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FUJI ELECTRIC REVIEW

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Technical Achievement and Outlook in FY2017

Fuji Electric

Innovating Energy Technology

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REVIEW

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Through our pursuit of innovation in energy and environment technology, Fuji Electric creates environmentally friendly products and systems for using energy stably and most efficiently. We have been conducting research and development to thoroughly pursue value for customers by creating competitive components, building distinctive systems characterized by the use of these components, and leveraging the Internet of Things (IoT) technology to connect these systems. This issue compiles the technical achievements of FY2017 and summarizes the outlook for the future. We hope that this issue will be helpful to create a new society.

Cover Photo:

Fuji Electric's IoT solutions use field devices and analysis and optimization technologies to create new value for customers such as optimized energy use. They help create negawatt power and achieve the energy mix by saving labor and energy in stores, controlling plant motors with environmentally resistant inverters in harsh environments that have prevented inverters from installing, controlling EV drive-trains using power modules, and using renewable energy from geothermal binary power generation.

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Technical Achievement and Outlook in FY2017

Preface

Through our Pursuit of Innovation in Energy and Environment Technology, We Contribute to the Creation of Responsible and Sustainable Society That Places Equal Emphasis on Economy and Environment

Since its inception in 1923, Fuji Electric has always pursued technological innovations in energy and the environment, making its wide contributions to society in the fields of industrial and social infrastructure. The international community today is moving toward a balance between economic growth and social challenges concerning energy, the environment, human rights and so on, as seen in the Paris Agreement, which is an international framework for reducing the emission of greenhouse gases, and the Sustainable Development Goals (SDGs).

At Fuji Electric, we established the Power Electronics Systems Business Group in April 2017. The purpose was to pursue global business expansion in the areas of "energy solutions" for stable and optimized power supply and "industry solutions" for plant automation and energy saving. Our energy and environment projects are in alignment with the requirements and needs of society today. We create and deliver to our customers' high-value, environmentally aware products and systems through our world-leading power semiconductors, power electronics equipment that incorporates them, and system solutions that combine sensor and controller systems with the Internet of Things (IoT).

For research and development activities, we explore the synergy between semiconductors and power electronics. As more and more automotive systems are electrified today, we focus on this field and are developing automotive discrete, compact and lightweight automotive power semiconductor modules for high power density, and sealed high-voltage contactors (HVC) for automotive applications. Using these components, we are also developing automotive power electronics equipment.

In the semiconductor sector, we have developed products using a next-generation material, silicon carbide (SiC). Compared to conventional Si semiconductors, SiC reduces watt loss up to high ranges of switching frequency and can be operated in a high-temperature environment. The SiC-based Schottky barrier diode (SBD) and SiC trench-gate MOSFET can achieve both performance and stability at the world's highest level.

Leveraging this technology in our power electronics equipment, we have developed the "FRENIC-eFIT" environmentally resistant, totally-enclosed self-cooled inverter with a fan-less cooling system. It can be used in a wide scope of applications in a harsh environment, such as the outdoors and a corrosive gas atmosphere. We are offering SiC-based semiconductor modules for various types of equipment of power electronics with potential added value.

Concerning the industry solutions sector, there is steady growth in the field of factory automation, backed by proactive investments for introducing automation into plants. Fuji Electric offers products such as the "FRENIC4800VM6" medium-voltage high-capacity inverter with a water-cooling system, designed for the drive of factory machinery such as large rolling mills, blowers and pumps. In ways like this, we provide our customers with ease of use and enable them to save labor. We offer motion control technology for the automation of factories that require high-precision control using our unique components, such as the "SPH3000D" motion controller and the "ALPHA 7" servo system that we have continuously developed since FY2016. We have also developed the "MICREX-OnePack" equipment information collection system that can gather several different types of data from processing equipment in aggregate units per production cycle. It facilitates the introduction of IoT into production lines.

In the process automation sector, we have core technologies in drive control, measurement control and industrial electric heating. They constitute components and systems for ensuring the reliable operation of production equipment and reducing energy unit consumption. In the steel and nonferrous sector, the "MICREX-VieW XX" with enhanced features has been used for renewing the large-scale monitoring and controlling system for steel plants. In the cement sector, we have developed a monitoring con-

trol system package that offers a platform of features necessary for plant control. It facilitates easy engineering for our partners and users across the world.

In the energy solutions sector, we are developing uninterruptible power systems (UPS), plant power systems and air conditioning systems for data centers, leveraging our power electronics technology. Data centers continue to grow as ITC systems become highly sophisticated and involve cloud technology. To meet the needs of such centers, we have developed the "UPS7400WX-T3U" large-capacity UPS with applied module control to satisfy the requirements not only for enhanced efficiency, but also for a reliable power source. It is comprised of modules with a capacity of 330 kVA each, thus enabling the total capacity of the system to be adjusted so as to flexibly cater to the needs of client equipment.

In the power and new energy sector, Fuji Electric strives to realize a low-carbon society and is proactive in advancing technologies for utilizing renewable energy, such as geothermal energy, solar and wind power generation coupled with power storage technology, and biomass thermal power generation. In Japan, we have helped the country's largest geothermal binary power plant come into commercial operation.

In the food and beverage distribution sector, we aim for global expansion and leverage the technologies that we have gained through the development of cup vending machines to develop dispensers of real drip coffee for the international market. Fuji Electric also undertakes the development of new products and services in order to address the labor shortage and to assist with work style reform for the distribution and retailing industries in Japan. To this end, we leverage our technological expertise in IoT, mechatronics and cooling and heating, focusing on the three key concepts of convenience, labor savings and energy savings.

With reference to IoT, which is used as a company's common technology, we have developed an IoT platform based on general cloud technology. It is equipped with security functions; interfaces that facilitate the development of services easily; communications functions between the cloud and edge controllers, which collect and process data from on-site devices; and a mathematical engine for diagnosis, analysis, prediction and optimization of the data. Several projects including our own factories have used this platform to improve productivity, product quality, operation efficiency, maintenance efficiency, and plant efficiency and to provide process quality traceability. In this way, we are accumulating the use cases.

Our research and development is focused on the development of fundamental technology widely applicable to various products and advanced technology with an eye to the future. For example, we develop model-based designing technology to pursue innovation of design processes in product development. As for materials technology, we integrate experiments and computing science to strengthen theoretical evidence for solid insulation, semiconductor interface analysis, and prediction of metal corrosion, which is useful for remaining life assessments on turbines.

Our corporate philosophy is "We, Fuji Electric, pledge as responsible corporate citizens in a global society to strengthen our trust with communities, customers and partners." Our slogan is "To be enthusiastic, ambitious and sensitive." We have enthusiasm for making contributions to society through our new technologies and products; we have ambitious goals backed by firm determination to overcome any difficulty; and we have sensitivity that derives from gratitude toward our customers, colleagues and family members, who support us.

This slogan is the anchor point for our teams of diverse members, as we strive to achieve SDGs and contribute to the creation of a responsible and sustainable society. As we at Fuji Electric engage in these challenges, we would like to ask all of our stakeholders for their continued support and understanding.

KITAZAWA, Michihiro
President and Chairman of the Board of Directors

Leveraging Open Innovation to Create Customer Value in Product Planning and R&D

MOTOHASHI, Kazuyuki Professor, Department of Technology Management, Graduate School of Engineering, the University of Tokyo

KONDO, Shiro Corporate General Manager, Corporate R&D Headquarters, Executive Officer, Fuji Electric Co., Ltd.

China and other emerging economies are on the rise and new technologies, such as IoT and AI, are transforming business models. The business environment today is becoming increasingly harsh and challenging for Fuji Electric. In-house technologies and resources have their limitations for continuously producing sales items that meet customer demand. How can we gain impetus for open innovation? Professor Kazuyuki Motohashi, a leading specialist in open innovation research from the University of Tokyo's Graduate School of Engineering, talks with Shiro Kondo, Fuji Electric's Corporate General Manager from the Corporate R&D Headquarters, about the approach to open innovation in customer value creation.

Business strategy first, before open innovation

Kondo: Manufacturers such as Fuji Electric have been performing R&D for a long time by following relatively clear modalities of competition for each product type. However, these modalities are becoming outdated due to the latest technological advances and environmental changes. For example, one of the power electronics products is a power converter, which stabilizes voltage and frequency, or converts direct current to alternate current. Fuji Electric offers a wide range of power converters to deliver diverse modes of application that customers worldwide require. Power conversion efficiency is one of the main modalities of competition in power converters. We have already achieved 98.8% power conversion efficiency, and not all customers require the remaining 1.2%. In this sense, we find ourselves in, as you might say, a "good enough market" (where products with sufficient performance suffice). Accepting this reality, we are keenly aware that it is crucial to captures customer value in planning and R&D. We are therefore proactively considering exploring paths such as open innovation in order to create value.

You are an expert in the field of open innovation and have ample knowledge backed by research on various businesses. I hope you will share some of it with us today.

Motohashi: Thank you for having me here today.

Kondo: Fuji Electric will celebrate its centennial anniversary in 2023, which is in five years. Keeping this in sight, we have been reforming our business and R&D structures in order to achieve sales of one trillion yen by this milestone.

There are four business groups at Fuji Electric, namely, power electronics systems, power and new energy, electronic devices, and food and beverage distribution. Each of these business groups has its own product development department.

On the corporate side, the Corporate R&D Headquarters undertakes research into shared fundamental technology and advanced elemental technology, marketing technology, planning R&D, and managing intellectual property. There is also a team that promotes open innovation at the R&D headquarters.

MOTOHASHI, Kazuyuki

1986: Entered the Ministry of International Trade and Industry (now Ministry of Economy, Trade and Industry)
1998: Economist, Directorate for Science, Technology and Industry, OECD
2002: Associate Professor, Institute of Innovation Research, Hitotsubashi University
2004–present: Faculty Fellow, Research Institute of Economy, Trade and Industry
2004: Associate Professor, Research Center for Advanced Science and Technology, the University of Tokyo
2006: Professor, Research Center for Advanced Science and Technology, the University of Tokyo
2006–present: Professor, Department of Technology Management, Graduate School of Engineering, the University of Tokyo

Motohashi: Some R&D projects may be undertaken both by one of the business groups' development department and the Corporate R&D Headquarters. In such case, which side takes the lead? This is an important point for pursuing innovations.

Kondo: This is precisely where we'd like to hear your opinion. As I mentioned earlier, our current system is a result of reorganizing roles. The business groups undertake product development while the Corporate R&D Headquarters engages in technology marketing as well as the development of elemental and fundamental technologies. We think it necessary to enhance the overall optimization. In order to strengthen the company as a whole, we need to consider how and at which phases the sectors should work laterally with one another, from the viewpoints of better efficiency in R&D or creation of customer value and innovation.

Motohashi: As you mentioned earlier, the market is undergoing a significant change today. As technologies are advanced, customers demand not only good quality for products, but also better usability. Developing countries, meanwhile, are showing remarkable progress, and they present a great marketplace for developed countries. They are, at the same time, great business rivals. They do not seek the best of bests, but something that is "good enough." As the emerging economies rapidly grow strong by producing good enough products at low cost, they are beginning to pose a threat to some Japanese businesses.

One of the recent buzzwords is "from *monozukuri* (manufacturing) to *kotozukuri* (value creation)." Here, the term *kotozukuri* refers to the creation of new value by integrating the objects of manufacturing and the associated services. Japanese businesses have competed for a long time through *monozukuri*, meaning producing high-quality products. However, amid increasingly harsh global competition, *kotozukuri* is becoming the path that cannot be avoided.

Having acknowledged that technology alone can no longer satisfy customer needs, however, it is still an important point that manufacturers try to differentiate their products technologically. Finding out how to adapt technology to the market. This perspective will remain necessary amid major market transformations in the future.

Open innovation is a very effective means in terms of *kotozukuri*. While operating within the framework of *monozukuri*, companies did well to promote their research and development using their own resources. However, this practice does not work so well in *kotozukuri* due to its speed and wide range of scope. This is what brought attention to open innovation, engaging in R&D involving external collaborations.

Open innovation is one means of innovation. This means that a corporation must first of all have its innovation strategy before considering open innovation to determine whether it is a viable means of proceeding.

In developing innovation strategies, it is vital to understand how leading customers—ones who are at the forefront of their industries—consider their business five to ten years into the future. So, you must consider how to organize your point of contact with the customers. The organizational structure comes after this.

There are three processes: exploration, development and monetization

Motohashi: The open innovation consists of three processes: exploration, development and monetization. Exploration is a process in which new technology is researched and bound into a new product concept. Development refers to the process of producing an actual product or service, where efficiency is important. Monetization points to the process of formulating a business model that yields economic value from the product. As these processes are significantly different from one another, it is always important to be clear about which of the processes is in question. Otherwise, talking about open innovation without distinguishing these processes will be confusing.

