Product Evaluation of Power Distribution, Switching and Control Equipment Components

MIYAZAWA, Hidekazu* HATA, Junichiro* NUMAGAMI, Takeshi*

ABSTRACT

In the development process for distribution, switching and control equipment components, product evaluations encompassing many items are required to satisfy product specifications and meet market demands. Fuji Electric builds product quality by implementing four kinds of evaluation: a screening evaluation on factors determining product performance, a reliability evaluation in view of a product use environment, an interface evaluation that considers handleability, and a characteristic evaluation based on product standards. With these evaluations, Fuji Electric makes our products meet their specifications to increase customer satisfaction while improving the efficiency of our overall development.

1. Introduction

Fuji Electric's major products for power distribution, switching and control equipment components include magnetic starters, low-voltage circuit breakers, operation indicators (command switches), middle-voltage circuit breakers and power monitoring equipment.

The development of these products requires technologies for breaking low-to-middle voltage currents by opening and closing the circuit in the air or in a vacuum, for operating them manually or remotely with an electromagnet or with an opening and closing mechanism, and for detecting or measuring electric currents. We prepare concept designs based on these technologies and establish the basic structure that satisfies the development-required specifications by using partial prototypes of opening and closing mechanisms, contact blocks or other parts which are the elemental technologies for the products. We then use type test prototypes to evaluate the performance required for the products and elaborate their quality. With mass-production prototypes in the final stage, we establish the quality that ensures stable manufacturing.

This paper explains the product evaluation process that verifies a product's performance while considering quality elaboration and various product usages in the market.

2. Product Evaluation

As globalization progresses, Fuji Electric's power distribution, switching and control equipment components are required to conform to or comply with not only Japanese JIS but also overseas standards such as IEC and UL as shown in Table 1. They need to satisfy multiple standards and obtain standard certifications.

In the development process, product evaluation encompassing the many items shown in Table 2 is required to satisfy product specifications and meet market demands. Fuji Electric elaborates product quality by implementing four kinds of evaluation: a screening evaluation on factors determining product performance, a reliability evaluation in view of a product's use environment, an interface evaluation that considers handleability, and a characteristic evaluation based on product standards.

(1) Screening evaluation on factors determining product performance

In the early stage of development, design factors are screened through simulation or other methods. Selecting optimum materials is especially of great importance. In the prototyping stage, design parameters such as the shape, dimensions and adopted material of the components are evaluated experimentally to determine optimum values that satisfy the target perfor-

Table 1 Japanese and overseas standards for each product

Model	Japan	Overseas	
Magnetic starters	JIS C 8201-4-1	IEC 60947-4-1	UL60947-4-1
Low-voltage circuit breakers	JIS C 8201-2	IEC 60947-2	UL489
Operation indicators (command switches)	JIS C 8201-5-1	IEC 60947-5-1	UL508
	JIS C 8201-5-5	IEC 60947-5-5	
Middle-voltage circuit breakers	JEC-2300	IEC 62271-100	–
Power monitoring equipment	JIS C 1102-□	IEC 61000-□	–
	JIC C 1216	(IEC 255-3)	

* Technology & Manufacturing Group, Fuji Electric FA Components & Systems Co., Ltd.

Table 2 Product evaluation

Item	Evaluation verification technology	Product evaluation standpoint
Operation evaluation	High-speed/high-accuracy measurement technology Visualization technology Automatic measurement technology Mechanism analysis technology Optimization technology (application of quality engineering)	(a) Screening evaluation on factors determining product performance Design control factor parameters that cannot be determined only through design consideration are identified experimentally to determine design values. (b) Reliability evaluation in view of a product's use environment Evaluation is implemented in accordance with the load to be used. Stability is evaluated in the envisaged use environment. (c) Interface evaluation that considers handleability Handleability is tuned based on the understanding of the limits. (d) Characteristic evaluation based on product standards A test method conforming to the standard is used to efficiently confirm that the characteristic values satisfy the acceptable product standard. Product knowledge 
Breaking evaluation	Large current evaluation technology Transient phenomenon analysis technology Arc observation technology DC evaluation technology Magnetic field analysis technology	
Life span evaluation	Prediction technology Actual load simulation circuit technology Accelerated evaluation technology	
Environmental resistance evaluation	Statistics technique application technology Material technology Failure analysis technology	
Current carrying performance evaluation	Thermal analysis technology	
Insulation evaluation	Middle-voltage measurement technology	
Vibration/shock evaluation	Combined evaluation technology	
EMC evaluation	EMC&EMS measurement technology High accuracy measurement technology	
Handleability evaluation	Quantification technology Visualization technology	

mance.

