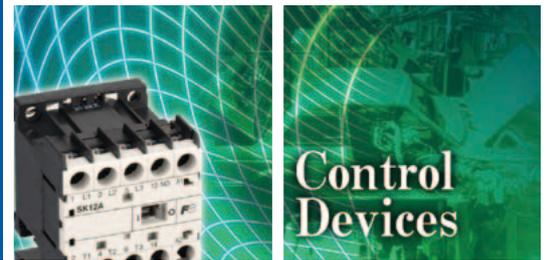


# FUJI ELECTRIC REVIEW

Switching, Operation/  
Display and Control Devices



2012 VOL.58



Control  
Devices

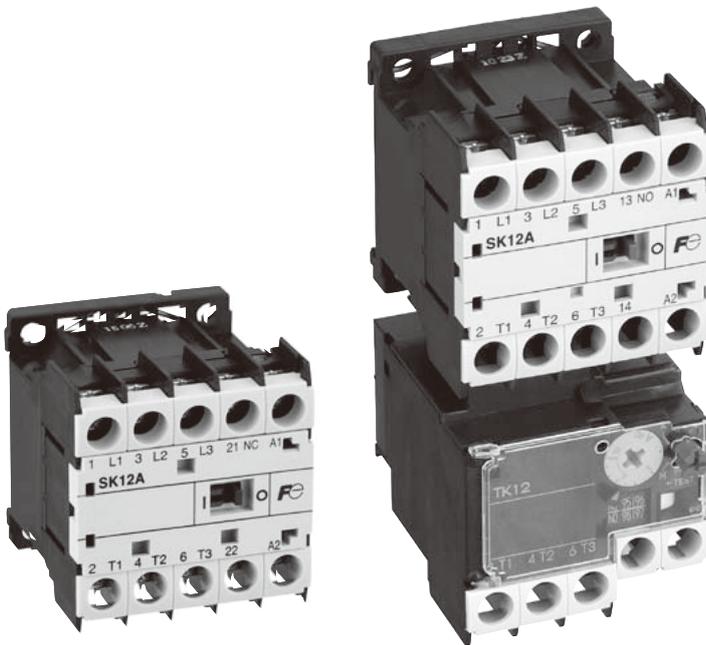


Electric  
Distribution

# Mini Contactors and Thermal Overload Relays SK Series

The Smallest class in the world of magnetic contactors and thermal overload relays have been launched !

Employ SK Series for all the small capacity applications of 12A (AC-3 440V) or less.



- > Smaller size and lower consumption
- > Providing more various line-ups and options
- > More improved safety and practicality
- > Conforming to world's major standards

Comparison with existing magnetic contactors

Smaller footprint

87% to existing models

Comparison with FUJI's SJ Series

Smaller volume

55% to existing models

Comparison with FUJI's SJ Series

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

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# FUJI ELECTRIC REVIEW

# 3

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Switching, Operation/  
Display and Control Devices

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#### Cover photo:

Technology for supplying electrical energy stably and efficiently has attracted particular attention in recent years. The ability to configure high-reliability power distribution and power supply systems that are space-saving and energy-conserving is becoming increasingly important for office buildings and commercial facilities, as well as plants and manufacturing facilities.

In response, Fuji Electric has supplied miniature devices, energy-conserving devices and facility monitoring devices optimally suited for power distribution and power supply equipment and machinery, and has expanded its offerings of models that support multiple standards and specialized models for emerging markets.

The cover photo depicts control devices such as a mini contactor, thermal relay, and a command switch that have been incorporated into mechanical and control systems, and a power distribution system being supported by a vacuum circuit breaker, protective relay, high-voltage DC breaker, energy monitoring device and the like.

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# Current Status and Future Outlook for Electric Distribution and Control Devices

ASAKAWA Koji †

## ABSTRACT

Electric distribution and control devices have greatly evolved as the indispensable elements of electrical equipment that drives industry. Fuji Electric has made various efforts with market trends in mind. We have proceeded product globalization by complying with major foreign standards and have strengthened the product capability to apply energy and environment conscious market fields through the development of high-voltage direct current equipment. For the electric distribution facilities that support advanced information system, Fuji Electric has increased the stability and reliability of power supplies while also has reduced lifecycle costs by simplifying maintenance inspections. We have also achieved the miniaturization and performance enhancement of switching devices, low-voltage circuit breakers, dedicated products intended for developing countries such as China and Asia, and power monitoring equipment.

## 1. Introduction

With the aim of realizing a resource-recycling society, Fuji Electric is focusing efforts on its environment and energy business, and supplying electric distribution and control devices (see Fig. 1), which have supported such business and made dramatic advances as the main constituent elements in electrical equipment that drive industry. This paper describes the changes that have occurred in the market and environment so far, and while reflecting upon Fuji Electric's history of interaction, introduces recent products and describes future efforts.

## 2. Market Trends and Fuji Electric's Efforts

Fuji Electric has sought to accurately grasp the

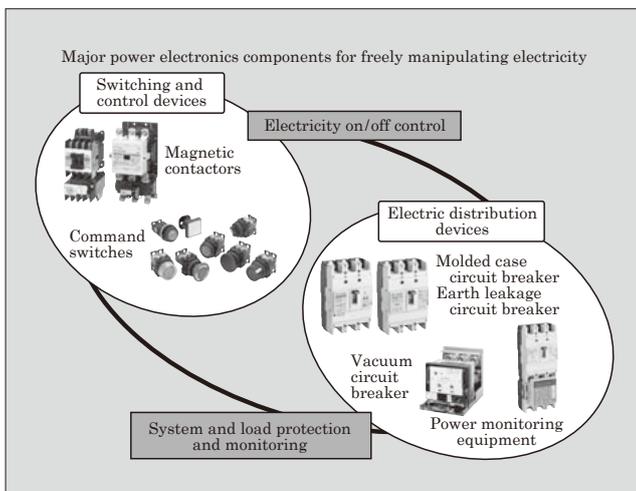


Fig.1 Fuji Electric's electric distribution and control devices

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

changing market trends and to supply products with which can provide a large added value to the customer. The progress of the main electric distribution and control devices is shown in Fig. 2. Additionally, recent electric distribution and control equipment products are listed in Table 1.

### (1) Response to globalization

In 1993, the EC directive\*1 was issued, and in 1995, CE marking was made mandatory. Systems for standard certification are getting strict in every nation, and in China, for example, compliance with CCC compulsory certification\*2 has become essential. In recent years, with the acceleration of overseas business expansion of our customers, JIS adoption of IEC standards, and the global spreading of IEC standards, development has been pursued to make Japanese domestic standard products compliant with IEC standards. Furthermore, multi-standard products such as the "G-TWIN Breakers" for example, that support not only IEC standards, but also UL and other major overseas standards, have been developed and introduced to the market.

Additionally, for machinery and production equipment, safety requirements are increasing and various international standards have been issued, including ISO12100 "Safety of machinery—Basic concepts, general principles for design". In Japan, these standards were sequentially incorporated into JIS. In response to this safety standard and to the safety standards of the "Industrial Safety and Health Law" that was revised in 2006, Fuji Electric has strengthened its lineup of emergency stop button switches, and has provided low-voltage circuit breakers with an isolation function

\*1: EC directive: See "Explanation 1" on page 139

\*2: CCC compulsory certification: See "Explanation 2" on page 139

Year		1990	2000	2010
Market needs	Economic environment	○ Bursting of the bubble economy	○ Asian currency crisis Accelerated trend toward advanced information capability Global environmental issues	○ IT recessing Expansion of emerging markets ○ Lehman bankruptcy ○ Great East Japan Earthquake Accelerated development of new energy
	Regulations and standards	○ CE marking	○ Kyoto Protocol ○ JIS adoption of IEC standards ○ Energy Conservation Law revised (1) ○ JIS adoption of safety standards	○ CCC (China Compulsory Certification) ○ Environmental regulations (RoHS directive) ○ Environmental regulations (REACH regulation) ○ Environmental regulations (Convention on POPs) ○ Energy Conservation Law revised (2) ○ Energy Conservation Law revised (3) ○ Industrial Safety and Health Law revised ○ Energy Conservation Law revised (4)
Progress of electric distribution and control devices	Switching	○ New SC Series ○ FC Series	○ NEO SC Series	○ FJ Series ○ SK Series
	Control	○ φ22 AR22 ○ φ30 AR30	○ φ22 AM22 ○ Increase of models with emergency stop feature	○ φ16 minico Series
	Low voltage	○ TWIN Breaker Series ○ Super TWIN Series	○ α-TWIN Series	○ G-TWIN Series ○ Compact 63 AF ○ DC high-voltage
	High voltage	○ Multi VCB ○ Intelligent VCB	○ Auto V ○ VMC·HN Series	○ QHA Series
	Power monitoring	○ F-MPC04	○ F-MPC60B/50/30 ○ Fe-PSU	○ F-MPC Web ○ F-MPC04E

Fig.2 Progress of electric distribution and control devices

Table 1 New electric distribution and control devices products in recent years

Market needs	Equipment group	New products
Globalization	Switching devices	“SK Series” of mini contactors and thermal relays
	Control devices	“Minico Series” of φ16 command switches
	Low-voltage circuit breakers	125 to 800 AF “G-TWIN Series” Compact 32 to 63 AF low-voltage circuit breakers
For emerging markets	Switching devices	“FJ Series” of mini contactors
Energy and environment	Low-voltage circuit breakers	High-voltage DC breakers
	Power monitoring equipment	“F-MPC04E” single-circuit AC power monitoring unit
Advanced information capability	Low-voltage circuit breakers	Low-voltage circuit breakers for IDC
	Power monitoring equipment	“F-MPC Igr” Igr insulation monitoring device
	High-voltage equipment	“QHA Series” of digital protective relays for high-voltage electric distribution Vacuum circuit breakers for dry-air sealed-type cubicles

as a standard to meet the requirements of standards for supply-disconnecting devices. With the “SC Series” (SC-03 to SC-N16) electromagnetic contactor, safety standards were met by providing, as a standard function, positive opening mechanism contacts (positively-driven contacts) and safety opening function contacts (mirror contacts).

(2) Response to market expansion in emerging economies

China’s market liberalization has proceeded since 1990, and China has evolved from the “world’s factory” to the world’s largest market. In the future, China and other Asian nations will continue to grow, and investment in public infrastructure is increasing. Moreover, with the recent appreciation of the Japanese yen, the Japanese manufacturing industry’s export business tends to shift to local production in this region. To ensure a competitive advantage in this market for customers who have expanded into this region, Fuji Electric is establishing an optimized product lineup to meet a low-price level in this region.

(3) Response to energy and environmental tendency

Interest in preserving and improving the local environment increased in the latter half of the 1990s, and attention has focused on eco-products, energy savings

and new energy. In accordance with a framework for action based on the “Kyoto Protocol” adopted at the Third Conference of the Parties to the United Nations (COP3) Framework Convention on Climate Change in 1997, the Japanese “Law Concerning the Rational Use of Energy” (Energy Conservation Law) was repeatedly revised, and the coverage of regulation was expanded from large-scale businesses to small-scale businesses. For power monitoring devices, Fuji Electric has responded to the strengthened regulations thus far with a model change of its “F-MPC Series” and an expansion of product lineup. Additionally, ever since the Great East Japan Earthquake, renewable energy usage has been expanding and awareness of energy savings and conservation has been increasing more than ever. For general residential buildings, the model of energy savings called eco-house through the use of direct current (DC) has been attracting attention. In the information and communication field, 400 V DC-class equipment is under consideration primarily for use at data centers.

In the expanded usage of renewable energy, photovoltaic power has been attracting attention. For photovoltaic power generating facilities to be used at mega-solar plants, improved efficiency of energy utilization and the use of higher voltages above 1,000 V DC to reduce the cost of power generation are being advanced worldwide. Fuji Electric increased the voltage of its “G-TWIN Series” DC circuit breakers (and switches) that were released in 2007. Responding to requests for even higher voltage, Fuji Electric is intensifying its efforts for DC high-voltage products (750 V DC, 1,000 V DC)

(4) Response to advanced information capability

As of the mid-1990s, the Internet and PCs started to become popular, and society had arrived at an advanced information age. At high-voltage electric distribution facilities, in order to prevent service loss in advanced information systems, the power supply stability and reliability must be improved, and these requests have become increasingly severe in recent years. Products such as the multi VCB and Auto V that aim for a compact size, lighter weight and more advanced functionality had been developed thus far; moreover, in order to reduce the lifecycle cost (LCC) further, high-voltage breakers are being developed in response to requests for longer intervals of periodic maintenance and inspection, a reduced number of inspection items, and preventative maintenance.

Moreover, in order to minimize the spillover effect when power supply trouble occurs, the protective relay used is required to provide reliable operation and protective coordination, and to facilitate the installation and the usage of equipment through reducing the burden of daily inspections and so on.

Additionally, as a result of the expanded usage of distributed power sources such as photovoltaic power, products that support grid-connection have become

necessary. Based on such market trends, Fuji Electric has developed new protective relay products.

At data centers, semiconductor factories and the like, 24-hour non-stop operation is required and reliability is especially critical. The ability to configure highly reliable electric distribution and feed systems in a small space and with energy savings is getting increasingly important at not only plants and manufacturing facilities, but also at office buildings and commercial facilities, and in response, Fuji Electric is expanding its lineup of low-voltage breakers and power monitoring equipment for this field.

### 3. Efforts for Miniaturization and Performance Improvement of Switching Devices, Control Devices and Low-Voltage Circuit Breakers

In response to requests for the globalization of switching devices, control devices and low-voltage circuit breakers, Fuji Electric has continued to develop products that lead the industry while realizing smaller size, increased performance and improved ease of use through enhanced wiring and the like. Figure 3 shows the trend in downsizing for the example of low-voltage circuit breakers. The latest model of the 100 AF class of low-voltage breakers has been miniaturized to 63% the size of the TWIN Breakers of the 1990s, while achieving higher performance.

#### 3.1 Switching devices

Fuji Electric began manufacturing and selling switching devices, such as magnetic contactors for starting and stopping electric motors and thermal relays for overload protection, for the first time in Japan in 1954, and has driven the industry as the Japan’s top brand capable of responding quickly to market needs and customer needs. Fuji Electric’s total production volume is approaching 300 million units. Figure 4 shows the historical changes thus far.

In 1988, Fuji Electric developed the “New SC Series” of 2.2 to 4 kW small-capacity magnetic contac-

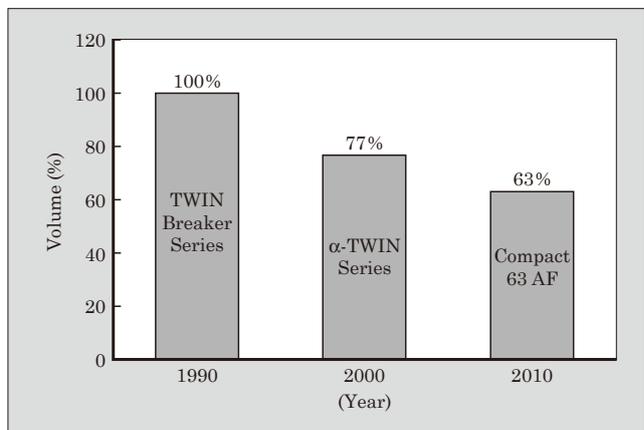


Fig.3 Miniaturization of low-voltage circuit breakers

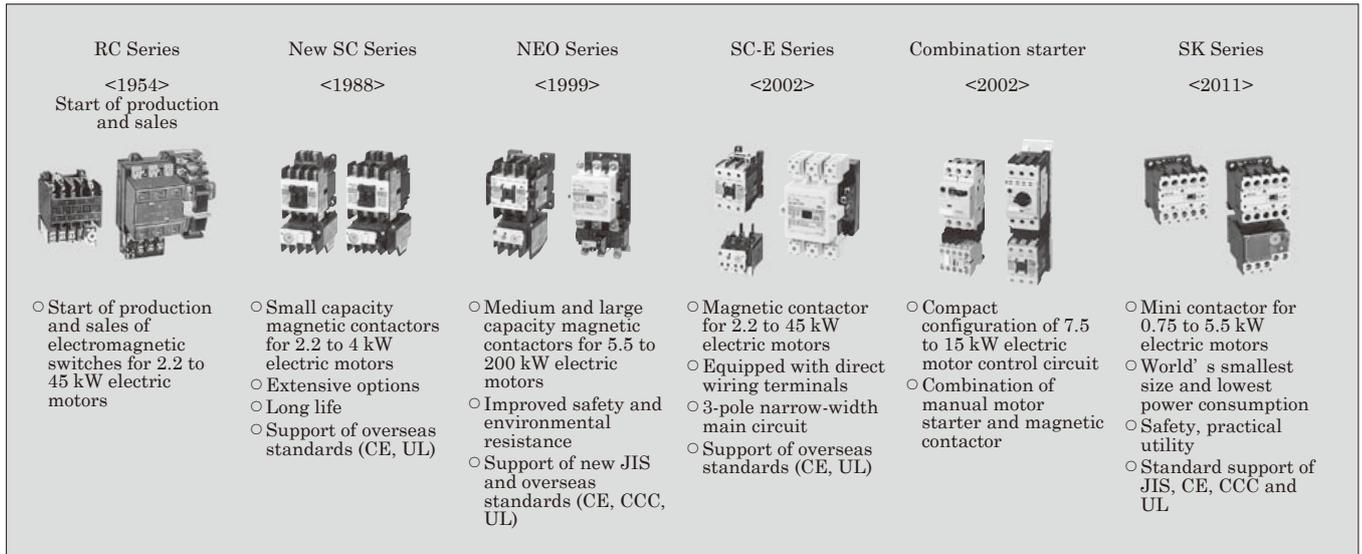


Fig.4 History of Fuji Electric's switching devices

tors for electric motors, featuring extensive options, a long service life, and certification of international standards (CE, UL).

In 1999, Fuji Electric developed the “NEO SC Series” of 5.5 to 200 kW large-capacity magnetic contactors that complied with safety standards, environmental regulations, the new JIS and international standards (CE, UL and CCC).

In 2002, Fuji Electric developed and launched the “SC-E Series” as a product for the global market, featuring small-size de facto width of 45 mm for the global-market direct wire connection terminals, a 3-pole main circuit, modularization, linked contacts available, and compact size. Additionally, Fuji Electric developed a manual motor starter (MMS) featuring advanced motor circuit protection that compactly integrates a molded case circuit breaker and a thermal relay. The MMS features a high level of short-circuit protective coordination and a busbar system that enables a reduction in wiring work. Additionally, ease of use has been improved with a combination starter that combines an MMS and a magnetic contactor.

In this manner, by responding globalization with conformance to overseas standards, and specifications, and proposing the safety with linked contacts, advanced combination of a molded case circuit breaker, magnetic contactor and thermal relay, and the use of a busbar system or the like to reduce wiring work, Fuji Electric has advanced switching devices while anticipating global trends.

In recent years, market needs have increased for further miniaturization of control panel size, higher safety function including electric shock protection, more frequent use of a DC control power supply, etc. In response, Fuji Electric developed the “SK Series” mini contactors and the “TK12” thermal relays that, while realizing the world's smallest size, are truly global-compliant and conform to all standards in Japan

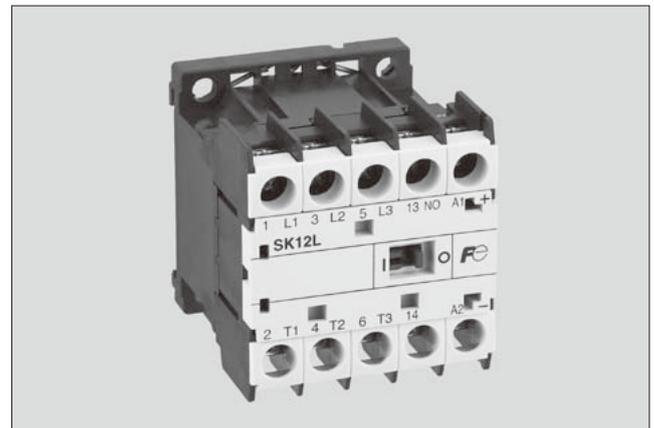


Fig.5 “SK Series” mini contactor

and overseas.

(1) “SK Series” mini contactors

The SK Series, the world's smallest mini contactors, also realize the world's smallest class of low power consumption (86% compared to existing models) for motor control applications of 2 kW and below. This series is also equipped with safety features such as electric shock protection and mirror contacts, and conforms to the world's major standards (JIS, IEC, CCC, UL and TÜV) as a standard product feature.

Figure 5 shows the appearance of an SK Series mini contactor, and its features are listed below.

- World's smallest mini contactor
  - Dimensions: W45×H48×D49 (mm)
  - Same external dimensions of both AC control products and DC control products
- Low power consumption
  - 86% compared with existing model (low-power DC coil 1.2 W)
- Extensive lineup
  - 3 ratings: 6, 9 and 12 A
  - Control coil: AC, DC and low-power types

- (d) Extensive options
    - Additional auxiliary contact unit (2 poles, 4 poles)
    - Coil surge absorber unit
    - Interlock unit
    - Connection module (MMS combination)
  - (e) Improved safety function and easier use
    - Standard provision of detachable terminal cover (IP20)
    - Provided with mirror contact function
    - Short-circuit current rating (SCCR): 480 V AC 50 kA
    - UL rated 480 V AC 5HP
    - IEC rated 480 V AC 12 A (AC3)
  - (f) Standard products are certified for the world's major standards
    - JIS, IEC, GB (CCC), UL and TÜV
- (2) "TK" of thermal relays

The TK12, while realizing improved wiring and safety, also achieves a significantly smaller size than previously in the combination with a magnetic contactor. To improve safety function, a protective element is provided for each phase to realize specifications that enable open phase protection. To improve wiring while realizing a compact size, a terminal layout was adopted whereby the main circuit terminals and auxiliary terminals are arranged in a parallel configuration so that the main circuit and the auxiliary circuit wires do not interfere with one another at the time of wiring. Figure 6 shows the appearance of a TK Series thermal relay, and its features are listed below.

- (a) Improved safety
  - 2E thermal relay with overload and open phase protection in a standard product
- (b) Miniaturization
  - 87% size of existing model in combination with magnetic contactor (installation area), 55% by volume
  - Dimensions: W45×H97.5×D55 (mm)
- (c) Improved wiring capability
  - Round-type crimped terminals can be connected
  - Wire lead-out capability from secondary side of

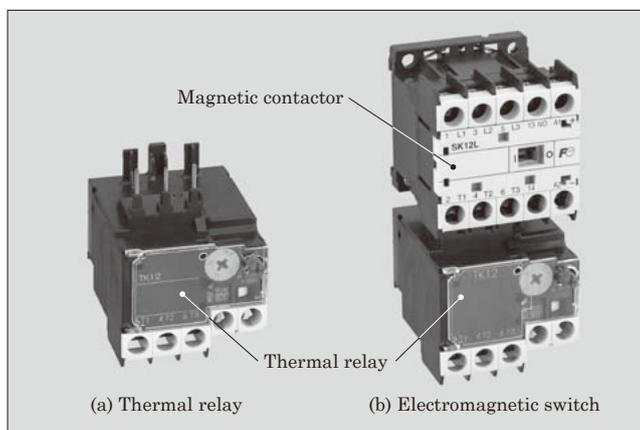


Fig.6 "TK12" thermal relay and magnetic contactor

- magnetic contactor
  - No interference from main circuit and auxiliary circuit wires by employing parallel terminal layout when performing wiring work

(3) Combination starter

Fuji Electric has established a lineup of combination starters that combine an MMS and a magnetic contactor (see Fig. 7).

As a manual switch for electric motors, the MMS is sometimes used by itself; however, it is more often used in combination with a magnetic contactor in general. An MMS provide high current-limiting capability, such combination therefore can contribute to higher short-circuit current rating (SCCR). Since the combination starter couples an MMS and a magnetic contactor with dedicated wiring components, it streamlines the wiring work and reduces space.

### 3.2 Low-voltage circuit breakers

Since 1968, Fuji Electric has been manufacturing and selling low-voltage circuit breakers (molded case circuit breakers and earth leakage circuit breakers) that provide line protection and electric shock protection, and for over 40 years has been developing products that anticipate the needs of the market. Figure 8 shows the historical changes thus far.

In 1990, the 30 to 225 AF "TWIN Breaker Series" was developed and was well accepted as the industry's first "TWIN" feature model which means both molded case circuit breakers and earth leakage circuit breakers having the same external size. At present, such uniform size concept has been established as the de facto standard in the Japanese market. Also, unified basic dimensions among frames, higher breaking capacity, advancing miniaturization, and more expansion of options and derivative products have been provided.

In 1992, expanding the TWIN Breaker development concept to larger capacities, the 400 to 800 AF capacity "Super TWIN Series" was developed. With



Fig.7 Combination starter

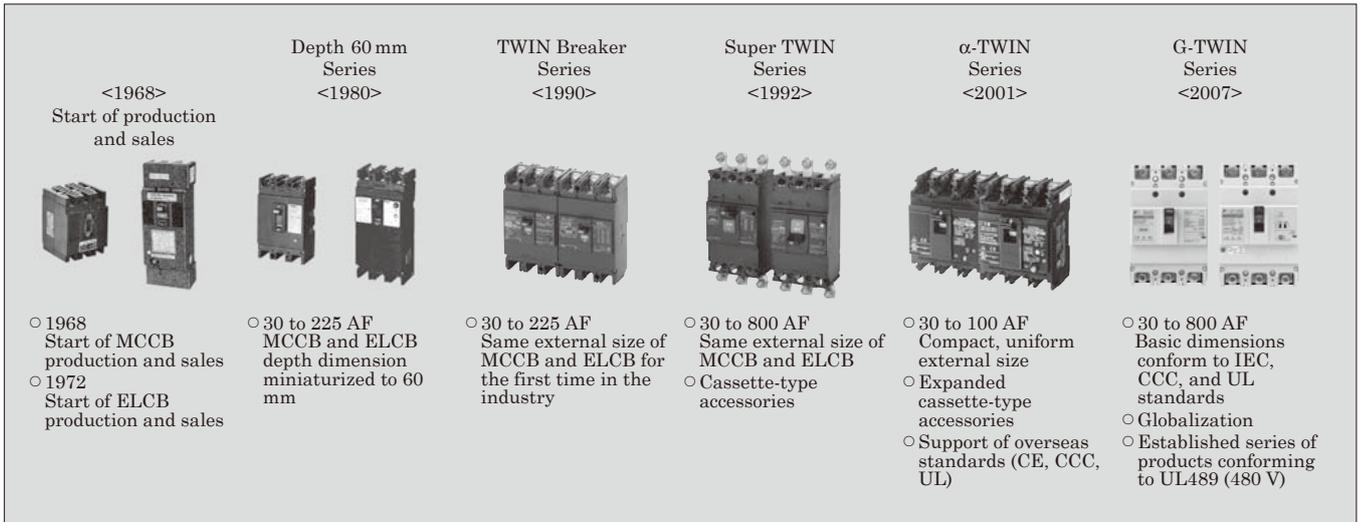


Fig.8 History of Fuji Electric's low-voltage circuit breakers

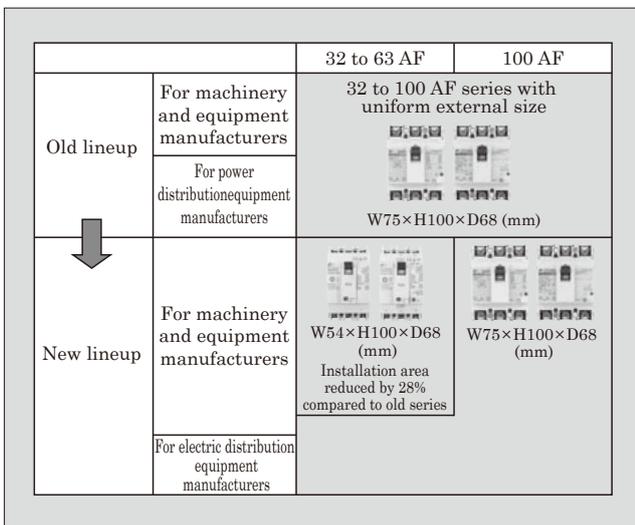


Fig.9 New and old lineups of 100 AF and below low-voltage circuit breakers

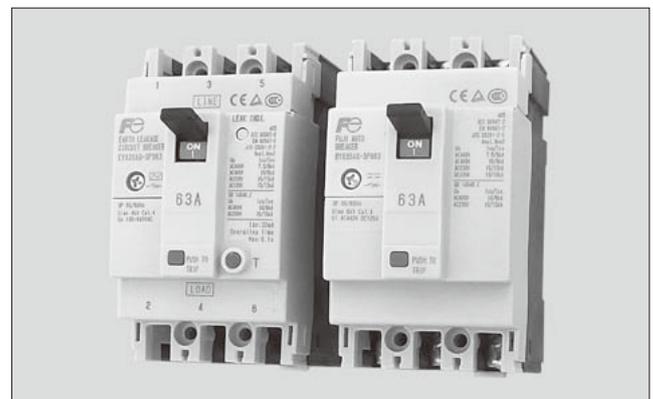


Fig.10 32 to 63 AF compact low-voltage circuit breakers

this Super TWIN Series, internal accessories could be installed by the customers themselves.