Kondo: At present, our efforts in open innovation are mostly focused on the development process, and we need to address ways to expand into exploration and monetization.

We have set up a team within the Corporate R&D Headquarters to promote technology marketing, with a special focus on the exploration process. They conduct research into the technology necessary for us to maintain our competitiveness based on probable

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1984: Joined Fuji Electric Manufacturing Co., Ltd. (now Fuji Electric Co., Ltd.)
2007: Director, Fuji Electric Advanced Technology Co., Ltd.
2012: President and Chairman of Fuji Electric Holdings (Shanghai) Co., Ltd.
2013: General Manager of Instrumentation and Control Systems, Industrial Infrastructure Business Group, Fuji Electric Co., Ltd.
2016: Deputy Corporate General Manager of Corporate R&D Headquarters, Fuji Electric Co., Ltd.
2017: Executive Officer of Fuji Electric Co., Ltd.
Corporate General Manager of Corporate R&D Headquarters.

future market trends.

One famous machine manufacturer, which you may also know about, works to deliver ICT solutions to customers as its strategy so as to reduce time and financial burden on the customer side. To realize this strategy, the company takes ICT technology that it lacks from external sources both in Japan and abroad. Meanwhile, it ensures within the company that its machines are fit for the market. This system would nicely incorporate the exploration phase.

Put Fuji Electric in this context—our customers are always faced with the challenge of reducing CO_2 emissions. In some cases, we are not entirely clear about what we should carry out ourselves and what we expect from external sources in order to provide solutions to that challenge. Given this as a context, will open innovation still be a viable option to create business opportunities?

Motohashi: As you say, this company has a clear strategy to expand its business through services catering to the needs of the construction industry, which is the client. With a clear strategy in place, it can explore the market through open innovation.

Conversely, open innovation would not work very well without having a clear strategy. For example, take energy as a field. Should the market to focus on be in Japan or abroad? What will be the future trends in the energy mix, such as thermal, renewable, and nuclear power generations? It is a good exercise to prepare several scenarios of future prospects. In this exercise, you should consider whether you will choose to get involved with the energy industry as a whole, like the machine manufacturer did, or rather focus on just one part of it. Then, this becomes your strategy.

Kondo: That means, what we need to do is to correctly understand our strategy from the viewpoint of how our strengths are seen from outside. We need an appeal to be chosen as a partner when engaging in open innovation.

Motohashi: Industry-academia collaboration is also a mode of exploration in open innovation. However, it is not always easy in terms of efficiency to turn the cutting-edge technology that these universities propose into marketable products. The point of entry should be as close to the exit point as possible. If this were a startup company, the exit point would be much closer as such businesses tend to align themselves with the marketplace. In this sense, corporate venture capital (CVC) also offers itself as a path for exploration.

Kondo: As far as CVC is concerned, we are willing to collaborate with companies on a business basis if it generates synergy in terms of business or technology. However, we are not absolutely sure that the concept is congenial in Japan in terms of the mentality and speed.

Motohashi: That is a big question. In recent years, China has been giving rise to numerous startup companies. Some data indicate that their investment almost equals the venture capital investment in the United States for 2015. That is 50 times the figure for Japan. I conduct research on VC and venture businesses in Shenzhen from the Sun Yat-sen University in Guangzhou. I find that they make investment decisions very quickly, far speedier than our counterparts in Japan.

Kondo: There was a time when Fuji Electric had laboratories in China and the United States, aiming to accelerate localization. It is important that local needs are properly understood in the local context, be it research or product development. There are also differences in how customer collaboration is employed in performing the development processes. The idea was to have a function, in order to address these aspects, for the development of a commodity or modification to suit local practices. We no longer have these independent laboratories as we have fully established produc-

tion and engineering bases. Thus, we are coming to the point where it is necessary to consider, once again, how to bolster the exploration function.

Nevertheless, given the internal and external situations, it may be worth considering reinstating those laboratories outside Japan. The big issue is what functions these laboratories should have.

Motohashi: I think that localization depends on the market. For example, foreign affiliate companies, including those from Japan, would not be able to engage with State Grid Corporation of China independently for national security reasons. It would be necessary to participate in a joint project with Tsinghua University, which is involved in national projects. In this case, direct involvement from the Japan side is not possible, and therefore an independent local base is needed.

If you aim to collaborate with foreign startup companies that possess their own technology, small local bases would suffice. China is advanced in image recognition technology, and the United States and Europe similarly have their strong suits. In this case, it is a good idea to have local bases in respective areas, and have dedicated staff members travel between them globally, reporting to the Japan headquarters by teleconference once a week, for example. Ultimately, these bases could also function as information radars, catching and transmitting information on local suppliers, joint research projects at local universities, and so on.

Two roles for enterprises in the ecosystem

Kondo: What would you say about the monetization phase?

Motohashi: One of the important concepts in monetization is "ecosystem." This is a concept that Harvard Business School professor Marco Iansiti advanced. It refers to an aggregate organism of businesses that complement each other concerning one instance of innovation. In this business ecosystem, there are two roles: keystones and niche players.

For example, the Android OS of Google LLC is a keystone. It is not there simply for the company's profits, but as an attractive platform for many niche players to make profits. In this way, it grows the ecosystem itself.

Whether to aim to be a keystone or make profits as a niche player is a major decision to make as a business.

Kondo: There is also competition among different ecosystems.

Motohashi: That's right. Fuji Electric must have been benchmarking competitors so far, but the future is to consider them in terms of ecosystems. Which competitor supplies to which ecosystem? There may be some companies that are involved in several ecosystems.

Kondo: For Fuji Electric to survive in the 21st-century market, we should aim to establish ourselves as an indispensable player for the ecosystems that keystones will build upon considering the world's major trends.

When we created the IoT Strategy Department two years ago, we set the objective of not becoming a platform provider, but being a provider of applications compatible with any platform. In order to be able to offer solutions that correctly address customer needs, we focus our efforts on bolstering our applications and the technology that supports value creation for them.

Motohashi: I think that niche players offer tremendous value. Data is a determinant factor for services, and it is generated in a niche area. The platform provider does not possess all the data.

Moreover, the B to B environment today has developed a great number of platforms. Therefore, it is an

excellent strategy to aim for universal compatibility in case one of them outplays the others.

It may become necessary to be selective about the company's own core technology. In such a case, the most important point is that customers' intended directions to proceed in are understood appropriately. It is also important to have confidence in the company's competence so that, if necessary, it could make alternative suggestions to the customers.

Competent personnel in open innovation

Motohashi: Line managers are normally fully occupied in their regular responsibilities. Ideally speaking, therefore, open innovation should be pursued from one level up, such as a CTO for open innovation.

Kondo: There seems to be a trend of establishing a division within a company, dedicated to open innovation.

Personnel selection for such a division must be vital. In your opinion, is there ideal competence for this role? At Fuji Electric, we formed a team of individuals who came from diverse technical backgrounds, such as devices, power electronics, system engineering and overseas business.

Motohashi: I have, for a long time, been a project leader at the 21st Century Public Policy Institute under the Japan Business Federation. As part of our research into open innovation, I have conducted surveys on business enterprises on several occasions. There, many companies report that they lack personnel for open innovation. Several reasons come to my mind, but the major one could be that sales personnel in Japanese companies tend not to have connections outside their business domain. By comparison, researchers often know someone outside their specialized areas as they take part in academic conferences. In this sense, I think that researchers are rather competent in the role of engaging in open innovation. Other than this, there should be a few persons competent in managing the operation as a whole. The CTO office of the machine manufacturer that we talked about earlier is staffed with fewer than ten members. No large organization is necessary for this purpose.

Kondo: How should we evaluate the effectiveness and outcomes of open innovation? We find it difficult to establish key performance indices (KPIs) as some research projects take a long time before commercialization.

Motohashi: An example may be useful from the initiative taken at a certain company. They made it mandatory that R&D project proposals include a comparison of cases using internal and external resources. With this exercise repeated regularly, the overall R&D management will become accustomed to cases of open innovation as regular features. By integrating these cases into a budgeting system, KPIs will take form by necessity.

Kondo: We currently estimate possible investments for the research projects conducted by universities, supposing that we carried them out internally. We can simply extend it to budgeting.

This conversation has made clearer the challenges in open innovation. Essentially, the key is to have innovation strategies of Fuji Electric, paving way to the future of the company's businesses. We would like to proceed them by giving consideration to these accounts, together with the role distribution and the organizational structure.

Motohashi: Devising strategies requires rich and deep insight, not only into the trends at immediate competitors, but also clients, their competition at clients, or information about suppliers. It is an idea to leverage information obtained from consultants or think tanks, or even agents specializing in match-making for open innovation. This is also a point which requires an open attitude.

Kondo: I see. It reminds me once again that we should convey the strengths of Fuji Electric appropriately to outside communities while it is equally important to take in external information.

It has been a very informative time and I've deepened my understanding about open innovation. Thank you very much for your invaluable observations and opinions.

Achievements and Future Outlook

Solutions That Create Customer Value Through Competitive Components, Systems and Use of IoT

KONDO, Shiro
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Executive Officer, Fuji Electric Co., Ltd.

1. Introduction

Fuji Electric pursues innovation in energy and environment technologies and utilizes its world renowned semiconductors technologies as a core in order to offer distinctive components for power electronics equipment. Furthermore, we are enhancing our system products by combining measurement and control technologies with these components and using Internet of Things (IoT) technologies to collect data in order to provide customers with new value through data analysis that uses the latest mathematical techniques.

We set "promoting efficient R&D that creates customer value and increases sales and profits" as one of our R&D policies and have reformed our R&D activities. We have consolidated product development functions into the Development Division of each business group since FY2017. We have now completed the desired reorganization and have clearly established a system in which the Corporate R&D Headquarters is in charge of common fundamental technologies and advanced technologies. Moreover, for Design Review, which functions as stage gate review, to enhance its upstream processes, we have constructed a framework for verifying customer value while we also improved product planning capabilities by establishing a technology marketing department. We have also strengthened our advanced technologies and common fundamental technologies to create further competitive components and systems.

2. Solutions That Utilize IoT to Create Customer Value

IoT is a general term used to describe the concept of systems that collect and accumulate on-site data to create new value in cyberspace. Fuji Electric has been promoting utilization of IoT by treating it as techniques to improve productivity and quality and reduce costs from the viewpoint of users, as well as to expand business and reform business models from the viewpoint of vendors. In FY2017, we completed the basic development and cloud-migration development of an IoT platform that acts as the infrastructure for easily integrating field devices and analysis and optimization technologies (Data analytics). Specifically, we have developed IoT platforms with various functions, including an interface function useful for easily constructing

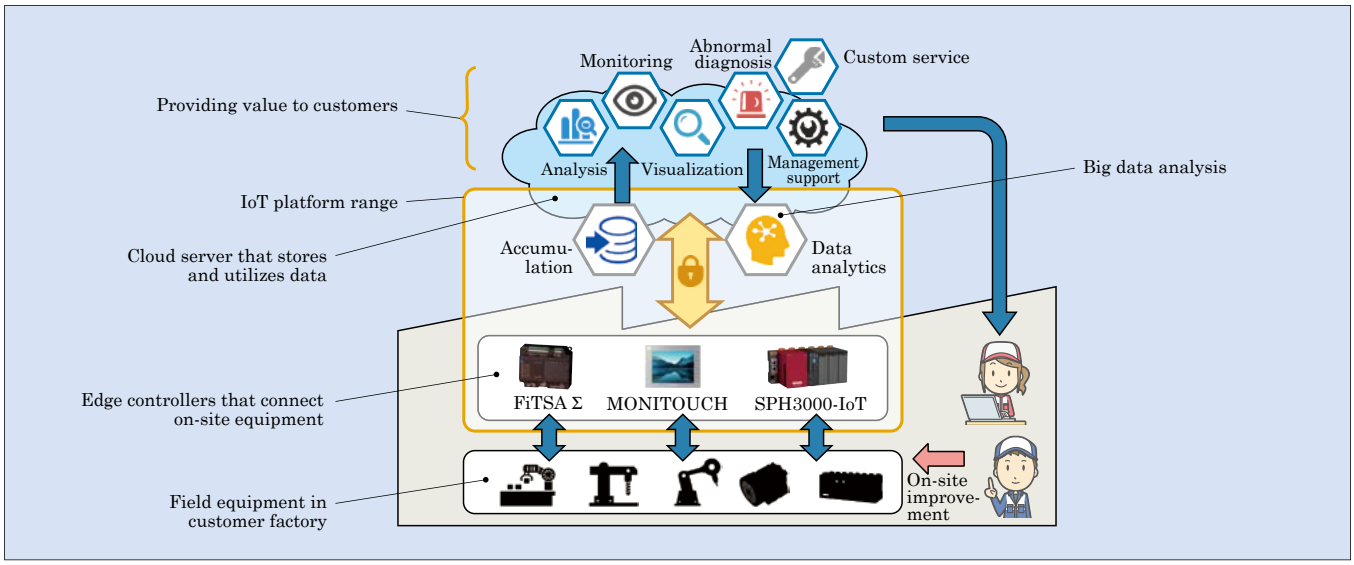


Fig.1 IoT platform

services based on general-purpose cloud technologies, communications functions that connect the cloud with edge controllers that collect and process data from on-site equipment, security functions, and a mathematical engine that diagnoses, forecasts and optimizes data (see Fig. 1). In addition to developing these platforms, we have used IoT in our factories and promoted projects for verifying the effectiveness of IoT solutions in customer fields. Performing these verifications, we have increased use cases for improving productivity, enhancing manufacturing quality, improving operation and maintenance efficiency, strengthening plant efficiency, and ensuring process quality traceability. Fuji Electric has adopted the motto "Small, Quick Start & Spiral-Up" to expand use of IoT and collaborated with our customers using quick start IoT to create customer value.

