Achievements and Future Outlook

Providing Powerful Component Based Energy Solutions

EGUCHI, Naoya

Corporate General Manager, Corporate R&D Headquarters
Executive Officer and Director, Fuji Electric Co., Ltd.

1. Introduction

Fuji Electric has been manufacturing the most energy efficient products through our pursuit of innovation in electrical and thermal energy technology, and we formulated the brand statement “Innovating Energy Technology” based on our concept to realize a safe, secure and sustainable society. With the attaining of this goal in mind, Fuji Electric has been concentrating its research resources on developing technologies for supplying and using electrical energy safely, securely and efficiently and technologies for utilizing thermal energy with no loss, as well as on developing a technology for optimally controlling these technologies. During our mid-term management plan for 2013, we described our research policy for providing energy solutions. This policy positions our power semiconductor and power electronics as core technologies, while also developing our thoroughly differentiated components, which include measurement and thermal components, in order to create a platform and package for our control technologies based on our core technologies and components (see Fig. 1). This paper introduces our latest developments based on this policy.

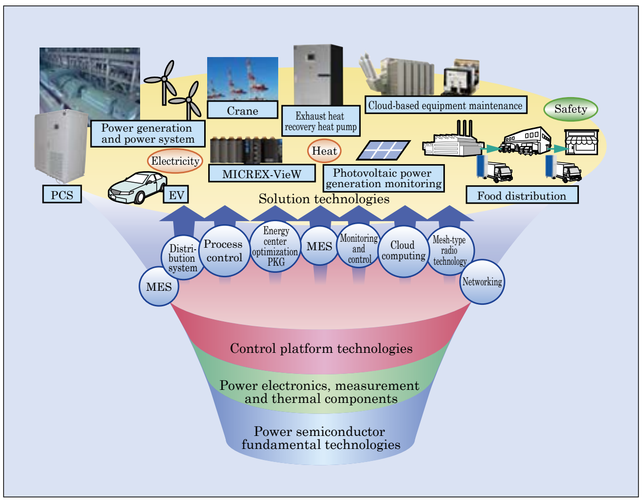


Fig.1 Fuji Electric’s core technology and areas of focus

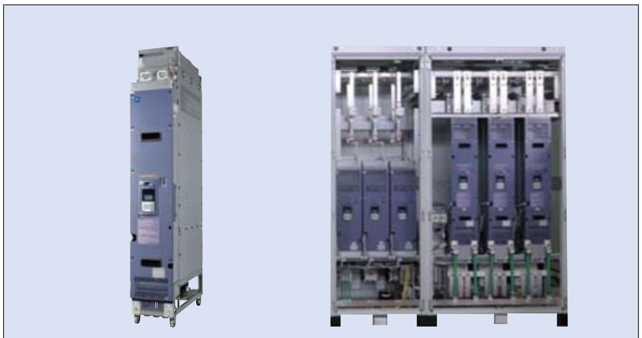
2. SiC Devices and Their Application Products Aiming for the World’s Top Level

As a strategy to develop extremely differentiated components using the synergy between power semiconductors and power electronics technologies, we are focusing on developing silicon carbide (SiC) power semiconductors as next-generation devices capable of exceeding the physical limitations of Si devices and dramatically decreasing loss, as well as power electronics components that can apply these semiconductors.

The SiC manufacturing facilities at the Matsumoto Factory, which is our manufacturing base for power semiconductors, is the first in the industry to start operations of an SiC 6-inch wafer processing line. This line is manufacturing Schottky barrier diodes (SBDs) with a 600 to 1,700-V withstand voltage and metal-oxide-semiconductor field-effect transistors (MOSFETs) with a 1,200-V withstand voltage. Both of these components were developed under collaborative research with the National Institute of Advanced Industrial Science and Technology (AIST). At the same time, we are also developing various ultra-small, highly reliable modules that are characterized by maximizing the performance possessed by SiC devices through high-temperature operation, heat dissipation and low inductance features.