In 2001, the 32 to 100 AF “α-TWIN Series” was developed, featuring the industry’s smallest uniform size, high breaking capacity, compact size, safety features such as an isolation function, and certified compliance with overseas standards (CE, CCC and UL).

In 2007, the 125 to 800 AF “G-TWIN Series” was developed. In basic dimensions it conforms to major overseas standards such as IEC, CCC and UL. Moreover, through providing a series of devices that conform to UL 489 (480 VAC), complying with IEC specifications for earth leakage circuit breakers (standard 3-phase applicable, withstand voltage test switch), unifying the internal accessories and complying with environmental regulations, truly global products have been developed.

In this manner, Fuji Electric has proposed the concept of a compact and uniform size, and has responded

to a wide range of market needs for machinery and equipment, control panels, electric distribution switch-gears and the like. The α-TWIN Breakers are small-size products from 32 to 100 AF, and are used in a wide range of fields (see Fig. 9).

In recent years, as in the case of switching devices, small size and enough safety feature, including electric shock protection, is required of low-voltage circuit breakers. Although there exist machinery, equipment and control panel applications that seek smaller size, there are also electric distribution applications with equipment with uniform external sizes to standardize, power distribution panels, and therefore the market environment is getting polarized in terms of the functions required of low-voltage circuit breakers. For this reason, Fuji Electric developed 32 to 63 AF compact low-voltage circuit breakers for machinery, equipment and control panel applications (see Fig. 10).

The compact 32 to 63 AF low-voltage circuit breakers, while achieving the industry’s smallest size, also realize high breaking performance, an extensive variety of available accessories, safety protection of the terminals and compliance with the major overseas standards (JIS, IEC, CCC, UL, TÜV), and have the fol-

lowing features.

- (1) Product external size
  - External size of 3-pole product: Industry's smallest width of 54 mm
  - Small installed footprint: 72% compared to existing models
- (2) Breaking capacity
  - 1.5 times existing models
  - $I_{cs} = 100\% \times I_{cu}$  (AC200 V system)
- (3) Terminal area
  - IP20 standard compliance
- (4) Accessories
  - Extensive variations of internal accessories
  - Extensive accessory functions such as side by side mounting
- (5) Two types of mounting, with screws or a DIN rail
- (6) Conformance to various overseas standards; two types of lineups are provided to fit the application
  - Standards: JIS, IEC, CCC, TÜV
  - Global: JIS, IEC, CCC, TÜV, UL489
- (7) Standard compliance with various environmental regulations including the RoHS directive\*3

#### 4. Dedicated Products for Emerging Country Markets

As for switching device, low-voltage circuit breaker and control devices, the trend toward the JIS adoption of IEC standards has advanced in Japan, and the mainstream of products are having the same specifications for Japan and overseas. As for the crimped terminal connections that are commonly used in Japan, however, because of the different method used overseas based on an industrial tradition of direct wire connections, Fuji Electric's electromagnetic switch lineup includes the SC-E Series for use in overseas markets and that supports direct wire connections, so as to be compatible with any market in the world.

In emerging economies such as China and other Asian countries, for important safety related circuits used in equipment for export or in elevators, the same high quality, long switching life, and conformance to major overseas standards as in Japan are sought; however, these are not always required in equipment for local use.

For this reason, as dedicated products for local equipment, the "FJ Series" that conforms to local standards was developed and launched in China in April 2011.

In the future, while monitoring overseas markets and customer trends, Fuji Electric plans to expand its lineup of dedicated products for overseas market following such contactors.

\*3: RoHS directive: EU (European Union) directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment

#### 5. Fuji Electric's Efforts Involving Power Monitoring Equipment

The Japanese Energy Conservation Law was revised in 2010, and with the expansion of energy management obligations to factories, offices, stores and other small businesses, further simplifications of the energy management tasks is requested.

In response to this need, the DIN rail-mounting type "F-MPC04E" single-circuit AC power monitoring equipment was developed and the F-MPC Series lineup was expanded. Since the display was provided as an option, the volume was reduced by 1/2 compared to the existing "F-MPC04S" panel-mounted type. In addition to the RS-485 communication function provided as a standard feature, the MODBUS/RTU protocol as well as the standard protocols of the "F-MPC Series" power monitoring systems is also supported to enhance compatibility.

Additionally, the PowerLogic Series (manufactured by Schneider Electric in France) is able to monitor power quality, and is provided with a function for preventing equipment trouble before it arises and a function for facilitating an early resolution in the event of trouble. Fuji Electric's lineup of power monitoring devices has been expanded with the PowerLogic series, together with the F-MPC Series (see Fig. 11).

Furthermore, in addition to the need for energy savings, there are also electrical safety-related needs for automating equipment inspections and extending the interval between periodic inspections mainly at data centers, semiconductor manufacturing plants and other places of businesses where a system shutdown would not be acceptable because of its severe loss.

To meet these needs, continuous monitoring of the current leakage by a method that is not affected by the capacitive element to ground and the harmonic wave element of the cable is needed.

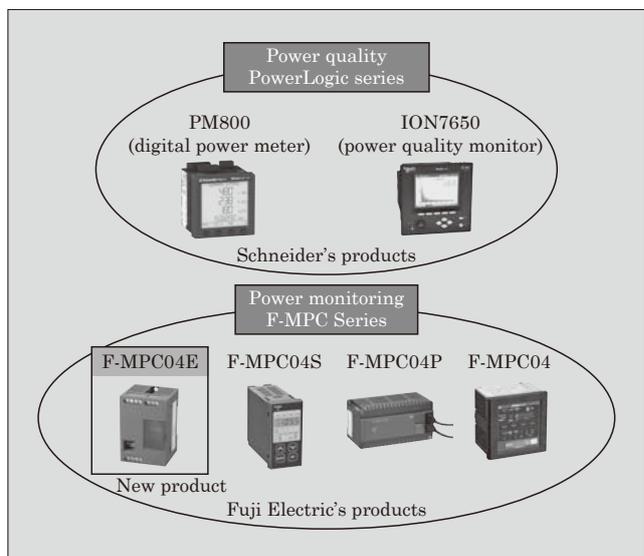


Fig.11 Lineup of power monitoring devices

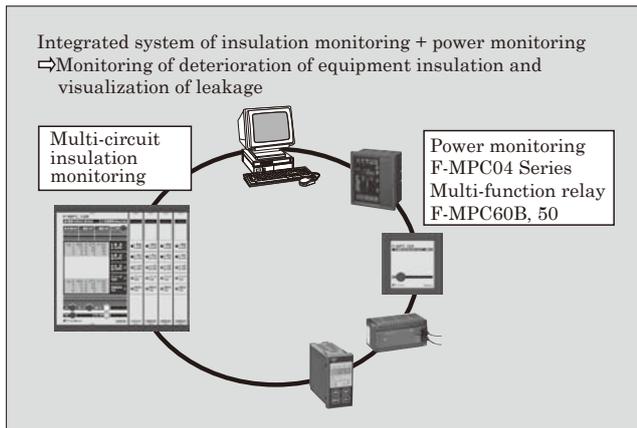


Fig.12 Power monitoring and insulation monitoring in the same system

To realize this in a way that is applicable regardless of the phase and wiring scheme, Fuji Electric has developed an Igr insulation monitoring equipment that can detect insulation deterioration without being affected by imbalance of the capacitive element to ground among phases. A lineup of integrated measurement equipment for 4 circuit and 8 circuit applications, selectable according to the system size has been established, and these equipment can easily be connected to F-MPC Series devices through a RS-485 communication interface, so that power monitoring and insulation monitoring can be linked and managed in the same system, using the same protocol (see Fig. 12).

## 6. Postscript

Amidst the trend of advancing globalization, society and the marketplace are changing rapidly, and the ability of agile response is needed. Fuji Electric's mission is to sense changes in the market and the evolution of technology with a keen perceptiveness while looking ahead to the future, and to provide products in a timely manner through technology development with concentrating intelligence while continuously responding to the needs of the customers.

Through continuing to provide equipment and services that meet the diverse needs of the customers, Fuji Electric aims to become a "best partner" for society and industry.

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# “SK Series” of Miniature Contactor

OKUBO Koji † TSUTSUMI Takashi † HATA Junichiro †

## ABSTRACT

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Demands for downsizing and energy saving are increasing for production facilities and machines. The miniature contactor SK Series featuring the world’s smallest size has been developed to meet these demands.

The reduction in external dimensions gives the wide scope of installation locations, while the addition of strong insulation properties make these contactors possible to be used for high voltage applications. We devised isolation mechanism and heat-resistant insulation materials in the contact structure, as well as we pursued minimization and efficiency of spring load characteristics in electromagnet structure. Fuji Electric also provides product conformance to overseas standards and rich lineup of options to meet the various demands of the customers.

## 1. Introduction

As magnetic contactors are used in many applications such as in the control panels and machinery of manufacturing equipment, they are essential devices for starting and stopping electric motors, opening and closing power supply circuits, and so on. Since the use of contactors to isolate the electrically charged circuit mechanically has become widespread in innovative electrical equipment and machinery, responsibility of the contactors is recently increasing importance. As part of the energy saving and ecology movement trends of recent years, downsizing and power savings have been advanced further than ever before in manufacturing equipment and machinery.

Since launching the “SJ Series” small-size, low power consumption contactor in 1986, Fuji Electric has continued to supply products that contribute to the downsizing and the reduction of power consumption of control panels. Up to the present time, marketplace trends toward miniaturization and power savings have intensified, and there have been increasing requests for a change in the main circuit power supply voltage from 200 V to 400 V so that equipment can run more efficiently, for a wider range of device options to enhance usability, for improved safety, for compliance with international standards, and so on.

The “SK Series” miniature contactor is the world’s smallest size contactor which have been developed by incorporating these market requests and the latest technology, such as three-dimensional arc drive analysis and electromagnetic analysis. This paper describes the features, structure and miniaturization technology of the SK Series

## 2. Development Goals and Product Features

### 2.1 Development goals

Miniature contactors are mainly built into dedicated machinery such as mounting equipment and molding machines, and are used to start and stop electric equipment such as motors and to switch on and off the primary power circuits to inverters. As machinery becomes smaller, magnetic switches that combine a contactor and thermal relay must be installable in ever smaller spaces. Additionally, in consideration of the energy-saving trend of equipment, it is desirable that the control power supply for a magnetic switch consumes less amount of power. Further, in addition to the requests for controlling the main circuit, there are also various other requests concerning the number of auxiliary contacts and variations of the contacts (normally closed, normally open) so that the control circuit can be switched on and off with fewer devices.

The JIS standard for magnetic switches was unified with international standards in 1999. With the differences in specifications between Japanese domestic products and overseas products having been eliminated, the magnetic switches become the control devices used worldwide. In order to support the exportation of customer products to overseas, even Japanese domestic customers are strongly requesting a change in the main circuit voltage of their products from 200 V to 400 V. Accordingly, improved high-voltage interrupting performance is desired for small-sized contactors. Thus, as an alternate to the SJ Series, which had been designed to target use in Japan, in consideration of anticipated global applications, there has emerged a need for the development of a small contactor having high switching and interrupting capability. Fuji Electric’s SK Series complies with the international standard IEC 60947-1, as well as EN 60947-1 and JIS C 8201-

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

1, and has also acquired UL and CSA certification in the United States and China Compulsory Certification (CCC\*1) in China.

## 2.2 Product features

The SK Series of miniature contactors provide world-class performance with the following features.

- (1) Low-power consumption drive
  - This series can be driven by AC and DC power supplies, respectively
  - Each product has world's lowest class of power consumption (As of November 2011, based upon in-house research)
  - AC operation: 22 VA on closing, 4.5 VA on holding
  - DC operation: Standard type 2.4 W, low-power type 1.2 W
- (2) Small size
  - Same external dimensions for both AC and DC driven products
  - W45×H48×D49 (mm)
  - World's smallest contactor having power switching capability
- (3) Product line-up with wide range of options
  - Complementary functionality to support various customer requirements
- (4) Safety and usability
  - Complies with safety requirements for electrical danger
  - Terminal cover protection with standard IP20 protection class from front direction
  - Compliance with IEC standard types I and II through combination of various circuit breakers and fuses
  - High short-circuit protection performance with protection coordination of 5 to 65 kA through combination with manual motor starter (MMS)

Moreover, as one feature that differs from overseas products, the terminal structure that supports Japan's unique wiring connections with screw terminal is also provided. In addition to having world-class level of performance, the products are also easy to use in the Japanese market.

## 2.3 Product lineup

The SK Series provides a sufficient product line with a rich set of options to meet the needs of all customers (see Fig. 1).

- (1) Operation indicator unit
 

The operation indicator unit can be add-on to the contactor itself that provides notification with an indicator lamp when a coil voltage has been applied.
- (2) Coil surge absorption unit
 

The coil surge absorber unit prevents malfunction

of the electronic circuitry by absorbing surge voltages when the coil is in the off-state. The surge absorption circuit contains a varistor to cut the peak waveform of the surge voltage. DC operated coils are equipped with internal varistors as a standard feature, and a coil surge absorber unit with operation indication and a coil surge absorber unit with an operation indicator lamp are available.

- (3) Auxiliary contact unit
 

4-pole versions with five contact configurations of 4a, 3a1b, 2a2b, 1a3b and 4b, and 2-pole versions with three configurations of 2a, 1a1b and 2b are available, and the number of auxiliary contacts can be expanded with "one-touch" operation.
- (4) Small auxiliary contact unit
 

This low-profile small-size auxiliary contact unit is limited to a 1a1b contact configuration, and is well suited for environments that require space-saving installation.
- (5) Interlock unit
 

By using a reversible wiring kit and an interlock unit in combination, the reversible contactor to perform forward and reverse operation and the like can be configured easily. The interlock unit mechanically prevents the simultaneous switching on of 2 contactors.
- (6) Connection module
 

The connection module is used to combine the MMS and contactors. The combination of these devices allows a more compact configuration of the electric motor control circuit, and protects the motor more reliably from accidents due to short circuits and overcurrents in the three-phase electric motor circuit.
- (7) Main circuit surge absorber unit
 

This unit absorbs surge voltage generated from the three-phase motor when the contactor opens and closes.

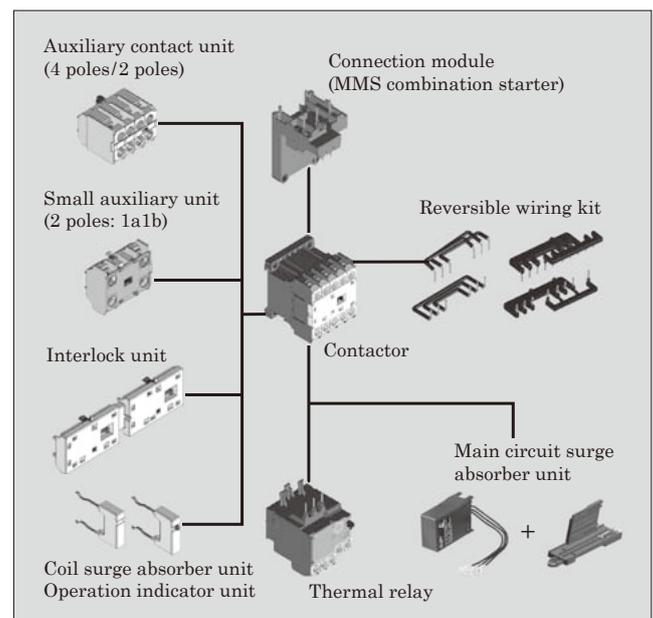


Fig.1 Set of options for the "SK Series"

\*1: CCC: China Compulsory Certification (See "Supplemental explanation 2" on page 139)

es, and suppresses the influence of the surge voltage. The main circuit surge absorber unit may be mounted

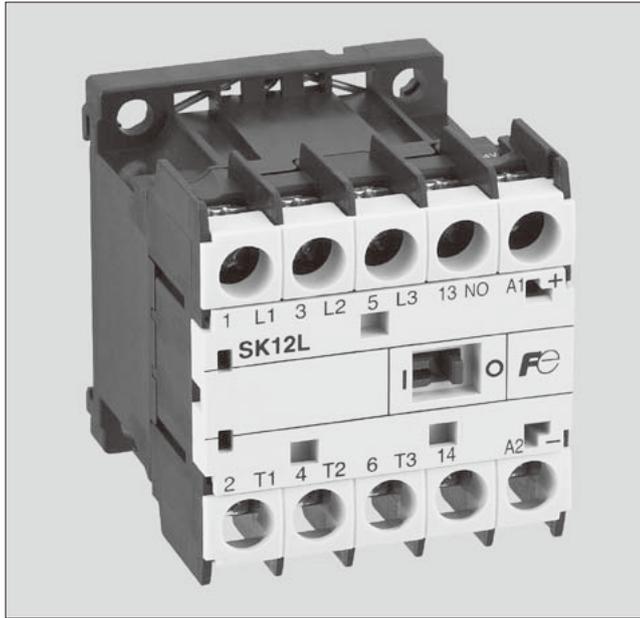


Fig.2 “SK Series”

as a set with an adapter, separately from the contactor.

## 2.4 Specifications and ratings

### (1) Contactor specifications

Figure 2 shows the external appearance of a SK Series contactor, and Table 1 lists the contact configuration and durability specifications of this series. The lineup of class AC-3 rated contactors include 6 A, 9 A and 12 A products that have a 3-pole main circuit and a single pole auxiliary circuit configuration.

Table 2 lists the contactor product lineup and the main circuit ratings.

### (2) Auxiliary relay specifications

Table 1 Contact configuration and durability specifications of contactors

		6 A product	9 A product	12 A product
Contact configuration	Main circuit	3a		
	Auxiliary circuit	1a or 1b		
Durability	Electrically (AC-3)	1 million times		
	Mechanically	10 million times		

Table 2 Contactor product lineup and main circuit ratings

			6 A product	9 A product	12 A product
Type	AC driven product		SK06A	SK09A	SK12A
	DC driven product (2.4 W)		SK06G	SK09G	SK12G
	DC driven product (1.2 W)		SK06L	SK09L	SK12L
Rated capacity (kW)	3-phase squirrel-cage motor (AC-3)	200 to 240 V	0.75	1.5	2.2
		380 to 440 V	2.2	3.7	5.5
		500 to 550 V	2.7	3.7	5.5
Rated operating current (A)	3-phase squirrel-cage motor (AC-3)	200 to 240 V	6	9	12
		380 to 440 V	6	9	12
		500 to 550 V	5	7	9
	Resistive load (AC-1)	200 to 240 V	12	16	20
		380 to 440 V	12	16	20
Open thermal current (A)			20	20	20

Table 3 Auxiliary relay product lineup and ratings

		Standard (high reliability product)			High capacity product		
		AC coil	DC coil (2.4 W product)	DC coil (1.2 W product)	AC coil	DC coil (2.4 W product)	DC coil (1.2 W product)
Type		SKH4 A	SKH4 G	SKH4L	SKH4 AH	SKH4 GH	SKH4LH
Additional auxiliary contact unit		4 poles or 2 poles		2 poles	4 poles or 2 poles		2 poles
Open thermal current		10 A			Same as on the left		
Contact configuration		4 A, 3a1b, 2a2b (1a3b and 4b not available)			Same as on the left		
Rated operating current AC-15 (coil load)	AC100 to 120 V	3 A			6 A		
	AC200 to 240 V	3 A			6 A		
	AC400 to 440 V	1 A			6 A		
	AC500 to 600 V	0.5 A			3 A		
Minimum operating voltage and current		DC5 V, 3 mA			DC24 V, 10 mA		

Table 4 List of compliant standards

Model	Type	Compliant standards			Certified standards			EC directive	Certifying authority
		JIS	IEC	EN	UL	CSA	GB (CCC)	CE mark	TÜV
		Japan	International	Europe	US	Canada	China	Europe	Germany
Contactor	SK***A SK***G SK***L	○	○	○	○ *	○ *	○	○	○

\* : Certified by cULus

The SK Series includes a lineup of auxiliary relays which are optimal for low-load switching because their four contacts are all configured with auxiliary contacts (see Table 3).

Two product lines are offered: standard type that support electronic devices with twin contacts to increase the contact reliability and high capacity type that feature significantly larger contact capacity.

The auxiliary relays comply with EN60941-5 and have a linked contact function that conforms to EN60204-1, which is a requirement of the Machinery Directive of the EC. The linked contact function enables the configuration of a safety circuit with monitoring the welded contacts of the auxiliary relay.

### 2.5 Compliant standards

Table 4 shows the standard certification and acquisition status of the SK Series. The SK Series complies with the world’s major standards, and has also obtained various certifications.

## 3. Miniaturization Technology

### 3.1 Aim of miniaturization

Recently, the control panels in machine tools, lifts and the like have been made smaller and thinner, and requests for the miniaturization of electric distribution and control devices are also intensifying.

For small electric distribution and control devices, as in the case of the MMS and contactor shown in Fig. 3, the de facto standard width for products is 45 mm. In order to combine peripheral devices within a control panel of limited space, a high level of space utilization is required, and therefore the realization of a dense layout and the use of a general-purpose wiring member (busbar) that corresponds to the interval of 45 mm are essential.

Additionally, as a result of the prevalent usage of distributed control, demand is increasing for small-size control panels to be installed in each machine and equipment terminal. In case where installation space is limited, a reduction in the product depth direction is strongly requested in order to accommodate a thin control panel in addition to the conventional installation footprint reduction.

In support of these industry standards and changes in the size of the installed control panel, Fuji Electric aims to miniaturize product dimensions in or-



Fig.3 Combination of MMS and contactor

der to expand the scope of customer applications.

### 3.2 Structure of the contact part

#### (1) Insulation enhancing structure

In the contactor, the contact part is responsible for the basic function of switching the current. For miniaturization, it is essential that a rated insulation voltage of 690 V, which is the highest-class insulation performance, can be realized within a small space.

Insulating performance is necessary between phases, and the ability to control the flow of arc gas and to limit the drop in insulation resistance is important issues at the time of current interruption.

#### (2) Interphase insulation structure

Miniature contactors also achieve lower power consumption of the electromagnet (to be described later). In consideration of the limited motion space of the electromagnet and moving contact due to miniaturization, and of the efficiency of the electromagnetic attractive force, a horizontal drive method in the interphase direction was adopted for driving the contactor. Additionally, a multi-structure that allows both “a” and “b” contacts in each phase was incorporated, thus enabling changeover to an auxiliary relay or the like. With a conventional structure in which an inter-phase barrier is disposed between fixed contacts, the inability to ensure motion space around the contacts was a problem.

As shown in Fig. 4, by positioning the main inter-

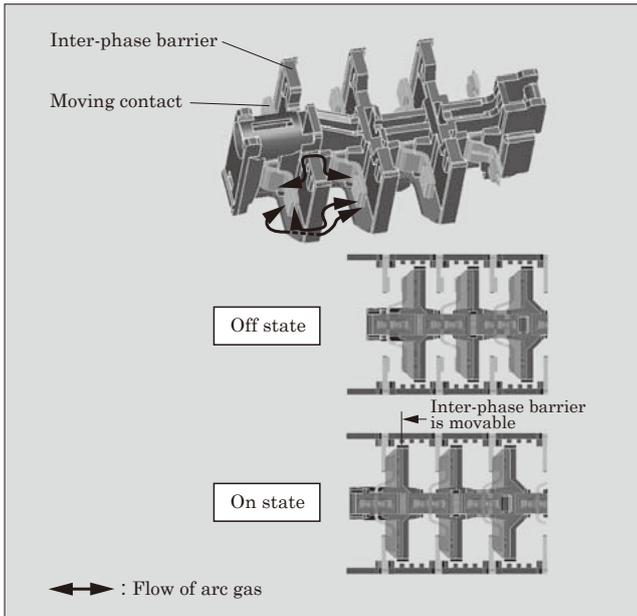


Fig.4 Barrier structure of movable parts of contact

phase barrier at the contact support, which is a movable part, to ensure motion space, and by coupling the inter-phase barrier movement with the switching operation, the interruption space in the vicinity of open contacts can be expanded, thus leading to stabilization of the interruption performance, such as by cooling of the arc gas. Further, by providing a rib structure that retains the passing arc gas on the inter-phase path connected to the arc generation point of the contact, in-flows to adjacent phases can be suppressed temporarily and the insulation performance improved.

(3) Structure for insulation resistance suppression

The arc gas resulting from current interruption forms a carbonization layer on the inter-phase insulating barrier and other surfaces, thereby degrading the insulation performance. The positioning of the inter-phase insulating barrier at the movable part, as was described in the preceding paragraph, resulted in a problem with ensuring the insulating performance because the frame that holds the fixed contacts cannot possess a significant barrier.

Therefore, in order to improve the insulation per-

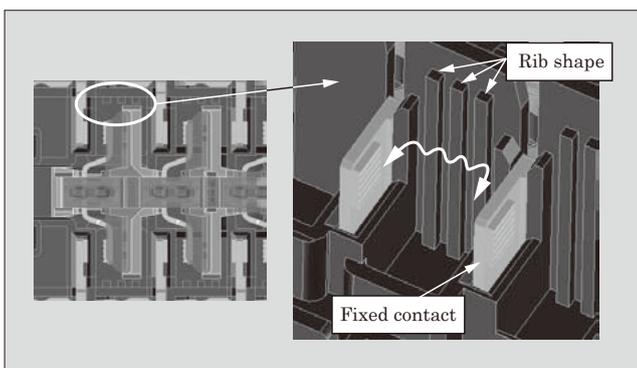


Fig.5 Frame rib shape

formance of the frame, the rib structure shown in Fig. 5 is provided between fixed contacts so that arc gas flowing in the gaps between the fixed contacts and inter-phase insulating barrier of the movable part can be retained. Additionally, the formation of a surface carbonization layer due to the arc gas can be kept partially, thus, leading to suppress insulation resistance decline along the creepage surface. The groove that can be formed between these ribs has a width of about 0.88 mm (height of 0.7 mm). According to the compliant standards, the inner wall creep surface portion of the groove is not valid as a creep distance, but there is a substantial effect against a creep decrease in insulation resistance, and this is one miniaturization technology used to ensure performance.

3.3 Use of heat-resistant insulating material

Because both “a” and “b” contacts can be accommodated in each phase, installation space must be ensured for the contact spring that outputs the contact pressure of the moving contacts. A contact spring must be housed inside the contact support that holds the moving contact (see Fig. 6). Previously, thermosetting resin having high heat resistance was used for the contact supports that touched moving contacts in the conducting parts, and thin-walled molding was difficult to accomplish. However, the use of cross-linked nylon based on a thermoplastic resin for the contact supports enables thin-walled molding and, as a result, a structure that is both heat resistant and able to house the spring.

In addition, the previous contact support consisting of a single component has been divided into two components, and an fitting structure has been adopted. As a result, assembling the contact spring to be housed and the moving contact is improved significantly, thus enabling automated assembly.