3. Synergy between Power Semiconductors and Power Electronics Technology

The rapid spread of electric motorization in the automobile field has been a motivating factor for us in the development of automotive discrete modules, automotive power semiconductor modules, and sealed high-voltage contactors (HVC) for automotive applications, as well as automotive power electronics equipment that utilize these components. For automotive power semiconductor modules, important features to create customer value are reduced switching loss, size and weight reduction and high power density. In this respect, we have developed a high-power, direct liquid cooling insulated gate bipolar transistor (IGBT) module for automotive applications that utilizes a reverse-conducting IGBT (RC-IGBT), which mounts diodes and IGBTs on a single chip; a cooling system that integrates a lightweight aluminum high-performance heat-dissipating water jacket; and packaging technology using lead-frame for internal wiring (see Fig. 2). These technologies have enabled us to achieve the development of a 6-in-1 IGBT module with a large rated capacity of 750 V/1,200 A.

Silicon carbide (SiC) has been attracting attention as a next-generation semiconductor material that achieves lower loss even at higher switching frequencies and higher operating temperature than conventional Si semiconductors. We have developed a trench-gate structure based SiC metal-oxide-semiconductor field-effect transistor (SiC-MOSFET) and SiC equipped Schottky barrier diode (SBD) as devices that achieve world-class performance and stability. We have developed an All-SiC module with a newly structured package that uses copper pin connections and resin molding technology. This newly structured module not only reduces internal inductance, but also makes high-temperature operation possible, thus enabling the development of high-speed and highly reliable SiC devices. We have expanded our product line-up of All-SiC modules that have a new structure: a 1,200-V/25- to 400-A rated module equipped with SiC trench MOSFET chip with a breakdown voltage of 1,200 V, and a 1,700-V/max. 270-A rated module equipped with newly developed SiC trench MOSFET chip with a breakdown voltage of 1,700 V (see Table 1).

As a power electronics product that makes use of this SiC-MOSFET module, which is characterized by its low loss, low heat dissipation and high operating temperature, we have developed the "FRENIC-eFIT" fanless environmentally-resistant inverter with a totally-enclosed self-cooled structure (see Fig. 3). It is expected to expand the range of applications in harsh environments and those susceptible to corrosive gases. We will use semiconductor modules that use SiC for various power electronics equipment that can create

Table 1 All-SiC module series

Package		Type 1B	Type 2B	Type 3LB
Dimensions (mm)		W 62 × D 20 × H 12	W 68 × D 26 × H 13	W 126 × D 45 × H 13
Rated voltage	Gate structure			
1,200 V	Trench	25 A, 50 A	75 A, 100 A	200 A, 300 A, 400 A
1,700 V	Trench	–	–	<270 A

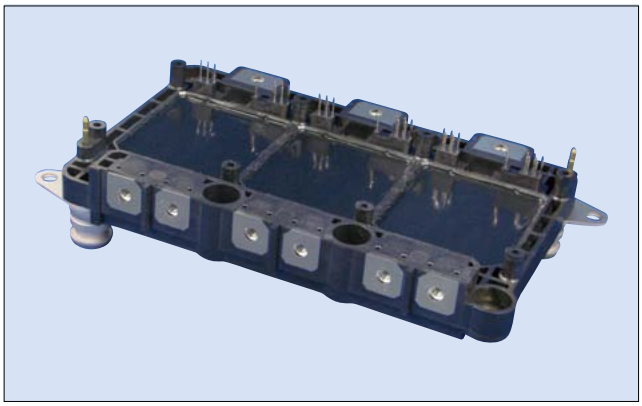


Fig.2 High-power, direct liquid cooling IGBT module for automotive applications

Fig.3 "FRENIC-eFIT" environmentally resistant inverter

added value.

4. Industry Solutions Field

The factory automation (FA) field has continued to grow as a result of active investment in factory automation. Fuji Electric has been working to meet the various customer needs in this field by developing competitive components and systems by using technologies of power electronics, control, and measurement equipment as core technologies.

We have launched medium and high capacity industrial inverters, such as the “FRENIC4400VM6” and “FRENIC4800VM6” and delivered them to steel and nonferrous manufacturers in Japan. These products are not only characterized by basic performance improvements such as expanded output frequency and enhanced control functionality, but also improved ease-of-use through expanded user support functions.

We have contributed to factory automation that require precise control by providing our motion control technologies using distinctive components, such as the “SPH3000D” motion controller and the “ALPHA7” servo system, which has been continuously developed since FY2016.

A system example for the automobile industry field that uses these technologies is a tire testing machine that is compliant with the Worldwide Harmonized Light Vehicles Test Procedures (WLTP) (see Fig. 4). By fully utilizing electric inertia control in combination with driving technology and precision control technology, driving load can be controlled in various types of driving mode, ranging from light vehicles to 4-t trucks.

Fuji Electric has been promoting IoT application for manufacturing processing lines and has developed the “MICREX-OnePack[(1)]” facility information collection system. This product can collect and aggregate data from manufacturing equipment by one cycle, which help a data collection system to be compact and low cost.

In the process automation (PA) field, we offer components and systems that contribute to the stable operation of production equipment and the reduction of energy unit consumption rates by using technologies of

Fig.4 WLTP compliant tire testing machine

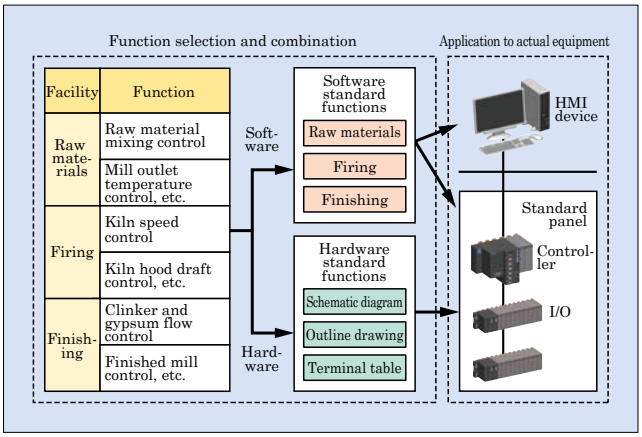


Fig.5 Monitoring and control system package for cement plants

drive control, instrumentation control and industrial electric heating as core technologies.

We have increased the functionality of the “MICREX-VieW XX” to enhance the stabilization of product manufacturing and facility operation and improve the usability of the monitoring functions. For the steel and nonferrous manufacturing field, we have replaced the large-scale monitoring and control system of steel plants with this system. For the cement industry, we have developed a monitoring and control system package for cement plants as an application platform that provides the functionality required in plant control (see Fig. 5). This package will encourage the engineering activities of partners and users all over the world. In addition, we are also continuing to supply various monitoring systems in the food and beverage and power generation fields.

5. Energy Solutions Field

For the energy solutions field, we have provided switchgear, transformers, power system protective relays, power system monitoring and control systems, and distribution automation systems for the social infrastructure and industry field. These products are mainly based on large-capacity power electronics technology, which are used for substation systems and power distribution systems, and energy monitoring and control technology. In addition, we are developing uninterruptible power systems (UPS), facility-use power supply equipment and air conditioning equipment for data centers. As the data center market continues to grow due to the advances in information and communications systems and cloud technology, demand is increasing for UPSs with high reliability in addition to high efficiency. For the North American market, we have developed the “UPS7400WX-T3U” large-capacity UPS, which employs a module control function to meet this demand (see Fig. 6). Having a capacity of 330 kVA per module, this UPS can incorporate multiple modules to meet capacity needs. In addition, it can control the modules so that the load current value of each module is within the maximum efficiency region, and it can be

Fig.6 “UPS7400WX-T3U” large-capacity UPS for North America with module control function

repaired while supplying power, allowing it to be flexibly adapted for customer facilities.

We are also working on the development of smart inverters for which Europe and North America are leading the industry ahead of other regions in response to the increasing importance of creating measures to solve power system problems due to the large-scale adoption of renewable energies. Fuji Electric has developed a power conditioning system (PCS) equipped with system support functions and an intelligent electronic device (IED) that enables communication connection via IEC 61850 communications. Furthermore, we have developed a distributed energy resource management system (DERMS) for verifying its remote monitoring and control functions performed between smart inverters and a DERMS via IEC 61850 communications. We have delivered this system to Tokyo Electric Power Company Holdings, Inc. The system is currently in validation in the “Research and Development Project on Technologies to Respond to Power System Output Fluctuations” commissioned by the New Energy and Industrial Technology Development Organization (NEDO) (see Fig. 7).

We have developed various products that contribute to reducing controlboard wiring work, including new screwless products such as “GT-Λ” molded case circuit breakers and earth leakage circuit breakers, “SK” magnetic contactors, “TK” thermal overload relays, “CP30F” circuit protectors, and spring terminals for relay and timer sockets. All models utilize an easy-to-use push-in mechanism that requires no special skills. All wiring gets connected by simply inserting the product. These products have also acquired major overseas standard certifications, such as IEC and UL (see Fig. 8).

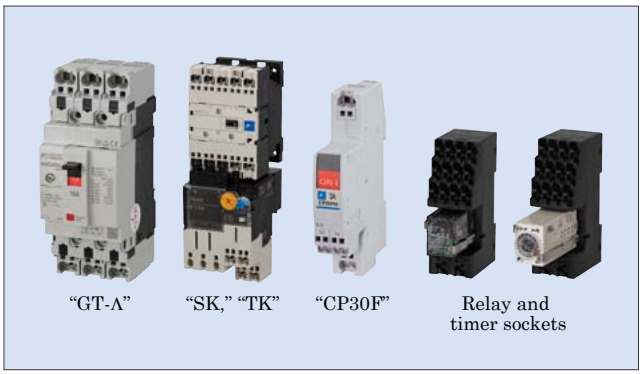


Fig.8 Push-in type labor-saving devices

6. Power Generation Field

In the field of power generation, in addition to thermal power and fuel cell technologies, we have been actively pursuing the use of renewable energies, such as geothermal, photovoltaic and wind, to help realize a low carbon society. We will deliver our complete power supply technologies to contribute to society.

We have delivered binary power generation facilities (Gross output: 4,990 kW) to Kyuden Mirai Energy Company, Incorporated. We received this order as engineering, procurement and construction projects (excluding civil work). Commercial operation of the facilities began on February 23, 2018 (see Fig. 9). This facilities effectively utilize hot water that has conventionally been returned to the ground without being used. Normal pentane has been used as a working fluid.

In the field of photovoltaic power generation, we received an order of photovoltaic power generation facilities with a rated capacity of 32.14 MW DC as the main contractor. Commercial operation of the facilities began in May 2018.

Furthermore, we participated in a NEDO project with the goal of developing a highly-efficient solid oxide

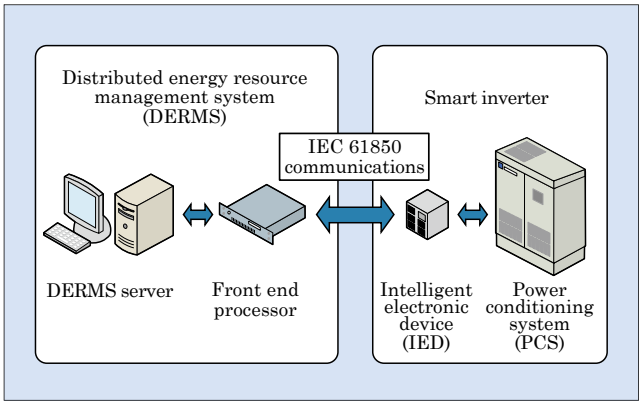


Fig.7 Smart inverter development

Fig.9 Binary power generation facilities

Fig.10 Solid oxide fuel cell (SOFC) system

fuel cell (SOFC) system. In the end, we developed a 50-kW class demonstration unit and evaluated it for a running time of 3,000 hours (see Fig. 10).

