restart relay combines the three functions of instantaneous restart, timed restart and prohibited restart in response to a power failure, and makes possible the safe implementation of the motor restart control. Also, a variety of safety standard-compliant devices such as emergency switches, trip wire switches, safety door switches, light curtains, safety mats, two-hand control stations and safety relay units are provided and help to reduce the risk associated with machinery and equipment.

1. Introduction

In recent years, concern for the reliability and safety of machinery and equipment has heightened as a result of the occurrence of accidents at public facilities such as railways and elevators and of large-scale industrial accidents at factories and manufacturing plants. This paper describes the roles and presents application examples of a "short interruption restart relay" for safely controlling the restarting of a motor after a power outage and "safety standard-compliant devices," which are key components used in the construction of a safety system.

2. Short Interruption Restart Relay

Short interruption restart relays are used in factories or manufacturing plants, in which multiple motors have been installed, to restart the motors automatically after a short-time power outage has occurred in the main circuit. In addition to preventing the loss of time and the like involved in recovery work, system crashes due to insufficient capacity can be prevented even when using small-size power source equipment since the inrush current is distributed over time when restarting and the maximum current flow into the main circuit is reduced, and as a result, lower investment costs and energy savings are anticipated.

Fuji Electric's newly developed "MB4" is shown in Fig. 1, and details of its specifications are described below.

2.1 Improvements in the MB4 Short interruption restart relay

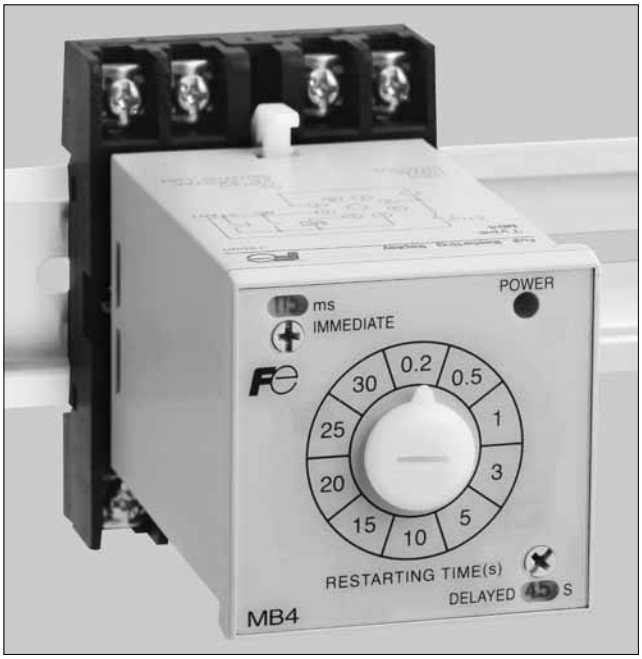
(1) Adjustable prohibited restart function

The previous model (MB2) had a fixed setting for determining whether restarting would be allowed or disallowed according to the time duration of the power outage. With the MB4, the user is able to adjust the time setting so as to improve the ease of use.

(2) Small size and common sockets

The MB2 previous model had a large external shape, and used a custom ATX1PS socket for installation and wiring. In contrast, the MB4 has a smaller size that occupies only 65% of the volume of the previous model and uses common TP48X sockets, which are used with the MS4S series of general-purpose timers. As a result, unlike the previous model, the MB4 can be mounted on a DIN rail.

Fig.1 Short interruption restart relay "MB4"



† Fuji Electric FA Components & Systems Co., Ltd.

2.2 Operation of short interrupt restart relay

Figure 2 shows a connection diagram for the short interrupt restart relay. The operation when the power has been restored will differ according to the duration of the power outage and this difference is explained below using the operating pattern shown in Fig. 3.

(1) Instantaneous restart

In the event of a power outage, first, the self-holding function of a magnetic contactor (MC) is released. Then, if the power is restored within an instantaneous restart time t_1, the output contact T_a turns ON in a pulse form. As a result, the magnetic contactor MC again implements its self-holding function and the motor restarts automatically.

(2) Time delayed restart

If the time duration of the power outage exceeds the abovementioned instantaneous restart time t_1, the output contact T_a will turn ON after a timed delay restart interval t_d has elapsed following the restoration of power. In the case where multiple restart relays are being used, by setting the time delay t_d to the desired time lag, the restart timing can be shifted for each motor so as to restart the motors sequentially. Since the motor inrush current will be distributed, the maximum current flow to the main circuit will be lowered.

(3) Prohibited restart

If the duration of the power outage exceeds the t_2 time setting, then even if power has been restored, the output contact T_a will not turn ON, and restarting will be disallowed until the START switch is turned on manually.

