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

Katsunori Kuboyama † **Shunsuke Shikano** † **Masashi Tsukihana** †

ABSTRACT

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

1. Introduction

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

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

2 Trends in renewable Energy Usage and Energy Savings

2.1 International and domestic trends

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

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

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

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

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

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

2.2 Photovoltaic power generation system

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

In AC circuits, switching devices ensure the insula-

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

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

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

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

Fig.1 Example configuration of photovoltaic power generation system

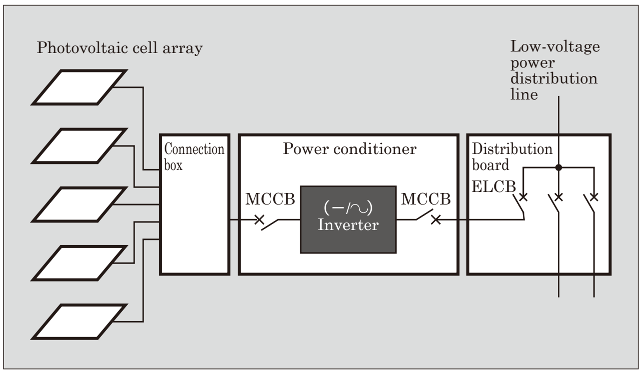
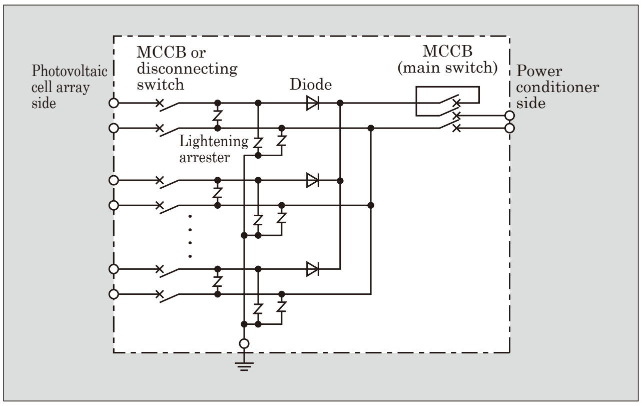


Fig.2 Example of internal circuit diagram and component devices in connection box



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

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

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

Fig.3 Comparison of AC and DC power supply systems

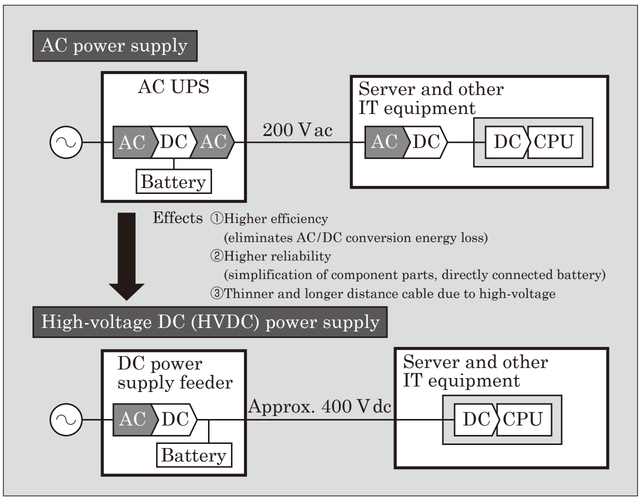


Fig.4 High-voltage DC (HVDC) power supply system diagram

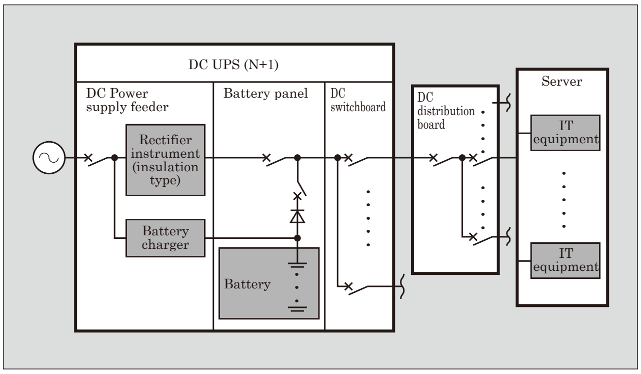


Figure 4 shows an example configuration of a high-voltage DC (HVDC) power supply system. The DC starter normally uses a breaker such as a molded case circuit breaker (MCCB) or miniature circuit breaker (MCB). When selecting equipment, in addition to considering the DC voltage and load current, the DC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

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

3. Application of Low-Voltage Equipment to DC Circuits

3.1 Application of low-voltage breakers to DC circuits

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

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

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

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

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

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

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

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

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

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

Fig.5 "Compact NS Series"