By utilizing a 1,200-V withstand voltage SiC-SBD in a free wheeling diode (FWD), we have developed and are supplying the market with a hybrid module that applies Fuji Electric’s 6th-generation “V Series” to the insulated gate bipolar transistor (IGBT) chip. When using this hybrid module in an inverter, it is possible to reduce generated loss by up to about 30% (this reduction effect is most significant during high frequency operation) compared with the use of conventional Si devices[1]. Furthermore, we are also supplying a hybrid module that utilizes a 1,700-V withstand voltage SiC-SBD in a FWD (see Fig. 2), and started selling the 690-V inverter “FRENIC-VG Stack Series,” which is equipped with the hybrid module, in November 2014 (see Fig. 3). The hybrid module is capable of reducing generated loss by about 30%. Since this module performs high-speed switching, it needs to optimize the

Fig.2 SiC hybrid module



(a) External appearance (b) Storage example for panel

Fig.3 690-V inverter “FRENIC-VG Stack Series”

current sharing of devices connected in parallel and implement electromagnetic compatibility (EMC : Not producing electrical or magnetic interference or being influenced by the same) noise reduction. In order to achieve this, we implemented an impedance matching design using electromagnetic analysis simulation[2].

Furthermore, we have developed an All-SiC module that utilizes SiC-SBD and SiC-MOSFET[3], and have adopted it in our mega solar power conditioning sub-system (PCS)[4] (see Fig. 4). This module is wired using copper pins formed on the power substrate, as opposed to wire bonding, in order to accommodate high-density mounting for the SiC device. In addition, by adopting a silicon nitride substrate formed by bonding a thick-copper substrate for achieving low thermal resistance, as well as utilizing technologies such as an epoxy resin sealing technology, we have created an ultra-small and highly reliable module that achieves high-temperature operation, heat dissipation and low inductance.

(a) Mega solar power conditioning sub-system (b) All-SiC module

Fig.4 Mega solar power conditioning sub-system and All-SiC module

Mega solar PCS equipped with this module are able to achieve a high level of efficiency up to 98.8%. Also, the footprint size has been reduced to 60% by optimally combining the DC booster circuit and inverter circuit. This product was awarded First Prize in the FY2015 Japan Electrical Manufacturers’ Association Technical Achievement Award.

Furthermore, we are promoting the development of SBD and MOSFET devices and modules that have high withstand voltages such as 3,300 V, which are capable of demonstrating the benefits of SiC. We are currently evaluating our prototypes and quickly advancing in the development of power electronics products that utilize them.

As mentioned so far, we are combining our latest SiC devices and module technologies, which maximize the performance of these devices, as well as developing compact, low-loss differentiated power electronics products that are equipped with these devices. By doing this, we are aiming at producing the world’s top level of SiC devices and applicable products.

3. Differentiated Power Electronics Products

Power semiconductors and power electronics are Fuji Electric’s core technologies, and by making use of the synergies of these two technologies, we have been developing components characterized by their energy saving features even when not applying SiC devices.

We are currently developing a module that utilizes reverse-conducting IGBT (RC-IGBT) for mounting to inverter units of mild hybrid vehicles that can produce power and drive force via a single motor. RC-IGBT is a device that integrates IGBT and FWD on a single chip. We developed a low-loss RC-IGBT with a 650-V withstand voltage by means of the most advanced thin wafer processing technology based on a field-stop IGBT, which is being manufactured at Fuji Electric. This has enabled us to develop a device that is 20% smaller than conventional IGBT and FWD combinations.

The Top Runner Program that stipulates efficiency regulations for motors was put into effect in April 2015 in Japan to improve the efficiency of motors, which account for approximately 40% of the world’s energy consumption. We have developed the “Premium Efficiency Motor” as a motor compliant with these regulatory standards. We have satisfied the efficiency regulations by utilizing finite element methods and electromagnetic field analysis to reduce copper loss and core loss through slot shape optimization and by adopting a thermal design that utilizes a thermal fluid network approach to reduce windage loss[5] (see Fig. 5).

We have also developed a motor with a built-in inverter, which equips the motor with built-in inverter functionality for operating the fan of the air-conditioning equipment (see Fig. 6). Cooling is implemented through the cooling wind of the fan, and both a thermal design and vibration-resistance analysis were implemented for the motor. Overall, the motor is 38% smaller and 31% lighter than other products that combine a general-purpose inverter and standard electric motor. When compared with damper control, the motor achieves energy savings of more than 40%[6].

We have developed a rich lineup of inverter products for the global market, which include the "FRENIC-VP Series" for the Chinese fan and pump market and the 575-V power-supply compatible "FRENIC-HVAC" for the North American air conditioning market, as well as the enhanced "FRENIC-Lift" inverter for elevators in the European market.