Fuji Electric's instantaneous restart relay is equipped with the abovementioned three operating modes that correspond to the power outage duration, and as a result, enables highly reliable automated control can be implemented in unattended electrical equipment.

In the case where automatic restarting after the motive power has been interrupted could pose a danger to the operator of the machinery or equipment, a preventative measure must be implemented using the safety relay unit introduced in section 3.2 below, or the like.

Fig.2 Short interrupt restart relay connection diagram

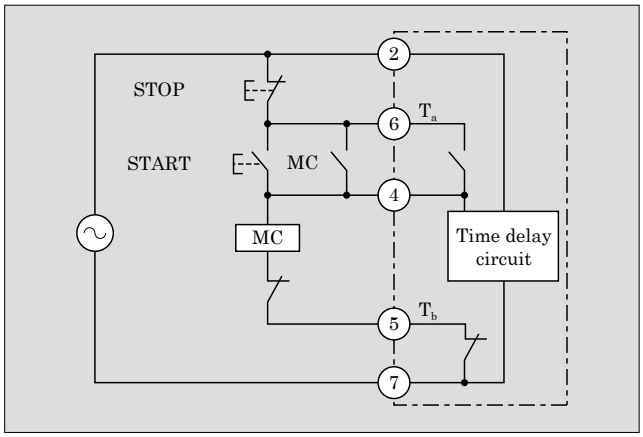
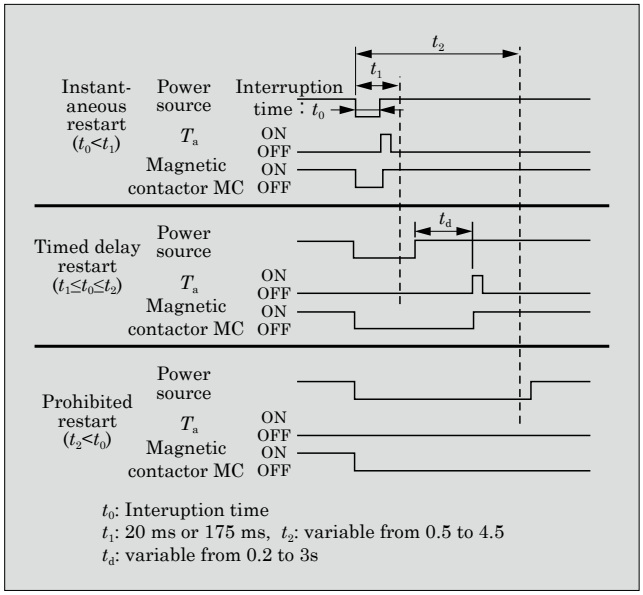


Fig.3 Operating pattern for restart



3. Standard-Compliant Devices

3.1 Market trends of safety devices

In Japan, with the adoption of international standards for machinery safety such as ISO 12100 (Safety of machinery: Basic concepts) and ISO 14121 (Principles of risk assessment), in order to ensure worker safety, safety measures for machinery and equipment are implemented in advance, and it is required the failure or misuse of such machinery and equipment will not harm people. Previously in Japan, the assurance of safety was highly dependent upon the skill of workers, and safety measures for machinery and equipment were not advanced. With the revision of the Japanese "Industrial Safety and Health Law" in 2006 and the "Guidelines for the Comprehensive Safety Standards of Machinery" in 2007, the concept of machinery safety in accordance with international standards began to gain ground in Japan.

Table 1 Functions and types of safety standard-compliant devices

Function	Type
Switch to stop machinery when dangerous situation arises	Emergency stop switch Trip wire switch
Sensor for notifying operator of the open or closed state of a guard that isolates dangerous locations	Safety door switch
Sensor for detecting the intrusion or presence of a person	Light curtain Safety mat
Switch for securing a person in a safe location while operating the machinery	Two-hand control station Foot switch
Device for safely controlling the abovementioned devices	Safety relay unit Safety controller

The devices used for safety have the following characteristics in order to improve the reliability of the safety functions. These devices are different from general-purpose devices.

(a) Designed with redundancy
(b) Designed with diagnostic functions and the like so as to be safe side even during a failure
(c) Provided with a function for preventing defeat of the safety mechanism

The safety devices shown in Table 1 and Fig. 5 are individually described below.

3.2 Characteristics of Safety standard-compliant devices

(1) Emergency stop switch

Developed in 2007, Fuji Electric's "minico Series" of command switches help to achieve space savings in the control panel and have been well-received. As an expansion of this series, the "AR16 V" emergency stop switch was launched in October 2008 and its features are introduced below (see Fig. 4).

(a) Multi-contacts

Fuji Electric's conventional emergency stop switches were typically provided with 1 to 2 contacts, but redundant circuitry is being required for electrical safety, and multiple contacts are desired. To meet these needs, the AR16 V is provided with up to 4 contacts.