(2) Reliability evaluation in view of a product's use environment

Due to efforts in recent years for renewable energy, efficiency improvement and energy saving, our products have been used in various ways and the adoption of high-energy efficiency equipment and DC equipment is increasing. In order to deal with such diversification, we ensure our products are reliable by understanding their adaptation to customers' equipment or their use environment such as their mounting location and conducting accelerated evaluation considering their age-related degradation.

(3) Interface evaluation that considers handleability

The portions directly operated by worker must be easiest to operate. They also require a fail-safe design providing the strength and safety to withstand every operation imaginable during an emergency. We therefore refer to data on previous usage, evaluate operations with strong force exceeding the recommended value or using tools, and grasp the strength limit values or breakdown process to verify it is fail-safe.

(4) Characteristic evaluation based on product standards

To evaluate mass-production prototypes, we conduct tests to check their characteristics within the range between the minimum and maximum values while taking the drawing tolerance of the design values into account, and confirm that the characteristic values are within the reference values for acceptable products. Since products such as power monitoring equipment must be usable in a wide variety of conditions of customers, we implement tests efficiently to obtain electric energy measurement data in every envisaged combination of those conditions. Moreover, in order to obtain standard certifications, we establish trusting relationships not only with Japanese certification authorities but also with overseas authorities such as the UL and CCC and carry out the evaluation tests faithfully based on those standards.

3. Case Examples of Product Evaluation Tests

3.1 Screening evaluation test on factors determining product performance

(1) Operational and life span evaluation of magnetic contactors

A magnetic contactor roughly consists of a contact opening/closing part and an electromagnet part. The major components that make up the contact opening/closing part are moving contact, fixed contact, contact spring and contact support. The electromagnet part

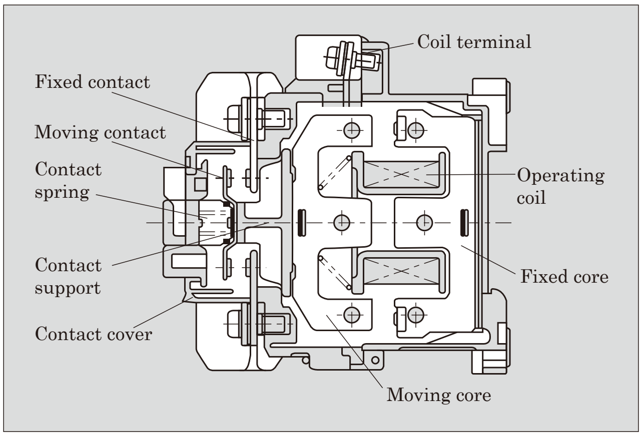


Fig.1 Magnetic contactor components

consists of a moving core, a fixed core and an operating coil, and it is covered with a resin-molded frame part (see Fig. 1).

In a magnetic contactor, when voltage is applied to the operating coil, electric current flows and generates magnetic flux inside the core, and the moving core is attracted to the fixed core. In conjunction with this action, the contact support connected to the moving core moves accordingly, causing contact between the fixed contacts on the frame and the moving contacts, resulting in flow of electric current.

This switching action is conducted at high speed of about 10 to 20 ms. We therefore utilize an optical displacement meter and a high-speed camera that can visualize movement to evaluate the operation accurately and check for problems with the optimization of the spring load to allow stable contact making and with the connection shape of the contact support and moving core. As for the AC power supply, we implement efficient evaluation by changing the phase of the voltage applied to the coil within the range of 0° to 180° to enable automatic measurement of the operation.

In the life span evaluation, we conduct an accelerated test by simulating starting/stopping of the motor. Figure 2 shows an example of the measurement of contact dissipation amount caused by contact-making operations and the generated arc energy. We reduced the arc energy by using contact material/shape (A) to optimize the operation. Furthermore, we determined an optimum contact shape and used contact material/shape (B) to satisfy the target wear limit and achieved the target life span.

Through such optimization and limit design, the "FJ Series" has been downsized by about 28% to 38% in volume, while satisfying the price level applicable to overseas markets (refer to "Magnetic Contactor 'FJ Series' and 'SK Series' Line Expansion" on page 163).