With regard to electric distribution, switching and control devices, we have developed control devices that can meet the needs of facilities and control systems that require space-savings and high reliability. Our compact magnetic contactor "SK-Series" 32-A product (SK32 type) has a slim width of 53 mm and a decreased installation area of 33%. We have also newly developed a polarized electromagnet, which utilizes a permanent magnet. This development has greatly reduced the volume of the electromagnet (see Fig. 7). As shown in the figure, the magnetic flux of the permanent magnet is optimally utilized so as to ensure that the plunger operates only after a voltage is applied to the coil and the current of the coil rises sufficiently. By doing this, we have been able to eliminate unstable operation due to voltage drop during plunger operation. As a result, the holding force, directly before charging takes place, between the permanent magnet and plunger has been increased to stabilize operation, and the compact electromagnet has secured a sufficient amount of magnetic attraction.

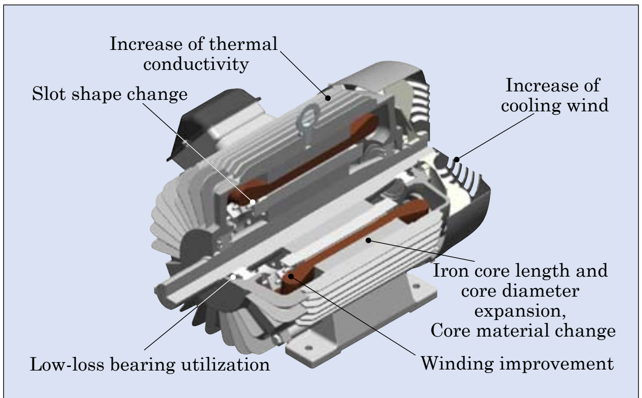


Fig.5 Motor loss reduction masures

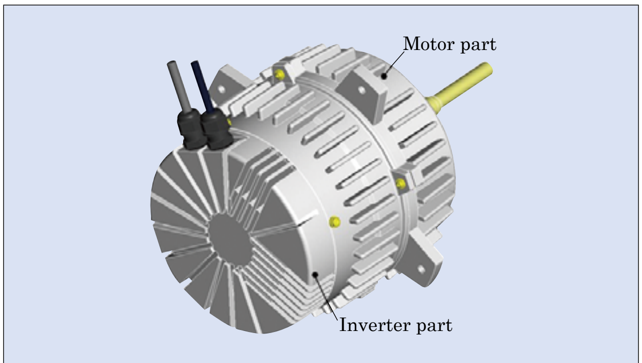


Fig.6 Motor with built-in inverter (development machine)

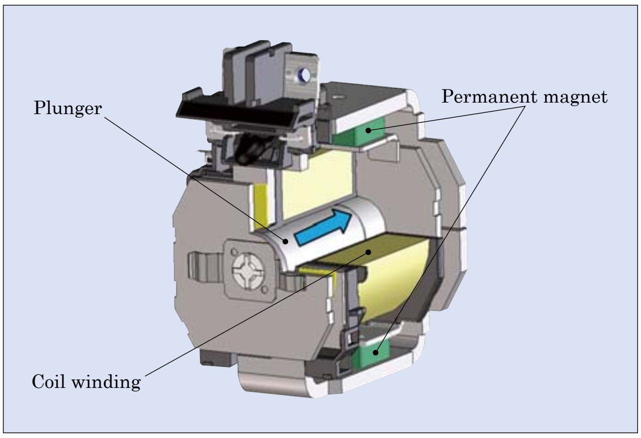


Fig.7 DC electromagnet

Furthermore, we have developed a safety-enhanced circuit protector that does not expose the charging part. We have been able to decrease the outer dimensions of the product by 20% compared with previous products by integrating into the product the terminal cover function for protecting the control circuit. In addition, the time necessary for wiring has been significantly reduced through the adoption of a screw-up type terminal as a standard feature of the product.