The minico Series employs an integrated structure with built-in contacts; its body can be inserted directly into a ϕ16 mm mounting hole and is arranged so that 4 contacts can be efficiently arranged in the limited body space.

(b) Improved operability

According to IEC 60947-5-5 (Electrical emergency stop device with mechanical latching function), a safety device is required to be able to withstand an operating force of five times the mounting hole diameter. In the case of a ϕ16 mm mounting hole, the corresponding required force withstand capability is 80 N, but during an emergency, it would be difficult to adjust the operating force according to the switch diameter. The AR16V has a structure capable of easily withstanding 150 N, which corresponds to a standard maximum diameter of ϕ30 mm. Also, the two release methods of turn-reset and-pull reset exist in the market, as consequently, the operation will vary depending on the machine, and this may invite confusion. Turn-reset and pull-reset structures are both capable of implementing the release with the AR16V, and as a result, safety is ensured and the customer's ease-of-use is improved.

(c) Lineup of illuminated-type products

Particularly for large-size machinery, there is a need to improve the visibility of emergency stop switches so that they can be located quickly. Emergency stop switches compatible with ϕ16 mm mounting holes have been added to Fuji's lineup as the first illuminated-type products. In addition, LEDs are used as the light source, helping to reduce power consumption and CO_2 emissions.

(2) Trip wire switch

If an emergency stop system is needed along a long conveying line or the like, a trip wire system that activates a stop function when a wire is pulled is well suited for this purpose. As shown in Fig. 6, a trip wire switch can be operated from anywhere within the workspace so that workers are able to avoid the direct

Fig.4 Appearance of "AR16 V" emergency stop switch

Fig.5 Example installation of safety standard-compliant devices

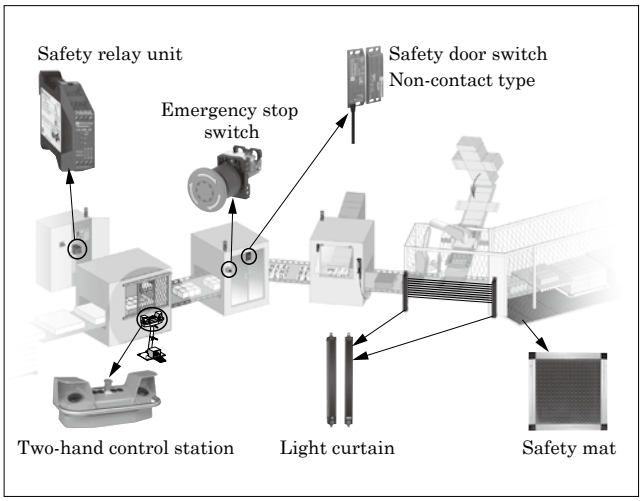
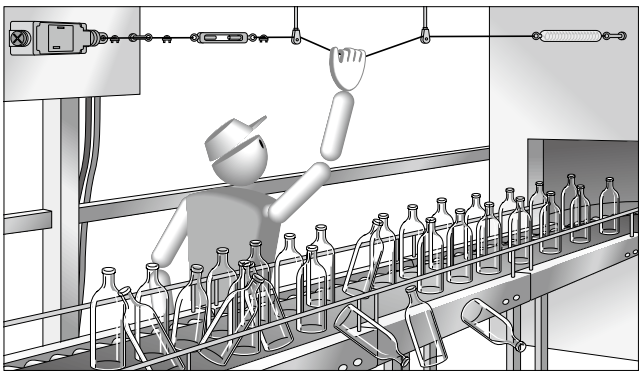


Fig.6 Trip wire switch



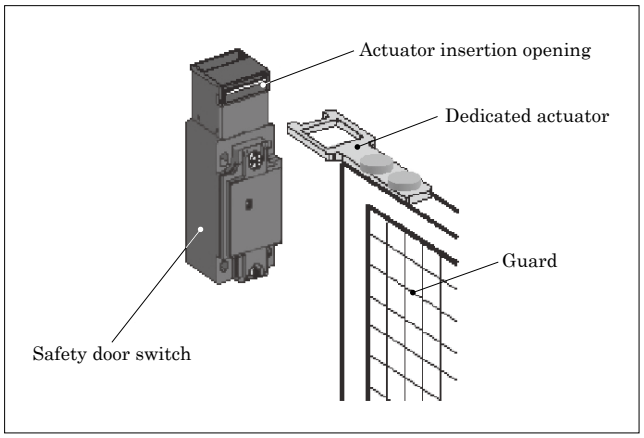
risk of danger. Compared to the case in which multiple emergency stop switches are installed, the implementation of a trip wire switch enables a significant reduction in the time required for wiring.