(2) Middle-voltage DC MCCB breaking evaluation test

Low-voltage distribution equipment, such as molded-case circuit-breakers (MCCBs) and earth-leakage circuit-breakers (ELCBs) are designed to detect over-

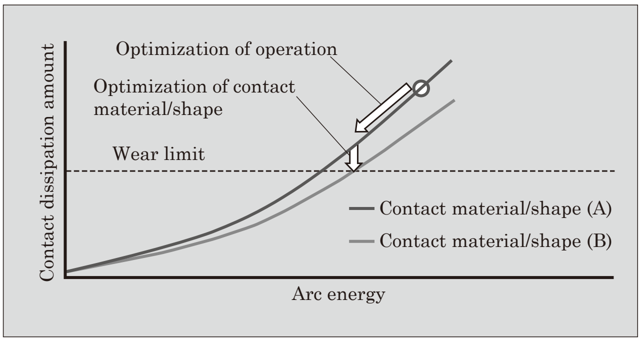


Fig.2 Relationship between arc energy and contact wear

current or ground fault and break the circuit for alternate currents up to 600 V.

In order to confirm that MCCBs or ELCBs can safely break the current specified in their required specifications, we take advantage of a short-circuit generator facility to create an actual accident current (150 kA max.) that could possibly occur in the market, and evaluate the transient breaking phenomenon in 10 ms or less, to determine the dimensions and material of the portions around the contact.

In recent years, DC power feeding (300 to 400 V) has been increasing with the proliferation of renewable energies such as photovoltaic power generation and data centers, and the request for circuit breakers supporting middle voltage DC (1,000 V) is increasing to reduce transmission loss. Normally with an AC circuit, we controlled the arcs generated between contacts before reaching zero points of the current that occur periodically, and ensured insulation to break the current. Since no zero point exists in a DC circuit, we need to extend the arc in a limited space and increase the voltage, which occurs between the contacts, to be higher than or equal to the power supply voltage (see Fig. 3).

As for circuit breaking, JIS C 8201-2 specifies that you only need to check the rated current (800 A) and rated breaking capacity (5 kA). We, however, conduct verification in all regions up to the rated breaking capacity in order to ensure reliable breaking in DC circuits with actual load.

Breaking a direct current requires commutating an arc into an arc-extinguishing grid instantaneously and extending it to increase the voltage between con-

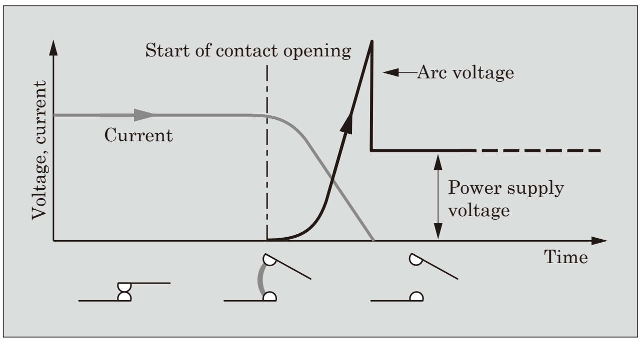


Fig.3 Waveform at the breaking of DC circuit

tacts. We used simulation to efficiently refine the design parameters including the inner wall shape of an arc control device and the grid shape and its quantity. We also used a high-speed camera to visualize the phenomenon in 10 ms to determine the structure that enables arc commutation most easily for current breaking at 1,000 V DC (see Fig. 4).

The direct current breaking performance is proportional to the number of contacts (poles). To use four poles to handle 1,000 V DC, a breaking performance of 250 V DC per pole is sufficient. Consequently, we used a single-phase 250 V DC test circuit for the evaluation.

By using the developed arc control device and the testing condition of single-phase 250 V DC, we evaluated the length of the arcing time and arc energy to judge whether the breaking was successful or not in the entire current range guaranteed for the normal/reverse connection. We confirmed that the product could unfailingly break a direct current when 1,000 V DC was applied. As for the life span, we conducted a switching durability test 1,000 times with a rated current based on the JIS C 8201-2 standard. In photovoltaic power generation, it is expected that the current will sometimes become extremely small depending on the amount of sunlight. With direct current, the arcing time is generally long in the range of small currents of about 10-odd A as shown in Fig. 5. We conducted evaluation on the assumption that switching would be also frequently performed in this region, and confirmed that our products have sufficient durability even when