4. Measurement and Thermal Components

We have developed the world's first battery-operated household-use gas alarm by using our specialized micro electro mechanical systems (MEMS) technology to reduce the size of the sensors, as well as by making battery-powered operation possible through the reduction of power consumption to less than 1/1000 of conventional products. The gas alarms will be available for purchase from Osaka Gas Co., Ltd. starting in May 2015 and from Tokyo Gas Co., Ltd. starting in October 2015. The long-life reliability of the gas alarms has been verified through cooperative research with Osaka Gas Co., Ltd. under the support of the New Energy and Industrial Technology Development Organization (NEDO) through its "Technological Development for a Next-generation Highly-reliable Gas Sensor" grant project.

We have developed the hybrid air-conditioner "F-COOL NEO" as a differentiated thermal component that combines the cooling characteristics of vapor compression and outside cold air systems to achieve energy savings in the air conditioning equipment of data centers (see Fig. 8). We have developed a system that adopts an indirect system for making use of outside cold air in a manner that is mostly unaffected by dust and corrosive substances contained in the outside

Fig.8 Hybrid air-conditioner “F-COOL NEO” evaluation equipment

air. It also automatically controls the operation ratio for the combined cooling system depending on the temperature of the outside air and cooling load. The unit achieves significant energy savings with estimated yearly power consumption, based on actual measured data for a module type simulated data center, being approximately a third of conventional air conditioning systems. “F-COOL NEO” was awarded the Japan Machinery Federation’s President Award in FY2014.

5. Control System Platform

We have been developing various control solution packages that contribute to the stable supply of energy, energy savings, safety, security, automation and efficiency. As core elements of various control solution packages, we have developed the control system platform that consists of a control system layer, a software library layer, and an engineering environment[(7)].

As solutions for improving the quality of products and stability and efficiency of operations in factories, we have also developed drive system solutions based on a high-speed controller and large-capacity network. As shown in Fig. 9, machine control systems, which have conventionally been configured with two controllers consisting of an integrated controller and dedicated motion controller, can now be configured with a single controller via the “SPH3000MM” high-speed and high-precision controller. The SPH3000MM is equipped with two “E-SX bus” high-speed field buses, which when compared with the conventional “SX Bus,” are capable of 4 times the transmission speed and more than 100 times the tact accuracy.

Furthermore, it is possible to operate multiple controllers at the same time by adopting the “SPH3000MG,” which is a high-speed and large-capacity network compatible controller mounted with an E-SX bus and the high-speed and large-capacity control network “SX-Net.” Moreover, high precision can be achieved for the plant control system by configuring it with a control network that connects multiple controllers and operation and monitoring equipment. Figure 10 shows an application example of using the SPH3000MG as a drive master controller (DMC) that controls an inverter and a controller that integrates the various sections of the control system for steel processing lines. A single DMC can control up to 64 inverters, thus making it possible to greatly reduce the number of controllers.