3.4 Structure of the electromagnet

(1) Minimization of spring load

The challenges in miniaturizing an electromagnet involve minimizing the spring load, such as contact pressure, and increasing the efficiency of the electro-

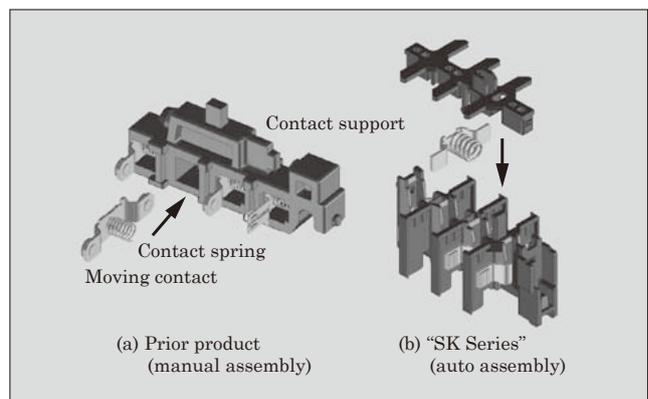


Fig.6 Contact support assembly

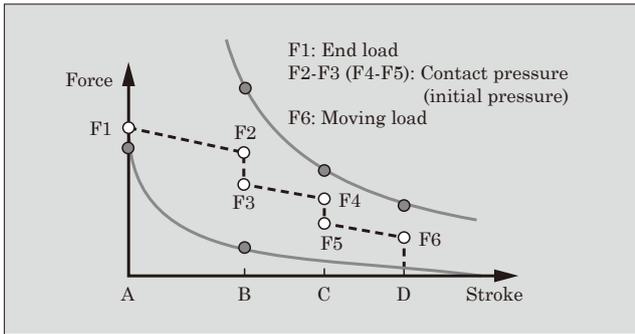


Fig.7 Spring load

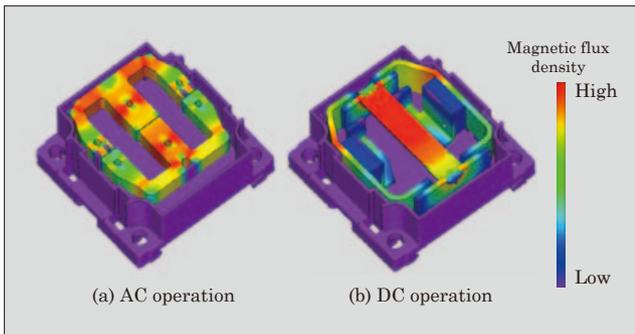


Fig.8 Magnetic field analysis

magnet, and the main determinant factors are listed below.

- (a) Contact pressure (initial pressure)
  - Reduce mass of moving parts and contact bounce
- (b) Moving load
  - Resistance to malfunction by mechanical shock of “b” contact in off-state
- (c) End load
  - Determinant factor of no-load voltage (Attractive force at time of no-load < end load)

To establish each of these determinant factors, a two-pronged approach was adopted of pursuing critical performance through kinematic analysis and experimentation, and of adjusting for the attractive force

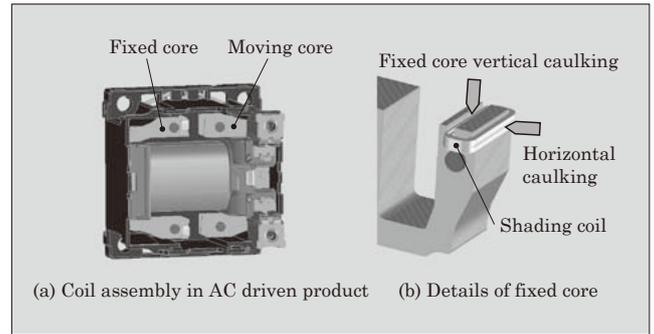


Fig.9 Fixed core horizontal caulking method

characteristics in the electromagnet design to realize a reduction in spring load (see Fig. 7).

#### (2) Pursuit of higher efficiency

By efficiently producing the attractive force of the electromagnet within a limited space as in the case of the contact parts, and optimizing the magnetic path through electromagnetic analysis shown in Fig. 8, and so on, the following low-power consumption products were realized.

- AC driven product: 4.5 VA (60 Hz : 1.3 W)
- DC driven product (standard type): 2.4 W
- DC driven product (low power type): 1.2 W

Additionally, in the fixed core of the AC driven product, horizontal caulking from the one side (see Fig. 9) was adopted for the first time as the method for caulking the shading coil, and as a result, the pole contact area was maximized and the space utilization was improved.

#### 4. Postscript

The miniature contactor “SK Series” was developed based upon Fuji Electric’s many year experience and accumulated technology, and is a product series that will certainly meet the needs of the market. So as to continue to be responsive to diversifying needs in the future, Fuji Electric intends to enhance this series further.

# Miniaturization Technology in the “TK12” Thermal Overload Relay

Fumihito Morishita † Yukinari Furuhashi †

## ABSTRACT

As resource and energy saving continue to progress, there are demands to reduce the size and improve the energy efficiency of the control panels and machinery used in production facilities and other industries. There is also a higher demand to reduce the size and power consumption of the thermal relays which are the components in such equipment. Applying ever accumulated technology, Fuji Electric has developed the “TK12” thermal relay pursuing miniaturization with reduction of part quantity, implementation of thermoplastic material for the housing, and improvement of the heating section design. The relays also meet global demands for safety and operability, and are equipped with terminal covers that conform to IEC 60529 as standard.

## 1. Introduction

Thermal type, electromagnetic type, induction type and static type are available to apply overload relays for low-voltage induction motors. As in recent years, the electronic control of motors using inverters and the like has become popular, electronic technology for over-current protection has also become progressed.

Thermal type overload relays are not only more economical than other methods but they also facilitate harmonization with motors in thermal characteristics since they utilize the heat generated by the input current. Accordingly, thermal overload relays, in combination with magnetic contactors, are still essential devices for automation and labor-saving in various facilities and equipment.

A thermal relay converts the input current of an internal heater of each phase into heat, and detects the warp of the metal heated. Thermal relays consist of 2-element type having a heater only in phases R and T of three poles and 3-element type having a heater in all three phases R, S and T. Since low voltage of 200 V is used for industrial applications and the use of earth leakage breakers has become widespread, 2-element thermal relays have been popular in Japan. With the globalization of Japan domestic manufacturing industry, industrial machinery and manufacturing equipment are increasingly placed overseas, thermal relays are, therefore, requested to support high safety requirement, usage environment compatibility applicable to various situations, and high usability.

## 2. Development Goals and Product Features

### 2.1 Development goals

The “TK12” thermal relay can be combined with the “SK Series” miniature contactor to configure electromagnetic switches. Amidst the recent trends toward resource and energy savings, the machinery and control panels used in manufacturing equipment and the like become smaller in size and more energy efficient. Miniaturization and lower power loss from the heater are required for the electromagnetic switches and also the thermal relays that configure the electromagnetic switches used in the equipment. Additionally, since there is growing awareness of motor protection safety and motors are increasingly operated with higher load factors in order to drive equipment more efficiently, improved detection accuracy of



Fig.1 “TK12” thermal overload relay

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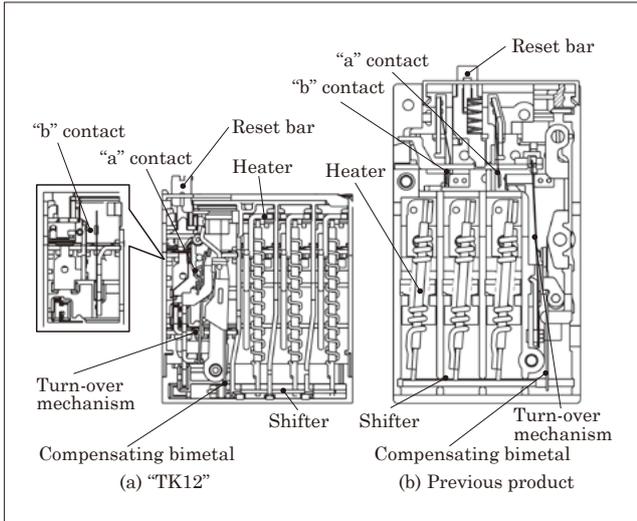


Fig.2 Overview of product structure

the thermal relay is highly anticipated.

In response to these requests, the TK12 was developed to have the world's smallest size, enhanced operating characteristics and accuracy, low power loss, improved safety functionality and ease of use. Figure 1 shows the appearance of the TK12 and Fig. 2 shows an overview of the product structure.

### 2.2 Product features

As operation safety is considered deeply in recent years, requests concerning the reliability of protective functions for thermal relay to be applied globally have been increasing more than ever before in distribution

circuit conditions in worldwide as well as in Japan. Fuji Electric's lineup of thermal relays previously included the three variations of 2-element device, 3-element device, and 3-element with phase-loss protection device for 3-pole main circuit. The TK12 aggregates all these variations into a single high-performance 3-element phase-loss protection device, enabling overload protection and phase-loss protection for motor circuits in any application throughout the world. The TK12 supports both global specifications and the major requirements of the Japanese market. For example, since the TK12 is provided with a terminal shape and terminal cover structure designed to facilitate wiring with the round-type crimped terminals that are commonly used in Japan, it must be easy-to-use products for Japanese users as well.

Furthermore, in terms of standards certification, since this series has acquired the world's leading cer-

Table 1 Operating characteristics in balanced circuit

Standard	Limit of operation		Overloaded operation (hot)	Constrained operation (cold)
	No-operation	Operation		
IEC 60947-4-1	105% $I_e$ (less than 2 h)	120% $I_e$ (within 2 h)	150% $I_e$ less than 2 min	720% $I_e$ 2 to 10 s
JIS C 8201-4-1				

Table 2 Operating characteristics in imbalanced circuit

Standard	No-operation	Operation (hot)
IEC 60947-4-1	2-phase: 100% $I_e$ (less than 2 h)	2-phase: 115% $I_e$ (less than 2 h)
JIS C 8201-4-1	1-phase: 90% $I_e$	1-phase: 0

Table 3 Heating element rating in "TK12"

3-phase standard motor full load current (ref. value)				Heating element rating (A)					
4P 400 V 50 Hz		4P 200 V 50 Hz		Electromagnetic switch					
Capacity $P$ (kW)	Current $I_e$ (A)	Capacity $P$ (kW)	Current $I_e$ (A)	SK06*W		SK09*W		SK12*W	
				0.1 to 0.15	0.1 to 0.15	0.1 to 0.15	0.1 to 0.15	0.1 to 0.15	0.1 to 0.15
				0.13 to 0.2	0.13 to 0.2	0.13 to 0.2	0.13 to 0.2	0.13 to 0.2	0.13 to 0.2
				0.18 to 0.27	0.18 to 0.27	0.18 to 0.27	0.18 to 0.27	0.18 to 0.27	0.18 to 0.27
0.1	0.34			0.24 to 0.36	0.24 to 0.36	0.24 to 0.36	0.24 to 0.36	0.24 to 0.36	0.24 to 0.36
				0.34 to 0.52	0.34 to 0.52	0.34 to 0.52	0.34 to 0.52	0.34 to 0.52	0.34 to 0.52
0.2	0.7	0.1	0.68	0.48 to 0.72	0.48 to 0.72	0.48 to 0.72	0.48 to 0.72	0.48 to 0.72	0.48 to 0.72
				0.64 to 0.96	0.64 to 0.96	0.64 to 0.96	0.64 to 0.96	0.64 to 0.96	0.64 to 0.96
0.4	1.2			0.8 to 1.2	0.8 to 1.2	0.8 to 1.2	0.8 to 1.2	0.8 to 1.2	0.8 to 1.2
		0.2	1.3	0.95 to 1.45	0.95 to 1.45	0.95 to 1.45	0.95 to 1.45	0.95 to 1.45	0.95 to 1.45
0.75	1.8			1.4 to 2.1	1.4 to 2.1	1.4 to 2.1	1.4 to 2.1	1.4 to 2.1	1.4 to 2.1
		0.4	2.3	1.7 to 2.6	1.7 to 2.6	1.7 to 2.6	1.7 to 2.6	1.7 to 2.6	1.7 to 2.6
				2.2 to 3.4	2.2 to 3.4	2.2 to 3.4	2.2 to 3.4	2.2 to 3.4	2.2 to 3.4
1.5	3.1	0.75	3.6	2.8 to 4.2	2.8 to 4.2	2.8 to 4.2	2.8 to 4.2	2.8 to 4.2	2.8 to 4.2
2.2	4.6			4 to 6	4 to 6	4 to 6	4 to 6	4 to 6	4 to 6
		1.5	6.1		5 to 7.5				
3.7	7.5				6 to 9				
		2.2	9.2				7 to 10.5	7 to 10.5	7 to 10.5
5.5	11						9 to 13	9 to 13	9 to 13

tifications such as UL, TÜV, CE and CCC, it must become a true global standard.

### 2.3 Specifications and ratings

Table 1 lists the operating characteristics in balanced circuit, and Table 2 lists the operating characteristics in imbalanced circuit.

Table 3 lists the heating element ratings in TK12, and the standard application of heating element ratings corresponding to 3-phase standard motor capacity.

## 3. Miniaturization Technology of the “TK12”

The thermal relays have been miniaturized in four ways: use of a new turn-over mechanism, improvement of part fixing method, use a thermoplastic housing and improvement of the heater design.

### 3.1 New turn over mechanism

In order to realize both miniaturization and stable high-performance operating characteristics, the TK12 uses a toggle turn-over mechanism configured with a tension spring for the turn-over mechanism as shown in Fig. 3. The existing leaf spring method has an advantage in which spring characteristics can be obtained with a single leaf; however, in miniaturizing the TK12, there was a limit to the size of the leaf spring to obtain the I/O characteristics. As a solution, a tension spring was adopted in the turn-over mechanism. In order to optimize load and displacement I/O characteristics and to optimize space efficiency, the dimensions, load and other parameters were analyzed at more than ten locations that form the turn-over mechanism so that it realized stabilized operating characteristics and space savings.

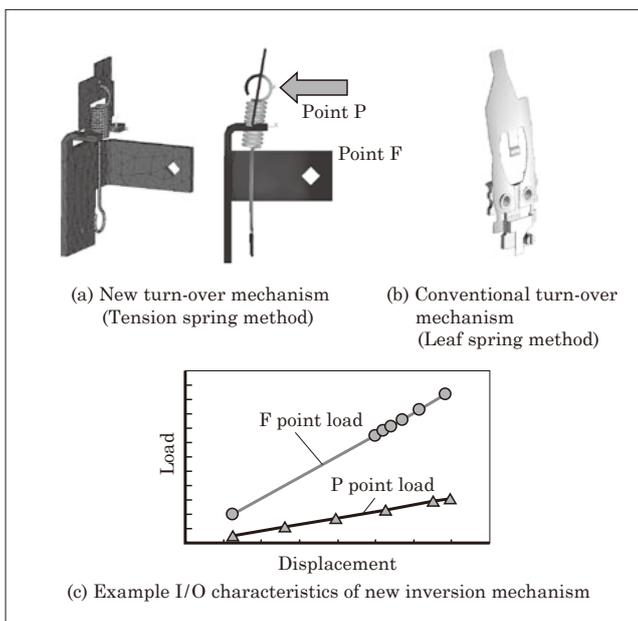


Fig.3 Turn-over mechanism

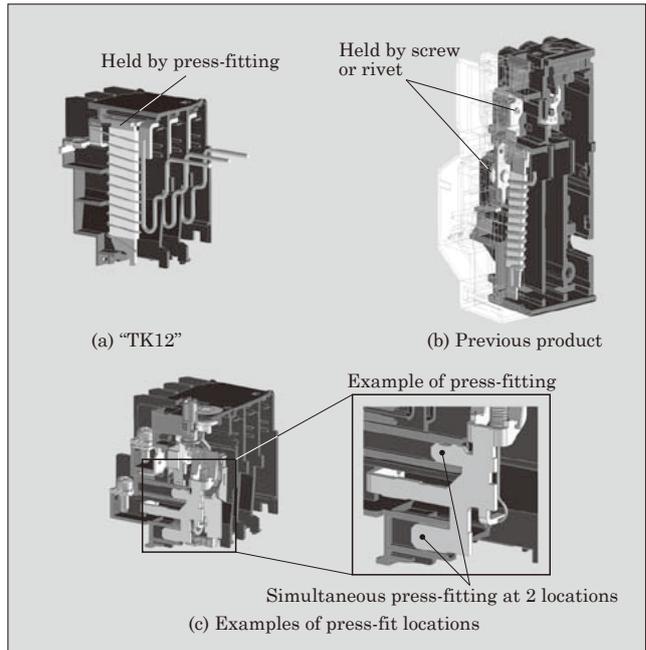


Fig.4 Example of press-fit parts

### 3.2 Parts fixing method

To realize minimum external dimensions, the size and number of individual parts must be reduced.

To minimize all the parts used, a method was adopted in which the metal parts were fixed by press-fitting them into a mold. When using a press-fit structure, however, ensuring the positional accuracy of each fixing part was a subject. As shown in Fig. 4, this was solved by optimizing the press-fit location of each part. Additionally, miniaturization was realized by providing metal parts with only the essential functional shape, and without extra locations for fixing to the mold, thereby significantly reducing the number of steps essential for assembly. The part count was reduced by 25% compared to existing products of the same type.

### 3.3 Use of thermoplastic material for the housing

In order to utilize a press-fit structure, the selection of materials for the housing is critical. To ensure sufficient holding strength after press-fitting, a thermoplastic material with fracture toughness was used for the housing. Conventional heat-curing material has not enough fracture toughness, and therefore press-fit structure had not been applicable. To fix the parts, additional parts such as rivets and screw fasteners increased the number of parts, and the space required for fixing parts with them led an increase in the external dimensions of the product. Farther-more, since thermoplastic material is renewable, it was used for all other molded parts in consideration of the environmental performance. Consequently, as shown in Fig. 5, the housing volume was reduced to 55% compared to that of an existing product of the same type. It was the first time in Japan that thermoplastic mate-

rial had been used in the housing of a thermal relay.

Because thermoplastic material is susceptible to deformation by thermal stress, the wall thickness of the molding material was made uniform and the location of the mold gate was optimized so that the molded parts would not become deformed or warped. Moreover, creep deformation in the vicinity of the self-heating heater must also be considered. Thus, in the TK12, by the deformation analysis as shown in Fig. 6 at the time of injection molding, the optimization of the gate location and minimization of the amount of deformation was verified in advance, as well as the stress analysis performed during the design stage.

### 3.4 Heater design

To improve the miniaturization of thermal relays, reducing the size and increasing the efficiency of the heater, as an output engine, and reducing thermal interference between phases by facilitating the dissipation of heat to the exterior in consideration of the small housing are challenges.

To realize this miniaturization, the amount of heat generated by the heater was minimized by using coupled analysis of the current, electric heating, and bimetal curvature as shown in Fig. 7, and a structure was adopted to ensure the amount of curvature by heating the bimetal efficiently.

Additionally, to miniaturize the bimetal and maxi-

mize the amount of curvature, the heater structure was formed by laser-welding with the bimetal and the retaining parts (see Fig. 8). As a result, compared to the effective length of the bimetal of the existing structure, a 7% increase was achieved.

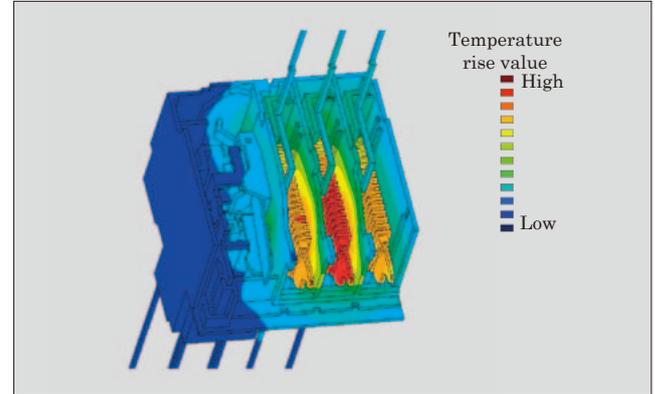


Fig.7 Coupled analysis example of current-electric heating-bimetal curvature

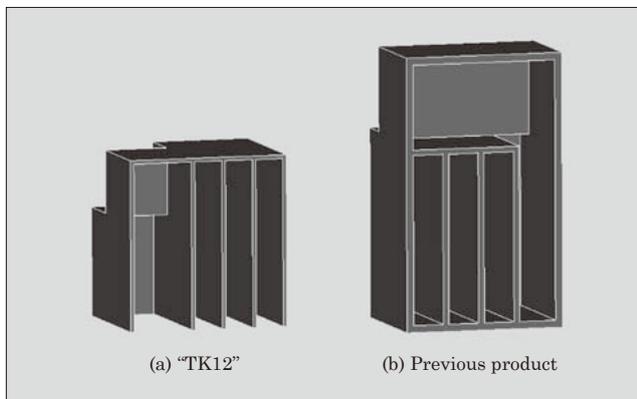


Fig.5 Comparison of housing volume ratios

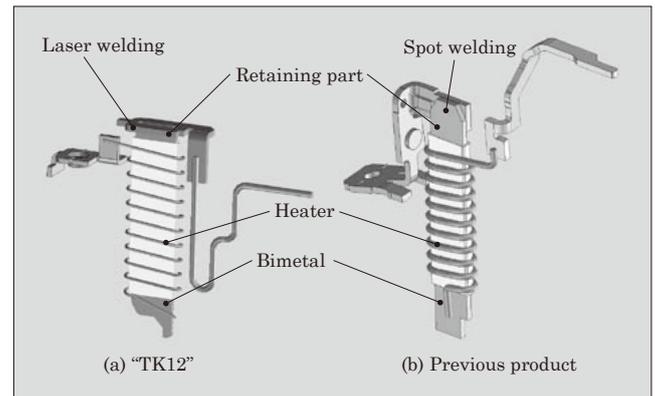


Fig.8 Laser welding method

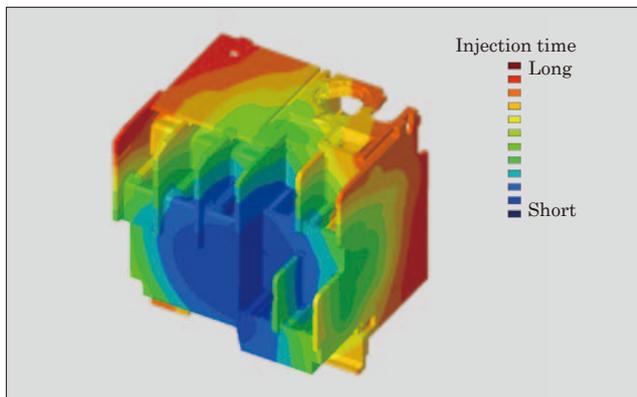


Fig.6 Example of molding flow analysis of housing

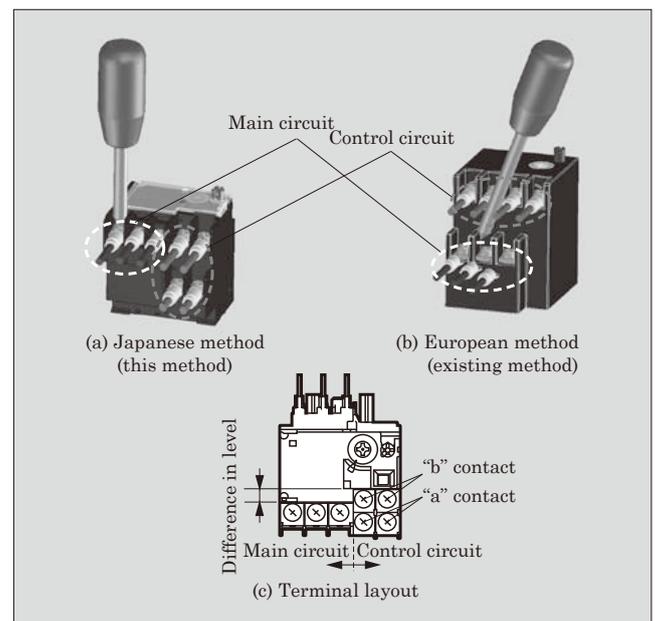


Fig.9 Diagram of the main circuit wiring

## 4. User Interface

### 4.1 Customer installation and wiring

In a typical thermal relay, auxiliary circuit terminals are located at the front and the main circuit terminals are located at the back of the control panel. The terminals are arranged in either Japanese-style or European-style layouts, and the wiring view of the main circuit is shown in Fig. 9.

Overseas, the main circuit is typically wired first, followed by the wiring of the auxiliary terminals of the control circuit. In Japan, however, it is often the case that wiring of the control circuit is performed by the panel manufacturers, and the wiring of the main circuit is performed onsite. Therefore, with a European-style terminal layout such as described above, the main circuit terminal is situated behind the control circuit wiring and is therefore difficult to reach with tools, and if the thermal relay is positioned near a wiring duct, the wiring work would be difficult to carry out. To resolve these problems, in the TK12, the main circuit and auxiliary circuit are positioned side-by-side, and a structure was adopted that facilitates the wiring work, for either type of wiring arrangement. Additionally, the main circuit and the control circuit are set at different levels in order to prevent incorrect wiring between the main circuit and the control circuit.

As for the arrangement of control circuit terminals, since the “b” contacts (NC contacts) are typically required as self-holding circuits for magnetic contactors, they are located on the panel face.

### 4.2 Safety and operability

In order to ensure globally-acceptable safety, the TK12 is equipped with a terminal cover that conforms to IEC 60529 (see Fig. 10). Additionally, since a transparent cover that can be opened and closed is mounted on the front of the product, close of the cover can prevent improper operation of the current setting

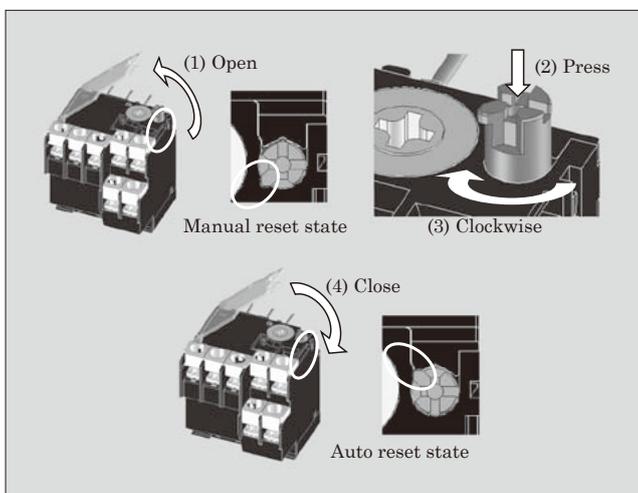


Fig.10 Automatic reset mode switching method

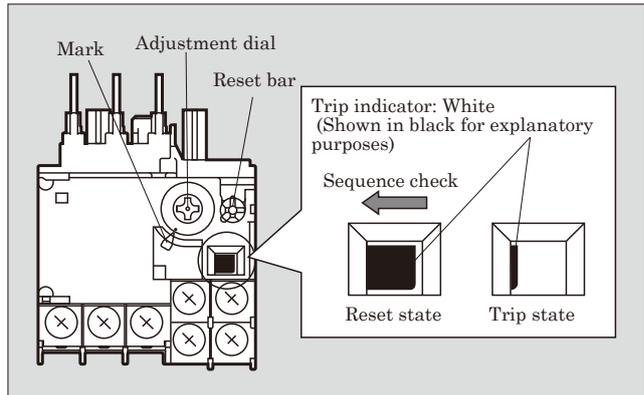


Fig.11 Sequence check

value of the adjustment dial, and improper operation of the manual and automated switching of the reset bar. Moreover, the transparent cover is provided with a sealing hole so that the cover does not open and close unintentionally.

As shown in Fig. 11, the operating state can be identified from the front view of the main body, and this display can be used to check the operating sequence.

## 5. Product Traceability

In the production of the TK12 of relays, in order to manage production traceability, a system that uses a QR code on a nameplate has been introduced to record the production history for each individual device (see Fig. 12).