7. Food and Beverage Distribution Field

In the food and beverage distribution field, we took advantage of the technology we cultivated in cup vending machines to create a full-fledged drip coffee machine for overseas markets (see Fig. 11). By acquiring UL and NSF standard certifications, we have demonstrated a high-degree of safety, and we have been expanding this field of our business to markets all over the world including the United States and Asian countries such as China.

In Japan, we have partnered with Asahi Soft Drinks Co., Ltd. to develop a vending machine that makes it possible to sell cold beverages of subfreezing temperatures. These beverages utilize a supercooling phenomenon that “freezes through shock” and provide experience such as seeing a product freeze in front of one’s eye and enjoying snow-cone like texture in one’s mouth. Vending machines can help delivering effects to encourage consumption instead of simply selling things. Moreover, Fuji Electric is combining its expertise in IoT, mechatronics (system technology) and cooling and heating technologies to develop new products and services based on the 3 keywords of convenience, labor savings and energy savings in order to deal with labor shortages and reform the way people work in the distribution and retail industries in Japan.

Fig.11 Drip coffee machine for overseas markets

8. Fundamental and Advanced Technologies

Fuji Electric continues to implement research and development into fundamental technologies that commonly support the various technologies mentioned above and advanced technologies that contribute to future products. With respect to common fundamental technologies, we are engaged in experiments, evaluations, analysis and simulations related to the fundamental technologies of electromagnetism, insulation, electromagnetic compatibility, thermal fluids, machinery, resins and metallic materials. With respect to advanced technologies, we are engaged in research into semiconductor materials that can support future developments beyond SiC, as well as computational science that can predict material property and deterioration phenomena.

In the field of material technology, we have developed simulation technology that can predict the progress of corrosion in geothermal turbines through the use of a multi-phase field method (see Fig. 12). This technology can be used in product design and predictive maintenance in that it enables the uniform handling of ion diffusion and metal dissolution in corrosive fluids and can respond to various corrosive environments and corrosive modes. In addition to these applications, we will also apply the technology to make use of experiments and computation science in analysis of solid insulation and semiconductor interfaces.

In order to reduce the number of prototypes, we have developed a model-based design technology and are promoting innovative reforms in the design process stage of product development. We have established and confirmed the performance enhancements of a multi-purpose optimization technique for the temperature and sound properties of power electronics equipment through parametric 3D-CAD shape transformation and

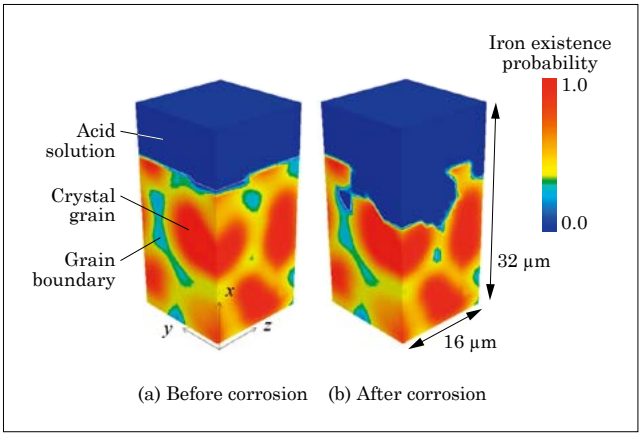


Fig.12 Simulation technology for predicting progress of corrosion

automation of analysis settings. In the future, we will apply this technique to product development through front loading.

In the field of thermal energy technology, we are currently developing a device for effectively generating high-temperature steam of 150 °C to effectively utilize conventionally unused low-temperature exhaust heat. For this development, we have developed a technology capable of two-stage compression in a single compressor to supply steam of high temperatures that cannot be achieved by conventional heat pumps that use 120 °C exhaust heat.

9. Postscript

In this paper, we have briefly introduced several of Fuji Electric's initiatives in technical development: technologies for safely and efficiently using electric energy while pursuing innovation in energy and environment technologies, technologies for effectively using thermal energy to contribute to energy savings, and solutions technologies for optimally controlling the above mentioned energies and connect them via IoT to increase added value. Fuji Electric has initiated the process reform in new product development and is constructing research and development system, which helps plan products that contribute to creating customer value and facilitates the research and development to contribute to these products.

In this way, we will pursue technical innovation and provide our customers with high-value-added, environmentally friendly products and systems to contribute to the creation of a responsible and sustainable society.

References

(1) Fujikawa, Y. et al. FA Solution That Applies IoT and Motion Control Technology, FUJI ELECTRIC REVIEW. 2018, vol.64, no.1, p. 11-15.

Reusable Storage Battery System for Consumers Compatible with Virtual Power Plants

Fuji Electric has been developing and demonstrating technologies by participating in the Virtual Power Plant (VPP) Demonstration Project promoted by the Ministry of Economy, Trade and Industry since FY2016, along with the Kansai Electric Power Company, Incorporated and others. In FY2017, we developed a reusable storage battery system for consumers that is compatible with VPP, cooperating with Japan Benex Corporation and Sumitomo Corporation. We have developed a standard system for the VPP Demonstration Project, whose electricity storage control is based on our technology. The following functions can be used as needed:

(1) Peak cut and demand control functions
(2) Business continuity planning (autonomous operation) function
(3) State of charge (remaining capacity) control function
(4) VPP linkage function

Furthermore, the electricity storage unit has achieved a loading efficiency twice that of previous products as the result of using the high-density loading design technology of Japan Benex Corporation. Reusable storage batteries equivalent to 24 EVs are housed in a 20-foot container. We will offer various customers this product as an auxiliary power source mainly at times of peak power demand in factories and buildings.

"WX Series" Large-Capacity UPS, Employing Module Control Function

In the UPS market, demand of high power supply reliability is increasing for UPSs used especially for data centers, which are expected to grow. The "UPS7400WX-T3U" of the "WX Series" large-capacity UPS employing module control function is designed for the North American market. Each UPS module is configured with a capacity of 330 kVA, and multiple modules can be combined to flexibly adapt to the customer facilities. The figure shows, from left to right, a UPS configuration composed of an I/O module, control module and 4 UPS modules.

(1) A module redundancy control function allows the inverter to continuously supply power even when a failure occurs by disconnecting a failed module. Furthermore, the disconnected module can be repaired while the UPS continues to supply power, thus improving the reliability of the UPS power supply.
(2) The UPS efficiently operates over a wide range of equipment loads by controlling each module to run and stop so that the load current value of each module can be within high efficiency region.

"GT-Λ"

"SK," "TK"

"CP30F"

Relay and timer sockets

New Push-In Type Products That Contribute to Reducing Wiring Hours for Panels

Fuji Electric has offered new screwless products that contribute to reducing wiring work of controlboards: "GT-Λ" molded case circuit breakers and earth leakage circuit breakers, "SK" magnetic contactors, "TK" thermal overload relays, "CP30F" circuit protectors, and spring terminals for relay and timer sockets.

All models utilize a push-in mechanism, which requires no special skills and allows anybody to quickly complete wiring by simply inserting the product, delivering usability. The use of this push-in type design is a Japan first for components for main circuits (molded case circuit breakers, earth leakage circuit breakers, magnetic contactors, etc.).

Moreover, these products have acquired major overseas standard certifications such as IEC and UL.

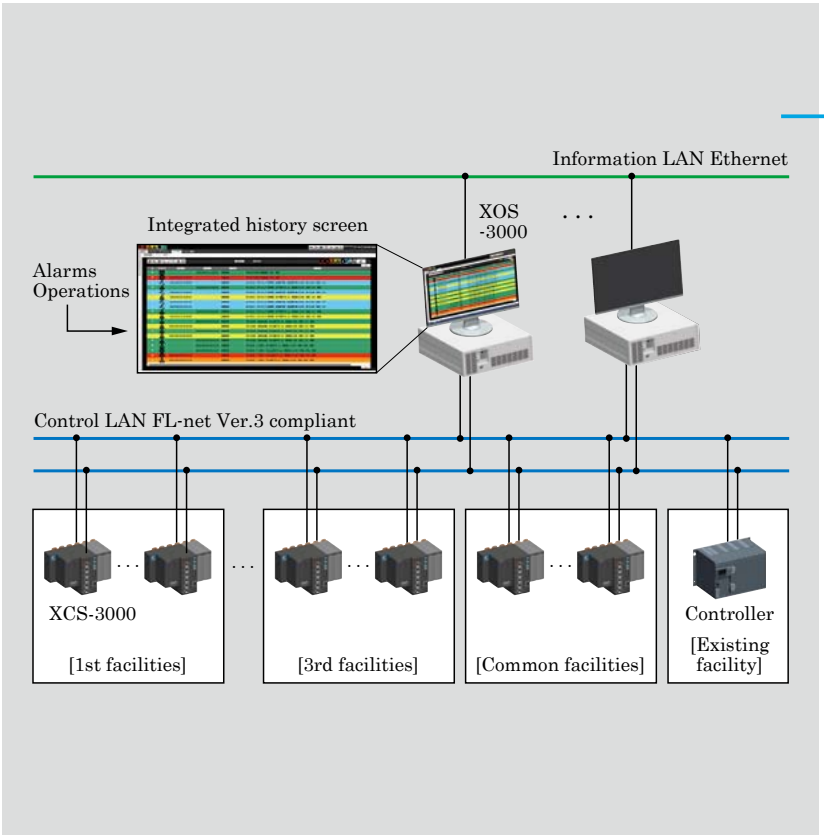
"FRENIC-eFIT" Environmentally Resistant Inverter

We developed the "FRENIC-eFIT" as an inverter that can be installed without using a protection housing in harsh environments such as outdoors or in the ambience susceptible to corrosive gases where inverters cannot usually be installed. The main features are as follows:

(1) Compliant with IEC standards environmental parameters (4K4H, 4C4, 4S3) and capable of a wide range of applications even in harsh environments.

(2) Equipped with low-loss All-SiC modules, It achieves a totally-enclosed self-cooled structure with fanless cooling for all capacity models. Furthermore, it provides maintenance-free operation without requiring fan cleaning or replacement.

(3) Optionally available with a Bluetooth keypad panel. A user can remotely edit function codes and monitor information of the inverter using a mobile device.



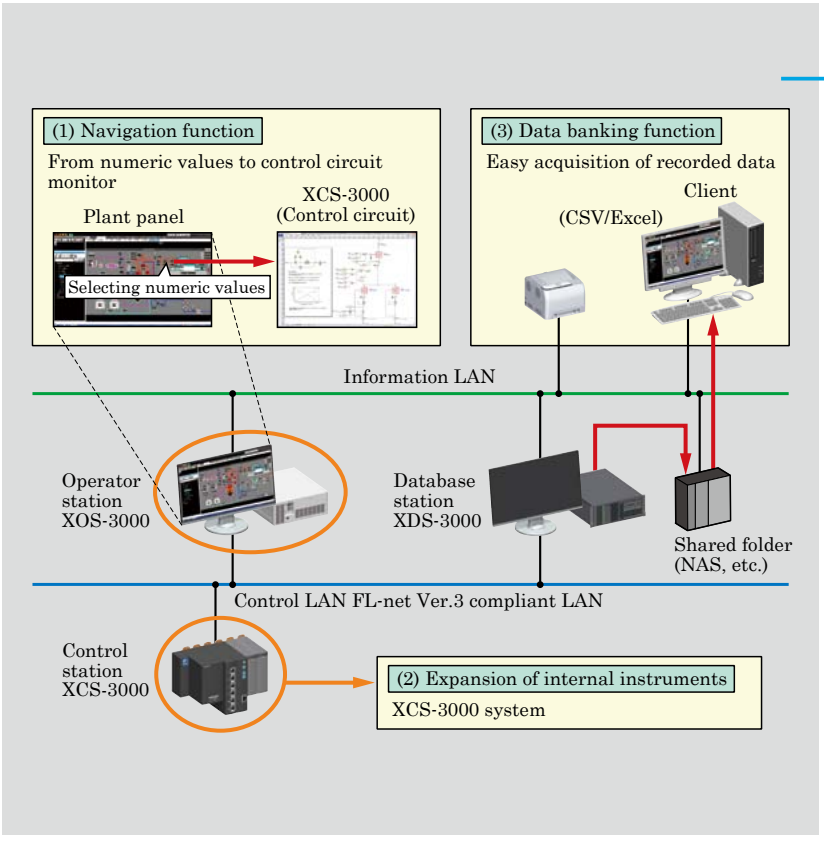
Replacement of Large-Scale Monitoring and Control System of Steel Plants by Using "MICREX-VieW XX"

Fuji Electric has replaced the large-scale monitoring and control systems of a steel plant by utilizing the latest model "MICREX-VieW XX." The features of the system after the replacement are as follows:

(1) The "XOS-3000" operator station's integrated history screen makes it easy to correlate operating actions with abnormalities by the facilities, thus speeding up the identification of abnormality causes.