6. Energy Solutions

We are continuing to advance in our supply of en-

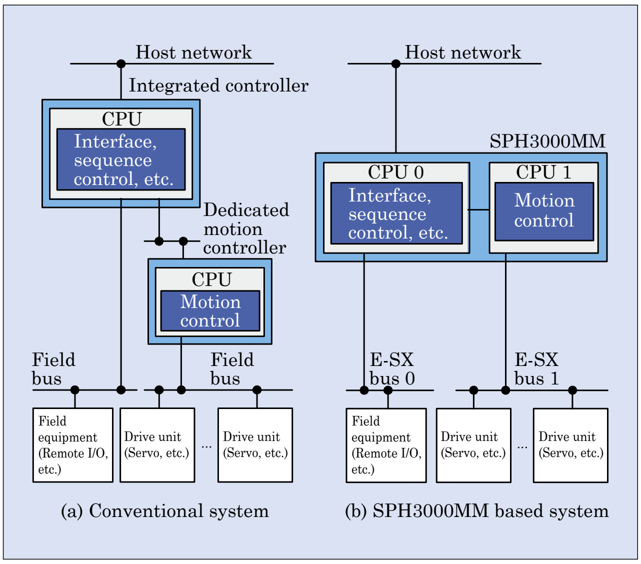


Fig.9 Conventional system and “SPH3000MM” system

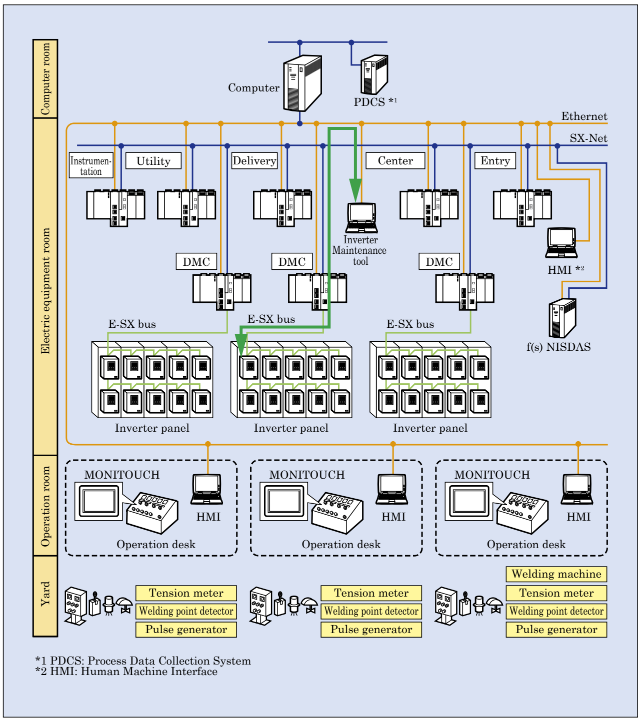


Fig.10 Conventional system and “SPH3000MM” system

ergy solutions for improving the efficiency of thermal power generation and geothermal power generation. In addition, as we aim to construct a smart community, we are also developing various energy management systems (EMSs) that realize energy savings through optimizing the control of electrical and thermal energy.

The "Next-Generation Energy and Social Systems Demonstration Project" started in FY2010 by the Ministry of Economy, Trade and Industry has been held in four regions (Yokohama City, Toyota City, Keihanna Science City and Kitakyushu City) to expand horizons for the achievement of next-generation energy systems. The goal has been to achieve a stable and highly-efficient usage of renewable energy in these regions, as well as to develop and test energy management systems (EMSs) such as a building energy management system (BEMS), a home energy management system (HEMS), a factory energy management system (FEMS) and a retail energy management system (REMS). Fuji Electric has been actively participating in the demonstration projects being done in Kitakyushu City and the Keihanna Science City and completed testing in those regions in FY2014.

In Kitakyushu City, we have developed a cluster energy management system (CEMS) centering on Smart Community Center called "Setsuden-sho" and implemented various demonstration tests. Since the CEMS requires energy conservation, individual households decided on whether or not to participate in the demonstration test. Depending on participation, demand adjustment was tested through the use of eco-point credits that could be exchanged into prepaid cards. Furthermore, "Fall Season Critical Bottom Pricing (CBP)" was also initiated to stimulate demand on days in which light loads resulted in surplus power being generated by photovoltaic power generation facilities.

In the demonstration project held in Keihanna Science City, we developed and tested an elemental technology for a visitor prediction algorithm to be used in commercial facilities, hotels and other facilities that make use of BEMS or REMS. The algorithm is used to predict energy demand by using event schedules and estimates regarding the number of visitors.

We have also been developing an enhanced energy-saving control solution to be used at refrigerating warehouses by making use of our measurement control and air-curtain technology, which is based on the airflow control technology that we cultivated in our store showcase products.

Recently, the concept of an Internet of Things (IoT), in which all things are connected to the Internet, has been gaining increased attention. Fuji Electric is working to provide its customers with various services and solutions that utilize the cloud to analyze and optimally apply uploaded data. As one example, we have developed "Integrated Cloud Service." This is a service that supports total optimization of facilities at all lifecycle stages including installation, operation and upgrade. The service carries out optimization by uploading to the cloud data collected through our specialized sensing technology in order to analyze it using technologies such as energy-saving analysis technology, demand prediction technology, quality trend analysis technology and facility deterioration diagnosis technology, and after this, providing appropriate support with integrated functions such as energy management and energy-saving control support, facility operation monitoring and maintenance service support (see Fig. 11).