(3) Safety door switches

With ISO 14119 (Interlocking devices associated with guards), safety door switches are required to have a function for preventing the safety interlocking mechanism from being defeated. As shown in Fig. 7, the "XCS Series" has a functional structure only when a dedicated actuator has been inserted. This prevents workers from using wire and common tools to defeat the switch and operate the machinery in a dangerous state. In cases where the machinery does not stop immediately by inertia after the issuance of a stop command, an "XCSE," having a function for locking the opening and closing of doors, is used together with a stop detection unit, which will be described later.

With the "XCSDM" non-contact type safety door switch, there is no mechanical contact between a magnetic actuator and sensor unit. Therefore no particulate debris is generated as a result of abrasive wear. In addition, these "XCS Series" safety door switches are provided with an IP67 protective structure and are well suited for use in semiconductor manufacturing equipment and in food machines that use water.

Fig.7 Safety door switch "XCS Series"



(4) Light curtain, safety mat

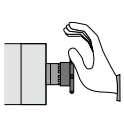
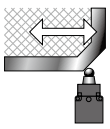
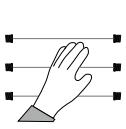
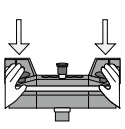
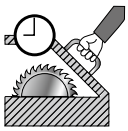
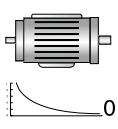
The "XU Series" of light curtains are sensors for detecting the intrusion of a person and comply with IEC 61496 (Electro-sensitive protective equipment). Various models are available for finger detection, hand detection and human body detection and the sensor transmitter and receiver can be separated by a long distance of up to 20 m. These light curtains can also be used as a substitute for a safety fence.

Since a light curtain is installed in the periphery of a hazardous area, it is difficult to distinguish between the presence of a person or machine inside the hazardous area. In such a case, a "XY2TP" safety mat spread out on the floor is well suited for detecting the presence of a person. This safety mat has a relatively large detectable weight capability of 20 kg or more, and is resistant to mis-operation due to the dropping of tools or the like.

(5) Two-hand control station

The "XY2SB" two-hand control station requires the use of both hands to press switches to start the machinery, and consists of two mushroom-shaped push-button switches and an emergency stop switch integrated into a single unit. To ensure safety during operation, the two-hand control station complies with the requirements of ISO 13851 (Two-hand control devices). When used in conjunction with a custom stand, the height, direction and tilt of the switch installation

Table 2 Safety relay unit, safety controller and applications

Safety relay unit, safety controller model	Safety application								Compliance category * 1
	Emergency stop switch	Safety door switch	Non-contact door switch	Light curtain	Safety mat	Two-hand control station	Safety time delay	Zero speed detection	
									
XPS AF	○	○							4
XPS ATE	○	○					○		3
XPS AV	○	○					○		4
XPS VNE								○	3
XPS AK	○	○		○	○				4
XPS DMB			○						4
XPS BF						○			4
XPS MC	○	○	○	○	○	○	○		4
XPS MP	○	○	○	○	○				4

＊1：ISO 13849-1 (Safety related parts of control systems)

can be adjusted freely according to the physique and posture of the operator.

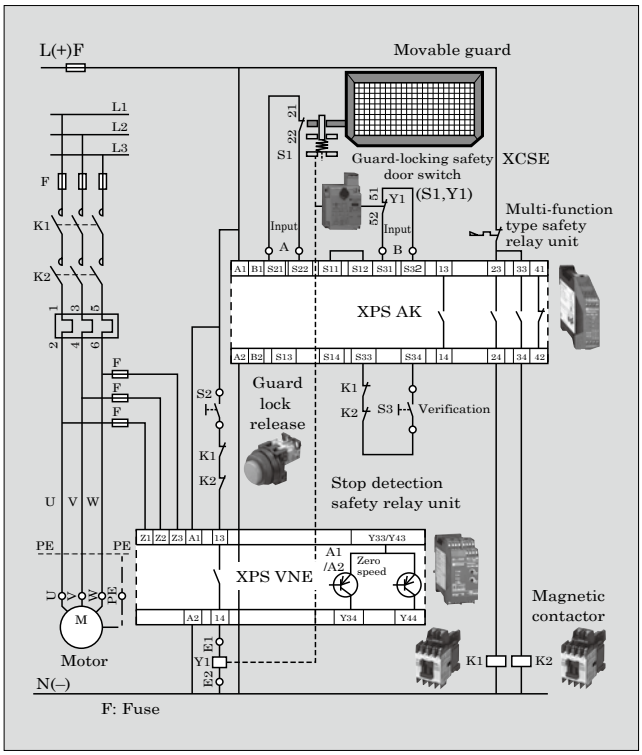
(6) Safety relay unit, safety controller

By combining safety relays equipped with forcibly guided contact mechanisms, a redundant safety circuit can be configured with diagnostic functions such as redundancy and welding detection, but the time and investment required for the development, design and standard certification of such circuits is a problem.