(2) The use of the "XCS-3000" high-speed large-capacity controller can integrate control functions to achieve an optimal system configuration and improve maintainability.

(3) Using an open network (FL-net Ver. 3 compliant) for the control LAN allows the system to increase the volume of communication data and integrate other systems, achieving high scalability.



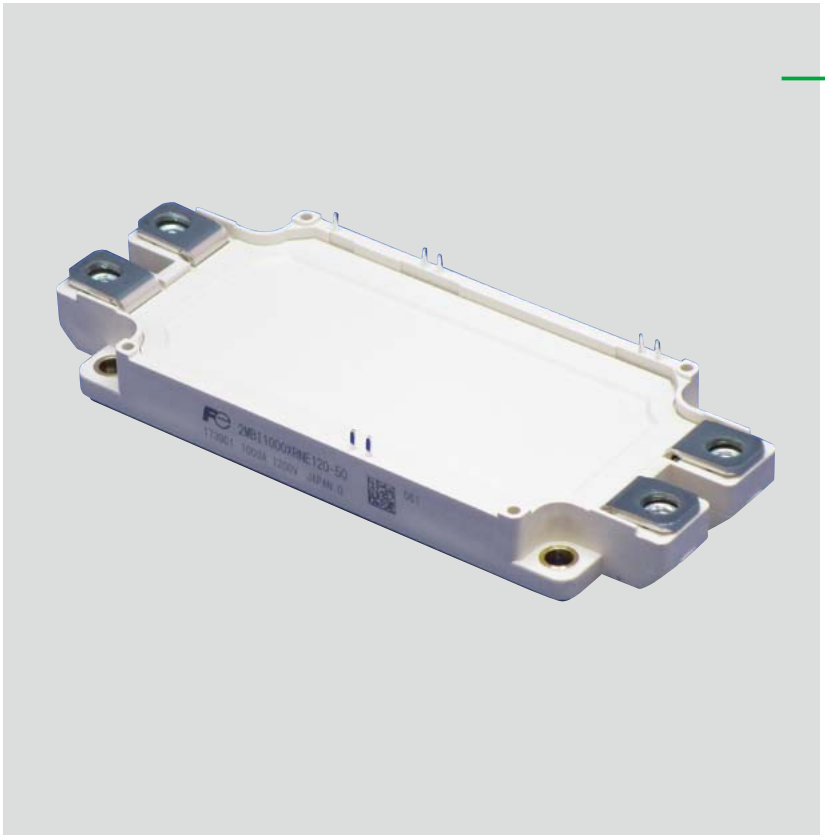
"MICREX-VieW XX" Functional Enhancement

Fuji Electric has enhanced the functionality of the "MICREX-VieW XX" monitoring and control system to help customers manufacture high-quality products, stabilize operation and easily monitor operation.

(1) We have developed the navigation function that links the value indication of a control loop (internal instrument) on a plant panel to a control loop application (control circuit), thereby making it possible to monitor the screen and check the operation of the control circuit.

(2) Cost effectiveness has been increased by improving the processing performance of the control station at each control cycle (200 ms and 1 s) by 20 % or more and increasing the number of internal instruments from 416 to 512.

(3) We have also developed a data banking function that makes it easy to retrieve recorded data such as historical data of operations, alarms, trends and reports from clients on an information LAN with csv or other format files.



7th-Generation "X Series" RC-IGBT Module for Industrial Applications "Dual XT"

In order to meet the market demand of the smaller size, lower power dissipation and higher reliability for IGBT modules, Fuji Electric has developed a reverse-conducting IGBT (RC-IGBT) that integrates an IGBT and a FWD on a single chip. We are expanding the line-up of the 7th-generation "X Series" RC-IGBT modules for industrial applications that has a rated voltage of 1,200 V and have developed the "Dual XT" equipped with RC-IGBTs.

The maximum rated current of the new module has expanded to 1,000 A, while the "Dual XT" of the 6th-generation "V Series" IGBT module for industrial applications have a maximum rated current of 600 A. Compared with the conventional product that uses the same package, the new product greatly improves the junction temperature rise of the chip during actual operation. It is expected that this module will contribute to the further increase of the output and the reliability for power converters.

Package		Type 1B	Type 2B	Type 3LB
Dimensions (mm)		W 62 × D 20 × H 12	W 68 × D 26 × H 13	W 126 × D 45 × H 13
Rated voltage	Gate structure			
1,200 V	Trench	25 A, 50 A	75 A, 100 A	200 A, 300 A, 400 A
1,700 V	Trench	–	–	<270 A

Series Expansion of Modules Equipped with SiC Trench MOSFETs

SiC devices have been attracting attention on account of their potential to help achieve a low-carbon society through reduced power consumption.

Fuji Electric has been developing All-SiC modules that utilize a newly structured package that uses copper pin connections and plastic molding technology. This newly structured package not only reduces internal inductance, but also makes high-temperature operation possible, thus enabling high-speed and highly reliable SiC devices. We have developed rated capacity 1,200 V/25 to 400 A All-SiC modules equipped with breakdown voltage of 1,200 V SiC trench MOSFET chips for the newly structured package. Moreover, we plan to develop an SiC trench MOSFET chip with a breakdown voltage of 1,700 V to expand the line-up of All-SiC modules with ratings of 1,700 V/max. 270 A.

Start of Commercial Operation of Yamagawa Binary Power Station of Kyuden Mirai Energy Company, Incorporated

The Yamagawa Binary Power Station is the plant (Gross output: 4,990 kW) that Fuji Electric received the order from Kyuden Mirai Energy Company, Incorporated as engineering, procurement and construction project (except civil work). This power station is located in the Yamagawa Power Station, which is a geothermal power plant owned by Kyushu Electric Power Co., Inc. The commercial operation began on February 23, 2018.

In the binary system, low-boiling working fluid is vaporized by the heat source and the turbine is rotated by the vapor. The generator coupled with the turbine generates electricity. This power station effectively utilizes the heat of the brine that had been directly returned to the reinjection wells at the Yamagawa power station. Normal pentane has been used as a working fluid.

The turbine and generator were manufactured at our Kawasaki Factory and Suzuka Factory, respectively. The brine is highly corrosive and accordingly, an appropriate corrosion resistant material was selected for the heat exchangers.

Multi-PCS for Storage Batteries and Photovoltaic Power Generation

Photovoltaic power generation has the advantage of being clean energy that does not emit CO_2; however, it has the disadvantage of supplying an unstable amount of power since output is influenced by solar radiation. The number of power plants using storage batteries to compensate the power fluctuation has been increasing because this output fluctuation brings instability for power systems. For these types of power plants, Fuji Electric can offer a multi-PCS that is capable of connecting photovoltaic cells and storage batteries through DC/DC converters. This multi-PCS has the industry's largest capacity with a DC input of 1.5 MW for both photovoltaic cells and storage batters and an AC output of 1.1 MVA. In the case of combining a conventional photovoltaic power generation PCS and a storage battery PCS, a power plant is required to use a system interconnection transformer for each PCS. In contrast, the multi-PCS enables interconnection via a single transformer, thus contributing to reduction in system costs and installation area.

Fresh-Brew Drip Coffee Machine for Overseas Markets

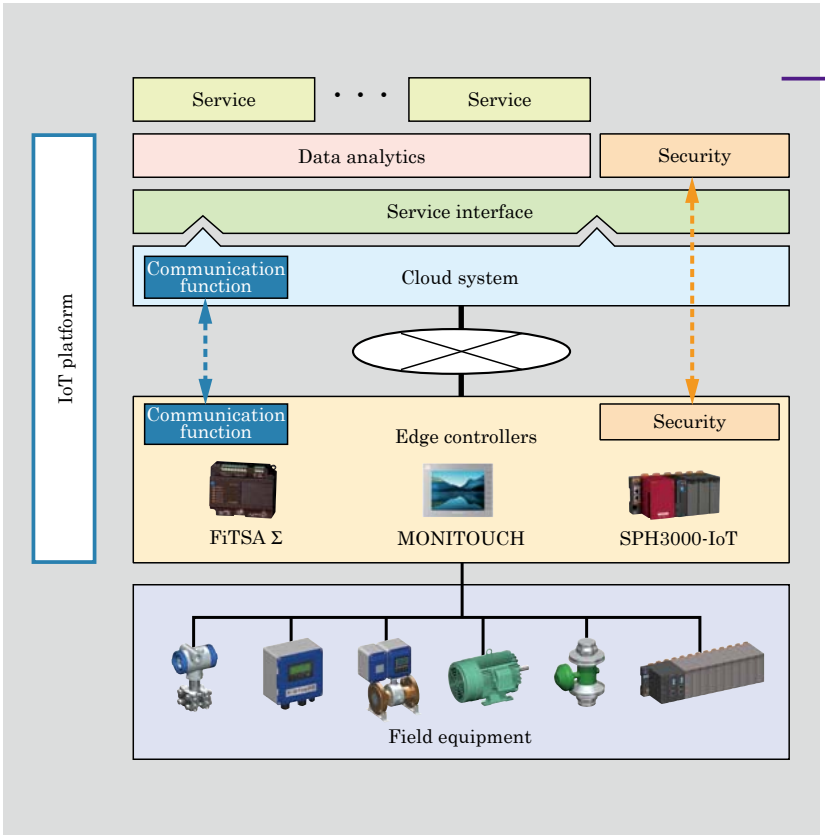
Fuji Electric has utilized the technology cultivated in the development of cup vending machines to create a counter-top fresh-brew drip coffee machine for overseas markets.

By acquiring UL and NSF standard certifications, we have demonstrated a high-degree of safety. We aim to offer this model to the global market, including the United States, China and other Asian countries.

The main features are as follows:

(1) The newly developed brewer (component for extracting coffee) uses our unique stainless steel mesh filter to extract high-quality coffee as good as coffee extracted with a paper drip method.

(2) The machine can supply larger volume of coffee than existing one to meet the wide-ranging requirements of overseas markets. It is also equipped with wide cup stage space that a large-size bottle cup be located in.



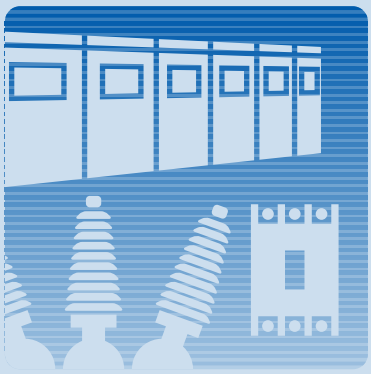
Fuji Electric's Common Infrastructure IoT Platform

The IoT platform is the infrastructure for IoT service that collects data from field equipment and provides new value for customers by utilizing data analytics technology. The platform equipped with service interface functions for easily implementing services on the basis of a general-purpose cloud system, edge controllers for collecting field data, communication functions for connecting the cloud system and edge controllers and security functions for protecting systems and data (see the figure).

The IoT platform delivers highly reliable and highly stable operation, reduces operating costs and facilitates the addition of new services, users and equipment by scaling out system resources.

We plan to start utilizing the platform in FY2018.

Energy Solutions in Power Electronics Systems



Energy Management
Power Supply and Facility Systems
Electric Distribution, Switching and Control Devices

Outlook

Energy Management

In the energy management field, Fuji Electric offers switchgear, transformers, power system protection relays, power system monitoring and control systems and distribution automation systems the social infrastructure and industry markets. These products are based on our core technologies, such as large-capacity power electronics technology for substation systems, power receiving and distribution substation equipment, and energy monitoring and control technology.

In Japan, we are mostly working to renew or extend the service life of existing facilities, but we are also engaged in meeting the needs of new facilities, such as those constructed for environmental or energy-saving needs or for the 2020 Tokyo Olympics and Paralympic Games. Overseas, there are some areas experiencing stagnation due to political instability, but on the whole, capital investment has been increasing slightly. We thus have been actively meeting this demand by strengthening our overseas bases.

In the electric power field, we have delivered 300-kV gas insulated switchgear (GIS) to a power company. In addition, we have developed and delivered 3-phase encapsulated gas insulated bus (GIB) in accordance with the standards of customer specifications.

In the industrial field, we have replaced an aging extra high voltage substation located in the vacant space in an existing substation using the structure directly connecting a cubicle-type gas insulated switchgear (C-GIS) with an extra high voltage transformer. Moreover, we have been working to develop the market for our small- and medium-capacity "S-Former Mini" along with the "S-Former" large-capacity rectifier for aluminum refining and chemical plants.

In the transportation field, we have delivered a regenerative power absorption system for a substation of an electric railway company. This system collects kinetic energy as electric power when trains brake, and then effectively use it as a power source for the lighting and electric facilities of train stations, thereby contributing to the reduction of electricity consumption. We have also delivered large-capacity storage battery equipment for emergency train running so that the trains can reach the nearest station even in the event of an extensive power outage caused by a disaster such as a large-scale earthquake.