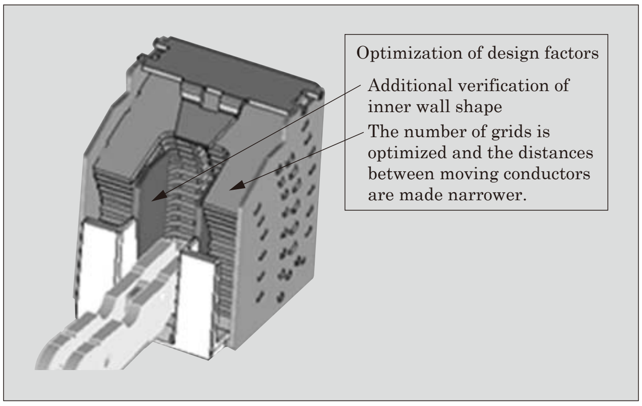


Fig.4 Shapes of arc control device and inner walls

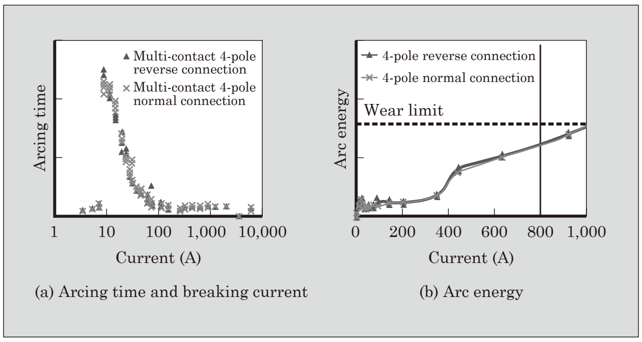


Fig.5 Arcing time and arc energy in the entire range

the current drops to lower than the rated current. As described here, we enhance the quality of non-polar DC breakers so that they can be used safely in all DC field including solar power generation facilities (refer to “No-Polarity Interruption Technology of Circuit Breakers for High-Voltage Direct Current” on page 174).

3.2 Reliability evaluation test in view of a product use environment

As inverters and servo amplifiers have become prevalent and popular in recent years, magnetic contactors have come to be used not only in the conventional application of direct motor start but also as a primary side switch for a drive control device. This section describes the evaluation test to ensure switching performance in the latter application.

When a magnetic contactor is used as primary side switch for an inverter or a servo amplifier, the performance of closing the capacitor charging current generated at power-on is important. While the inrush current during direct start becomes 6 times the rated current, the inrush current during capacitor charging is 8 to 15 times greater than the rating (see Fig. 6). We evaluated the welding resistant characteristics of the contact against this inrush current and the durability (life span) of the contact under repeated switching.

For utilization category AC-3 simulating the current at the startup of a motor (closing the current that is 6 times the rated current in half wave of 10 ms and opening the rated current), the current flowing when the contact is closed in the capacitor circuit forms a steep half wave of around 3 ms, and the contact loss will be approximately 10 times of that of AC-3. Figure 7 shows photographs of the contacts after the switching test. They indicate that the contact wear after switching 1 million times in the AC-3 test is equivalent to 100 thousands times in the capacitor switching.

It is normally possible to evaluate the life span of the contact by using the drive control device used in the market. In this case, however, you cannot increase the switching frequency because the capacitor charging/discharging time in an actual circuit is not uniform. Hence we used a typical drive unit to execute