In the "XPS Series" of safety relay units, the safety controller is integrated into a single unit, enabling safety systems to be realized easily. Table 2 shows the suitability of each model of this series according to the applications and categories prescribed by ISO 13849-1 (Safety related parts of control systems). Each unit in "XPS Series" supports category 3 (design such that the safety function is always retained when a single fault occurs) or category 4 (design such that an accumulation of faults shall not lead to the loss of the safety function).

A safety relay unit supports a single safety function, and the realization of multiple safety functions for large-scale machinery results an increase in the number of installed units and complicated wiring. With the "XPS MC" safety controller, up to 32 devices can be monitored from a single controller, resulting in a smaller footprint and requiring less wiring time. This product is equipped with both solid-state and relay outputs and can handle loads of up to 4 A, and is also capable of driving a magnetic contactor directly. In addition, because the software is constructed from certified function blocks, safety functions can be realized with simple programming techniques, and the monitoring of individual safety devices makes it possible to assess the status quickly when a failure occurs.

Fig.8 Example connection of rotation stop detection unit



3.3 Example application of motor rotation stop detection

The "XPS VNE" is a safety relay unit for detecting the rotational inertia of a motor, and utilizes a method for detecting the back electromotive force of the motor. Since rotation sensors such as proximity switches are unnecessary, use of the XPS VNE enables a reduction in the amount of work required for sensor installation and adjustment. The circuit configuration is described with reference to the typical application example shown in Fig. 8.

(1) Detection of rotation stop

Each U, V and W motor phase is connected to an input pin Z1, Z2 and Z3, respectively, of the XPS VNE, which detects and monitors the voltage between each phase. When the power to the motor is interrupted, a back electromotive force is generated in the stator windings. This back electromotive force is proportional to the rotational speed of the motor. Therefore, a determination to stop the rotation is made if the voltage being monitored drops below a certain threshold value.

(2) Failure diagnosis

If a difference in the voltages between pins Z1 and Z2 and between Z2 and Z3 is detected, a wiring abnormality is determined to exist between the motor and the XPS VNE, and mis-operation due to a broken wire or failure is prevented.

(3) Movable guards and control of magnetic contactors

The "XPS AK" safety relay unit monitors whether movable guards are closed and also the welding status of contacts for mirror contact-type magnetic contactors. In the case of occurring abnormalities such as contacts welding, for example, the output contacts 23-24 and 33-34 are turned off, and control is implemented to inhibit the motor from starting. Additionally, the "XCSE" interlocking safety door switch immobilizes the movable guards while the motor is rotating, but after confirmation that the rotation has stopped, in response to a command from the XPS VNE, drives a solenoid incorporated into the door switch to release the guard lock.

The configuration described above is able to ensure safety in an inertial system.

4. Postscript

In this paper, in addition to safety devices for unmanned equipment, characteristics of new safety standard-compliant devices that support the changing tide of the concept of global safety have been introduced. By offering a combination of safety devices and detection equipment and providing technical know-how, Fuji Electric will endeavor to promote safety solutions that contribute to society.

The Latest Technology for Expanding the Range of Applications for "MOLTRA"

Tsutomu Ishida † **Shunichi Sugawa** †

ABSTRACT

Fuji Electric's "MOLTRA" is a fire-resistant, maintenance-free, compact and lightweight molded transformer, that is also environmentally-friendly because it does not use oil. In new energy applications involving wind power systems, measures such as the use of smaller coils, removal of interphase barriers and barriers between primary-side panels, use of H-type insulation, and the application of a shielded structure for secondary terminals and inter-phase leads ensures 34.5 kV insulation performance and achieves a smaller size and lighter weight. For use in special power supplies for power storage devices, a transformer with approximately 4 times the overvoltage input tolerance as a general-purpose high-voltage MOLTRA has been developed. Moreover, the installation of Japan's largest MOLTRA in the electric room on an upper floor of a building was implemented by disassembling the MOLTRA, and using a jig to transport the disassembled pieces.