- Production lot, individual number
- Daily production status, defect rate
- Individual device adjustment history

This information is centrally managed in the factory, and therefore when a product problem occurs and its production history must be investigated, the QR code can be used to confirm the individual device adjustment history immediately, thereby enabling a quick response to our customers.

## 6. Postscript

In the industrial equipment sector of the globalized market, as a means of differentiation from competitors,

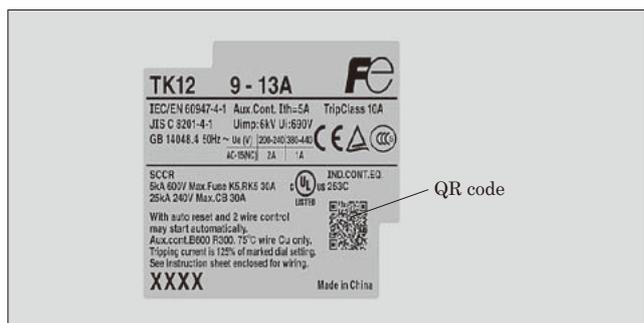


Fig.12 Faceplate

the trends toward miniaturization and higher level performance of equipment are increasing more and more. The thermal relays used to configure electromagnetic switches are no exception. Against this background, an overview of the miniaturization technology incorporated into Fuji Electric's newly developed ther-

mal relays has been presented herein.

In the future, Fuji Electric will continue to develop technology that meets the needs of the market, and aims to develop products that will meet the requirements of customers.



# 32 to 63 AF Compact Low-Voltage Circuit Breakers

HAMADA Yoshinobu †

## ABSTRACT

In order to meet diversifying market needs, Fuji Electric has developed 32 to 63 AF compact low-voltage circuit breakers as the new line-up of the global G-TWIN Series. The installation footprint was reduced to 72% of that of previous products, so that the circuit breakers can help reduce the size of panels and machines. In addition, breaking performance has been increased 1.5 times, thus they both provide industry-best compactness and breaking performance. Features of this product include the adoption of a new type of link mechanism and a thermal-electromagnetic over current tripping mechanism as miniaturized technology and the adoption of a unique one-contact arc commutation breaking method as advanced breaking technology. Furthermore, this production is highly extensible breakers designed to improve user interfaces through the expansion of the accessory line-up.

## 1. Introduction

In order to protect wiring, facilities, human bodies and the like from electric accidents such as overcurrent to the load, a short circuit, ground fault or earth leakage of an electrical line, low-voltage circuit breakers, as typified by molded case circuit breakers (MCCB) and earth leakage circuit breakers (ELCB), are installed in every type of machine, equipment, facility and building that uses electricity.

In 1990, Fuji Electric released its “TWIN Breaker” series that, for the first time in the world, featured MCCBs and ELCBs with common external dimensions. In 2001, Fuji Electric launched the “ $\alpha$ -TWIN Breaker” series of 32 to 100 AF products in the industry’s smallest size. These features contribute to the miniaturization and the design standardization of panel equipment and machines, Fuji Electric has, therefore, received the support of many customers. In response to the globalization of the market, in 2009, Fuji Electric launched the “G-TWIN Series” that conforms to international standards including IEC and UL<sup>(1)</sup>.

This paper describes the features, miniaturization technology and breaking technology of 32 to 63 AF compact MCCBs and ELCBs that have been developed as a new lineup for the G-TWIN Series.

## 2. Development Goals

In recent years, the specifications of MCCB and ELCB products have become more diversified. Stable product pricing that is unaffected by procurement market conditions (the rising of material prices), improved breaking performance and sharing of various types of accessories are common requests; however, different

specifications are required in each field.

One such requirement is for miniaturization of the devices that are necessary in order to realize smaller and lighter weight in machinery and control panel applications. Additionally, improved safety and compliance with international standards are also required. On the other hand, for power distribution panel applications, in order to simplify the panel design, unified external dimensions and compatibility with existing equipment, as well as an upgraded current rating to handle larger loads are requested. Furthermore, for power supply equipment and power generation facili-

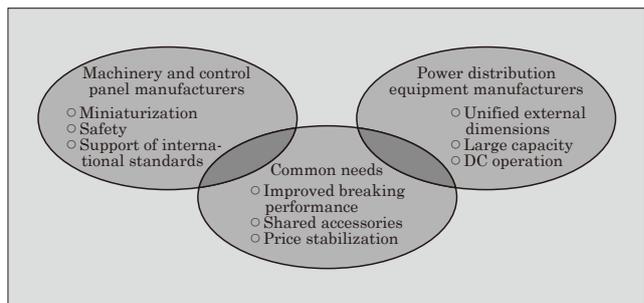


Fig.1 Market needs for MCCBs and ELCBs

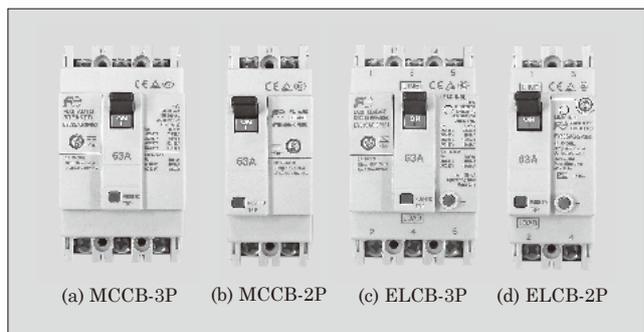


Fig.2 Product lineup

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

ties concerning recently increasing renewable energy applications, the ability to handle high DC voltage is necessary. In this manner, there has been a clear trend to use the optimal device for each industry and application (see Fig. 1).

Under these circumstances, Fuji Electric decided to develop a more compact lineup of 63 A and lower products (see Fig. 2), which are often used at the ends of branch circuits, for the market where miniaturization of device is strongly requested.

### 3. Product Features

Main features of the developed 32 to 63 AF MCCB and ELCB products are as follows.

- (1) 3-pole products are designed with the industry's smallest body size of 54 mm width (2-pole products have a width of 36 mm), reducing the installation footprint to 72% of that of existing products (see Fig. 3 and Fig. 4).
- (2) The breaking capacity has been increased 1.5 times comparing to existing products, achieving the industry's highest level of breaking performance in the same body size. In particular, for the 200 VAC lineup, the breaking performance is improved significantly with  $I_{cs}$  (rated service short-circuit breaking capacity) = 100% ×  $I_{cu}$  (rat-

ed ultimate short-circuit breaking capacity) (see Table 1).

- (3) In response to requests for electrical safety of devices, the terminal block incorporates safety design concepts that conform to IP20 (see Fig. 5).
- (4) As shown in Fig. 6, the use of cassette-type internal accessories installable by the customer and the lead routing along the side of the main unit enable close-contact body mounting. Additionally, with Fuji Electric's proprietary product accessory layout, combination variations (see Table 2) are provided, and the functions with accessories are enhanced.
- (5) Standard support of IEC 35 mm mounting rails enables two types of installation, either by mount-

Table 1 Comparison of breaking capacity (IEC condition  $I_{cu} / I_{cs}$ )

		Economy type	General type
Existing product (BW50EAG, SAG)	AC230 V	5/3 kA	10/5 kA
	AC440 V	2.5/2 kA	7.5/4 kA
Developed product	AC230 V	7.5/7.5 kA	15/15 kA
	AC440 V	2.5/2 kA	7.5/6 kA

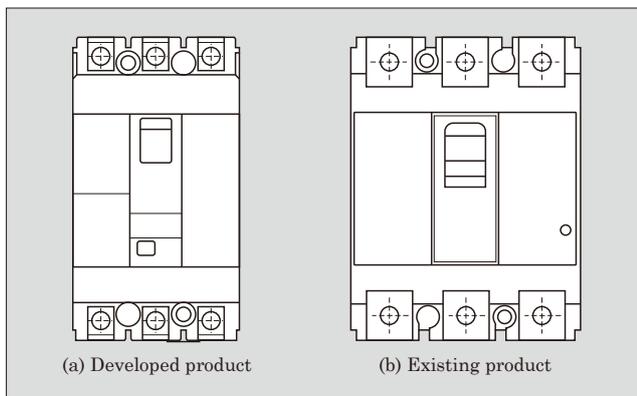


Fig.3 Comparison of external dimensions with those of existing products

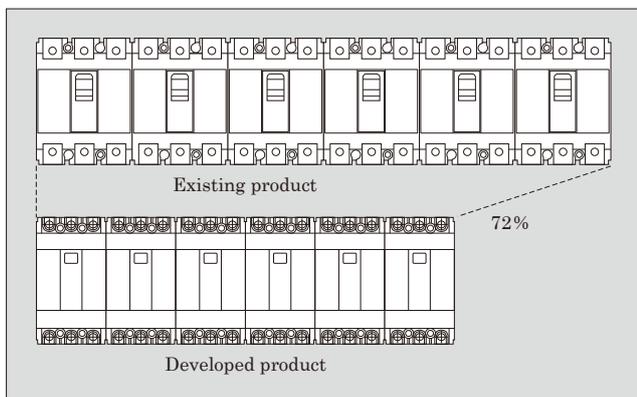


Fig.4 Miniaturization image on parallel installation

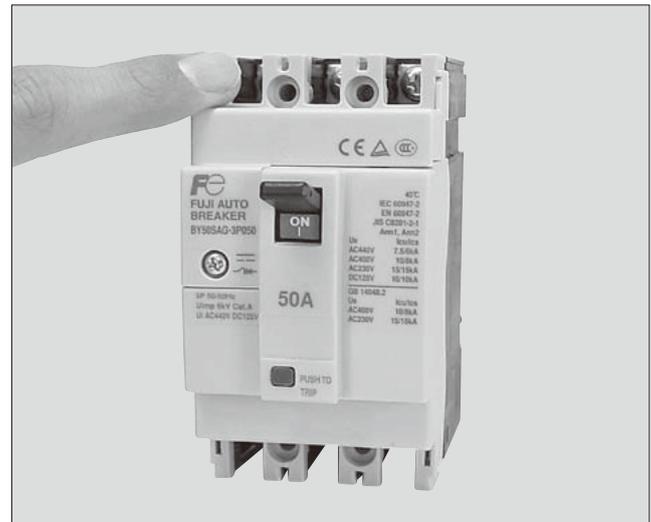


Fig.5 Terminal block safety (finger protection)

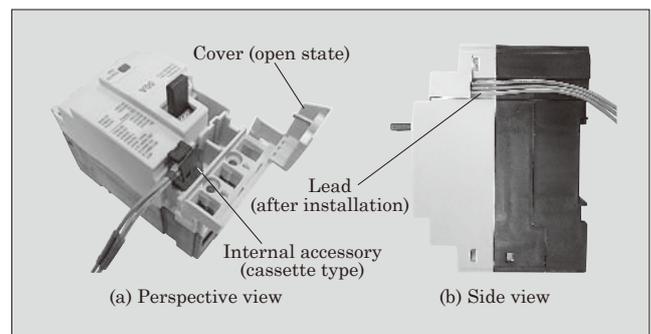


Fig.6 Installation example of internal accessory of developed product

Table 2 Examples of representative accessory combinations

		MCCB		ELCB	
		2P	3P	2P	3P
●: Auxiliary contact ▲: Alarm contact					
No. of poles		2P	3P	2P	3P
Auxiliary contact	W	○	○	○	○
	W2	—	○	—	○
Alarm contact	K	○	○	○	○
Auxiliary/Alarm	WK	○	○	○	○
Voltage tripping	F	○	○	—	○

ing screws or by mounting rails.

- (6) Two types of products lineuped according to the application to accommodate the various international standards.
  - Standard: Japan Industrial Standard (JIS), IEC, CCC
  - Global: JIS, IEC, CCC, UL489
- (7) Compliance with various environmental regulations including the RoHS directive\*1 contributes to a reduction in the environmental load.

#### 4. Product Miniaturization Technologies

In the newly developed products, each functional unit was miniaturized and made more efficient in order to realize a compact size and high performance, and the design was devised to optimize the quantities of the main conducting materials used, such as of copper and silver, in order to lessen the effect of the recent increase in material prices on the product price.

Moreover, in general, with MCCBs and ELCBs, their parts differ according to the rated current and the rated breaking capacity. Therefore, a modular structure (see Fig. 7) for each function was adopted to reduce the number of assembly steps for the product.

##### (1) Opening and closing mechanism

Because main components of the opening and closing mechanism in existing products were made of resin, miniaturization had been difficult due to subjects with dimensional accuracy and strength. Fuji Electric's newly developed breakers utilize an integrated structure with a new link mechanism and an outer frame using metal parts (see Fig. 8), and realize an opening and closing mechanism that has been miniaturized to 75% of the existing size, and a 20% improvement in contact opening speed with lighter weight

\*1: RoHS directive: European Union (EU) directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment

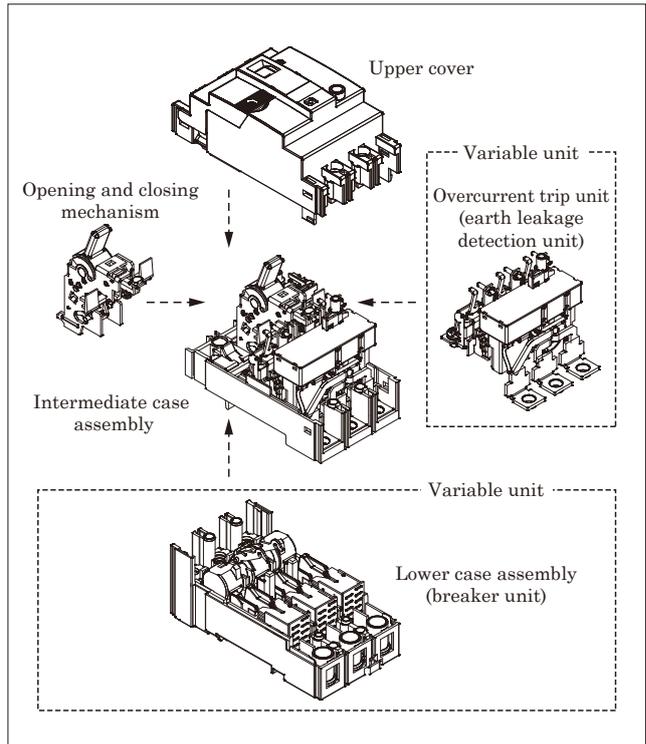


Fig.7 Modular structure of each functional unit

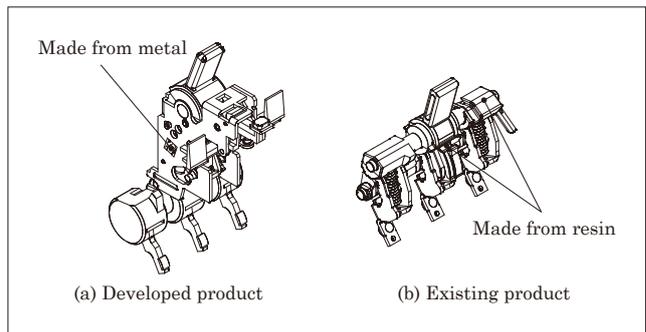


Fig.8 Opening and closing mechanism

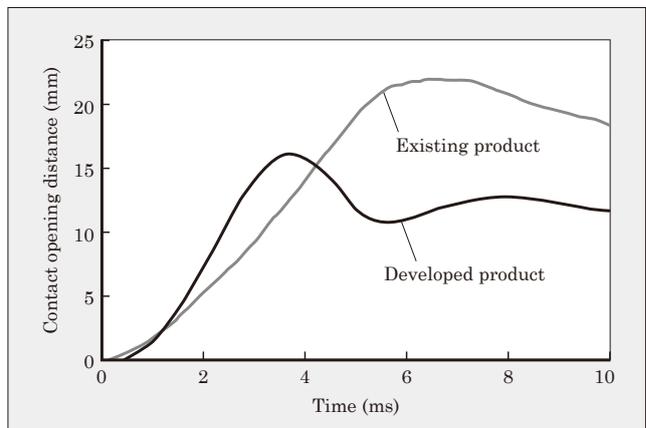


Fig.9 Comparison of contact opening characteristics

parts (see Fig. 9).

##### (2) Overcurrent tripping unit

As shown in Fig. 10, the attractive force of the elec-

tromagnetic tripping mechanism was examined using magnetic field analysis, the mechanism was miniaturized and the overcurrent tripping mechanism was changed from the existing fully electromagnetic method to a thermal-electromagnetic method. As a result, the size was reduced to 70% less than that of the existing overcurrent tripping unit, and overcurrent protection characteristics covering up to 10 times the rated value (fluctuation by differences in the mounting orientation and AC or DC operation) could be commoditized, thereby enhancing versatility.

Moreover, as efforts to reduce silver and copper usage in order to stabilize product prices, thermal analysis was performed to examine the temperature rise of a conducting element and the design was optimized (see Fig. 11). At the maximum rating products, copper and silver usage was reduced more than 30% compared to existing products.

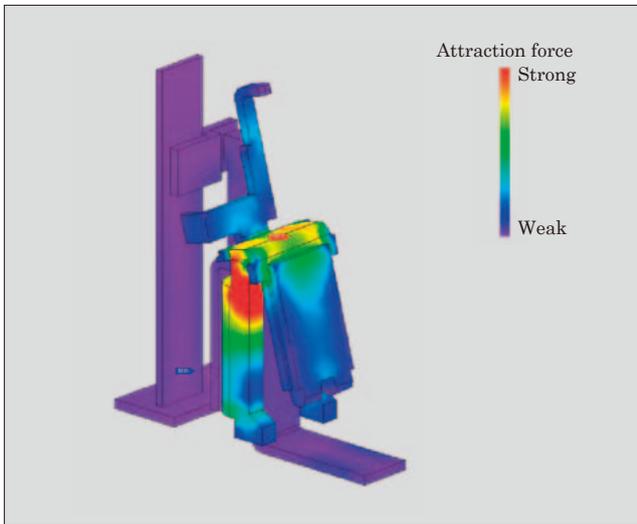


Fig.10 Examination of attraction force of electromagnetic tripping mechanism by magnetic field analysis

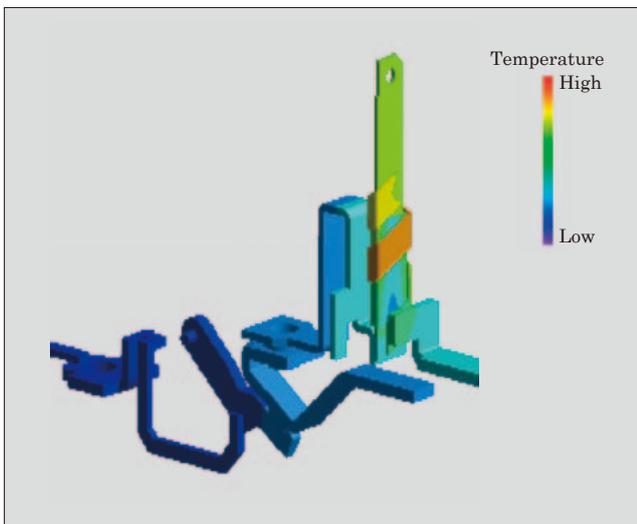


Fig.11 Examination of conductor temperature rise by thermal analysis

## 5. Arc Commutation Breaking Technology Realizing High Breaking Performance

To attain the small size and high breaking performance that are features of these products, the developed products use a proprietary single-contact arc commutation breaking method. With a typical MCCB, a commutation breaking method as shown in Fig. 12 is used. The structure is able to suppress short-circuit current by opening the contacts at high-speed, driving the arc to the arc-extinguishing unit, and increasing the arc resistance between contacts so as to instantaneously increase the circuit impedance.

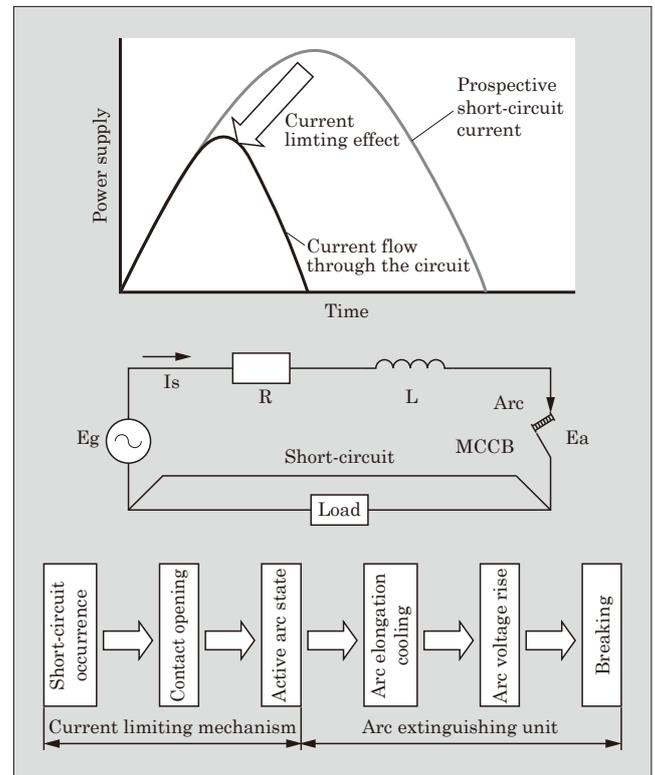


Fig.12 Current limiting breaking method

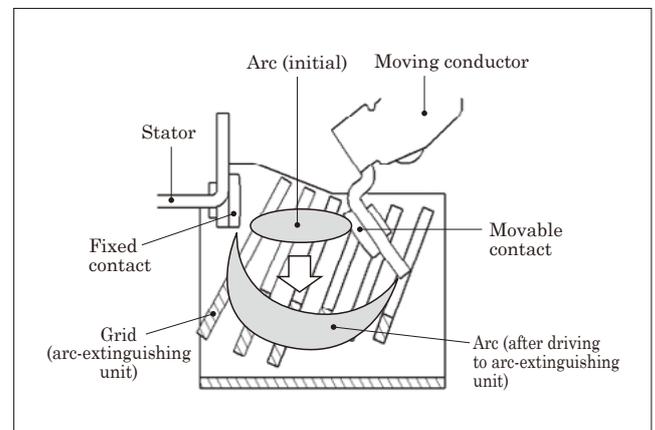


Fig.13 Schematic diagram of the breaking structure in an existing product

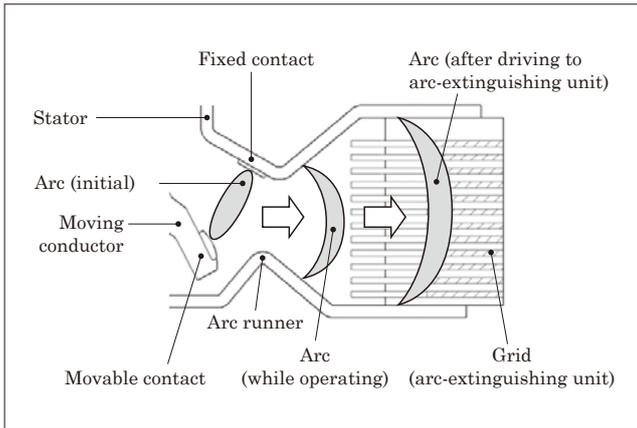


Fig.14 Schematic diagram of breaking structure in developed product

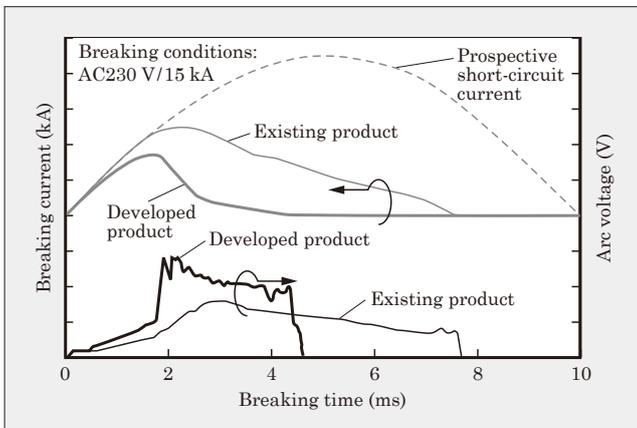


Fig.15 Breaking oscillograms of existing product and developed product

The breaking structure of an existing product (see Fig. 13) utilizes the electromagnetic force or rise in internal pressure to drive an arc, having been generated between the contacts, along the edges of the moving conductor and stator to an arc-extinguishing unit configured with a laminated magnetic metal body (grid). For this purpose, a large arc-extinguishing unit was needed to enhance the current limiting effect. Because

the arc-extinguishing unit was constrained in size in proportion to the contact opening distance (contact gap) of the moving conductor, it was difficult to enlarge only the arc-extinguishing unit in small products. Additionally, because arcs at the current breaking time are always generated in the vicinity of the contacts, there is the problem of greater wear of the contacts.

The breaking structure (see Fig. 14) of the developed product uses a breaking method in which an arc generated between contacts is commutated to a conductor known as an arc runner, and is driven at high-speed to an arc-extinguishing unit located a distance from the contacts. This method enables the arc-extinguishing unit to be made large even if the contact opening distance (contact gap) is small, and the contact wear to be reduced since the final position of the arc is far away from the vicinity of the contacts.

With this new technology, in the developed products, the time until reaching the maximum value of arc voltage can be reduced compared to existing products and, the pass-through energy (time integration of square product of the pass-through current:  $\int i^2 dt$ ) at the time of breaking can be suppressed to less than half by increasing the arc voltage (see Fig. 15).

## 6. Postscript

The featuring miniaturization technology and breaking technology of Fuji Electric's 32 to 63 AF compact low-voltage circuit breakers have been introduced. For electrical equipment used in Japan and overseas, a product lineup that supports diversifying market needs is expected to become even more important in the future. Fuji Electric intends to promptly embrace the requests of customers and to expand the lineup of products that meet market needs.

## References

- (1) Okamoto, Y. et al. New Technology of the Global Twin Breaker "G-TWIN Series." FUJI ELECTRIC REVIEW. 2010, vol.56 no.3, p.97-102.

# Devices for Facility and Energy Monitoring Systems –Expansion of “F-MPC Series”–

TAZAWA Yuji † TANI Toshiaki † MACHIDA Satoshi †

## ABSTRACT

Fuji Electric provides various products to reduce energy consumption and improve power supply reliability in power distribution systems. It offers several new products that promote a recent energy saving trend. One is the “F-MPC04E”, a compact electrical power meter that efficiently monitors terminal equipment, such as distribution panels. Another is the “F-MPC I/O unit”, a digital input and output unit which measures electrical metering pulses, monitors non-electric energy or other physical flow value, and outputs warnings. One more is the “F-MPC Igr”, an Igr type insulation monitoring device that constantly monitors for leakage of electricity from critical intelligent equipment. Combined with the existing “F-MPC Series” instruments and package software, it can provide electrical power monitoring and insulation monitoring simultaneously.

## 1. Introduction

With the revision of the Japanese “Law Concerning the Rational Use of Energy” (Energy Conservation Law) in 2010, the target of mandatory energy management has expanded from each factory and business office to each company and corporation. Furthermore, the range of factories that are obligated to monitor energy consumption was expanded, commercial sector including offices and convenience stores was added, and the number of factories, offices and stores that are subject to this law has increased significantly.

To solve the power supply shortage stemming from the Great East Japan Earthquake in March 2011, not only must the total energy usage be reduced and leveled through “energy savings,” but suppression of the maximum power usage must also be stepped up to the higher “power cutting-down stage.”

Moreover, as reduced energy usage is demanded, the automated inspection of facilities and longer intervals between periodic inspections are requested for facility maintenance work mainly at business sites such as data centers and semiconductor fabrication plants where it would be difficult to stop the facility.

## 2. Background of the Development

As shown in Fig. 1, Fuji Electric has advanced its response to meet the needs for energy monitoring primarily for the electric power in an electricity distribution system and for the status monitoring of electric equipment.

Through ascertaining these needs, this paper introduces monitoring system and the latest devices that aims to provide a stable monitoring of equipment and

to realize energy savings and power cutting-down.