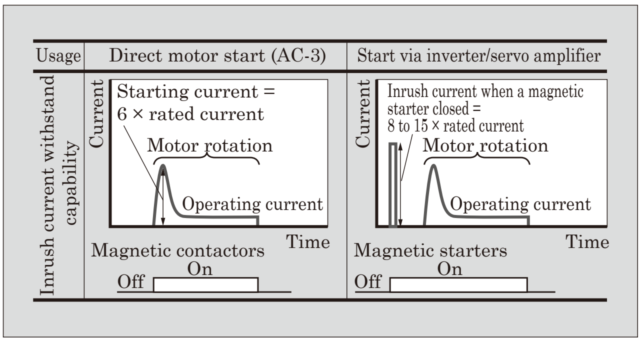


Fig. 6 Comparison of direct motor start and servo amplifier driving

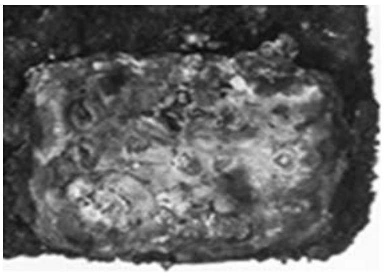
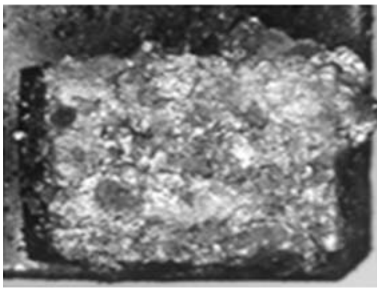
Testing conditions	Contact state after switching test
AC-3 (1 million times switching)	
Capacitor switching (100 thousands times)	

Fig.7 Photographs of contacts after switching test

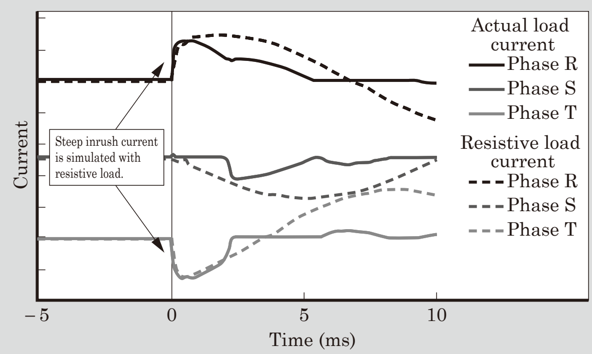


Fig.8 Waveform comparison between servo actual load and resistor simulated load test

actual opening/closing so as to obtain the voltage and current waveform. By simulating this actual waveform with a resistive load circuit of the contact closed, we enabled evaluation in a simulation circuit that generates an equivalent waveform of a rising current affecting the contact wear (see Fig. 8).

For the "SK Series," we used such actual load data to evaluate the life span of contacts and welding resistant limit, and expanded the models that satisfy the required switching life by considering the primary side switching of inverters/servo amplifiers.

3.3 Interface evaluation test that considers handleability

Command switches are used as operating switches or pilot lights of control panels or other equipment and machinery (operating panels) and have an important role to play as a quick and accurate human-machine interface.

Since an emergency stop pushbutton switch is operated by many different persons, it must provide an operating feeling to indicate that it operated just as the operating person expected and be activated by an appropriate operating force. In addition, since it is operated during an emergency, we should expect it to be handled harshly such as being hit by a tool. We basically tune the operating force in terms of ergonomics by assuming the force that can be exerted by a person. We, however, confirm and evaluate the actual force by operating it harshly by referring to previous data. Although it is out of specification and seldom occurs, we assume cases where the switch is hit with a plastic hammer or a padlock and its housing is cracked or damaged, and confirm the fail-safe design that does not impair its functionality. We synchronize the switch with electrical contact signals, use a high-speed camera to visualize the behavior of the mechanism in high-speed shots and confirm that there is no problem with its "cutoff" capability.

In order to quantify the operating force which varies depending on the way of hitting, the above evaluation has also adopted a method to replace the plastic hammer with a cylindrical rigid body weighing 1 pound (0.453 kg) and dropping it from the height at which the shock load used as judgment criterion is generated. The emergency stop pushbutton switch featuring the "Synchro Safe Contact," which is Fuji Electric's original structure, has been designed with consideration given to every safety factor. It is a product that undergoes substantial user interface evaluations including the handling described above and also provides fail-safe functionality and robustness (refer to "Emergency Stop Pushbutton Switches (ϕ22 and ϕ30) Integrating 'Synchro Safe Contact'" on page 169).

3.4 Characteristic confirmation test based on product standards

This section describes the evaluation for elaborating quality in the mass-production prototyping process based on the internal product standards for power monitoring equipment.

As a way of further streamlining energy usage, we commercialized the power monitoring unit "F-MPC04 Series" offering various model lineups satisfying the power monitoring needs of customers. To evaluate this product, we need to accurately assess the main functionality of the watt-hour meter function, combine all variable conditions of the factors required in the product standard (see Table 3) and complete 288 evaluations in a short period.

The F-MPC04 Series uses a voltage transformer (VT) and a current transformer (CT) to measure voltage and current as well as the phase difference of the voltage and current to obtain active power, reactive power and power factor.