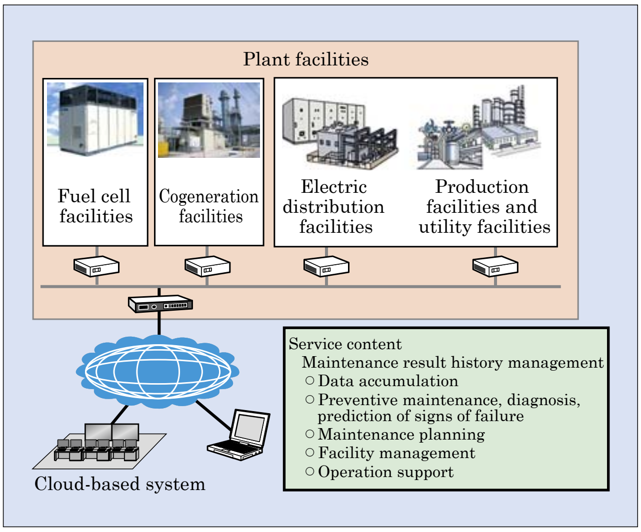


Fig.11 Integrated cloud service

In the future, we plan to continue to develop our various analysis and optimization technologies that make use of our distinctive sensing technologies and company know-how in order to create services and solutions that utilize IoT.

7. Fundamental and Advanced Technologies

The technologies that we have presented so far are commonly supported by our fundamental technologies, and we are continuing to do research and development so that we can create cutting-edge technologies for the future.

In order to provide differentiated IoT based services and solutions, it is important that the analysis technologies used on the collected data are also differentiated. We have developed an abnormality diagnosis technology based on multivariate statistical process management for diagnosing abnormalities in manufacturing processes. An application example of utilizing this technology in the vibration data analysis of a turbine shaft is shown in Fig. 12 and Fig. 13. For the vibration data in Fig. 12, there was an abnormality in the sensor represented in the B column of the figure. Even though the vibration was not greater than the determination threshold of 120 μm, it could not be determined if an abnormality occurred. On the other hand, Fig. 13, which shows the evaluation of statistics after constructing a multivariate statistical process management model as represented by the normal column (A column of the figure), shows that the statistics of the B column are significantly larger than other areas, thus