Unlike large-scale factories, business office which has newly added to the energy monitoring market by the revision of the Energy Conservation Law, are often unable to set up energy experts into the field. For this reason, Fuji Electric has been offering the “F-MPC Web unit” developed on the concept of easy-to-construct energy visibility system, even when an expert is unavailable. The F-MPC Web unit allows collected data to be checked easily from a general-purpose browser with Web capabilities. As analysis function screens, such as graphs of electric power consumption, trend information, group comparisons, and unit consumption display per production volume, can be viewed without dedicated software, the data can be verified at any time by all users, not just administrators, thus facilitating energy visualization easily.

Fuji Electric has proposed a power and energy monitoring system that uses “F-MPC Series” equipment and ranges from a high-voltage power distribution system to a terminal system (see Fig. 2).

Fuji Electric has also developed the “F-MPC04E”

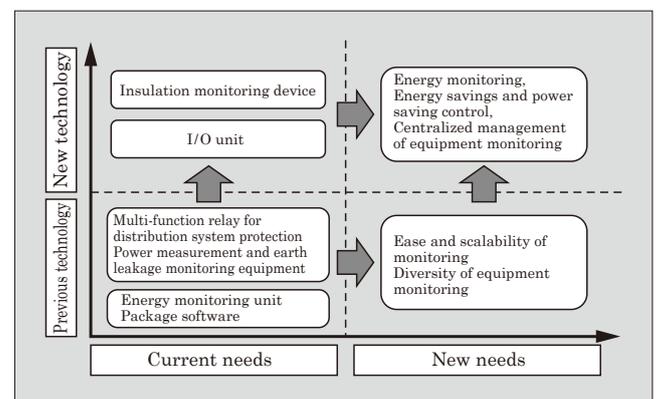


Fig.1 Status of power distribution monitoring

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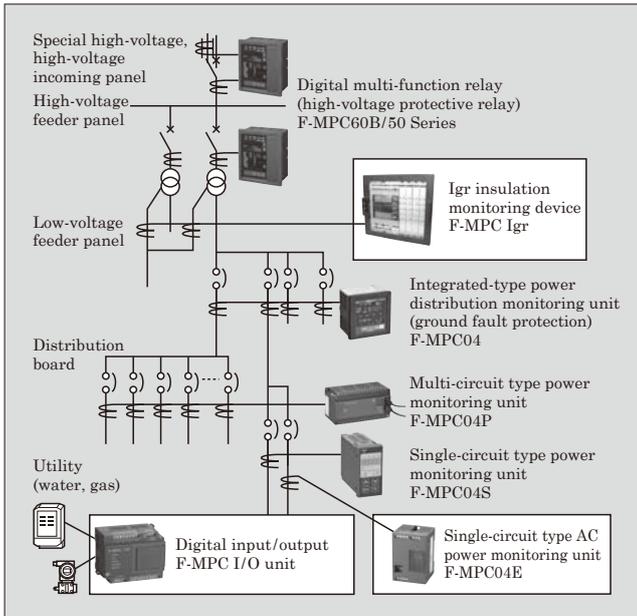


Fig.2 Application configuration diagram of "F-MPC Series"

electric power measuring unit, which accommodates the marketplace desire for a low-price measuring device, and the "F-MPC I/O" digital input-output unit, which facilitates the configuration of an energy control system. Additionally, as a facility monitoring device, Fuji Electric developed the "F-MPC Igr" insulation monitoring device which automates insulation monitoring and is highly compatible with the F-MPC Series of energy monitoring systems. Thus, in high-voltage through low-voltage power distribution systems, these F-MPC Series devices can be used to monitor the energy and facility status centrally using a common communication network.

### 3. Electric power Measuring Device Used in Distribution Panel Inside

As an addition to the "F-MPC04 Series" lineup of electric power measuring units, Fuji Electric developed a compact model, the F-MPC04E, which can be installed easily in an existing distribution panel. The F-MPC04E is a single-circuit type AC power monitoring unit that can be installed easily in a panel by rail-mounting. With a RS-485 communication interface provided as a standard feature, this unit can collect measured electric power values via a communication line, and is well suited for use as a power measuring terminal in an energy monitoring system. Additionally, a dedicated display is available as an option so that the measured values can be checked on a display panel. Figure 3 shows the external appearance of the single-circuit type AC power monitoring unit.

Since the required accuracy for energy monitoring with the F-MPC04E, as same as existing models, is equivalent to the ordinary class specified in JIS, the F-MPC04E is better suited for more economic sys-

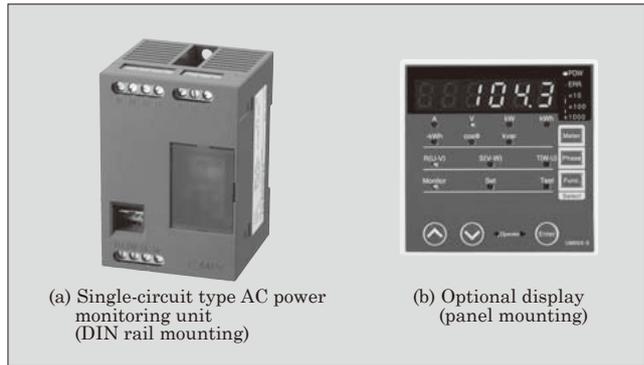


Fig.3 Single-circuit type AC power monitoring unit

tems than those existing models. Additionally, setting of the applied current transformer (only for F-MPC dedicated type) and the communication address can be carried out simply by switch operations on the main unit. Consequently, the configuration settings can be implemented easily, without having to connect and energize a display at the time of installation work. As for the measurement of electric power, in a distribution system in which an energy-creating equipment such as a photovoltaic power station is installed, the reverse power flow can be measured and the integrated watt hour value can be recorded in the forward and reverse directions. The F-MPC04E has the following characteristics.

- Size: H80×W55×D58 (mm) (1/2 size of prior model)
- Mass: Approx. 120 g (1/3 mass of prior model)
- Phase and wire system: Single-phase 2-wire, single-phase 3-wire, 3-phase 3-wire (automatic identification)
- Accuracy of the power monitoring: Equivalent to ordinary class specified in JIS
- Communication function: Selectable as either Fuji Electric's F-MPC-Net protocol or general-purpose Modbus/RTU
- Measurement function: Maximum current, average current, minimum current

Maximum current, average current, and minimum current data that are useful in facility management are calculated as root mean square (RMS) values per commercial frequency cycle, and are updated every minute. The latest data is held for 1 minute in the F-MPC04E so that the status of peak current or the like can be managed easily even with a RS-485 low-speed measurement communication line.

Previously, in order to measure the constantly fluctuating inrush current and the like in machinery, instantaneous (waveform) values had to be recorded using an expensive wave recording device. Even with such a recording device, however, data could not be recorded and monitored continuously and permanently, and it was difficult to constantly monitor the operating status of the facility.

For example, in a production line that uses arc

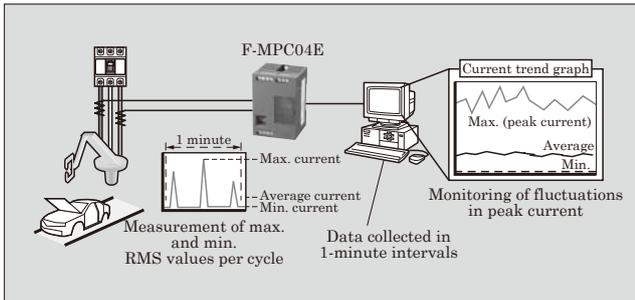


Fig.4 System configuration example of fluctuation monitoring in peak current

welding equipment, the value of the arc current is an example of data that is useful for facility management. Because the interval during which arc current flows is extremely short and only lasts for several cycles, it was difficult to manage the arc current with a general-purpose power monitoring system. By using this function of the “F-MPC04E”, however, the RMS values of arc current can be recorded and continuously monitored with ease, and can be used as facility management data. Figure 4 shows a system configuration example of the fluctuation monitoring in peak current.

#### 4. I/O Unit Optimally Suited for Energy Monitoring

Since the Great East Japan Earthquake, there has been concern about a supply shortage of electric power, and the purpose of energy monitoring has shifted to peak shaving of instantaneous power. If Japan faces a heat wave in the summer of 2012, a shortage of approximately 10% in peak power throughout Japan is predicted, and ongoing peak shaving should be continued. For this reason, specific measures must be undertaken in a timely manner as the next step after energy visualization. Aiming to facilitate the systematization of such management functions, Fuji Electric developed the “F-MPC I/O unit” that is optimally suited for use in an F-MPC energy monitoring system. The F-MPC I/O unit has the following features.

- Number of inputs and outputs: 6 inputs, 4 outputs
- Size: H80×W100×D58 (mm), same as “F-MPC Web unit”, can be installed in a thin-type distribution panel
- Communication function: Fuji Electric’s F-MPC-Net protocol or general-purpose Modbus/RTU

Combining the input and output functions of the F-MPC I/O unit and the F-MPC Web unit facilitates coordination for energy visualization with warning alarms and the like.

Figure 5 shows an example of a demand monitoring and alarm system. A single F-MPC Web unit is able to support the demand monitoring of two sites. The F-MPC Web unit sends an alarm message via an Intranet or the Internet when the expected value of

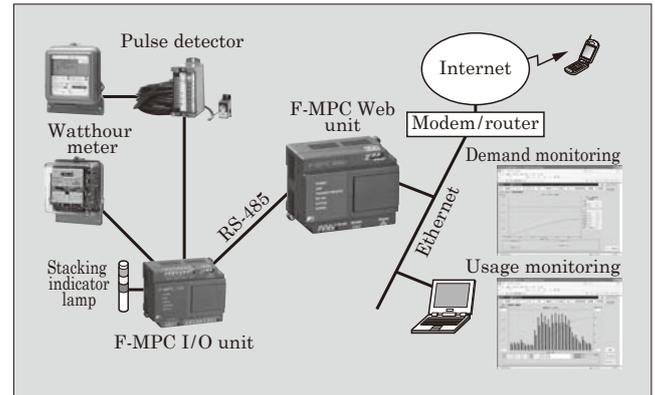


Fig.5 Example of demand monitoring

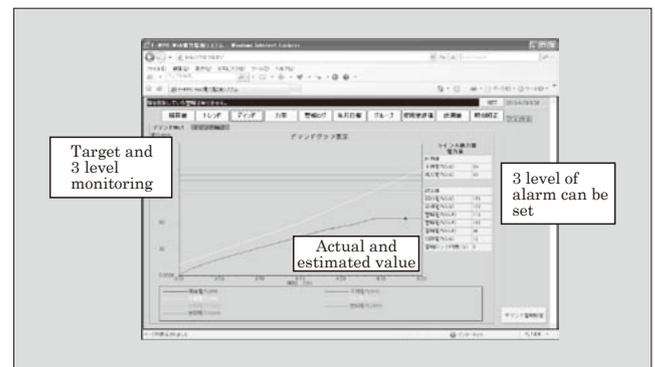


Fig.6 Demand monitoring screen

electric power is near exceeding a preset alarm level. The F-MPC I/O unit has six digital inputs, two of which are for receiving electric power pulses, and four digital outputs, all of which are relay outputs capable of directly driving a lamp or a buzzer.

In the example of this system, the F-MPC I/O unit counts received power pulses, and the F-MPC Web unit, using a demand monitoring function that estimates the peak power every 30 minutes, issues an alarm by email and by relay output when the target peak power is near to be exceeded. Figure 6 shows a demand monitoring screen of the F-MPC Web unit. Three level of alarm can be set for the target peak power, and because F-MPC04 Series measuring equipment can easily be connected to the RS-485 communication line of the F-MPC Web unit for data collection, the system can be expanded to a more detailed power monitoring system. In this case, an alarm can be output detecting the instantaneous power exceeding with the alarm setting of the F-MPC Web unit, and peak shaving can be realized toward a power-saving target.

Moreover, since the F-MPC I/O unit can count power pulses from a wathour meter for power management, pulses from water and gas meters, and pulses from calorimeters, as well as input power pulses, it can comprehensively manage other utility in addition to electricity.

## 5. Insulation Monitoring Unit for Equipment in a Live State

In accordance with Japan's "Electricity Business Act," insulation resistance must be measured periodically during power outages as part of the insulation management for low-voltage electrical circuits. For the general measurement of insulation resistance, a facility is required to stop temporarily and then a DC voltage is applied to measure the insulation resistance. The types of loads which cannot be measured with this method, however, are increasing year-by-year. In addition, there are problems such as not knowing the extent of insulation degradation while the facility is operating. Therefore, a function capable of continuous monitoring of the insulation condition during operation of the facility has attracted considerable attention.

According to the Japanese "Safety regulations of electric facilities for private use" that prescribe management of the insulation condition at a facility, by installing a monitoring device that continuously monitors the insulation condition online and outputs an alarm when the insulation condition exceeds a certain level, the inspection cycle can be extended from once a month to once every other month. At facilities such as data centers and semiconductor factories which operate 24-hours a day, the facility status can be monitored during operation, thus enabling prevention of unexpected power outages during operation and fewer pow-

er shutdowns for inspections, and therefore, there is increasing demand for an insulation monitoring device that has this type of function.

There are two methods of insulation monitoring, an Igr method which superposes the signal waveform being monitored, and an Ior method which uses the line voltage as a reference. Either of these monitoring methods can be used to manage the insulation condition by removing the higher harmonics contained in the earth leakage current, excluding the earth leakage current due to capacitive components of the cable and the load, and accurately detecting the earth leakage current of the resistance component only. In particular, because the Igr method can be applied to any type of line, can be used to monitor a grounding line and is unaffected by the imbalance among phases in the electrostatic capacitance to ground, the Igr method is superior to the Ior method.

For the F-MPC Series of power monitoring equipment, Fuji Electric developed the F-MPC Igr as an insulation monitoring device that uses the Igr method of superposing the monitoring waveform. Thus, to a conventional power monitoring system, by adding a function for monitoring the insulation state of a facility with the F-MPC Igr, a system can be provided that is capable of simultaneously monitoring both the energy usage status and the insulation status. Table 1 compares the insulation monitoring methods.

### (1) F-MPC Igr configuration

The F-MPC Igr consists of an injection device and an injection transformer to superpose the waveform for monitoring, and a zero phase sequence current transformer (ZCT) and measuring device to measure the current of each circuit (see Fig. 7). The measuring device is configured from a storage case for 4 or 8 circuits, a measuring unit for each circuit, and a base unit for collectively setting data to the measuring units and for displaying data. The conversion from high-voltage to low-voltage is performed by multiple transformers, such as a 3-phase transformer for motor use and single-phase transform for lamp use in a single high-voltage distribution system, and therefore the storage case is selected according to the applied system.

Table 1 Comparison of insulation monitoring methods

Item		Io method	Ior method	Igr method
Applicable circuits		All low-voltage circuits	Single-phase 3-wire, 3-phase 3-wire delta	All low-voltage circuits
Detection function	Effect of high harmonics	There is an effect	No effect	No effect
	Effect of electrostatic capacitance to ground	There is an effect	No effect if no imbalance among phases	No effect
	Detection of ground phase	Not possible	Not possible	Possible
Detected components		Magnitude of leakage current	Resistance component within leakage current	Resistance component of superposed low-frequency components
System configuration		Measuring device + ZCT	Measuring device + ZCT	Measuring device + ZCT + injection device + injection transformer
Installation cost		Low	Medium	High

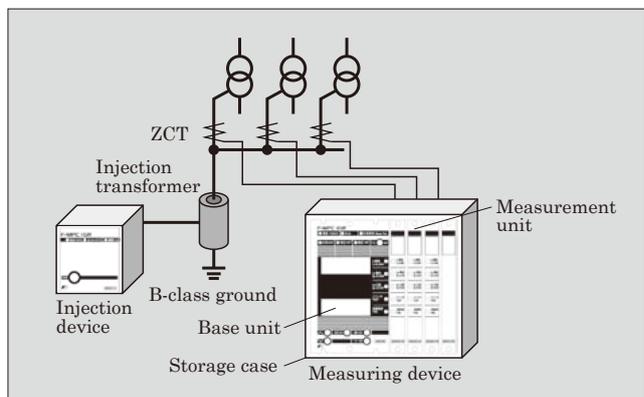


Fig.7 "F-MPC Igr" configuration

Table 2 “F-MPC Igr” specifications

Item	Specification
Superposed frequency	20/15/12.5 Hz
Superposed voltage	10/7.5/6.3 V (linked to frequency)
Injection transformer	30 mm $\phi$ , 20 turns
ZCT	30 mm $\phi$ , 1,000 turns
Control power supply	85 to 264 V AC
Measurement function	Leakage current: Io/Iob Resistive leakage current: Igr Capacitance to ground: C
Alarm function	Io/Iob alarm: 0.1 to 3 A, 0.1 to 120 s Igr caution alarm: 5 to 75 mA, 40 s Igr warning alarm: 10 to 200 mA, 10 s
Self-diagnostic function	ZCT connection check function Frequency setting consistency check function Insulation monitoring accuracy check function

## (2) F-MPC Igr specifications

Table 2 lists the specifications of the F-MPC Igr. The superposed waveform for monitoring has a minute voltage of 0.5 V or less, and is sufficiently small compared to the voltage of a commercial power supply. Minute earth leakage currents flowing in a circuit are detected with this monitoring waveform, and the F-MPC Igr unit converts the detected values to the voltage level of the applied system to display and monitor those values.

Applied circuit voltages are supported from a mini-

mum of 90 V to a maximum of 440 V in accordance with the distribution system of the manufacturing facility or building.

Utilizing a communication network, centralized monitoring can be performed using Fuji Electric’s “F-MPC-Net Web” power monitoring package software or the like. Moreover, in consideration of stand-alone usage, an alarm output contact is provided for devices collectively and for individual circuits, and the unit is capable of recording the alarm history with a timestamp for the previous 10 alarm occurrences.

## 6. Postscript

The “F-MPC Series” of devices for energy monitoring systems supports not only small-scale facilities, but also has superior expandability for supporting medium-scale to large-scale monitoring systems.

The devices introduced herein enable reductions in system cost, facilitate support of warning alarms that lead to energy savings and power cutting down as a next step after visualization, and enable systems to be expanded for facility monitoring.

While continuing to leverage the merits of these advantages, Fuji Electric intends to promote the expansion of systems and devices capable of making positive contributions to energy savings and power cutting down policies, and to contribute to measures for reducing energy consumption by the customers, leading to improvement of the global environment.



# The Transitions and Trends of Core Technology for Electric Distribution and Control Devices

TAKAHASHI Tatsunori †

## ABSTRACT

Demands are increasing for miniaturization, higher voltage direct current (DC) equipment that handles clean energy power sources. Interrupting and switching of DC requires a wider contact gap when equipment is miniaturized so that arc voltage rises over power-supply voltage instantaneously and stabilized; thus insulation quality can be ensured. This paper rearranged the transitions and trends of basic technology common to various types of equipment and unique inherent technology to solve this challenge regarding the core technology of electric distribution and control equipment, which until now has stored alternating current (AC) from the perspective of a product and manufacturing. By pioneering a contact-device technology field that is not constrained by methods for the interruption and switching of electric current in the air, Fuji Electric aims for device brand integrating AC/DC technology with high reliability.

## 1. Introduction

Fuji Electric began electric distribution and control devices business in the 1950s with the full-scale manufacture of ultra compact magnetic switches, and has subsequently expanded its control device line. In the 1960s, with the start of manufacture of molded-case circuit breakers and earth leakage circuit breakers as well as the commercialization of distribution equipment line-up applicable up to 36 kV, Fuji Electric expanded its business operations for all products in both areas. In recent years, an extensive product group that includes a line of products from French company Schneider Electric, a joint partner company, has been spread out.

Previously, the majority of products were used in AC applications, but recently, DC applications have been increasing. This increase is caused by the expansion of use of renewable clean energy sources such as photovoltaic power and wind power as stable power supplies based on the keywords of “energy” and the “environment.”

This paper describes the main products in the field of electric distribution and control devices, the evolution of their core technologies, and discusses the outlook for incorporation of novel products and technologies into new fields brought from the surrounding environment changes.

## 2. Market and Technology Trends<sup>(1)</sup>

### 2.1 Product development and the evolution of technology

Fuji Electric’s core products of electric distribution and control devices can broadly classified into three categories: electromagnetic switches, distribution

equipment and command switches (operation switches/displays).

The first category of core products is electromagnetic switches that were launched as the “RC Series” in 1954 based on introduced technology from the German company Siemens. Subsequently, by releasing “SRC Series” and “SC Series”, the compact and highly reliable brands were established, and Fuji Electric has been retaining the top market share to the present day (see Fig. 1). In these series, high reliability was realized with a simple configuration in which the main circuit contacts are controlled by electromagnetic driving, and opening and closing is performed remotely. Additionally, as in the SC Series of the 1980s, electronic control was introduced to drive electromagnets, and new technologies have been actively incorporated, such as optimal control of the contact function that makes outstanding reduce of contact wear. Fuji Electric has also developed solid-state contactors that use power semiconductors to realize non mechanical contact operation. Additionally, utilizing the highly

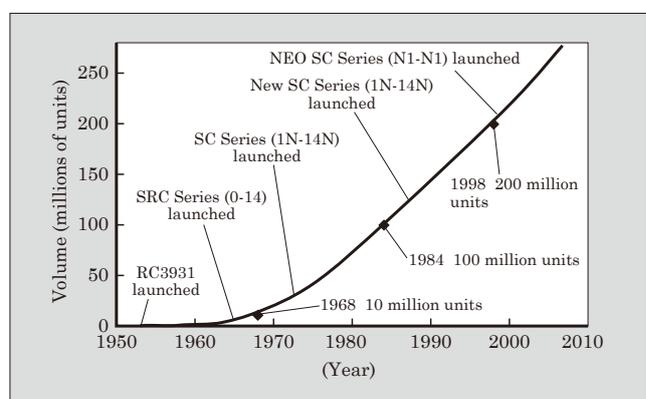


Fig.1 Changes in cumulative production volume of electromagnetic switches

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

reliable technology that has been cultivated in these types of industrial fields, the product lineup in the consumer field has been expanded with the “FMC Series” and the like, and the cumulative production quantity to date is approaching 300 million units.

Concerning the second category of core products as molded-case circuit breakers, the fundamental product among distribution devices, following the development of the “L Series” that is based on proprietary current-limiting breaking technology in the latter half of the 1960s, an earth-leakage circuit breaker was released onto the market for the first time in Japan. Since then, Fuji Electric has expanded its variety of products to air circuit breakers rated at 3,200 A. In particular, in the 1990s, due to advances in technology for achieving miniaturization and higher breaking capacity through arc control, twin breakers featuring the same external dimensions for both molded-case circuit breakers and earth-leakage circuit breakers, which had ever been impossible, were developed and subsequently became the industry standard. Additionally, for medium-voltage circuit breakers rated higher than the 600 V AC class, a technology shift from T-type circuit breaker (minimum oil circuit breaker) to compact vacuum circuit breaker (VCB) that handles the high-voltage breaking region was completed through the use of a vacuum valve method in which the contact electrode area is covered with vacuum-insulated tubing.

For command switches, the third category of core products, Fuji Electric developed the “Rca470 Series” first-generation products applied to  $\phi 30$  mm mounting holes, then miniaturized these products to a product with a proprietary  $\phi 25$  mm hole size, and subsequently expanded the lineup to include products that satisfy the international standard of  $\phi 22$  mm. Assembly and mass-production technology based on parts manufacturing technology of highly accurate metal processing and resin molding is used in the production of these products.

Besides these stand-alone devices, in response to the needs of equipment for monitoring and protecting the charged state of the main components that make up the main circuit system ranging from the main trunk to branches, and in distribution panels and control panels, in 1997 Fuji Electric launched the “F-MPC60 Series” of 6.6 kV-class digital-type multi-function relays for high-voltage distribution. This series performed microprocessor-based sampling control, and integrated a protective relay, an electric indicator, a display and operating switch functions. The series was also provided with self-diagnostic and communication functions, which had not been available in the electromagnetic and static type relays, and the need for power monitoring was commercialized in advance as distribution devices. So that detailed power monitoring of low-voltage distribution panels and distribution switch gears could be carried out efficiently, Fuji Electric’s lineup was additionally expanded to

include the “F-MPC04 Series” of single-circuit and multi-circuit types of monitoring units. Fuji Electric has responded flexibly to the needs for energy savings through energy monitoring and for the systematization of electric distribution and control devices.

## 2.2 Market needs and technical trends

The main uses, thus far, for low-voltage electric distribution and control devices have been in AC applications of up to 600 V, and there has been little demand for DC applications of up to 750 V. Recently, however, for electrical facilities and equipment that use green energy power sources, such as the power conditioner at a large-scale photovoltaic power generation facility, there has been increasing need for 1,000 V-class DC high-voltage applications. Industrial needs for 600 V AC and lower voltage applications have been met so far, but high-voltage DC applications for residential-use and commercial facilities have been increasing (see Fig. 2).

As specific examples of DC applications, as well as the previously mentioned green energy, building and facilities in Japan are also considering transitioning from the 200 V AC class to the 400 V DC class used in data centers and the like. Also in residential use, an evolution can be seen from the 100 V AC class to smart house applications that use photovoltaic cells and other high-voltage DC sources.

Moreover, from the experience of the Great East Japan Earthquake of 2011, the risk of dependence solely upon commercial power sources has become apparent, the need for countermeasures to handle long-term power outages is recognized, and there is increased interest in installing residential-use storage battery systems including photovoltaic cells. There is a concept of smart communities where the batteries installed in electric vehicles (EV) are interconnected to the system as a storage battery; therefore, the need for inexpensive electric circuit switches and protective devices that can be used in high-voltage DC applications is expected to increase rapidly.

As shown in Fig. 2, AC and DC applications for

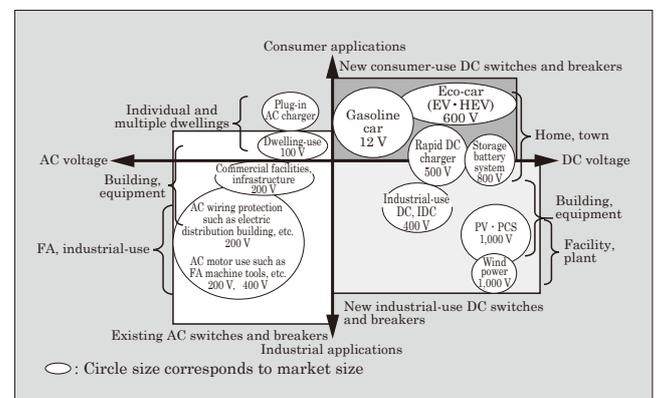


Fig.2 AC/DC application areas and trends of electric distribution and control devices

electric distribution and control devices are expected to expand from the AC low-voltage industrial applications at the lower left region to the following two regions. The first expansion is toward the right, to the new industrial field of DC high-voltage applications, which includes data centers and new energy plants. The other expansion is toward the upper right, to new consumer applications in which the batteries of EVs, HEVs and other types of eco-cars are used as power supplies

### 3. Technology Development in Electric Distribution and Control Devices

Table 1 arranges the list of the various elemental technologies that organize the technology development in electric distribution and control devices. The core technologies have been extracted from the following three groups. The first is electric distribution devices consisting mainly of molded-case circuit breakers for protecting electric circuits in low-voltage distribution systems from overcurrents due to short circuits and overloading. The second is earth leakage circuit breakers for protecting these circuits from ground faults and earth leakage. The third is a group of control devices consisting mainly of electromagnetic switches used to start and stop, preventing overloading and open-phase operation of electric motors. As the major component common among these devices, a central mechanism detects overload current in the main circuit and, based on the output signal thereof, drives the opening and closing of the contacts. This mechanism is followed by the technology including the opening and closing contacts and a breaking and insulating function by the extinguishing part for the arc generated when the contacts are open. In addition to technology development for product development, the development of new technologies is also being pursued to improve design, production and quality assurance.

With this common fundamental technology established as a platform for all electric distribution and control devices, Fuji Electric has developed and put into practice applied proprietary technology for each model.