1. Introduction

Fuji Electric's "MOLTRA" series of molded transformers have been used in practical applications since the early 1970s. Highly regarded as a fire-resistant, maintenance-free, compact and lightweight, low loss, low noise, and moisture resistant transformer having excellent short-time overload capability and high reliability, the use of the MOLTRA became widespread in applications in which grade H insulation dry-type transformers had been used previously. Because of the abovementioned advantageous features, the MOLTRA has been used widely in power receiving and transforming facilities at public facilities, buildings, hospitals and other such places where many people tend to gather. In recent years, as part of its efforts to help protect the global environment and curb global warming, Fuji Electric has expanded the MOLTRA lineup to include the low-loss Top-Runner MOLTRA and the Super Efficiency MOLTRA. With the development of molded insulation technology and other various technologies, the dielectric strength and other performance criteria have reached levels equivalent or superior to those of an oil-immersed transformer, and the MOLTRA's dimensions and loss levels are becoming smaller year-by-year.

In recent years, the achievement of a significant reduction in greenhouse gas emissions has been set as a global goal, and as an alternative to traditional fossil fuels, a migration toward new renewable forms of energy such as wind power and solar power is underway.

Fuji Electric's MOLTRAs for new energy applications, such as for wind-generated power and energy storage systems, which feature improved dielectric performance and environmental durability as compared to a general MOLTRA for power applications are introduced below. Also described is an example of the delivery of Japan's largest-class capacity MOLTRA to the electric room on an upper floor of a large department store in which the MOLTRA was dissembled and transported in pieces.

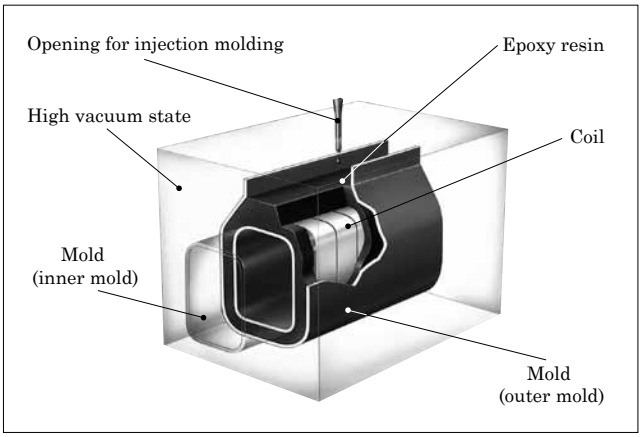
2. MOLTRAs for New Energy Applications

To ensure the dielectric performance of a molded transformer, it is especially important that there are no partial discharges. Fuji Electric's MOLTRAs use the following two technologies to ensure a high level of insulation reliability.

(1) Vacuum injection molding method

As shown in Fig. 1, a vacuum injection molding method using a mold is employed. With this method, as shown in Fig. 2, resin penetrates throughout the interlayer insulation in the windings, to form molded

Fig.1 Injection of epoxy resin in vacuum injection molding method



† Plant Business Headquarters, Fuji Electric Systems Co., Ltd.

windings that are free of voids, have excellent corona characteristics and highly reliable insulation performance. Moreover, the smooth winding surface provides excellent moisture resistance and dust resistance.

(2) Sheet windings

With sheet windings, since the burden voltage between conductive turns is minimized, the insulation reliability, surge resistance and safety are maintained during operation. Also, sheet windings typically have a high space factor and are therefore advantageous for making more compact and lighter weight windings.

In addition, special insulation performance enhancements are realized in these MOLTRAs for new energy applications.

2.1 MOLTRA for wind-generated power applications

Fuji Electric produces a MOLTRA for boosting the voltage of a wind turbine generator to the system voltage level of 34.5 kV. The main specifications are shown in Table 1. Since this MOLTRA is installed inside a wind turbine (nacelle) at the top of a tower several tens of meters tall, the following features are requested.

(a) Compact size that can be housed within a limited space

(b) Reduced insulation separation distance when installed

Additionally, the following features are requested of the installation environment for a wind power plant.

(c) Environmental durability (resistance to salt damage, etc.)

(d) Insulation performance that supports high altitudes above 1,000 m

Responding above requests, by implementing the following measures, 34.5 kV insulation performance, which is the highest voltage class for molded transformers, can be ensured and small size and light weight can also be realized.

(a) Review of the dimensions of insulation inside windings in order to reduce the coil size

(b) Removal of interphase barriers and barriers between primary-side panels

(c) Use of H –type insulation

(d) Application of shielded structure to secondary terminals and leads between phases

Moreover, the characteristic vibration of a wind turbine nacelle also affects the transformer, and therefore in addition to verifying the design with respect to the requested specifications, a vibration test is also carried out with an actual turbine under the conditions listed in Table 2 to confirm that there are no problems.