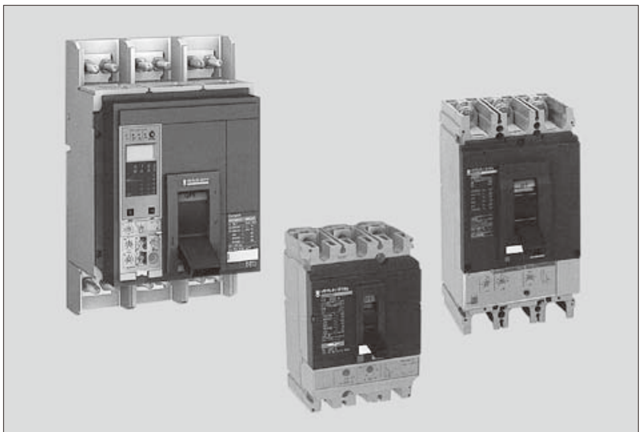
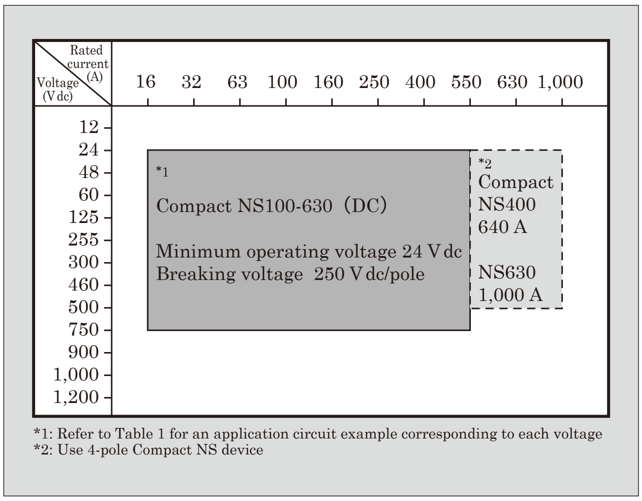


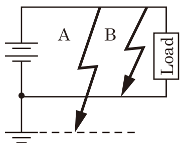
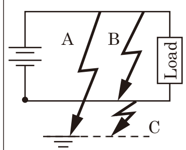
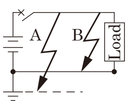
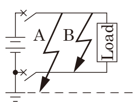
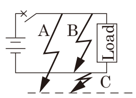
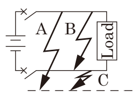
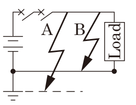
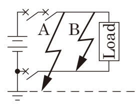
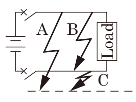
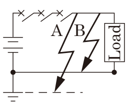
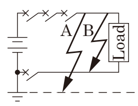
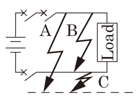
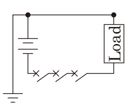
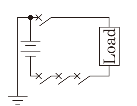
Fig.6 Applicability of "Compact NS Series" to DC circuits



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

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

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

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

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

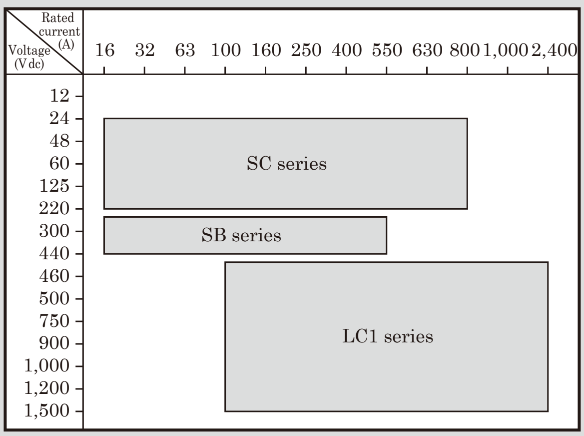
3.3 Revised Energy Conservation Law and power monitoring system trends

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

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

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

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



energy consumption.

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

4.1 Trends in electrical equipment standards

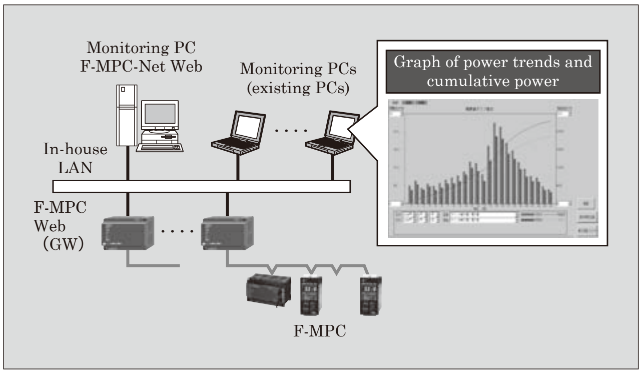
In Japan, conformance with the international standards for low-voltage electrical equipments and the components in use (IEC standards and ISO standards) is progressing rapidly. The "Interpretation of technical standards for electrical equipment" incorporates international standards (IEC 60364), and the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

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

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

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

Fig.8 Example configuration of power monitoring system



4.2 Compliance with SCCR requirements for low-voltage breakers

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

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

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

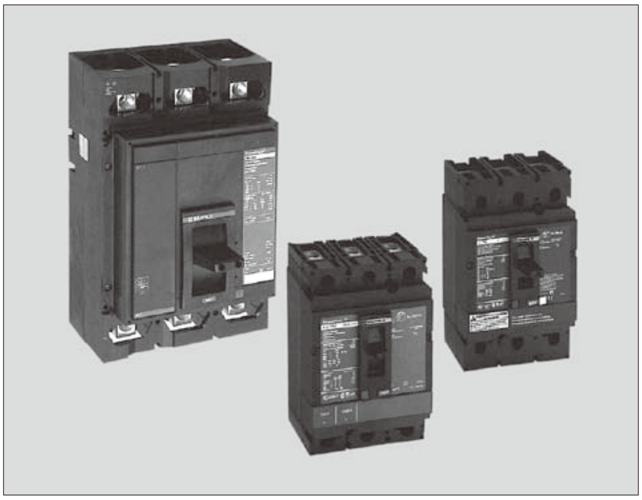
4.3 Machinery safety standard trends and Fuji's approach to equipment

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

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

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

Fig.9 "Power Pact Series"



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

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

5. Postscript

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

References

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

(2) NTT Facilities. "Results of High-voltage DC Power Supply System Verification Tests". NTT Facilities Mail Magazine. 2009-12-15, no.00134.