#### 3.1 Fundamental technologies

##### (1) Outer casing of the electric distribution and control devices

As technology development that forms a foundation for product development, the changes in the material of the outer casing of electric distribution and control devices are shown in Fig. 3 as the example of the SC Series electromagnetic contactor. Initially, a ceramic case that covered the arc-extinguishing part was used as an upper case to ensure heat resistance against arc plasma generated while contacts were opening as characteristic of electrical switching devices. Thereafter, by applying arc-suppression technology and the like, thermosetting resin molding mate-

rial came to be usable, and the shape design became more flexible. In recent years, the casing material has changed to thermoplastic resin molding material in

Table 1 Elemental technologies that configure electric distribution and control devices

Product development technology	Electromagnetic field technology	
	Contact opening and closing technology	
	Breaking/insulating technology	
	Light irradiation display technology	
	Safety technology	
	Environmental technology	
	Materials technology	Material properties and engineering technology Materials analysis technology
	Mechanical engineering technology	Mechanical elements Structure and configuration technology Packaging Mechanism technology Noise and vibration technology Tribology Heating and cooling
	Information processing technology	Embedded software System software Language programming Web, OSS, ASP Communication network, protocol
	Electrical and electronic technology	Digital-analog circuit technology Microcomputer application technology EMC technology Sensing technology
Manufacturing and production technology	Simulation technology	Phenomenon analysis technology CAE application technology
	Precision metal processing technology	Press processing technology Laser processing technology Bending and drawing processing technology
	Precision resin molding technology	Injection molding technology Thermosetting molding technology Insert molding technology Inline molding technology
	Mass-production die technology	Single press processing technology Progressive press processing technology
	Fastening and bonding technology	Brazing and bonding technology Welding technology Adhesive technology
	Surface treatment technology	Plating technology Painting technology
	Mass production assembly technology	Automated assembly technology Jigs, custom machines Anti-pollution technology
	Production line management technology	Parts and materials supply technology Optimal inventory technology Product supply technology
Design management technology	Facility maintenance technology	
	2-3D/CAD technology	CAD, CAM, CAT
	Design drafting	Drawing management Tolerance design
Quality evaluation technology	Development management	
	Line inspection technology	
	Traceability technology	

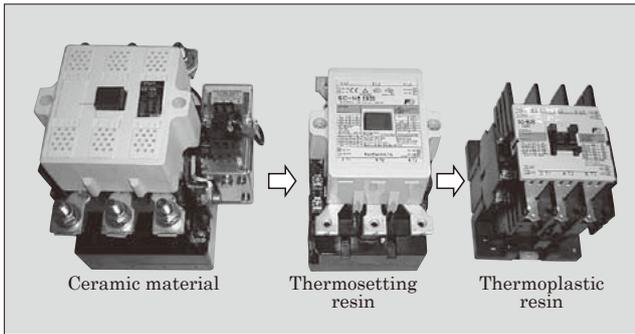


Fig.3 Change in material used for outer casing

consideration of its suitability for recycling; furthermore, an outer casing and components with charged contact parts which having high heat resistance and conforming to the UL standard for non-halogen flame retardant material content have come to be used.

#### (2) Elemental technologies

Electromagnetic contactors have a long opening-and-closing service life, with electrical and mechanical lives of 2 million times and 10 million times, respectively. In consideration of the tribology to the part where mechanical materials for moving and retaining the contacts are combined, including the lubricative coating of functional parts that retain and support contact sliding, and surface modification of both contacting materials, Fuji Electric has worked to develop friction-lowering elemental technology. Additionally, at the tripping latch and other parts at a high surface pressure in a low-voltage breaker, improvements are needed in the long-term stability of grease and in the balance between the conflicting factors of viscosity and coating uniformity. For this purpose, Fuji Electric has steadily continued to study, improve and accumulate know-how regarding the relationship between component strength and run-time friction through the optimal combination of surface treatment and surface roughness of metal parts.

#### (3) Design technology

3D CAD software running on a UNIX workstation, which had been popular since before the heyday of PCs in the latter half of the 1980s, was introduced and applied to the development and design of the 1st generation of twin breakers that were launched in 1991. At that time, sheet metal CAD data linked to CAM, which was in its infancy, was directly read-in to wire-cutting machines to shorten the prototype production period, without the use of drawings. Additionally, a rapid prototyping machine was also introduced to shorten significantly the development period for prototyping resin parts. At the same time, Fuji Electric also linked 3D CAD data to CAE, and developed operation analysis software for the contact opening and closing mechanism of a circuit breaker, and applied that analysis software in the development of command switches and the twin breaker series that uses an ultra-compact link mechanism. Figure 4 shows an example analysis of

the contact opening and closing mechanism applied to a molded-case circuit breaker, and Fig. 5 shows an example application to the micro-actuator of a command switch. As a result of pioneering analysis methods and design environmental improvements, simulation technology that the designers can professionally use by themselves has been developed.

In terms of compliance with the various standards, priority was first given to Japanese domestic standards during the early stages of a product launch. Subsequently, products were commercialized to support the individual international standards, and at present, Fuji Electric has adopted a policy of global standard conformance so that, as with the “G-TWIN Breakers”, nearly all international standards are supported with a single product.

#### (4) Manufacturing and production technology

With the introduction of wire-cutting machines in the 1980s, in addition to the use of iron core automatic measuring and calking machines, electrostatic coating machines, and the NC processing of sheet metal and machining, the fabrication of complex and precision dies has been sped-up dramatically. Additionally, combined machining technology in which different types of parts are machined simultaneously inside a die was also addressed with the development of an in-die tapping unit.

For treating the surface of components, Fuji Electric independently developed functional plating that applies Ag-C to the copper surfaces of conducting and sliding parts such as the moving contact of a breaker, and miniaturized and enhanced the perfor-

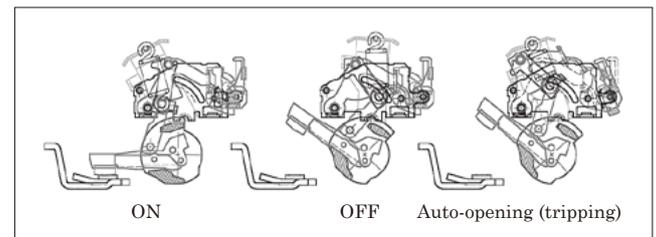


Fig.4 Example analysis of contact opening and closing mechanism used in molded-case circuit breakers

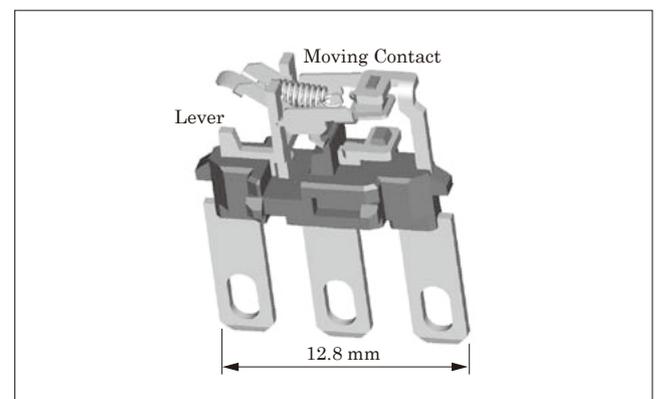


Fig.5 Example application to micro-actuator in command switch

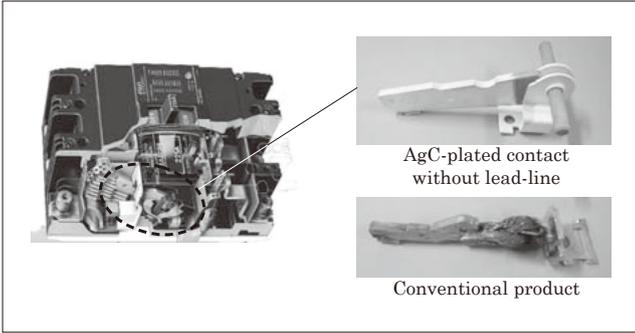


Fig.6 Example of AgC plating used in twin breaker series

mance of the conducting and sliding parts (see Fig. 6).

Technology such as CO<sub>2</sub> laser cutting and NC bending were also introduced along with wire-cutting machines in the 1980s as a pioneer in the industry. In terms of production, the start-up of an automated line for compact electromagnetic switches, the introduction of just-in-time production, the online availability of daily production plans and received orders, the implementation of a cellular production system for electromagnetic switch manual assembly and the like have formed the basis for the variable-mix variable-volume production of today.

### 3.2 Original technology

#### (1) Miniature actuator technology for electromagnetic switches

Electromagnetic switches have met the needs for smaller size and higher performance with each successive model change. In particular, the DC operating-type had larger outer dimensions due to its higher coil volume than the AC operating-type. For this reason, Fuji Electric paired an electromagnetic switch with permanent magnets on either side of the coil as shown in Fig. 7(a) to launch the “SK Series,” a new series of the world’s smallest mini contactors that features the same dimensions as the AC-operating type and ultra-low power consumption of 1.2 W for the 2.2 kW-class.

In the development of an actuator that combines permanent magnets and a coil, which contributes to miniaturization of the electromagnetic switch, the pow-

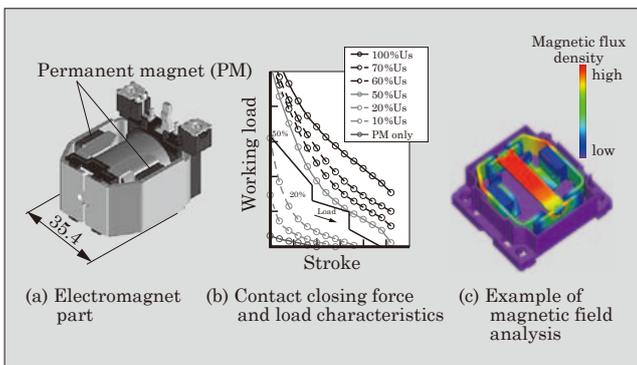


Fig.7 Miniaturization of electromagnet part of electromagnetic switch

er consumption was reduced so that closing operation occurs at 50% of the rated driving voltage of the coil, and release operation occurs at 20% of that rated value so as not to overlap with the polygonal line of contact load force shown in Fig. 7(b). For this purpose, electromagnetic analysis was used actively in 3D CAD, as is shown in Fig. 7(c).

#### (2) Current-limiting and breaking technology for twin breakers

The twin breaker series that established the industry standard of uniform external dimensions for molded-case circuit breakers and earth leakage circuit breakers was the result of accumulated technology development for smaller size and higher breaking capacity. By way of the L type, the first to be released onto the market, through the “EA and SA Series” that incorporate the current-limiting and breaking characteristics shown in Fig. 8 into a compact size, Fuji Electric has developed a moving contact turn-over mechanism at breaking time, a blowout magnet, and a method of arc driving control with an opening with 2 contacts subsequent to the twin breaker series. Furthermore, Fuji Electric has additionally developed advanced breaking technology such as arc gas flow control and a fork-type dual contact breaking (see Fig. 9). These technology developments are paying dividends and have led to the commercialization of the latest G-TWIN Breakers.

#### (3) Original technology in manufacturing and production

Fuji Electric has exercised its ingenuity to focus on the bonding of dissimilar metal materials. For example, the development of brazing technology using a press to crimp a thin copper plate while being heated and a technology for diffusion bonding have resulted in reduced silver usage and increased the reliability of metal bonding (see Fig. 10). In particular, as a result of the new diffusion bonding technology, instead of the former method in which brazing filler was placed between the silver alloy contact of an electromagnetic switch or the like and a contact plate made of copper material and then these two components were bonded

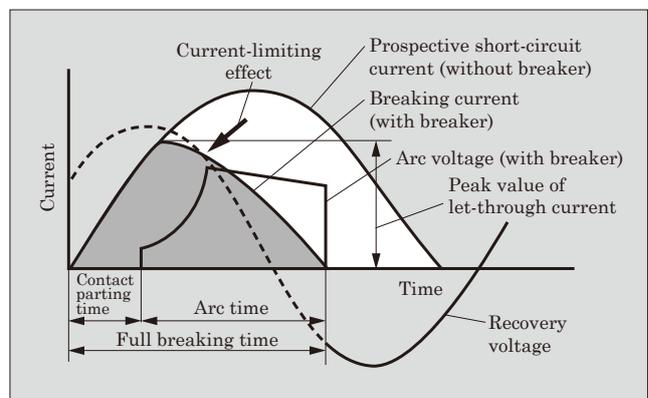


Fig.8 Current-limiting breaking characteristics for high breaking capacity

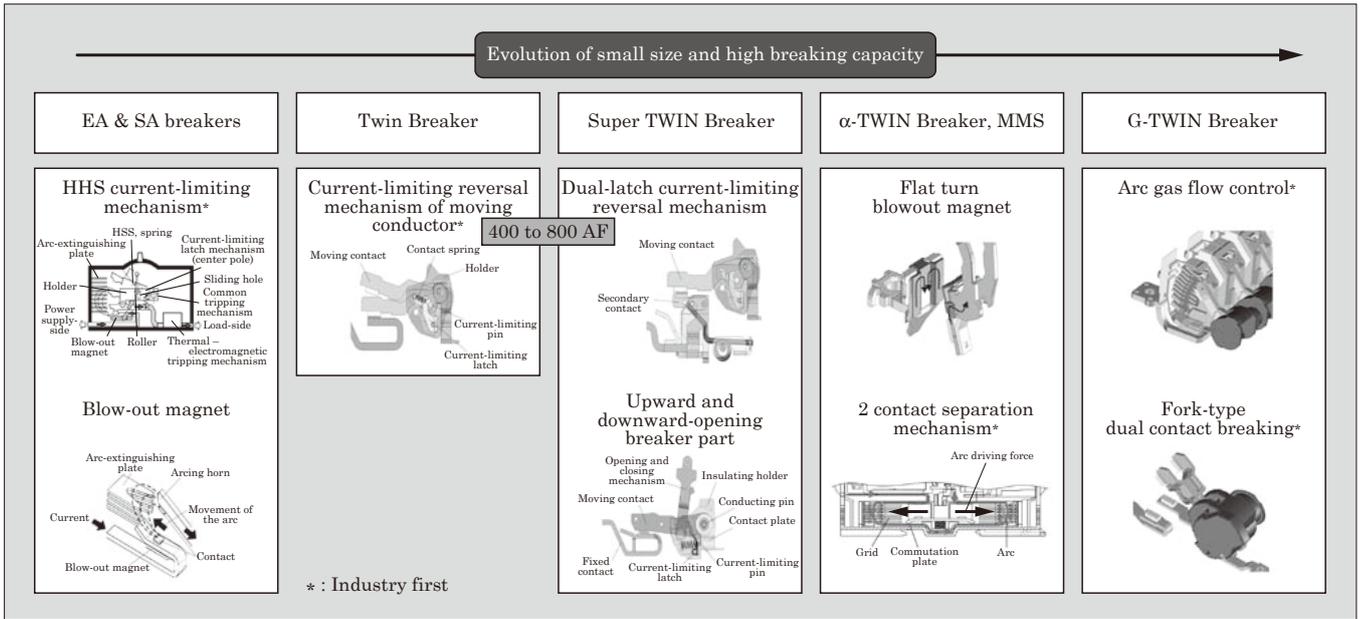


Fig.9 Technical development for higher breaking capacity of molded-case circuit breakers

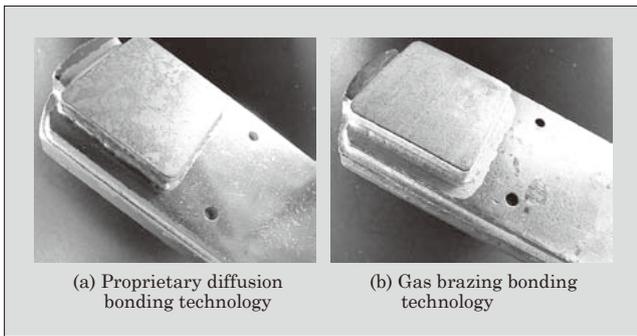


Fig.10 Examples of contact bonding in electromagnetic switch

together by gas brazing, the two components are now bonded together directly by applying the eutectic reaction of Ag and Cu, without using brazing filler.

In terms of original bonding technology, Fuji Electric has continued to advance technology development over a significantly long time, and has increased long-term reliability by improving its technology. For example, at the isolation valve where a contact electrode, which is an essential part of a vacuum breaker, is in a vacuum, ceramic and metal materials that have different rates of thermal expansion are bonded together using brazing technology through a metallization layer.

In terms of high-precision manufacturing and production technology, a method of tie bar processing was adopted for the contacts in an operation display device, and this advanced processing method has been continued through to the present. At the processing stage, metal strips for precision parts such as precision mechanisms that require micron-level dimensional accuracy are continuously tied together and then cut off just prior to assembly stage to realize automated assembly

with a high level of positional accuracy.

#### 4. The Cultivation of New Fields and New Markets, and Innovative Technology for the Future

In a “3-year rolling plan” that aims to cultivate new markets, Fuji Electric has announced its intention to focus development on DC high-voltage devices for use in new energy applications and in the field of data centers (see Fig. 11).

As a precursor, circuit breakers for DC high-voltage circuits in large-scale photovoltaic power generation equipment (mega solar) have been developed (see Fig. 12). Despite having the same external shape as the 400 to 800 AF “G-TWIN Series,” as well as supporting JIS, global standards such as IEC are also supported. Previously, the 600 V DC class was the upper limit, but with Fuji Electric’s newly developed products, applications of up to 750 V DC are supported with 3-pole products, and the high voltage region of up to

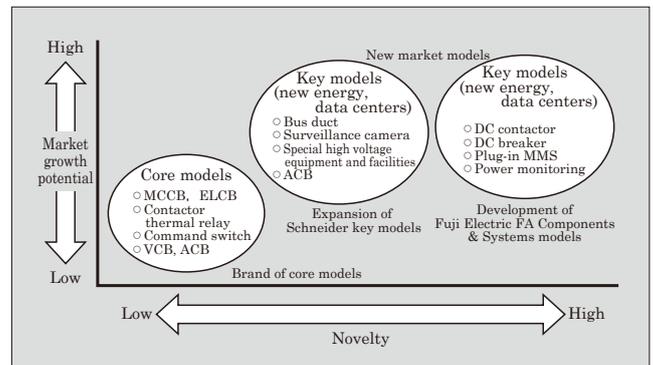


Fig.11 Measures for new fields and new markets (3-year rolling plan)

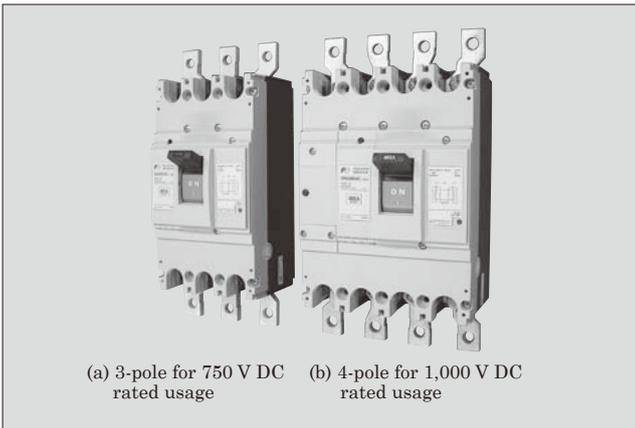


Fig.12 "G-TWIN Series" high-voltage DC breakers

1,000 V DC is supported with 4-pole products. With a DC high-voltage, because there is no current zero point that is in the case of AC and because arcing is continuous in the case of a short gap, breaking will not be possible, and an arc voltage must be generated greater than the power supply voltage established in consideration of the insulation recovery characteristics. In Fuji Electric's newly developed products, a combined method of arc gas flow control in the aforementioned arc-extinguishing part and the use of a permanent magnet for arc driving were adopted. In order to achieve the contact opening with a short gap in high-voltage DC breaking, the electromagnetic field analysis used in the development of the mini contactor SK Series was applied to control arc driving effectively and realize miniaturization.

In the future, the need for compact electric distribution and control devices that is capable of high-voltage DC breaking at voltages above 1,000 V is expected to increase. One conceivable approach is a configuration of hybrid breaking principles that combines semiconductors and electrical switching devices. Another example is DC breaking with a sealed chamber into which an electrode has been inserted in an airtight container, such as the vacuum valve of a vacuum breaker, that not only has been miniaturized and placed in a vacuum, but in which a gas other than air has been sealed and gas flow control is improved at the time of breaking.

Figure 13 shows the principles of high-voltage DC breaking in a gas-filled environment inside a chamber. The development of technology for an instantaneous arc voltage followed by stable insulation recovery is

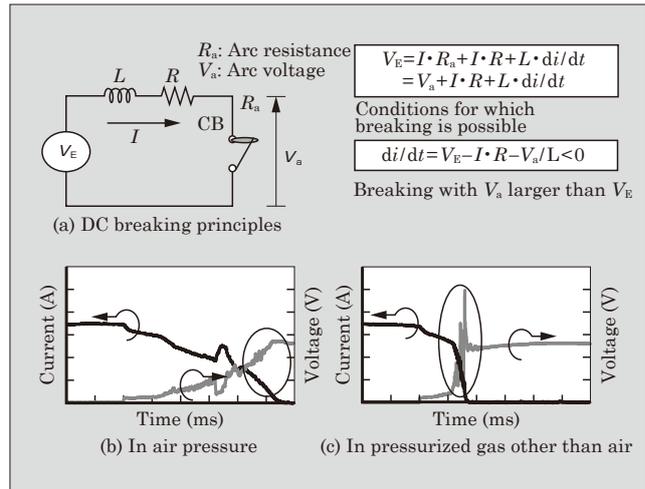


Fig.13 Basic study of high-voltage DC breaking

thought to hold the key for DC applications of the next generation of electric distribution and control devices.

## 5. Postscript

The history and trends of electric distribution and control devices have been categorized above. General-purpose equipment for industrial applications may lack the flashiness of consumer products such as consumer electronics, but plays an important role in supporting safe and secure public infrastructure. Fuji Electric has a nearly 60-year history of electrical switching device development, and has built a trusted brand. In the future, aiming for the realization of non-contact hybrid electrical switching devices such as arc-free AC switches or breakers, Fuji Electric shall move forward on a firm foundation of fundamental technology while embracing the notion of making dreams become real in future product development. With a renewed vigor for establishing future energy and environmental technology, Fuji Electric intends to push forward with new distinctive technology development and to contribute to the development of an affluent society.

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# Interruption Technology of Breakers for High-voltage Direct Current

MORIAI Hiroshi †

## ABSTRACT

Applications for direct current (DC) electric distribution have been spreading along with the increase of data centers and renewable energy facilities such as photovoltaic power generation. Fuji Electric has been expanding the application scope of DC circuit specified breakers to meet such market trend. This time, we developed breakers for high-voltage DC (750 V DC, 1,000 V DC) used in the power conditioners of photovoltaic power facilities. By verifying the arc voltage using interruption simulation and interruption testing, and by verifying the magnetic arc drive using magnetic field analysis and interruption testing, we optimized the structure of the arc-extinguishing chamber and achieved a better level of interruption stability at higher voltage than existing products.

## 1. Introduction

In recent years, as a result of a heightened awareness of energy issues and as a step toward reducing CO<sub>2</sub> emissions to prevent global warming, solar power has been attracting attention as a renewable energy source. With release of the G-TWIN Series of global twin breakers in 2009, Fuji Electric has expanded the application range of breakers including switches for DC circuits. In industrial-use solar power facility, according to system capacity increase, system voltage is getting higher in order to improve the energy utilization efficiency and reduce cost. In response to such requests toward higher voltage, DC high-voltage breakers (750 V DC, 1,000 V DC) have been developed.

This paper presents an example application of a DC breaker to a photovoltaic power plant and describes the main specifications, features, product lineup and elemental technology of DC high-voltage breakers.

## 2. Application of Breaker to Photovoltaic Power Plant

Figure 1 shows a typical photovoltaic power facility. From a photovoltaic cell array, a junction box, power conditioner (PCS) and a distribution panel are connected sequentially to configure the facility. The use of a breaker and switch in each block is described below.

### 2.1 Junction box

As shown in Fig. 2, DC power generated by the photovoltaic cell array is collected in the junction box, and sent to the power conditioner. The junction box minimizes the area affected by failure of the photovol-

taic cell array, and isolates and insulates circuitry in order to ensure worker safety at the time of maintenance and inspection. The junction box uses a breaker or switch that has the capability to disconnect the DC voltage of the photovoltaic cell and interrupt the operating current and short-circuit current.

### 2.2 Power conditioner

The power conditioner receives the DC power from the junction box, and converts the power into AC power with its inverter. A grid-connected power conditioner uses a DC breaker at the junction box side (input side) and an AC breaker at the distribution panel side (output side). According to IEC 60364-7-712, the installation of a switch at the input side is required in order to ensure worker safety at the time of maintenance and inspection, and in Japan, a DC breaker is typically

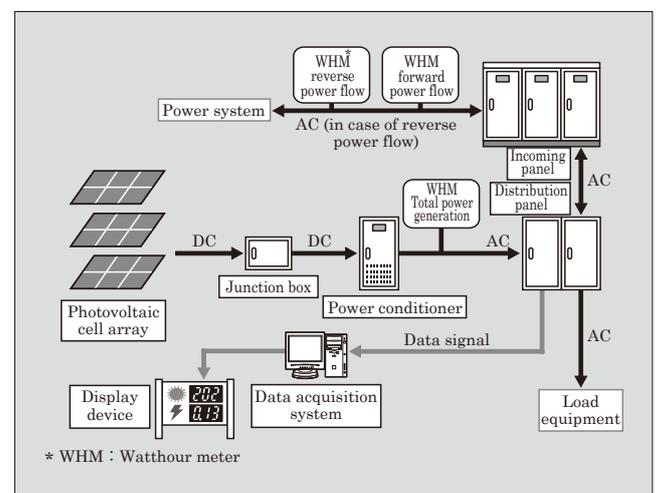


Fig.1 Block diagram of photovoltaic power facility

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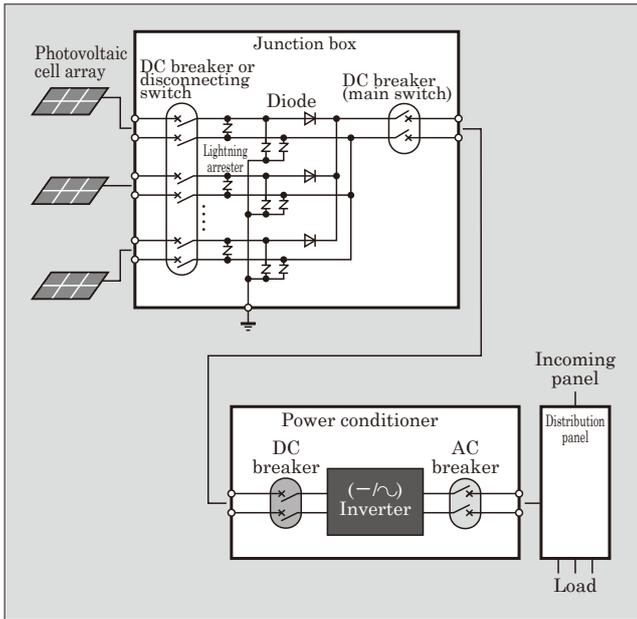


Fig.2 Circuit diagram of junction box and power conditioner

used for this purpose. As a result of the capacity increase of photovoltaic power systems, DC breakers capable of handling higher voltages and larger currents (750 V DC, 1,000 V DC) than ever before are being requested.

### 2.3 Distribution panel

The distribution panel receives the power that has been converted into AC power by the power conditioner, and distributes it to various electrical loads in a building. The distribution panel also forms a coupling point between the photovoltaic power system and the commercial power supply system from the incoming panel. An earth leakage breaker installed at the input

from the power conditioner for photovoltaic power generation can be connected by either a connection method A (see Fig. 3(a)) to the primary side of the distribution panel, or a connection method B (see Fig. 3(b)) to the load side. The connection method is determined as follows, in accordance with the grid interconnection code and indoor wiring regulations.