In the power distribution field, for a power company, we have developed and delivered a motor and synchronous generator with a rated output of 300 kW to reduce the impact on power systems at times of power grid accidents caused by the large-scale introduction of renewable energies. Although the equipment is rather large for commercial applications, it runs on battery without consuming fuels. Since increasing importance has been placed on solving system problems due to the large-scale adoption of renewable energies, we are working on the development of smart inverters, of which Europe and North America have been leading. In addition, we have developed, and delivered a simulated smart grid power generation system that can be used in simulated training exercises that require a stable supply of power in response to cyber attacks on social infrastructure. Furthermore, we have developed and delivered a reusable storage battery system for consumers that is compatible with virtual power plant (VPP) used for VPP demonstration projects commissioned by the Ministry of Economy, Trade and Industry.

We will continue developing technologies that solve customer issues and contribute to the market so that we can meet expectations in delivering new technologies and techniques for the social infrastructure and industrial markets while also accelerating the development of power system innovation and hybrid energies and satisfying the increasing demand for power stabilization and voltage control.

Power Supply and Facility Systems

In the field of power supply and facility systems, we use our core power electronics technology to offer uninterruptible power systems (UPS), facility-use power supply equipment and air conditioning equipment for data centers.

UPSs for continuously growing data centers, spurred by advances in information and communication

systems and cloud technology, are required to become more efficient and supply power more reliably. The "UPS7400WX-T3U," developed for the North American market, has a redundant system and can recover by the replacement of a failure module while feeding electricity. Furthermore, each module is controlled to operate within a highly efficient operating range, thereby improving the efficiency of the UPS at a wider range of equipment loads. Moreover, to meet the demand for a smaller installation footprint, we have developed the "7000HX" (500 kVA) and "6000DX" (100 to 300 kVA) that employ lithium-ion batteries with a high power density.

We are working on the development of a highly-scalable modular UPS platform to promptly meet the growing demand for controlling heat-dissipation and optimal air conditioning owing to the scale expansion of data centers and various regional characteristics and market needs lead by globally expanding markets. In this manner, we intend to continuously develop products that meet market demands and provide power supply and facility systems laying the foundations of social infrastructure to contribute to society.

Electric Distribution, Switching and Control Devices

In the field of electric distribution, switching and control devices, there is growing demand for distribution equipment and switching devices to efficiently and safely utilize electricity and control equipment to automate and optimize the performance of production facilities and production machinery in renewable energy related facilities, building and facility electrical equipment, and factory production line control systems.

As for low-voltage distribution equipment and switching devices, we have developed the "GT-Λ" molded case circuit breaker and earth leakage circuit breaker, which uses spring terminals to reduce control panel wiring work, "SK" magnetic contactor, "TK" thermal overload relay, "CP30F" circuit protector, and sockets for relays and timers. The use of this push-in mechanism is a Japan first for components used with main circuit systems.

For the protective relay for distribution equipment, we have developed the "F-MPC60G Series" multifunctional digital relay with color-LCD that improves visibility and operability. It has improved reliability with self-diagnosis functions based on a duplicated CPU and other features.

Energy Management

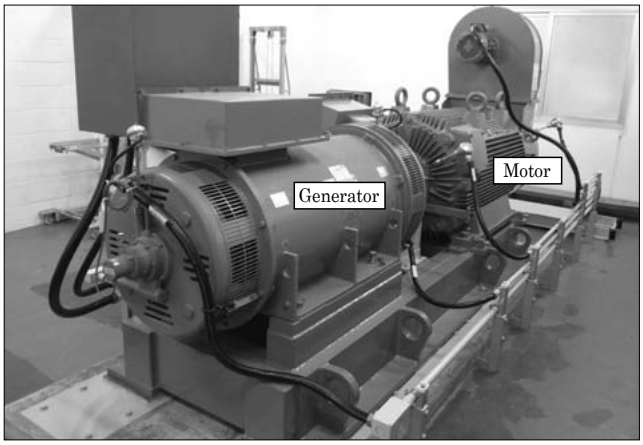
1 Motor and Synchronous Generator for Hateruma Power Plant of the Okinawa Electric Power Company, Incorporated

The Okinawa Electric Power Company, Incorporated was commissioned by Okinawa Prefecture to undertake the "Smart Energy Island Project" (a project for introducing renewable energy to a maximum extent at small remote islands). It is against this backdrop that Fuji Electric supplied the Hateruma Power Plant of the Okinawa Electric Power Company, Incorporated, with a motor and synchronous generator with a rated output of 300 kW. The main features are as follows:

(1) This recently delivered motor and synchronous generator are not restricted by the lower limit value of power generation, unlike conventional generators, thereby allowing it to contribute to the expanded use of renewable energy.

(2) The motor can run on storage batteries to create power to generate electricity, the power plant can thus interconnect with the grid by charging battery from renewable energies, instead of consuming fuel.

Fig.1 Motor-synchronous generator



Energy Management

2 Simulated Smart Grid and Power Generation System

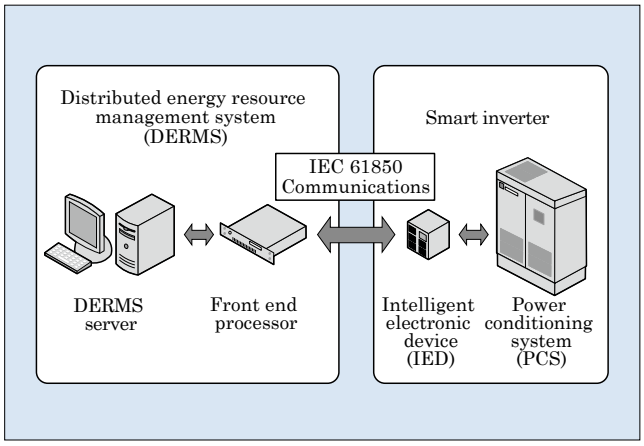
The Industrial Cyber Security Center of Excellence, Information-Technology Promotion Agency, Japan has been training personnel who will be able to respond to security risks through practical exercises and analysis of defense techniques against attacks by using a simulated plant to counteract the increasing number of cyber attacks launched on social infrastructure. Fuji Electric has delivered a simulated smart grid and power generation system to the Industrial Cyber Security Center of Excellence. The system is used to simulate an independent power system, such as one used on a small island, and is composed of an energy management system (EMS) and a simulated plant having a diesel generator, storage battery for frequency regulation, photovoltaic power plant, and wind power plant. The simulated plant simulates the operation that constantly maintain the grid frequency through governor free control for the diesel power generator and load frequency regulation of the EMS in response to demand fluctuations in the grid to provide a stable supply of electric power. In this way, it is used in exercises that simulate social infrastructure.

Fig.2 External appearance of simulated plant

3 Smart Inverters

The smart inverter is a power conditioning system (PCS) that has a grid support function with autonomous-control and communication interfaces conforming to international communication standards. In Europe and the United States, smart inverters have been increasingly used to address the system problems caused by the introduction of large amounts of renewable energy. Optimally operating smart inverters need to use a distributed energy resource management system (DERMS). Fuji Electric has developed a PCS equipped with grid support functions, such as Volt-Var control and Frequency-Watt control, and an intelligent electronic device (IED) that can connect the system via IEC 61850 communications. Furthermore, we have developed a DERMS system for verifying its remote monitoring and control functions between a smart inverter and DERMS through IEC 61850 communications. We have delivered this system to Tokyo Electric Power Company Holdings, Inc. and continue to verify it in the "Research and Development Project on Technologies to Respond to Power System Output Fluctuations" commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

Fig.3 System configuration of smart inverter and DERMS



Power Supply and Facility Systems

1 Large-Capacity UPS Using Lithium-Ion Batteries (LiBs)

The development of information communication systems in our IT based society has led to growth in data center markets all over the world, and it is against this backdrop that there is increasing demand for UPS systems to provide more stable operation, higher efficiency and a smaller installation footprint. Fuji Electric has used lithium-ion batteries (LiBs) manufactured by Samsung SDI Co., Ltd in expectation of space-savings for our 400-V UPS "7000HX" (500 kVA) and 200-V UPS "6000DX" (100 to 300 kVA). Specifications of LiBs per rack are as follows:

(1) Life expectancy

15 years (ambient temperature 25°C; 5% discharge/24 times a year; 100% discharge/twice a year)

(2) Rated capacity

34.6 kWh (400-V type), 24.4 kWh (200-V type)

Fig.4 Lithium-ion Battery rack

Electric Distribution, Switching and Control Devices

1 "F-MPC60G Series" Multifunctional Digital Relay

Various types of protective relays are used to detect power abnormalities, maintain and control equipment in power distribution facilities. Fuji Electric has developed the "F-MPC60G Series" multifunctional digital relay based on the concepts of "improved visibility," "enhanced operability" and "globalized product" The main features are as follows:

(1) Comes with a color LCD that improves visibility and operability.
(2) Configured with a duplicated CPU and peripheral circuits, a self-diagnosis function detects malfunction and prevents unnecessary operation.
(3) Compatible with previous products with respect to external size, mounting structure and wiring.
(4) Equipped with an accident waveform recording function that helps investigate causes during protective operation, a PC support tool enables data extraction.
(5) Compliant with IEC standards (IEC 60255 series), it can meet specifications of overseas customers.

Reference: FUJI ELECTRIC REVIEW 2017, vol.63, no.3, p.163

Fig.5 "F-MPC60G Series"

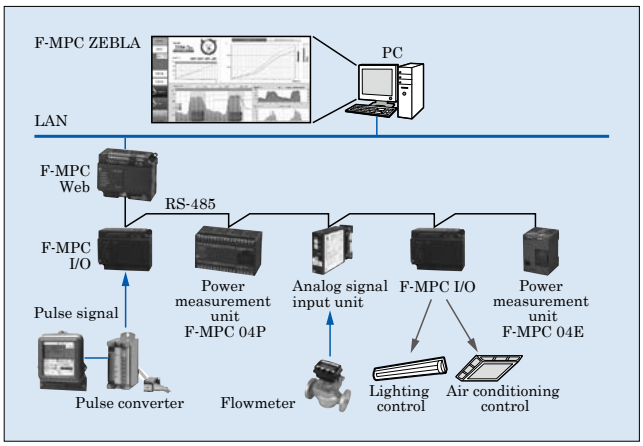
2 "F-MPC ZEBLA"

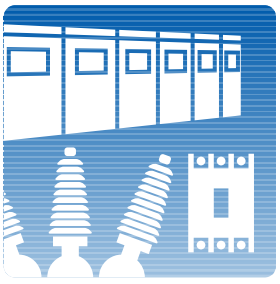
"F-MPC ZEBLA" is an energy management software package that has been developed for a medium and large scale building and energy management system (BEMS). The main features are as follows:

(1) Hourly demand for the day can be predicted on the basis of past energy demand data.
(2) As long as a user simply set annual energy reduction targets, the software automatically creates monthly and daily targets on the basis of past accumulated data and the operation schedule (calendar) of the plant. Energy-saving control based on hourly demand predictions is implemented so as not to exceed consumption targets.

Reference: FUJI ELECTRIC REVIEW 2017, vol.63, no.3, p.168

Fig.6 System configuration example of energy management system using "F-MPC ZEBLA"





Industry Solutions in Power Electronics Systems

Factory Automation
Process Automation
Social Solutions—Transportation and Radiation Monitoring
Information Solutions

Outlook

Fuji Electric creates competitive components to strengthen and develop systems for the industrial and social infrastructure fields, contributing to various fields through the expansion of these systems in overseas markets.

Factory Automation

For the field of factory automation, we offer components and systems based on our core technologies, such as power electronics , control and measuring equipment.

As for inverters, we have developed the "FRENIC-eFIT" that can be installed alone in harsh environments such as outdoors or in areas susceptible to corrosive gases. Furthermore, fanless cooling structure achieves maintenance free for all capacity models.

For rotating machines, we have developed brake motors compliant with the efficiency regulations of China and the United States. These motors have the same interface dimensions as conventional standard efficient brake motors, encouraging the replacement.

For the automobile industry, we have developed a tire testing machine that is compliant with the Worldwide harmonized Light vehicles Test Procedures (WLTP). By utilizing electric inertia control, it can control loads equivalent to a range of a light vehicle to 4-t truck.

For the field of factory energy saving, we have offered an exhaust-heat based steam generation heat pump that generates 150 °C steam by recovering the heat generated by hot wastewater. This product will make it possible to save energy in sterilization and drying processes. Moreover, expanding the functionality of ISO 50006-compliant energy management systems allows customers to reduce the analysis workload and increase the speed of operational efficiency improvement activities that use inverters and exhaust-heat based heat pumps.

For the field of measuring instruments and sensors, we will develop competitive components that can support systems by more clearly specifying application and usage locations. In order to expand applications in the petrochemical industry, we have developed the "FST" explosion-proof spool piece ultrasonic flowmeter, which achieves the accuracy level equal to Coriolis flowmeters at a more reasonable price.