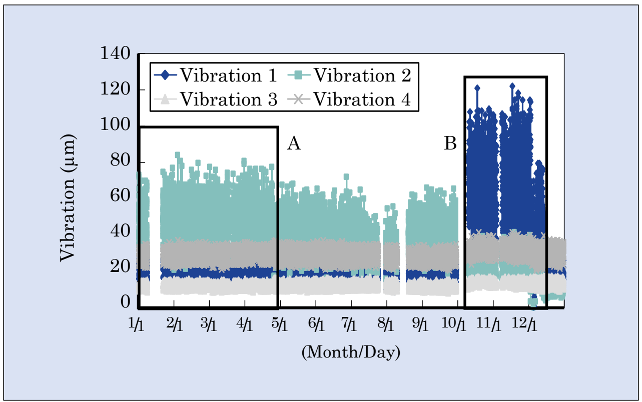


Fig.12 Turbine shaft vibration data

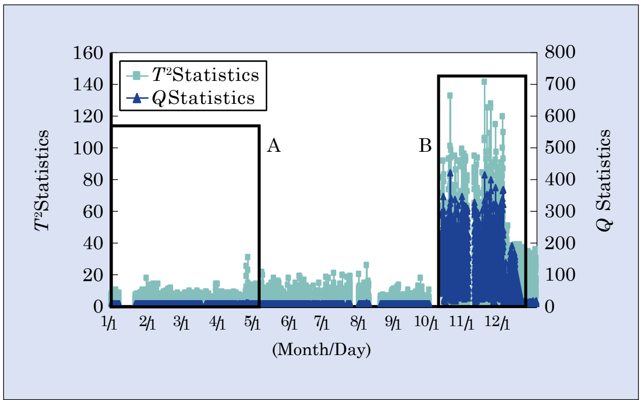


Fig.13 Vibration data analysis results

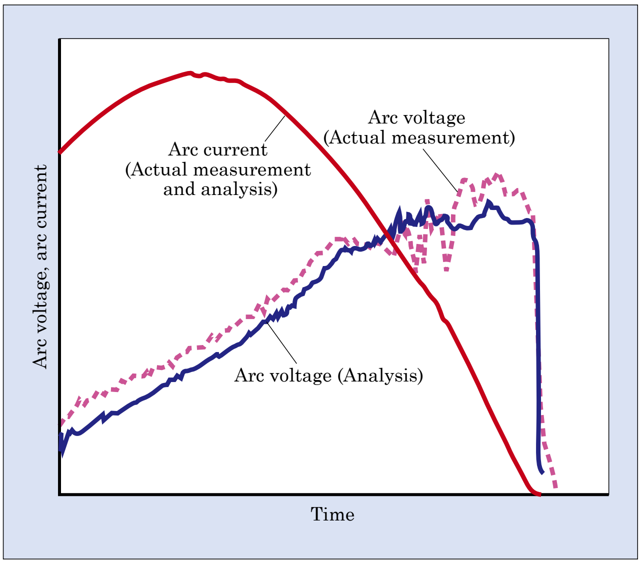


Fig.14 Arc current and arc voltage at cut-off

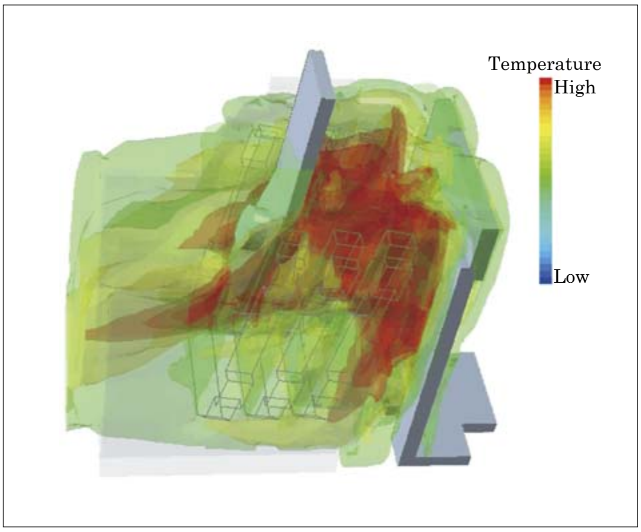


Fig.15 Circuit protector arc simulation results

making it apparent that this column represents an abnormality. In addition, we are developing optimization methods based on the partial least square method and formulas, as well as implementing application testing for real data.

Furthermore, we are also constructing various simulation technologies such as those for thermal fluids, structures, electromagnetics and EMC. Moreover, we have developed a technology for simulating the behavior of arc generated during the opening and closing of the contacts of electric distribution, switching and control devices, etc. By linking thermo-fluid analysis with electromagnetic field analysis, considerations can be made regarding the electromagnetic force of external magnetic fields and the arc itself, while also incorporating arc-generated evaporative gas into the model.

An application example of an arc simulation for a circuit protector is shown in Fig. 14 and Fig. 15. Figure 14 shows that the results of calculating arc voltage match up with the actual measurements very well. Furthermore, this simulation can be used to calculate time-sequentially temperature distributions, current density, gas flow rates, pressure, gas components and other values, while also facilitating design study in an arc-extinguishing chamber[8].

In addition, we are continuing to research and apply the most advanced simulation technologies such as thermodynamic simulations for predicting the corrosion of turbine materials.

With regard to our continued research and development of material technologies, we have been developing a resin that can withstand 250 °C for use with high-temperature operation device packages that utilize SiC, a dissimilar metal bonding technology that uses metallographic structure simulations, as well as a technology to analyze property changes due to heat and the residual stress of magnetic materials.

Furthermore, when developing products for the global market, it is increasingly important to comply with international standards. In light of this, Fuji Electric has also been enhancing its efforts to acquire international standards. We are actively making efforts to participate in international committee activities, especially those related to power electronics and smart communities. We have a successful track record of contributing to standardization activities related to inverter efficiency measurements and electromagnetic compatibility of PCS.

8. Postscript

We have introduced some of Fuji Electric's efforts mainly in developing technologies for supplying and using electrical energy safely, securely and efficiently and technologies for utilizing thermal energy with no loss, as well as a technology for optimally controlling these technologies.

During FY2014, we commenced several construction projects to reinforce our commitment to strengthening our research and development capabilities. They include the company-wide R&D building at our Tokyo Factory, the power semiconductor technology development center at our Matsumoto Factory and the R&D building for consolidating the functionality of evaluation testing devices for our tool and instrument business at the Fukiage Factory.

As we continue to passionately proceed with our research and development, Fuji Electric stands committed to its brand statement of creating products that can make the most efficient use of energy through the pursuit of innovation in electrical and thermal energy technologies in order to contribute to the goal of realizing a safe, secure and sustainable society. We are moving forward in our contributions to become a greater corporate citizen in our global society so that we can achieve our ideals.

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