#### (a) Connection method A

- Earth leakage breaker for photovoltaic power generation-use: Earth leakage breaker with overcurrent protection, model 3P3E or 3P2E, compatible with reverse connections, equipped with neutral line phase loss protection
- Main earth leakage circuit breaker: Earth leak-

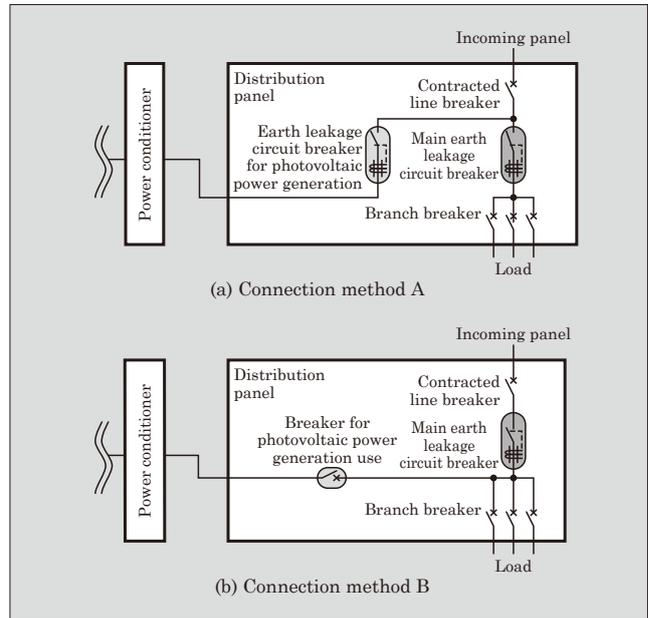


Fig.3 Distribution panel connection methods

Table 1 Breaker and switch specifications

#### (1) Breaker specifications

Frame size (AF)	400		630		800			
Basic type	BW400RAG		BW630RAG		BW800RAG			
No. of poles	3P	4P	3P	4P	3P	4P		
Rated insulation voltage $U_i$ (DC V)	750	1,000	750	1,000	750	1,000		
Rated impulse withstand voltage $U_{imp}$ (kV)	8							
Rated current (A)	250, 300, 350, 400		500, 600, 630		700, 800			
Rated breaking (kA) $I_{cu} / I_{cs}$	JIS IEC/EN	DC1,000 V	-	5/5	-	5/5	-	5/5
		DC750 V	10/5	10/5	10/5	10/5	10/5	10/5
Overcurrent tripping device	Thermal-magnetic type							

#### (2) Switch specifications

Frame size (AF)	400		630		800	
Basic type	BW400RAS		BW630RAS		BW800RAS	
No. of poles	3P	4P	3P	4P	3P	4P
Rated insulation voltage $U_i$ (DC V)	750	1,000	750	1,000	750	1,000
Rated impulse withstand voltage $U_{imp}$ (kV)	8					
Rated current (A)	400		630		800	
Rated short-time withstand current $I_{cw}$	5 kA · 0.3 s		10 kA · 0.3 s		10 kA · 0.3 s	

- age breaker with overcurrent protection, model 3P3E, with neutral line phase loss protection
- (b) Connection method B
  - Breaker for photovoltaic power generation use: Molded-case circuit breaker, model 3P3E or 3P2E, compatible with reverse connections, equipped with neutral line phase loss protection
  - Main earth leakage circuit breaker: Earth leakage breaker with overcurrent protection, model 3P3E, compatible with reverse connection, equipped with neutral line phase loss protection

### 3. Specifications, Features and Lineup of DC High-Voltage Breakers

#### (1) Specification and features

Table 1 lists specifications of the 750 V DC and 1,000 V DC breakers and switches required for use in the power conditioners at photovoltaic power generating facilities.

The main features are as follows.

- (a) In consideration of using environments of the breakers, tropical and cold climate specifications were developed for standard products.
- (b) The same basic structure was shared with that of the G-TWIN 400 AF, 630 AF and 800 AF, with common options (auxiliary switch, alarm switch, shunt trip device, undervoltage trip device, etc.)
- (c) Supports Japanese and foreign standards (JIS, IEC, EN (CE marking))
- (d) Product series consists of 4 types of breakers

Table 2 List of breaker and switch models

#### (1) List of breaker models (DC250 to 1,000 V)

Rated DC voltage (V)	Connection method	Rated current (A)																		Breaking capacity $I_{cu}$ (kA)
		5	10	15	32	40	50	63	80	100	125	160	200	250	300	350	400	500	600	
250	2 poles	BW32□AG-BW800□AG C2																		2.5 to 40
400	3 poles	BW32□AG-BW100□AG C4									2.5 to 5									2.5 to 5
500	3 poles	BW50SAG, BW100EAG (-02014, -02025), BW125□AG-BW800□AG-C5																		6 to 40
600	4 poles	BW125RAG C6 to BW800□AG-C6																		25 to 40
750*	3 poles	BW400RAG to BW800RAG C8, D8																		10
1,000*	4 poles	BW400RAG to BW800RAG C9, D9																		5

\* : Expanded range

#### (2) List of switches (DC250 to 1,000 V)

Rated DC voltage (V)	Connection method	Rated current (A)										Breaking capacity $I_{cu}$ (kA)
		30	40	50	63	100	125	250	400	630	800	
250	2 poles	BW32□AS to-BW800□AS										-
400	3 poles	BW32□AS to-BW100□AS										-
500	3 poles	BW50SAS		BW100EAS		BW125□AS to BW800□AS C5						-
600	4 poles	BW125RAS to BW800RAS C6										-
650	3 poles	BW50SAS										-
750*	3 poles	BW400RAS to BW800RAS C8, D8										-
1,000*	4 poles	BW400RAS to BW800RAS C9, D9										-

\* : Expanded range

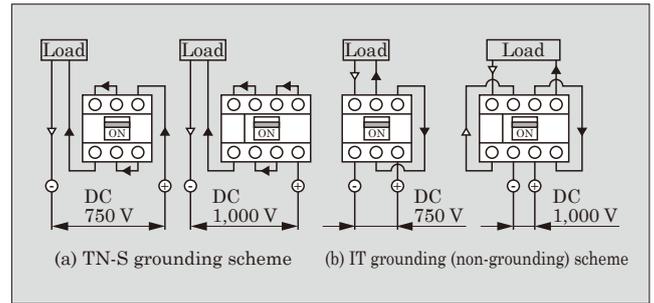


Fig.4 Grounding scheme and connection

for 750 V DC-use and 1,000V DC-use, supports a TN-S grounding scheme and an IT grounding (non-grounding) scheme (see Fig. 4).

#### (2) Lineup

Fuji Electric has continuously responded to user requests by developing a series of 30 to 800 AF switches and by expanding its lineup of 650 V DC small switches and parallel connection breakers for use in photovoltaic power generating equipment to contribute to higher applicable voltages and smaller panel sizes.

The lineup of 750 V DC and 1,000 V DC breakers, which are required for use in power conditioners, has been added to the series as a result of the development described herein. The expanded applicability of breakers is as shown in Table 2.

### 4. Elemental Technologies

#### 4.1 DC breaker technology

If short-circuit current flows through a breaker as

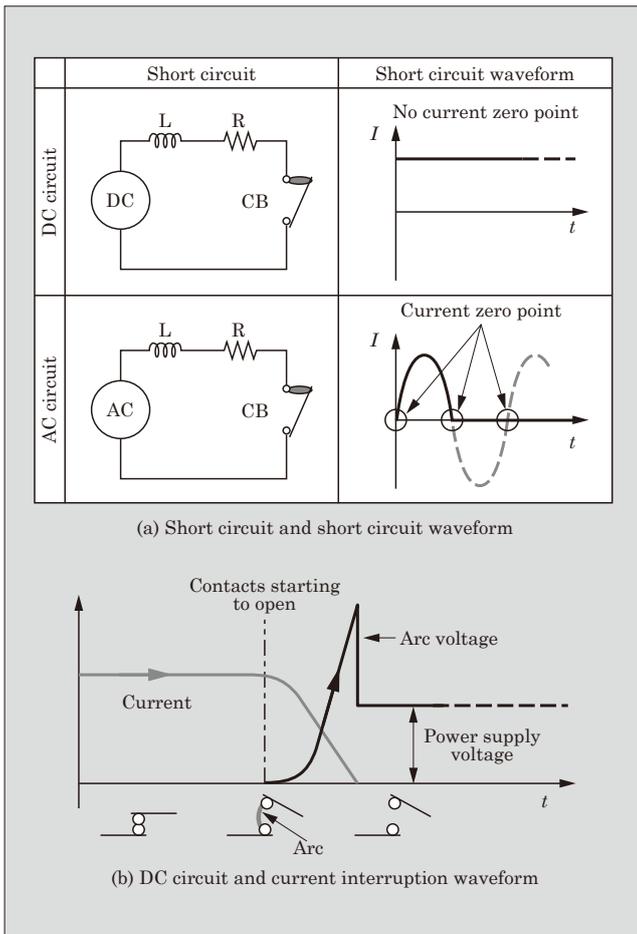


Fig.5 Current breaking and arc voltage

a result of a short-circuit accident, an internal current sensing device activates the switching mechanism of the breaker, the moving conductor moves to its open position, and a current breaking arc is generated between the movable and the fixed contacts. By driving the arc to an extinguishing grid, the arc voltage between the movable contact and fixed contact increases, then it makes the circuit impedance high instantaneously, and the short-circuit current is interrupted.

Generally, in an AC circuit, a current zero point exists periodically, and if the internal insulation can be ensured at the zero point, the current can be interrupted. With a DC circuit, however, the aforementioned zero point does not exist. Thus, for breakers used in DC circuits, technology is needed to interrupt the current (create a zero point) by making the arc voltage between contacts higher than the power supply voltage (see Fig. 5)<sup>(1)</sup>.

#### 4.2 Verification of arc voltage

The main factors that determine the arc voltage are the opening speed of the moving conductor, the contact opening distance, ablation effect, number of grids, and the arc driving force. To achieve both economic efficiency and good breaking performance, use of the existing structure for the opening mechanism,

as well as optimization of the number of grids and enhancement of the arc driving force were targeted. In conventional DC breakers, the maximum value of rated voltage had been 500 V DC for a 3-pole device and 600 V DC for a 4-pole device, and then it reveals an arc voltage of about 170 V or higher per pole by a simple calculation. However, to provide breaking performance of 750 V DC with a 3-pole device and 1,000 V DC with a 4-pole device, an arc voltage of at least 250 V per pole is necessary.

To estimate the actual value of arc voltage per one pole of a DC breaker, the arc voltage was investigated using an interruption simulator. The analysis showed that arc voltage values reached the vicinity of 1,000 V; however, because an arc voltage of at least 250 V per pole was not achieved, the number of extinguishing grids were increased, and the layout and shape were optimized so that the arc could be efficiently guided toward the grid within the limited range of the contact opening distance. The results of interruption testing with an actual device showed that while interruption can be achieved in the short-circuit current region, the arc is not driven to an arc extinguishing chamber grid and the interruption was unstable in the small current region of 100 A and below. Consequently, improvements have been made so that stable interrupting performance can be attained even in the small current region (see Fig. 6).

The results of the investigation with an interruption simulator are as follows.

- Analysis condition: 1,000 V/20 A DC, 2 ms time constant
- Analysis model: BW800RAG-4P (10 extinguishing grids)
- Analysis results:
  - Arc voltage 241 V/1 pole,
  - 964 V/4 poles < 1,000 V

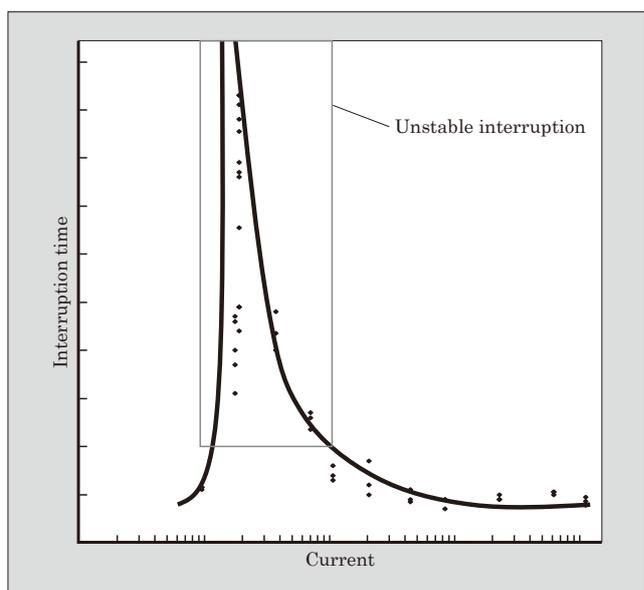


Fig.6 GT800AF DC500 V/2 DC interruption results

### 4.3 Arc driving in small current region

Figure 7(a) shows the relationship of the arc between contacts with the structure of the extinguishing grid, the moving conductor, the moving contact and fixed contact in a existing breaker.

Generally, as a result of the Lorentz force, the arc driving force increases as the current increases. In the small current region, an arc driving force is insufficient to guide the arc to an extinguishing grid. Accordingly, an arc voltage does not rise sufficiently, thereby causing unstable interruption.

Fuji Electric possesses various elemental technologies for DC current interruption. As one of them, the method in which a permanent magnet is installed inside the DC breaker unit was adopted for the basic structure.

To the existing arc extinguishing chamber, a function forcing a magnetic field using a permanent magnet was added to obtain an arc driving force, and the number of arc extinguishing grids was increased from 10 to 12 grids (see Fig. 7(b)). Using such a basic structure, the magnetic flux density and grid shape, as well as the positional relationship of components such as the permanent magnet were used as variable parameters to pursue optimization.

### 4.4 Magnetic field analysis

The arc-extinguishing grid, permanent magnet, moving conductor, moving contact, fixed contact and arc were modeled in three dimensions, and a vector

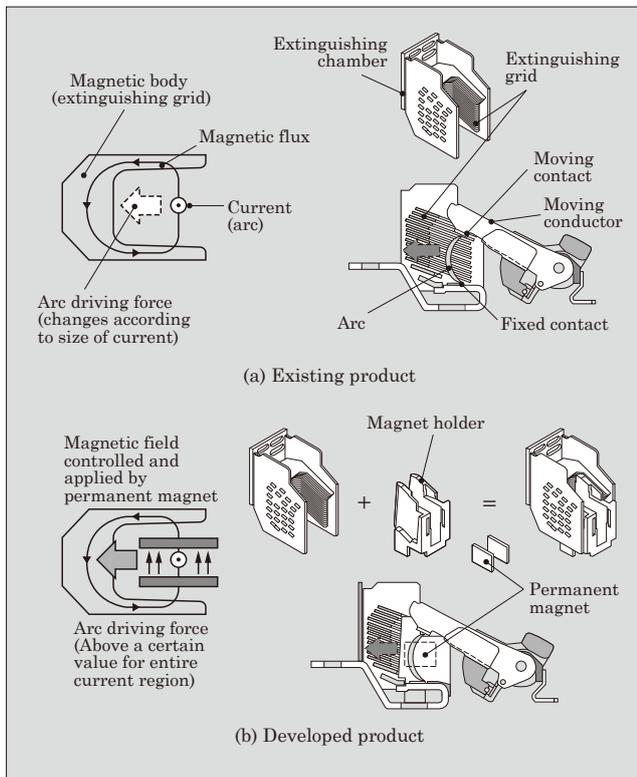


Fig.7 Basic structure of breaker

diagram of the magnetic flux density and the driving force (Lorentz force) that acts on the arc are calculated by magnetic field analysis. The structure of the arc-extinguishing chamber was determined based on the analysis results, and the interruption effect was verified by an interruption evaluation test. Additionally, the breaker actually used in the interruption test was disassembled, and the wear condition of the arc-extinguishing grid, moving contact and fixed contact, as well as the existence of arc marks were checked, and by providing feedback about the shape and positional relationship to the three-dimensional model for analysis, the structure was optimized while adjusting consistency between the analysis results and the interruption test results (see Fig. 8).

Figure 9 shows the state of the arc-extinguishing chamber after the interruption test. The actual arc diameter and path can be estimated based on observation of the arc marks. In the final structure, based

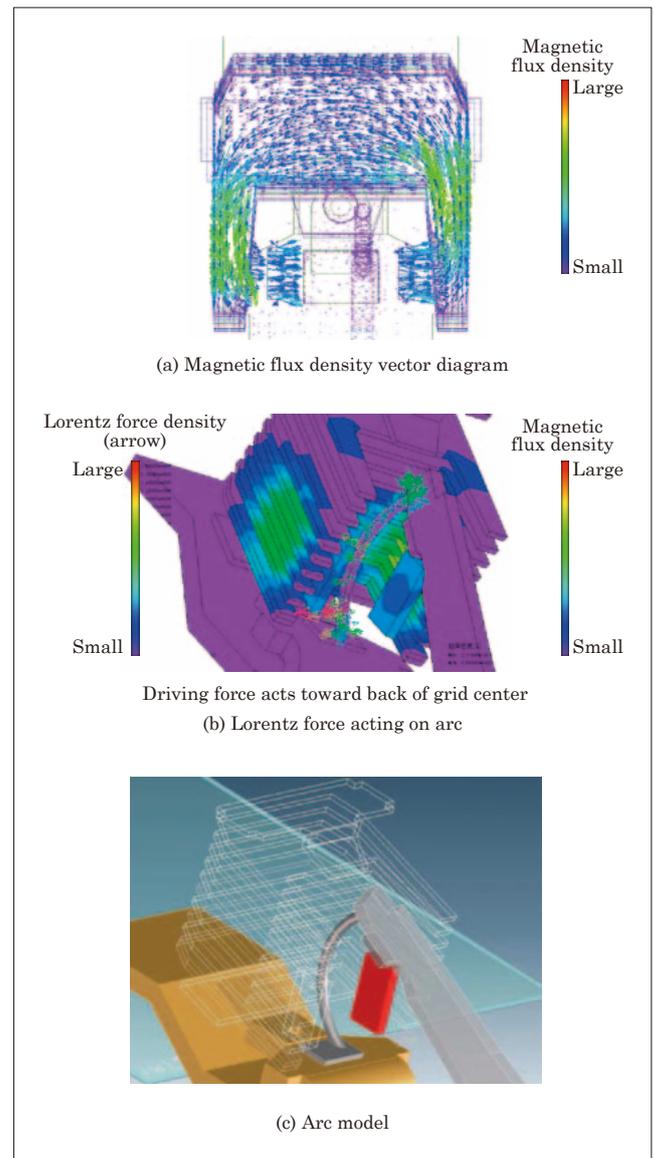


Fig.8 Analysis of magnetic flux density and Lorentz force

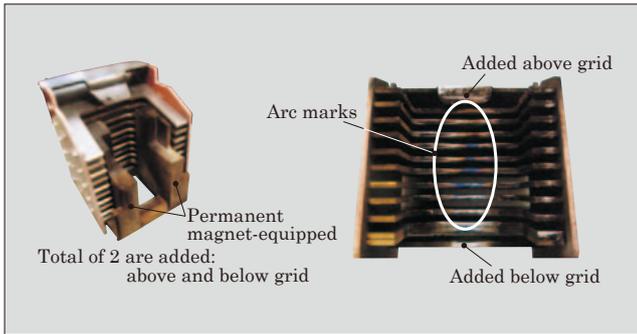


Fig.9 Status of arc-extinguishing chamber after interruption test

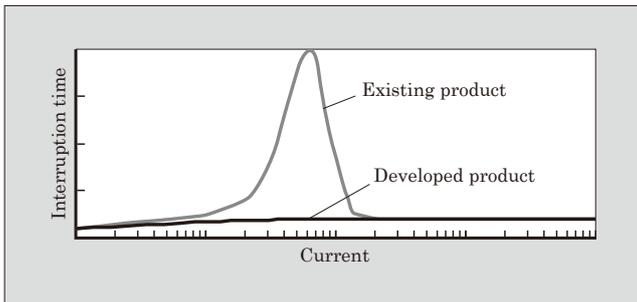


Fig.10 Results of all-area interruption

upon the magnetic field analysis results and the interruption test results, the distance between the arc-extinguishing grid with the magnet holder that holds the permanent magnets and the moving contact with moving conductor after opening were optimized.

#### 4.5 Results of interruption performance verification

With the addition of a permanent magnet to the arc-extinguishing chamber and an increase in the number of arc-extinguishing grids, stable interrupting performing is achieved even in the small current region, where interruption had previously been unstable, and interruption has become possible in the range of several amps to 10 kA, thereby ensuring switching safety (see Fig. 10).

With the addition of a permanent magnet, an arc driving force for guiding the arc to the arc-extinguish-

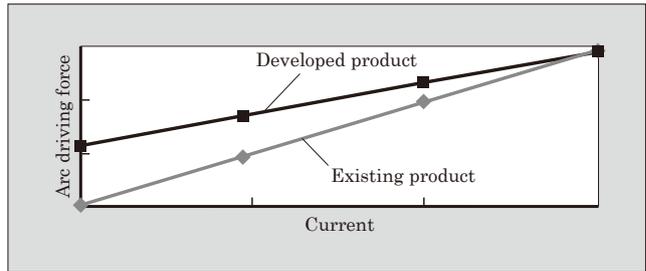


Fig.11 Effect of adding permanent magnet

ing grid can be obtained even in the small current region (see Fig. 11).

Moreover, as the effect of adding two arc-extinguishing grids, a stable arc voltage can be kept from the start until the end of interruption, and arc voltages of at least 250 V for 1 pole and at least 1,000 V for 4 poles were attained. As a result, interruption stability, which was a destabilizing factor in previous products, could be achieved.

## 5. Postscript

This paper has described interruption technology for high-voltage DC breakers suitable for use in large-capacity photovoltaic power generation (mega solar) plants for which future adoption is anticipated.

In the future, requests for a more reliable supply of power and greater safety of DC distribution equipment are expected to increase for new energy generation-related facilities and green data center-related facilities. By accurately assessing marketplace and customer needs, such as for product technologies that support higher voltages and the compliance with and acquisition of international standards and certifications, Fuji Electric intends to advance the research and development of interruption technology for DC breakers.

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# Simulation Technology to Support the Design of Electric Distribution and Control Devices

SAKATA Masayoshi †

## ABSTRACT

Simulation technology for electric distribution and control devices includes structural strength analysis to study case strength, the miniaturization of structural parts, and so forth, and mechanical analysis to improve efficiency of contact switching, handle operation, and so forth. Fuji Electric performs thermal analysis on the case, circuit board, and so on around heat subjects which directly affect the miniaturization of products, and the results are used to optimize the part layout. Other analyses are performed, including electromagnetic field analysis, resin flow analysis, and thermal conduction with electromagnetic field interaction analysis. It is currently possible to determine whether a design satisfies required functionality and specifications using simulations at the concept design stage.

## 1. Introduction

The transition to use of 3-D CAD in the design of electric distribution and control devices has made it possible to estimate at the conceptual design stage many factors such as product performance and cost, and ease of assembly and quality during mass-production. Development has become increasingly front-loaded, and improving the design quality early on in the development process allows the development to move forward without the need for backtracking.

At the conceptual design stage, the determination of the form in which to fabricate a part is highly influenced by accumulated product data and designer experience; however, simulation technology can now be used to determine whether the design satisfies functional and specification requirements. A designer can use a computer to determine whether his or her own ideas are feasible, and then fabricate a prototype.

This paper describes the simulation technology used in the development of electric distribution and control devices.

## 2. Simulation Technology

Electric distribution and control devices encompasses magnetic contactors, thermal relays, molded case circuit breakers (MCCB), earth leakage circuit breakers (ELCB), command switches and the like, which are the devices to switch the connection between equipment and an electric distribution system, or to protect the equipment and wiring from overcurrents. These devices have a mechanism for mechanically opening and closing contacts, and the attractive force of an electromagnet or the cumulative force of a spring

is used as the driving force of the opening and closing mechanism. Simulation technology is effective for verifying the opening and closing mechanism and the driving force.

### 2.1 Contactors

For contactors, lower power consumption for driving and smaller size, as well as longer service life of the switching contacts are required. To develop mechanisms that satisfy these requirements, Fuji Electric has been studying using simulations (see Fig. 1).

The electromagnetic force that drives a contactor can be predicted by electromagnetic field analysis. The electromagnet is designed in consideration of the balance between coil power consumption and current with the electromagnetic force. From coupled analysis of a vibrating system that includes the electromagnetic force and the contacts, the contact bounce in a transient state and the like can be predicted, and parameters can be examined to reduce the contact bounce.

Because the impact force affects the contacts when

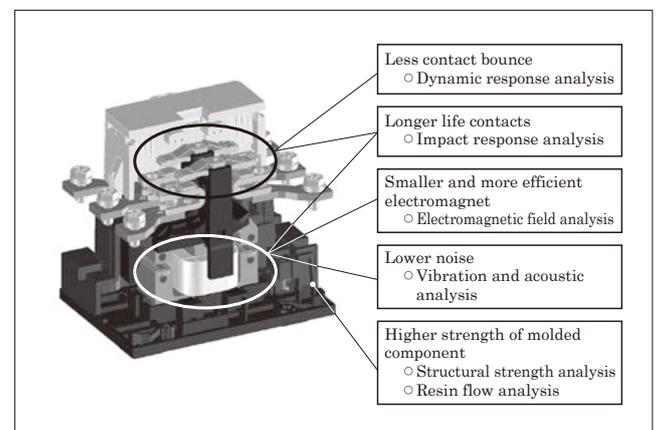


Fig.1 Simulation technology in contactor design

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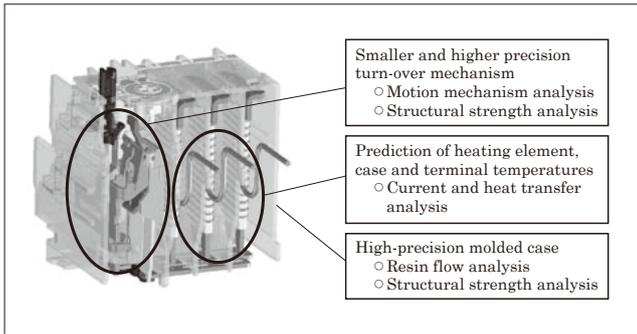


Fig.2 Simulation technology in thermal relay design

the core of the electromagnet collide with the end of the contacts, the effect must be known in advance for longer service life of the contacts. The results of these calculations can also be predicted by the aforementioned coupled analysis.

The case strength can be predicted using static and dynamic stress analyses, and by assessing the location of the weld line using resin flow analysis in advance, it can be studied whether the case strength is sufficient.

## 2.2 Thermal relays

Thermal relays are used in combination with contactors to prevent overloading of an electric motor, for example. A mechanical thermal relay is typically configured from a heater element, a bimetallic strip, contacts and so on. If an excessive current flows in the relay, the bimetallic strip gets heated up and bended. By this motion, the contacts will open and close. Figure 2 shows simulation technology which is used in the design of a thermal relay.

In addition to consideration of the heat generated by the heating element in a thermal relay, a coupled analysis of electric current and heat conduction that includes the bimetallic strip and wiring can be performed to predict the temperatures of the bimetallic strip, heating element, case body and terminals.

A key feature of the structural design is an analysis of the snap action mechanism which drives the contacts when the current exceeds a specified value. Structural analysis that includes elastic analysis of spring and contacts enables the operating characteristics to be predicted with higher accuracy.

## 2.3 MCCB and ELCB

Other representative examples of electric distribution and control devices are MCCBs and ELCBs. Figure 3 shows the simulation technology used in the design of these devices.