Process Automation

For process automation field, we offer components and systems that help stabilize production equipment and reduce unit consumption. These products are on the basis of our core technologies, such as drive control, measurement and control, and industrial electric heating for induction furnaces and induction heating equipment.

In the field of steel and non-ferrous metals, we have replaced the large-scale monitoring and control system of a steel plant with the system using the "MICREX-VieW XX." In overseas markets, we have delivered electrical equipment designed to meet functional safety requirements to a continuous hot-dip galvanizing line.

For the cement industry, we have developed a monitoring and control system package for cement plants as a platform that provides the functionality required in plant control. This package facilitates the engineering activities of partners and users all over the world.

For the industrial electric heating field, we have applied electromagnetic field analysis and thermal analysis technologies to induction heating equipment for sheet metal and intend to use these technologies in new applications.

Social Solutions—Transportation and Radiation Monitoring

In the field of rolling stock, we have delivered door driving systems to Singapore's Land Transport Authority (LTA). The systems use domestically proven rack-and-pinion door driving systems to improve the reliability and safety of the trains. The New trains using the systems started commercial operations in June 2017.

For the radiation monitoring equipment and systems industry, we have been promoting the development in new fields such as those that can be used in obtaining large projects, reactor decommissioning

measures and new services in Japan. Our new electronic personal dosimeter can simultaneously measure gamma rays and neutron rays with just a single device, thereby raising expectations of its usage in nuclear facilities that generate neutron rays. Furthermore, its communications functions enable it to connect with remote monitoring systems and contribute to reducing worker radiation exposure.

Information Solutions

In the field of information solutions, we are developing tools and systems that help streamline the operations of local governments and companies. We have developed the "ExchangeUSE" V11, which uses the usage history data stored on transportation IC cards, can reduce the amount of work required in adjusting traveling expenses. We have also developed "Karuwaza Web 7.0," having multi-language interface, allows non-technical users in administration departments to easily search and total information stored on various databases within the company.

Factory Automation

1 Brake Motors Compliant with Overseas Efficiency Regulations

There has been a continued expansion of efficiency regulations for motors (3-phase induction motors) in various countries and regions to save energy . Brake motors are also subject to the regulations. Fuji Electric has developed brake motors compliant with the efficiency regulations of China and the United States and obtained the following certifications:

(1) For China [0.75 to 15kW (4-pole, 6-pole rated at 11kW)]
GB18613-2012 GB2 (efficiency class IE3), China RoHS and CCC certification (only applicable models)

(2) For the United States [0.75 to 15kW (4-pole, 6-pole rated at 11kW)]
NEMA MG1-12-12 NEMA Premium (efficiency class IE3) certification

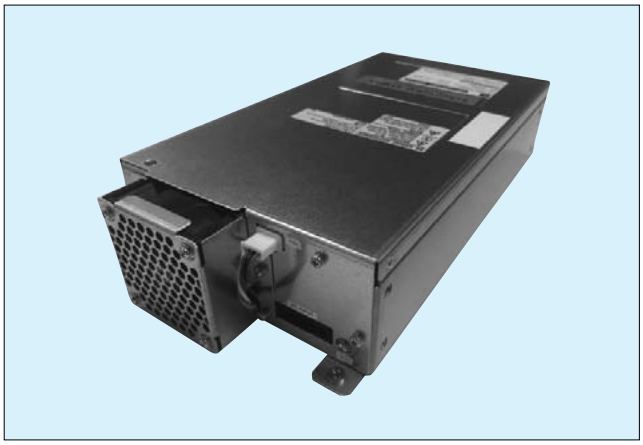
They have identical frame size and mounting dimensions with existing standard-efficient brake motors, facilitating replacement.

Fig.1 Brake motor with class GB2 certification for China

2 "FIP Series" DC Backup Power Supply for Industrial Equipment

There has been an increased investment in IoT in industrial fields worldwide and rising demand for automated manufacturing lines, especially in China, and these economic conditions are driving the market for manufacturing equipment such as semiconductor manufacturing equipment and industrial robots. AC-DC power supplies are often used for the operation and control of these types of equipment and are required to deal with requirements on an individual basis because the specifications, such as dimensions and outputs, of each piece of equipment differ. Fuji Electric has thus developed a DC backup power supply for industrial equipment that flexibly meets customer specifications by combining functional blocks. It has up to 4 outputs (output voltage: 5 to 48V) and can optionally provide communications and battery backup functions. This architecture enables samples to be provided to customers in one month in the fastest (one sixth the period of conventional custom power supplies), thereby greatly contributing to reduction in the development time and development cost of equipment for customers.

Fig.2 "FIP Series"



Factory Automation

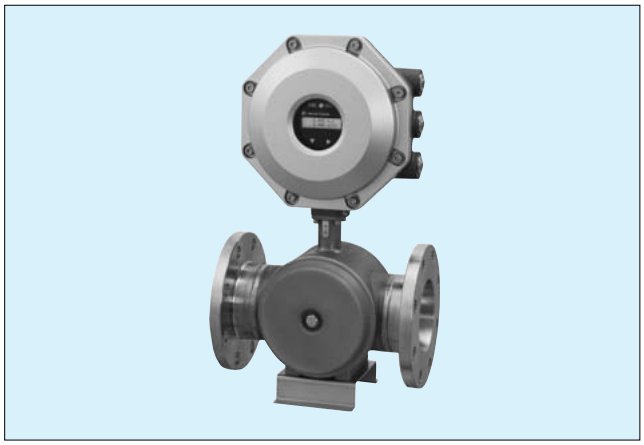
3 Acquisition of Explosion Proof Certification for "FST" Spool Piece Ultrasonic Flowmeters

Fuji Electric has acquired explosion proof certification for the "FST" spool piece ultrasonic flowmeter, offered in 2016, to further increase their marketability.

The FST has a high level of accuracy within ±0.2%, which compares with that of Coriolis flowmeters, by using a 3 parallel measuring path system (measurement via 3 pairs of ultrasonic sensors) and proprietary processing algorithm. Furthermore, it is particularly advantageous in that it produces no pressure loss and is reasonably priced.

By acquiring explosion proof certification, the "FST" can replace widely-used Coriolis flowmeters in the petroleum and chemical fields. Moreover, it can also measure non-conductive fluids such as oil and pure water, unlike widely-used electromagnetic flowmeters. We are thus marketing the FST as a replacement for electromagnetic flowmeters. The acquired explosion proof certifications are those of Japan, IECEx, ATEX and NEPSI.

Fig.3 "FST" (explosion proof type)



4 High-Temperature Heat Pump Technology Capable of Generating 150°C Steam Using Low GWP Refrigerant

There has been increasing demand for heat pumps, which are used for saving electric power and heating energy while reducing CO_2 emissions in factories. There is also worldwide demand for the practical use of refrigerants with a low GWP that can replace alternative fluorocarbon refrigerants. Fuji Electric has offered a heat pump that recovers heat from heated wastewater that has low utility-value and generates high utility-value steam. We have made use of NEDO's Research Grant Program to develop a high-temperature heat pump technology capable of generating steam at the industry's top level of 150°C by using a new refrigerant that has a low GWP and complete its prototype testing.

(1) Development of a high-efficiency refrigerant compression technology using new refrigerants
(2) Development of high-efficiency, low-cost refrigerant circuit and refrigerant control technology

We will perform the verification testing to develop and improve the reliability of follow-up control of heat load fluctuations.

Fig.4 Exhaust-heat based steam generation heat pump capable of generating 150°C steam

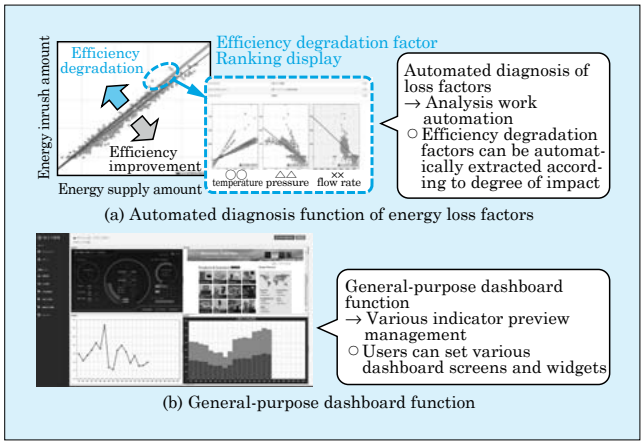
5 Energy Use Efficiency Diagnosis Compliant with ISO 50006

In addition to the energy-saving measures adopted conventionally for individual pieces of equipment, there has recently been increasing demand for equipment efficient operation that corresponds to specific energy demands more accurately. In this regard, Fuji Electric has developed Energy Performance Indicators compliant with the international standard ISO 50006 and new functionality of our energy management systems on the basis of a management framework for managing factors.

(1) Automated diagnosis of energy loss factors for each energy management unit (organization, production line, facility, etc.)
(2) General-purpose dashboard function for real-time management of energy efficiency (targets, results) and loss factors (control threshold values)

Using these functions allows customers to reduce the analysis workload and speed up the activities of operational efficiency improvement(PDCA cycle).

Fig.5 Energy use efficiency diagnosis compliant with ISO 50006



Process Automation

1 Steel Plant Standard System Package for Fuji Gemco Private Limited

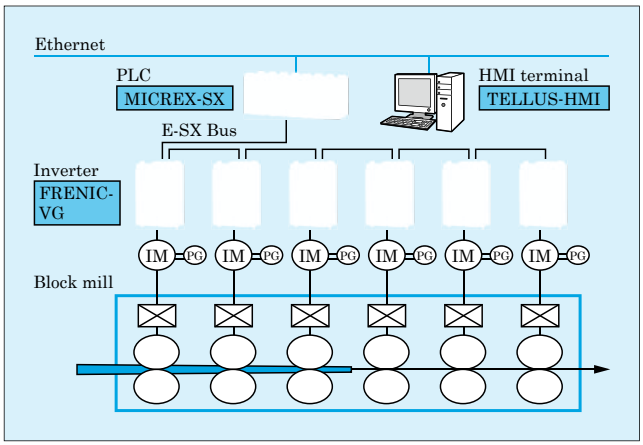
Fuji Electric has developed a steel plant standard system package for Fuji Gemco Private Limited, a company that specializing in steel rolling mill plants in India. The following types of packages are available:

(1) Standard mill package
(2) Block mill package
(3) Shear package

The packages are composed of the know-how of plant system and Fuji Electric components, such as programmable controllers (PLC), human machine interface (HMI) terminals and inverters, which are helping customers achieve an added-high-value plant system.

We plan to expand our business in the steel rolling market in India and Southeast Asia.

Fig.6 Package example (block mill package)

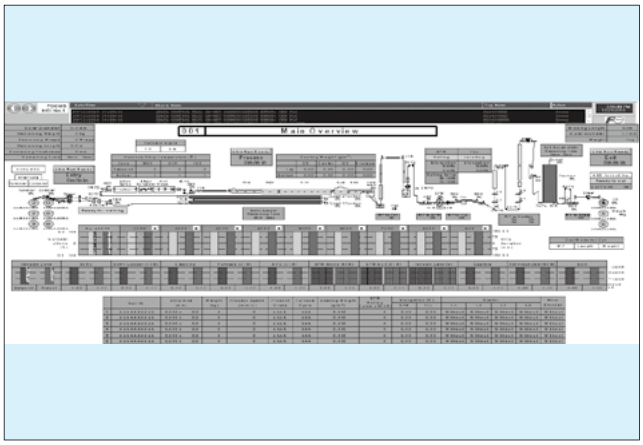


2 Delivery of Electrical Equipment for Continuous Galvanizing Lines

Fuji Electric has been delivered electrical equipment for continuous galvanizing lines to an overseas company. The introduced latest monitoring and control systems improve add-on functions for performance, reliability, maintenance and safety. The main features are as follows:

(1) The equipment consists of approximately 200 inverters, approximately 250 motors, 11 programmable controllers (PLC), approximately 100 controlboards, control software and a monitoring and control system.
(2) Each section controller and inverter control controller are networked via SX-net, enabling remote monitoring and fast data collection of several thousands of plant data (1,024 words/1 ms).
(3) The system is compliant with functional safety standards (IEC 61508).

Fig.7 Example of monitoring and control system's screen



3 Electrical Equipment of Continuous Unloader for Thermal Power Plants

Fuji Electric has delivered electrical equipment for continuous unloaders that handle the raw materials of thermal power plants in Japan and abroad. We have collectively delivered the electrical equipment of continuous unloaders to an overseas thermal power plant. The main features are as follows:

(1) The drive unit uses a PWM converter and high-performance vector inverter, delivering higher-harmonic suppression and high-precision control.
(2) The controlboard and motors are designed and manufactured in accordance with IEC standards, achieving safe electrical equipment.