Fig.2 Molded state of sheet windings

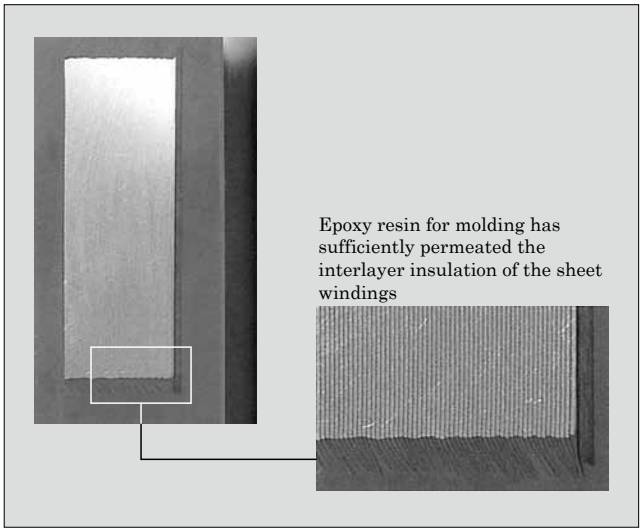


Table 1 Main specifications of MOLTRA for wind-generated power applications

Applicable standard	IEC-60076-11-2004	
Rated capacity (kVA)	2,700	
	Primary	Secondary
Rated voltage (V)	690	34,500
Frequency (Hz)	60	
Insulation class	H	
Max. ambient temperature (°C)	50	
Cooling method	Self-cooling	
Connection	Dyn11 (Δ/Yn)	
Dimensions (mm)	2,700 (W)×2,260 (H)×1,315 (D)	
Weight (kg)	6,500	

2.2 MOLTRA for energy storage system applications

Fuji Electric produces a MOLTRA that functions as a linking transformer between an energy storage system and a commercial grid system. The main specifications are listed in Table 3. So an inverter output could be connected without the use of a filter, insulation performance of approximately four times the overvoltage input withstand capability as that of a general high-voltage MOLTRA had to be realized in a compact size. A MOLTRA that satisfied the required specifications was developed by implementing the following measures.

(a) Application of a 22 kV class winding structure

(b) Review of insulation dimensions in order to reduce the size

(c) Analysis of electric field concentrations and measures to prevent

Table 2 Vibration test conditions

Vibration conditions	Acceleration 0.5 G (max. value for TR main unit: 3 G)
Frequency	5 to 100 Hz
Vibration direction	X, Y, Z directions
Post vibration test check	External appearance of structure, test of general characteristics

3. Larger Capacity and Disassembled Transportation of MOLTRAs

Data center buildings and shopping centers, for which demand has increased in recent years, are often equipped with indoor extra-high voltage facilities. Traditionally, oil-immersed or gas-insulated transformers had to be used because of the need for large capacity. However, to improve eco-friendliness and in support of disaster prevention measures, and also in response to requests for eliminating SF_6 gas and oil, the need for a large capacity MOLTRAs are increasing.

Below, an example of the delivery of Japan's largest-class capacity MOLTRA, as a transformer for the power receiving equipment of a spot network system, to the upper floor of a large department is described. Figure 3 shows the external appearance of the MOLTRA and Table 4 lists its specifications.

In this example, the onsite restrictions were severe with an allowable tower crane weight limit of 16 t, a height limit of 2,750 m along the transport route, and a 2-day transportation time limit. In order to comply with these restrictions, first, we had to design a MOLTRA structure that could be disassembled. To shorten the transportation time and improve the reassembly efficiency onsite, packaging for the disassembled parts was designed so as to minimize the amount of packaging and minimize the number of packages to

Table 3 Main specifications of MOLTRA for energy storage systems

Applicable standards	JEC-2440-2005, JEC-2200-1995	
Capacity (kVA)	1,200/2×600	
	Primary	Secondary, Tertiary
Rated voltage (V)	6,600	2×280
Frequency (Hz)	50	
Insulation class	H	
Max. ambient temperature (˚C)	50	
Cooling method	Self-cooling	
Connection	Dd0d0 (Δ/open Δ/open Δ)	
Dimensions (mm)	2,095 (W)×1,888 (H)×985 (D)	
Weight (kg)	4,900	