Because a handle is used to open and close the contacts in a MCCB, a key point of the mechanism design is to transmit accumulated spring energy efficiently to a contact lever. The design must be such that a switching action that complies with the specifications can be accomplished with an appropriate handle operating force, and that the mechanism will fit in a

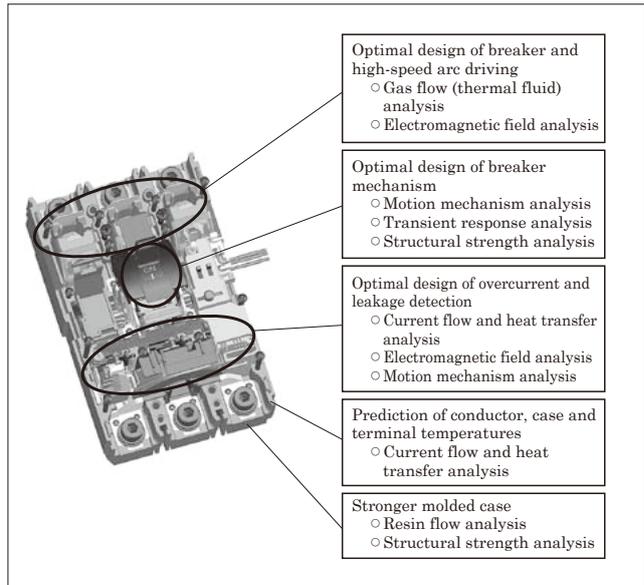


Fig.3 Simulation technology in MCCB and ELCB design

limited space. The use of motion mechanism analysis allows a designer's ideas to be visible immediately and quantitatively, and within the range of normal manufacturing dispersion, parametric design to be performed in consideration of their effect on the switching motion.

MCCBs and ELCBs are equipped with overcurrent protection and/or earth leakage protection functions, and some of them use bimetallic strips as in a thermal relay, or electromagnetic force. Their structure can also be studied by using thermal analysis and electromagnetic field analysis.

The technical challenge for a circuit breaker is to provide a large current breaking function at the time of a short circuit. The rapid transfer of an arc generated between contacts to an arc chamber, and the extinguishing of the arc are important aspects of the design. To assess this phenomenon, the arc motion can be estimated using gas flow analysis and electromagnetic field analysis.

In recent years, DC circuit breaker technology has been actively developed in response to an increasing need for DC electric distribution. In the case of DC circuit breakers, electromagnetic field analysis is used to determine the optimal location and shape of the electromagnet used for moving an arc in the low current region.

## 3. Application Examples

### 3.1 Structural strength analysis

The resin material typically used in electric distribution and control devices differs from steel in that its elastic region is indistinct. Moreover, resin filled with glass fiber exhibits a low level of plastic deformation. A linear-elastic model is sufficient to study strength qualitatively; however, analysis that considers the

elasto-plasticity properties is necessary in order to make a quantitative determination.

The strength can be studied with high accuracy by using values of the mechanical properties of the resin obtained from the results of a tensile test or bend test using a test piece.

Figure 4 reproduces the test piece tensile test by simulation. Simulations now allow such study to continue up until reaching material fracture.

Figure 5 shows an example of the stress analysis of a molded case at the time of a MCCB short circuit. During a short circuit, arc heat causes the internal pressure increase in the case, and the transient stress condition at the time when the entire case expands as shown in the figure was examined. In addition to MCCBs, this type analysis is also used for contactors.

Figure 6 examines the strength of a miniature contactor terminal cover, assuming the pressure which is generated by arcing at the time of short circuit test-

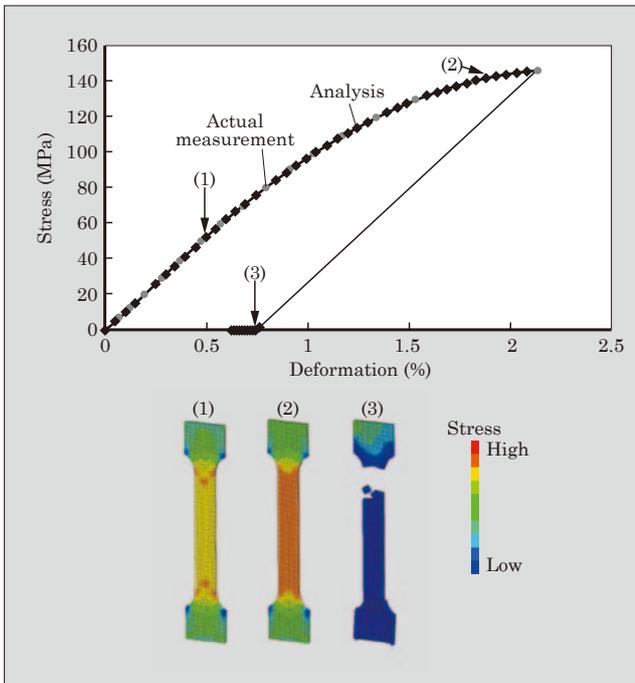


Fig.4 Simulation results of tensile tests

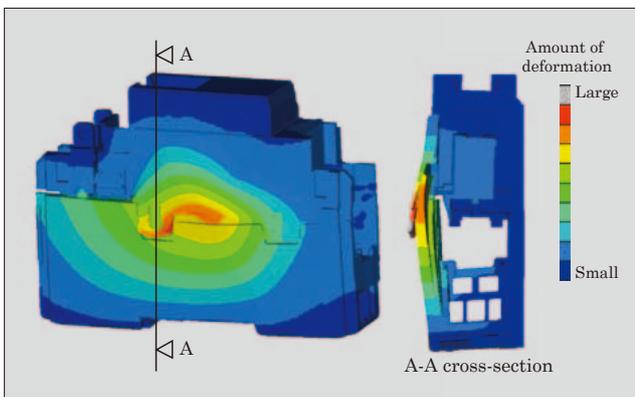


Fig.5 Stress analysis of MCCB at time of short circuit

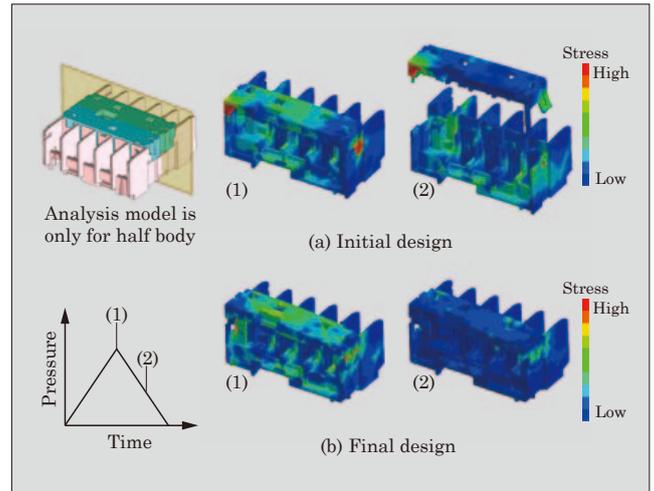


Fig.6 Stress analysis of miniature contactor terminal cover

ing of the mini contactor. For the initial design, it was predicted by simulation that the cover would fly off as the pressure increases. Consequently, the shape of the hook on the cover and the like were reconsidered, and a structure that does not fly off at that pressure was adopted.

Now that elasto-plastic analysis that includes an analysis of transient phenomena is carried out, product design can be implemented with a high degree of accuracy even in the early stages of design.

### 3.2 Motion mechanism analysis

Figure 7 shows analysis models of the contact mechanisms in a multi vacuum circuit breaker (multi-VCB) and a MCCB. Now that motion mechanism analysis is used, necessary parameters for the design, i.e., the handle operating force, contact switching speed, trip load, etc., can be predicted using a PC. Such motion mechanism analysis is also used in the design of shifters and differential mechanisms for thermal relays and the like, as well as in the design of switching mechanisms.

Figure 8 shows a shifter and a differential mechanism of a thermal relay. The thermal relay transmits the amount of bend of a bimetallic strip which has been heated by a heater element to a turn-over mechanism. In the case of overcurrent protection only, the shifter structure serially transmits the amount of bend of the 2-phase bimetallic strip to the turn-over

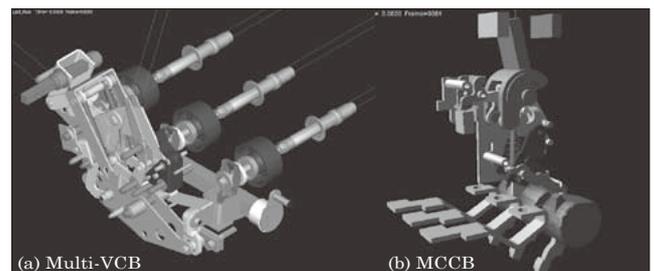


Fig.7 Example of motion mechanism analysis model

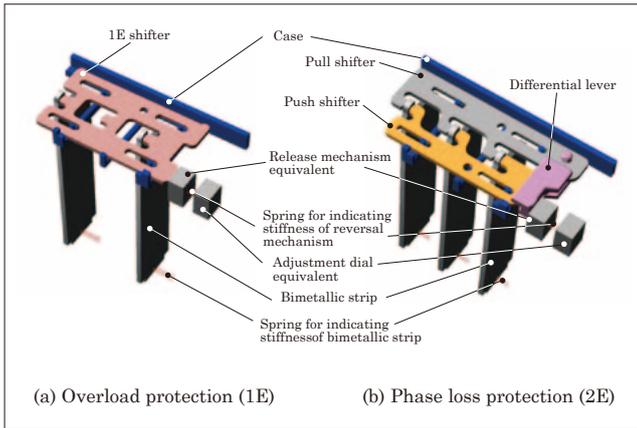


Fig.8 Motion mechanism analysis model of thermal relay unit

structure. On the other hand, in the case of phase-loss protection, because current stops flowing in one of the three phases, the bimetallic strip will be in a non-bend state, and a differential shifter is used to transmit the difference to the turn-over mechanism. The amount of curvature of the bimetallic strip is affected by many parameters including the stiffness of the bimetallic strip itself, the location of support of the shifter, resistance due to friction, the effect of stiffness of the turn-over mechanism, and so on. By using motion mechanism analysis, the part of the shifter causing resistance can be identified visually, thereby enabling the design of a shifter with low dispersion and good efficiency.

Moreover, in the development of thermal relays, the abovementioned motion mechanism analysis can be coupled with the thermal analysis described in section 3.3 to predict characteristics from current input to turn-over motion.

### 3.3 Thermal analysis

The heat sources in electric distribution and control devices include the Joule heat arising from current flow, contact resistance, the heater element, and the like. Because miniaturization directly affects thermal characteristic, the temperature distribution of a product must be known in advance.

Figure 9 shows an example of the thermal analysis

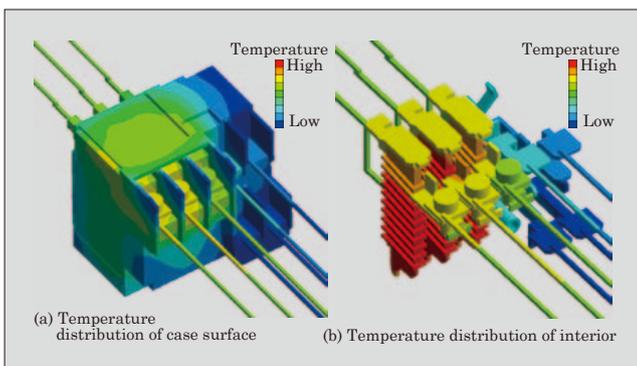


Fig.9 Thermal analysis of thermal relay

of a thermal relay. In products connected to wiring, modeling of the wiring is important since inflows and outflows of heat from the wiring are not negligible. Modeling of this part based upon previous actual measurement data improves the accuracy of prediction.

Through performing thermal analysis, in addition to predicting the temperature distribution of the bimetallic strip itself, the temperature of a compensating bimetallic strip, the terminals and the case can also be predicted. As a result, a determination as to whether the assumed structure is appropriate can be made at the evaluation stage, and development can proceed without redoing.

Many types of electric distribution and control devices contain integrated electronic parts, and thermal analysis is also applied to these various electronic parts. Figure 10 shows an example of thermal analysis carried out for the miniaturization of the printed circuit board of a contactor. The area of the printed circuit board of the new structure has been reduced to approximately 75% of the size the previous product. In miniaturization achieved simply by shrinking the previous layout, the effect on heat sensitive components such as capacitors and varistors would have been a concern. Therefore, thermal analysis was used to predict the temperature distribution and to determine an optimal layout.

### 3.4 Electromagnetic field analysis

Various types of AC and DC electromagnets are used in electric distribution and control devices. At present, small electromagnets that have low loss and high performance can be designed using electromagnetic field analysis. Electromagnetic field analysis is used not only for designing electromagnets, but also for predicting the behavior of tripping devices that sense overcurrents and earth leakage, small transformers for pilot lamps, the electromagnetic repulsion on contacts and arcing that occur when an overcurrent flows, and the like.

Figure 11 shows an example of the electromagnetic analyses performed in consideration of the arcing behavior in a 1,000 V DC-applicable breaker. The placement and size of the electromagnet shown in the initial design results in a weak Lorentz force for driving the

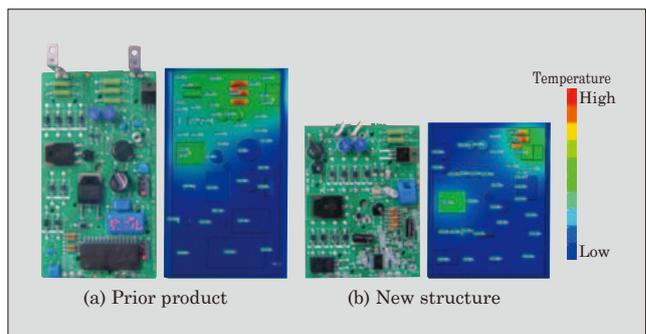


Fig.10 Thermal analysis of printed circuit board

arc; however, the final design clearly shows that a Lorentz force sufficient for driving the arc can be obtained. Accordingly, it has been possible to design low-loss, high-performance electromagnets.

Because a zero point does not exist for the electric current flowing in a DC circuit, the arc generated between contacts must be transferred within a short time to an arc chamber where the arc is stretched and cooled so that the arc voltage gets higher than the power supply voltage, and the current flow is cut off. In the case of a large current, the arc moves as a result of the magnetic field of the arc itself or by gas flow generated by a high-temperature arc; however, in the low voltage region, this effect cannot be expected and therefore the electromagnetic force of a permanent magnet is used.

In the early stage of development of a 1,000 V DC-applicable breaker, a study was carried out using electromagnetic field analysis, and the results have enabled a significant reduction of prototypes fabricated and have shortened the development term.

### 3.5 Resin flow analysis

Because resin material is used in many components employed in electric distribution and control devices, warpage and shrinkage after molding, weld locations and the like must be checked in advance.

Figure 12 shows an example of the crossbar of a low-voltage circuit breaker for which high dimensional accuracy is required. The crossbar is a component that transmits the deformation of a bimetallic strip or solenoid arising from overcurrent or earth leakage sensing to switching mechanism, and requires a certain degree of accuracy that corresponds to the warpage deformation. Because a large deformation after molding was predicted in the initial design, the thickness of the crossbar was equalized to lessen the warpage deformation.

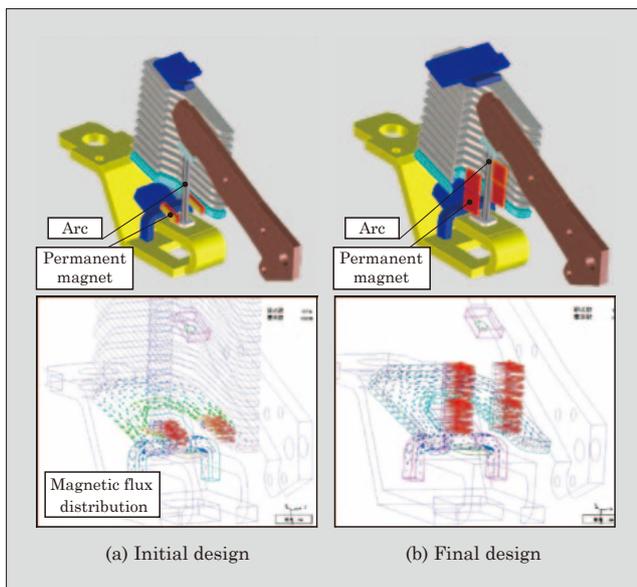


Fig.11 Electromagnetic analysis of MCCB cutoff part

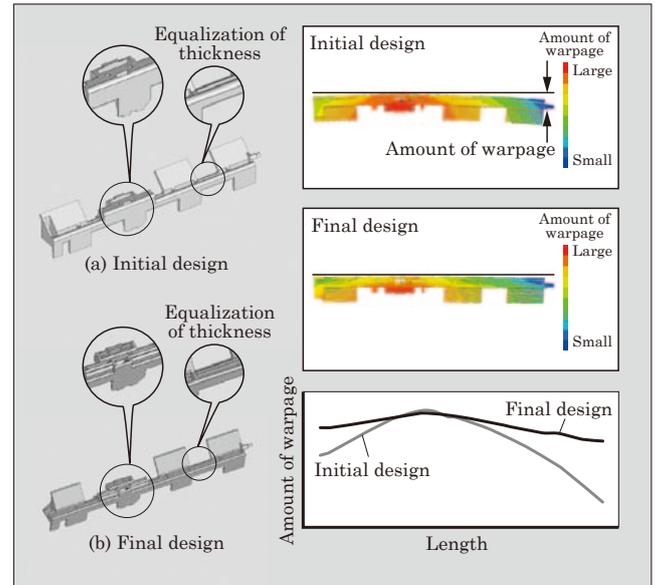


Fig.12 Resin flow analysis of crossbar

tion.

The problems of warpage and shrinkage after molding can be overcome in some cases by changing the gate location or molding conditions, but usually a design change is required. For this reason, performing resin flow analysis at the early stages of the design is important for shortening the development period.

### 3.6 Coupled analysis of thermal flow and electromagnetic fields

For electric distribution and control devices, predicting and controlling the behavior of arcing that occurs when the contacts are opening or closing are important challenges. Fuji Electric has previously responded to these challenges by using thermal fluid analysis of arc ablation and Lorentz force analysis of the arcing based upon electromagnetic field analysis. To increase the accuracy of predictions, Fuji Electric has developed arc behavior simulation technology that

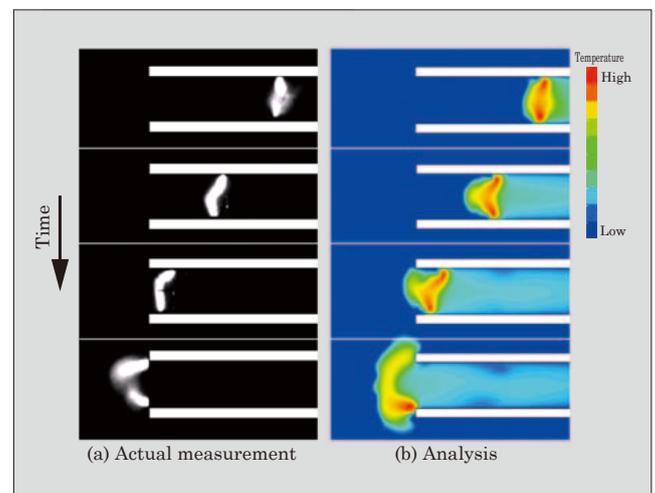


Fig.13 Simulation of arc behavior

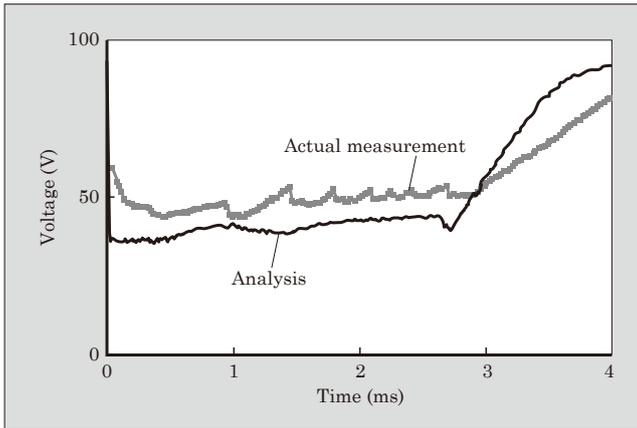


Fig.14 Comparison of arc voltage

couples thermal fluid analysis and electromagnetic field analysis.

Figure 13 is an example, reproduced through simulation, of the arcing behavior of parallel conductors. A current of 100 A is flowed between conductors spaced apart by 10 mm to generate arcing, and the arcing behavior and voltage levels at that time are compared.

Figure 14 compares the analysis and actual measurement values of the arc voltage. By using this analytic technique, the magnetic and electric fields that generate arcing, as well as the gas flow caused by arc heating, can be taken into account and therefore the effect that includes the magnetic field and pressure of the extinguishing chamber, and the influence of an

external magnetic field from a permanent magnet, can also be evaluated.

In the future, after further study, this analytic technique will be applied to actual electrodes.

#### 4. Postscript

Since simulation is a technology built upon a simplification of physical phenomena, it cannot reproduce all actual phenomena. However, in the product design stage, simulation technology is an extremely effective means for quantifying and visualizing the effects of various parameters. Prior to applying this technology as a tool, the physical phenomena that make up the product must be understood and the limits to which verification by simulation is possible must be known.

As a result of the higher level of performance of PCs and more sophisticated pre- and post-processing capabilities, simulation technology that previously could have only be implemented by analysis experts is now readily available for use by designers. In the early stages of development, the ability of designers themselves to run simulations of their own ideas is expected to create to good products.

Based on the data and knowhow acquired to date, Fuji Electric intends to contribute to the fabrication of even higher quality and higher performance products by advancing further the simulation technology available to designers.



# Supplemental Explanation

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## Supplemental explanation 1 EC Directives

EC Directives are enacted by the Council of the European Communities, and are common requirements to the products on the European market to activate European trade economy. Each Member State of the European Union (EU) must change their own country's laws to be consistent with EC Directives. There are wide-ranging directives that apply to all products, as well as directives that target individual products, and the following three types of individual directives

are relevant to electric distribution and control devices.

- (a) Machinery Directive: A directive relating to the safety of machinery
- (b) Electromagnetic Compatibility Directive: A directive relating to electromagnetic compatibility
- (c) Low Voltage Directive: A directive relating to the electrical safety of equipment operating at 50 to 1,000 V AC and 75 to 1,500 V DC

## Supplemental explanation 2 CCC Compulsory Certification

In China, in 1993, under the management of the State Administration for Entry-exit Inspection and Quarantine (SAIQ), the China Commodity Inspection Bureau (CCIB) implemented a product safety certification system (CCIB certification) for imported products such as electric and electronic products. Additionally, in 1994, under the management of the China State Bureau of Quality and Technical Supervision (CSBTS), the China Commission for Conformity Certification of Electrical Equipment (CCEE) implemented a product safety certification system (CCEE certification) for electric and electronic products sold in China. Thus, for electric and electronic products, two systems existed within a single country, and for some products, both CCIB certification and CCEE certification were

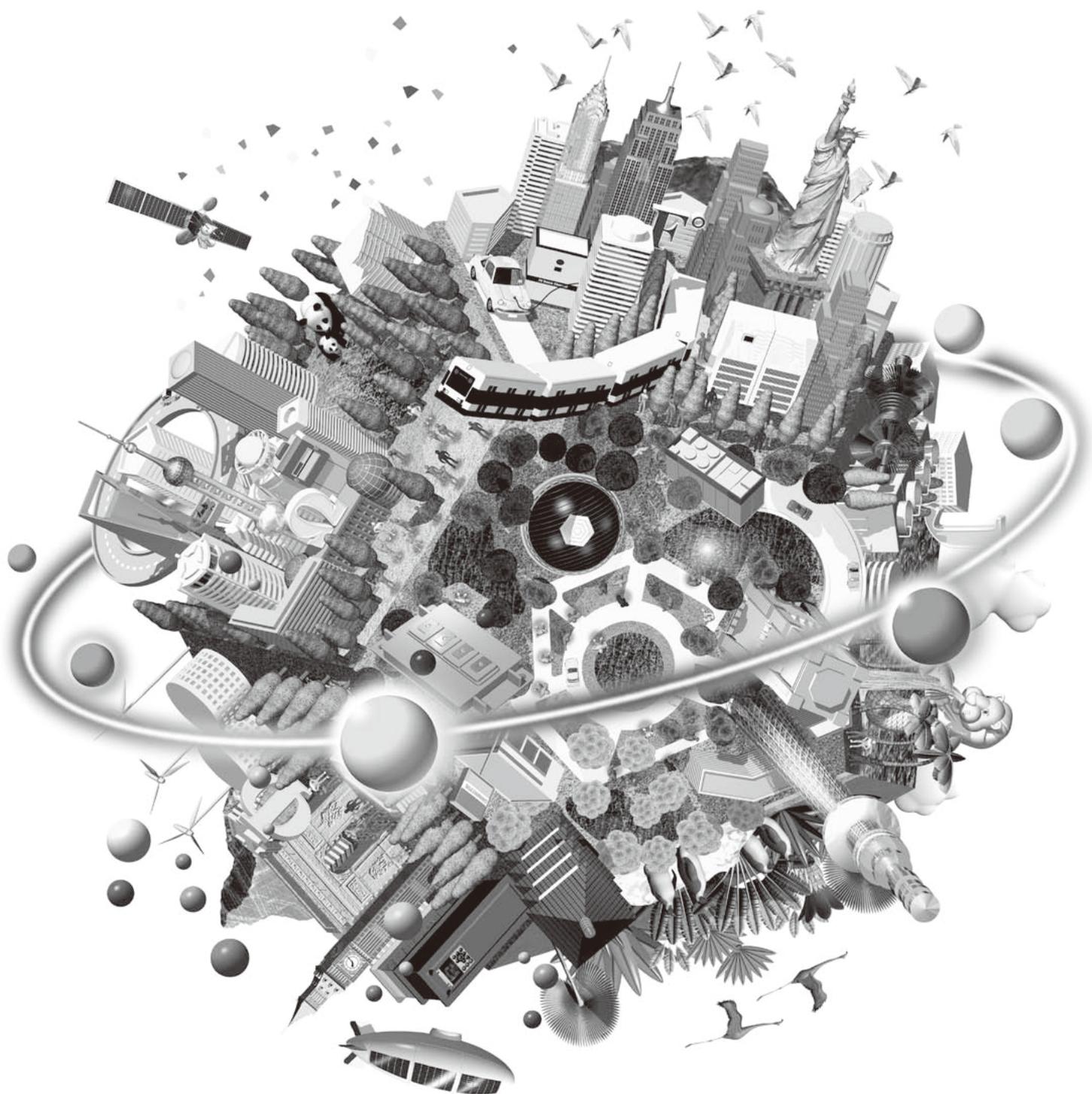
required.

In light of these circumstances, in November 2001, upon officially joining the World Trade Organization (WTO), China unified the two certification systems in accordance with WTO regulations and enacted a new compulsory product safety certification system (CCC: China Compulsory Certification).

The 19 types of products (132 categories) that are targeted for certification are listed in the "Products List for Primary Compulsory Products Certification" published as "Joint Publication No.2001-33 of The General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) and the Certification and Accreditation Administration of China (CNCA)."



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### Fuji Electric France S.A.S

Manufacture and sale of measuring and control devices

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Manufacture of low-voltage circuit breakers

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### Fuji Electric Taiwan Co., Ltd.

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### Fuji Electric (China) Co., Ltd.

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### Fuji Electric (Shenzhen) Co., Ltd.

Manufacture and marketing of photoconductive drums

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### Wuxi Fuji Electric FA Co., Ltd.

Manufacture and marketing of inverters in China

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### Fuji Electric Hong Kong Co., Limited

Sales of semiconductor devices and photoconductors

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### Shanghai Fuji Electric Switchgear Co., Ltd.

Manufacture and sales of switching equipment, monitoring and control appliances and related facilities

Tel +86-21-5718-1234

URL <http://www.csfuji.com/>

### Fuji Electric Motor (Dalian) Co., Ltd.

Manufacture of motors

### Hoei Hong Kong Co., Ltd.

Marketing, installation and repair of electrical machinery, control systems and electronic components

Tel +852-2369-8186

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### Fuji Electric (Changshu) Co., Ltd.

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### Fuji Electric India Pvt.Ltd.

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