The watt-hour meter of the F-MPC04 Series corre-

Table 3 Evaluation combination required for the product standard

Factor	Variable condition	
Applicable CT rating	5 A, 50 A, 100 A, 200 A, 400 A, 800 A	6 ratings
Voltage	110 V, 220 V, 440 V	3 conditions
Current	5% and 100% of CT rating	2 conditions
Frequency	50 Hz, 60 Hz	2 conditions
Power factor	1.0, 0.5	2 conditions
Electric energy direction	Normal, reverse power flow	2 conditions
Evaluation combination		288 combinations

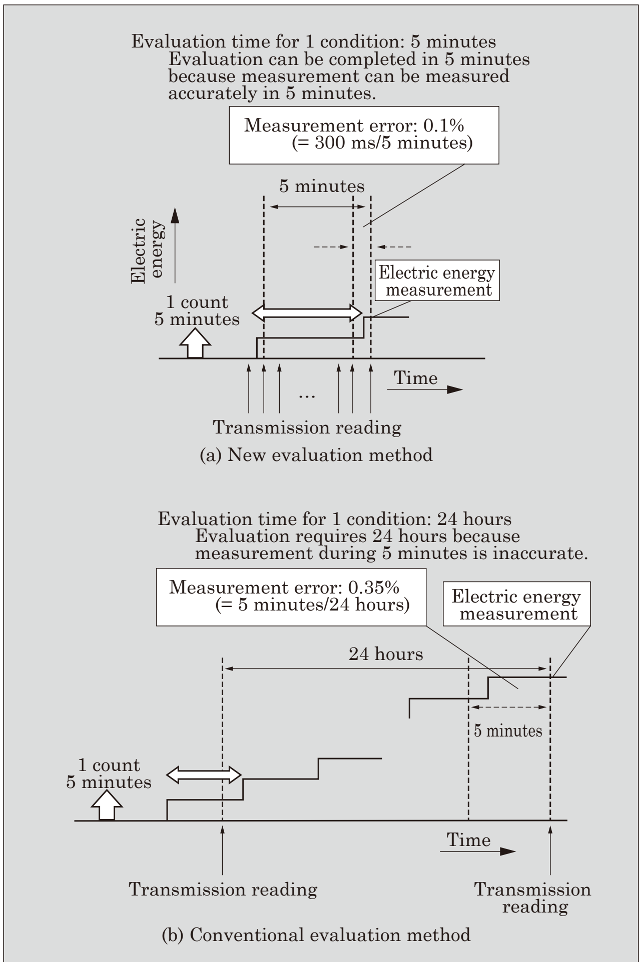


Fig.9 Comparison of electric energy measurement methods

sponds to JIS C 1216 ordinary watt-hour meters category. Consequently, we need to ensure a measurement accuracy of 2.0% even for a low current that is about 5% of the rated current of the CT. In order to decrease the measurement error in such a low current, we enabled transmission of the electric energy (watt-hour) at 300 ms intervals in 5 minutes per count, instead of the previous method of reading data only at the starting and ending times of a 24-hour period through transmission, so that the change in the electric energy could be measured accurately. Improving the measurement resolution has reduced the measurement error in the evaluation to less than 0.1% (300 ms/5 minutes) (see Fig. 9).

This improves evaluation accuracy as well as saves evaluation time. We then introduced automatic measurement technology to allow all combinations of evaluation conditions in a short period, instead of the previous evaluation of limited points.

Such evaluation has made it possible to add the multi-circuit type power monitoring unit F-MPC04P to the lineup. This is a model with improved quality as a watt-hour meter providing high measurement accuracy even under actual load.

4. Postscript

Construction of a new development building is underway at the Fukiage Factory, scheduled to be completed in December 2014. This building will be a global mother base for creating new products and new technologies for the renewable energy field and Asia and Chinese markets.

Since this new development building is next to the building in which the development design, production engineering and quality assurance departments are located collectively, Fuji Electric will further enhance the team power, increase customer satisfaction by achieving shorter development period and improved product quality, and improve the efficiency of overall development. Furthermore, we will augment a new breaking test facility supporting middle voltage DC products including solar power generation to enhance the product evaluation technology.

We at Fuji Electric continue to actively promote the development of products that anticipate the needs for power distribution, switching and control equipment components and provide product evaluation technologies to support our solutions including stable energy supply, energy saving, safety/security and the environmental conservation.

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