Fig.3 Appearance of Japan's largest class capacity MOLTRA

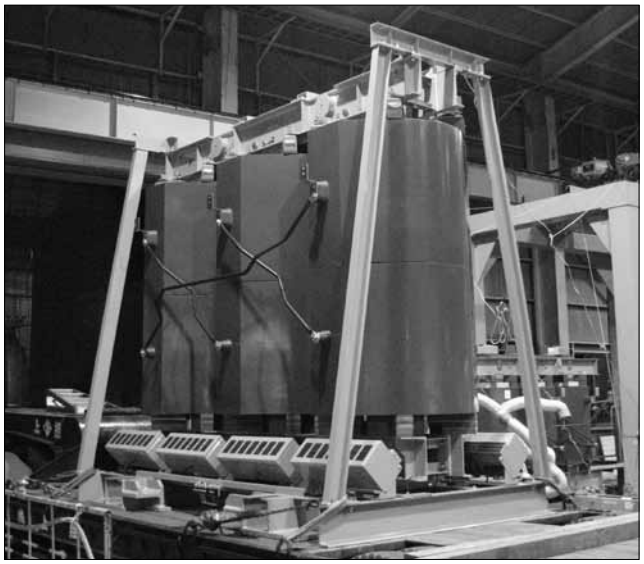


Table 4 Main specifications of Japan's largest-class capacity MOLTRA

Applicable standard	JEC-2200-1995	
Rated capacity (kVA)	13,000	
	Primary	Secondary
Rated voltage (V)	22,000	6,600
Rated current (A)	341	1,137
Test voltage value (kV)	LI95/AC50	LI60/AC22
Tap voltage (V)	F23000-R22000 -F21000-F20000	6,600
Frequency (Hz)	60	
Insulation class	H (Avg. temperature rise of windings: 120 K)	
Max. ambient temperature (˚C)	40	
Cooling method	Self-cooling (13,000 kVA) Air-cooling (16,900 kVA: 8 hours, 3 times per year)	
Connection	Dd0 (Δ/Δ)	
Dimensions (mm)	3,545 (W)×3,592 (H)×2,300 (D)	
Weight (kg)	24,700	
Cooling fans	250 W×8 units	
Earthquake-resistant horizontal seismic coefficient	1.5	

Fig.4 Sketch of transportation of core

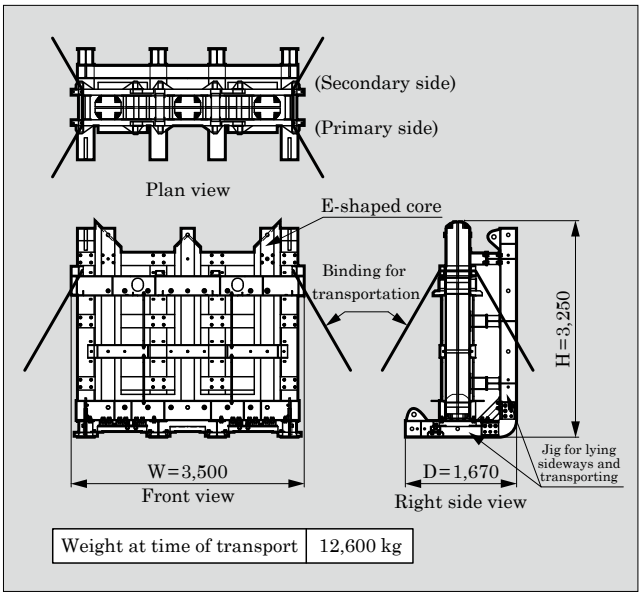


Fig.5 Schematic drawing of core being laid on its side

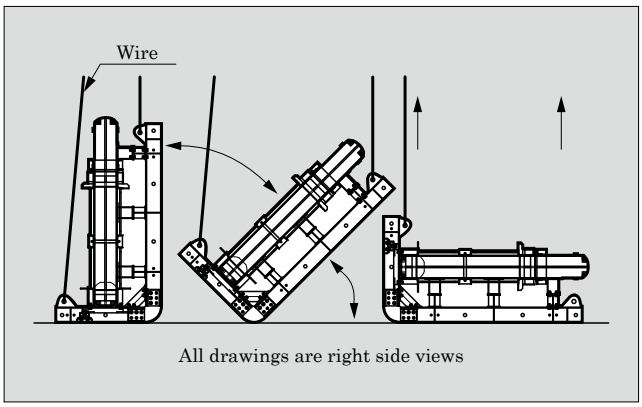


Fig.6 MOLTRA being assembled onsite

be transported. The core, which is the largest component, cannot be disassembled to reduce its height, and therefore we built an L-shaped jig as shown in Figs. 4 and 5 that enables the core to be laid on its side in order to comply with the height restrictions.

After the core was installed onsite, the MOLTRA was reassembled using a chain block as shown in Fig. 6 to hoist the coils and other components. Also, after the reassembly process was completed, the performance was verified with dielectric strength tests, phase displacement tests, transformer voltage ratio measurements and the like to confirm that there was no deviation from the factory test results.

4. Postscript

New technologies for expanding the MOLTRA application range have been presented.

Notwithstanding the trend toward more compact size and lower loss, there is increasing need for the ability to support higher voltages and higher capacities with a MOLTRA. Fuji Electric intends to continue to endeavor to expand the range of applications that can fully utilize the excellent eco-friendliness and disaster-prevention merits of these products, to intensify our efforts for improving insulation technology that will enhance the responsiveness of special products, and to continue to develop technology to realize superior MOLTRAs.

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