Fig.8 Overall view of continuous unloaders

Process Automation

4 "LEONIC-M700" DC Motor Control Units for Industrial Plants: Expanding Capacity Line-Up of Thyristor Stacks

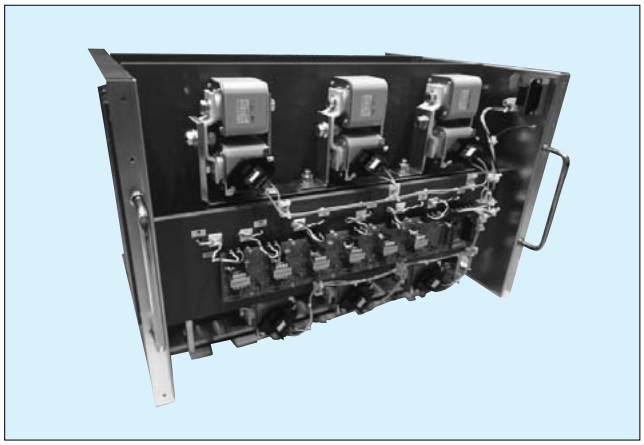
Direct current (DC) motors play a very active role in equipment for various types of industrial plants.

Fuji Electric has expanded the line-up of capacities for the thyristor stack of "LEONIC-M700" DC motor control units for industrial plants. The expanded line-up of capacities is as follows:

(1) Rated output voltage: Up to 440 V DC; Rated output current: 1,400 A
(2) Rated output voltage: Up to 750 V DC; Rated output current: 1,500 A
(3) Rated output voltage: Up to 750 V DC; Rated output current: 2,800 A

We will continue to be committed to the development of thyristor stacks to help extend the service life of industrial plant equipment that uses DC motors.

Fig.9 "LEONIC-M700" thyristor stack

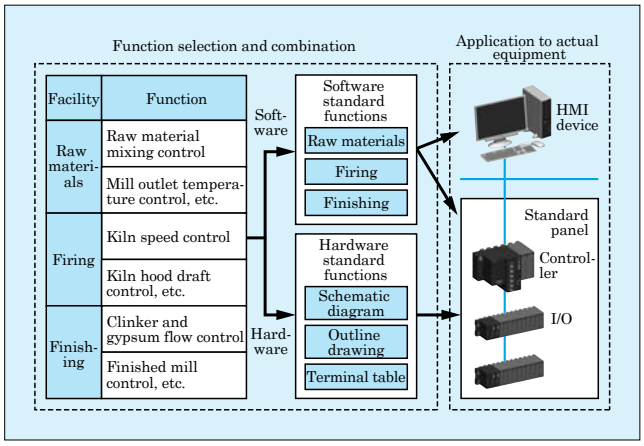


5 Monitoring and Control System Package for Cement Plants

Fuji Electric has delivered many monitoring and control systems to cement plants. We have developed a monitoring and control system package for cement plants that runs on the common platform "MICREX-VieW XX." It provides the functionality necessary for cement plant control in consideration of customer convenience. The main features are as follows:

(1) The standard functions of hardware, software and screens are incorporated to one package for each facility of cement plants: raw material, firing and finishing.
(2) Using the packages, which have been functionally verified, contributes system quality.
(3) Using the packages allows partners and users in Japan and abroad to facilitate engineering work.

Fig.10 Package overview



6 Monitoring and Control System for Industry-Owned Thermal Power Plant

Nisshin Steel Co., Ltd. has constructed a new power plant at its Kure Works that uses the by-product gas generated from steel manufacturing facilities as fuel. Fuji Electric has delivered the latest "MICREX-VieW XX" monitoring and control system. Commercial operation started on schedule in November 2017. The power plant at the Kure Works has the following requirements:

(1) The system can control combustion using various fuels: heavy oil, mixed gas (mixture of blast furnace gas and converter gas) and utility gas.
(2) Two air feeding systems (3 MPa and 1.4 MPa) of the plant can stably continue even when load rejection occurs.
(3) Plant air feeding during the operation of the boiler alone can be smoothly followed by the subsequent turbine coordination.

By sufficiently satisfying these requirements and finishing the commissioning even in a short period of time, we contributed to the on-schedule start of commercial operation.

Fig.11 No. 6 boiler and No. 11 turbine generators at Kure Works

Process Automation

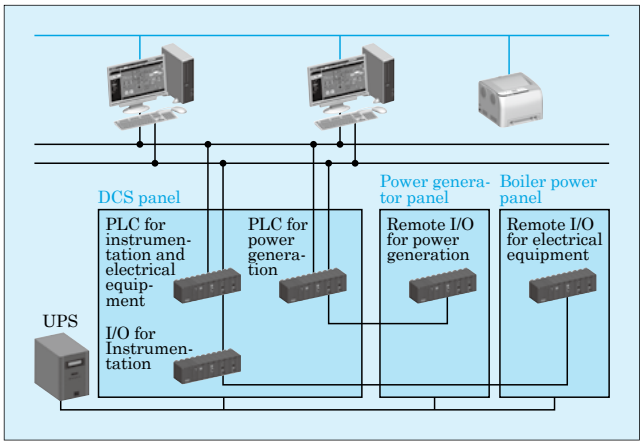
7 Monitoring and Control System for Biomass Power Plants

There has been a boom in the construction of biomass power plants since the start of the "Feed-in Tariff Scheme for Renewable Energy" (FIT). In this regard, small-scale power plants have been attracting attention in recent years particularly from the viewpoint of efficiently securing a source of fuels. In order to respond to these market trends, Fuji Electric has developed a compact and high-functional monitoring and control system. The monitoring and control system has the following main features:

(1) The monitoring and control system incorporates the control functions of electrical equipment, instrumentation and power generation, allowing a centralized operation.
(2) Using remote I/O system helps reduce panel size and save wiring labor-hours
(3) Equipment operation faceplate package automatically generates operation screens and control logic.

This monitoring and control system has contributed to reducing operator workload and improving maintainability.

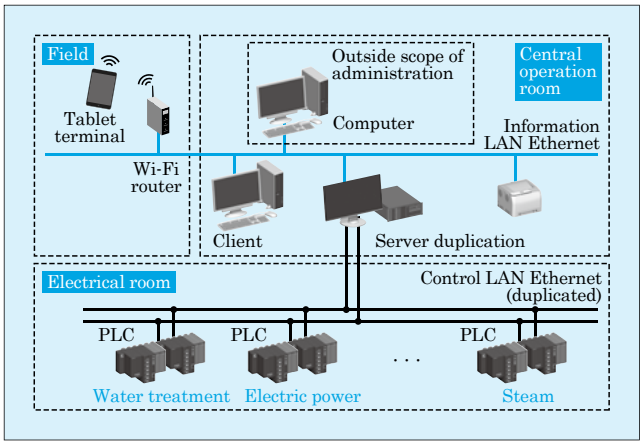
Fig.12 System configuration example



8 Replacing Monitoring and Control System of Food Factory

Fuji Electric has utilized the "MICREX-VieW FOCUS" in replacing the monitoring and control system for the utility and wastewater facilities of a brewing company. The system centralizes the management of energy with client-server configuration. Tablet terminals can serve as client devices, allowing users to reduce on-site operation and maintenance workloads. The existing system intermingled the control of water treatment, electric power and steam, while the renewed system has adopted a configuration that controls facilities by providing each piece of equipment with a separate controller in order to clarify function sharing. This enhancement enables optimum balance control for each utility. Furthermore, restoring accumulated "visualizing" data from the existing system to optimally operate energy, thereby raising expectations with regard to future improvement effects.

Fig.13 System configuration example



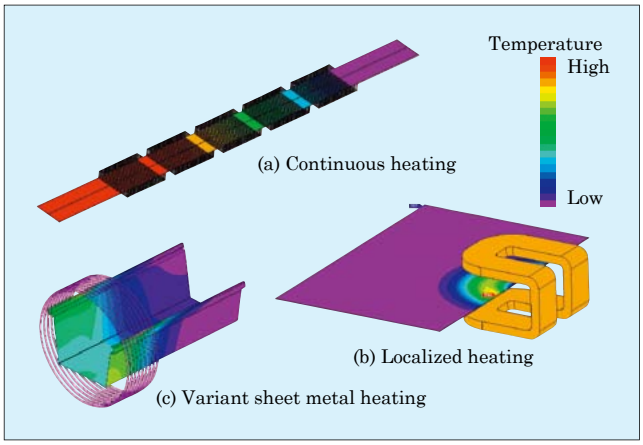
9 Simulation Based Induction Heating Equipment

Productivity improvement and advanced products have brought about increasing demand for improved heating control precision in material processing. Fuji Electric has been using its proprietary magnetic field and thermal simulation technologies to optimally design coils and power supplies. Here are some examples:

(1) Continuous heating equipment for sheet metal: To improve controllability, 5 pieces of small volume induction heating equipment continuously heat sheet metal to create a uniform temperature rise for the entire sheet.
(2) Local heating equipment for sheet metal: It selectively heats only the edges of continuously conveyed sheets.
(3) Variant sheet metal heating equipment: It uniformly heats rectangularly shaped sheet material.

We are providing induction heating for variously shaped materials other than sheet metal also to meet customer requirements.

Fig.14 Example of simulation results



Social Solutions—Transportation and Radiation Monitoring

1 Bulk Delivery of Electronic Products for C151B Trains Operated by Singapore's Land Transport Authority (LTA)

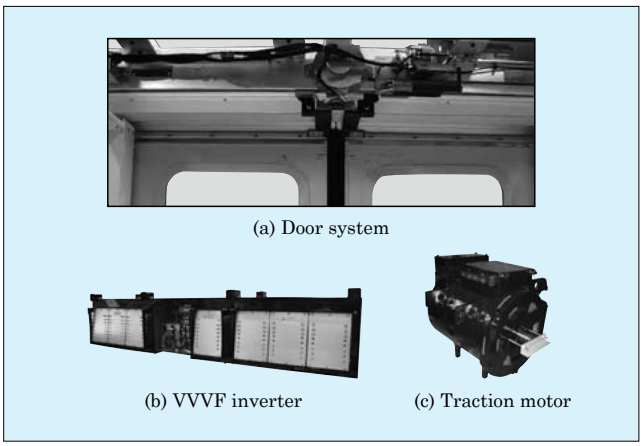
Fuji Electric has been continuously delivering drive equipment (VVVF inverters, traction motors, etc.) and auxiliary power supplies (APS) for rolling stock to Singapore's Land Transport Authority (LTA).

In addition to the above mentioned equipment, we have also delivered door driving systems that use permanent magnet synchronous motors for new C151B trains (45 consists, 270 cars) that started commercial operation in June 2017.

The main features of the door driving system are as follows:

(1) Using our domestically proven rack-and-pinion mechanism increases reliability and safety.
(2) A failure diagnosis function facilitates the investigation of failure causes.
(3) It achieves enhanced safety through improved obstruction-pulling characteristics at times when passengers or luggage is pinched by the doors.

Fig.15 Electronic products for C151B trains operated by Singapore's LTA



(a) Door system

(b) VVVF inverter

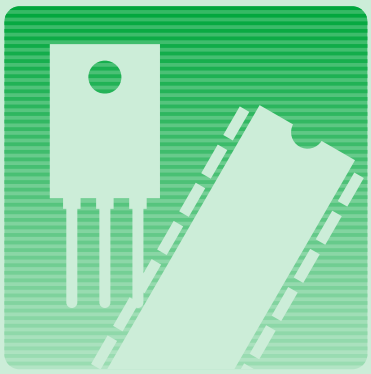
(c) Traction motor

2 "NRF51" New Electronic Personal Dosimeter

Fuji Electric has developed the "NRF51" as a new type of electronic personal dosimeter that can simultaneously measure gamma rays and neutron rays. The NRF51 inherits some of the functions of the conventional "NRF50" personal electronic dosimeter, such as a large dot-type LCD, wireless communication module (900-MHz wireless or Wi-Fi) and an emergency call button, while also coming equipped with a neutron ray measuring sensor, enabling it to simultaneously measure gamma rays and neutron rays with just a single device. It is compliant with the IEC 61526 Ed. 3.0 and ANSI N42.20 international dosimeter standards and comes standard with an IP65/67 waterproof rating. Furthermore, it can wirelessly connect with remote monitoring systems in real-time to help reduce worker radiation exposure, contributing to better management of exposure to neutron rays at nuclear power facilities.

Fig.16 "NRF51" new electronic personal dosimeter

Electronic Devices



Semiconductors
Disk Media

Outlook

Semiconductors

Power semiconductor industry is being faced with the situation that there are high expectations for power electronics technology, which utilizes electric energy efficiently to save energy and create energy. The technology, utilizing power semiconductors, can contribute to the prevention of world energy demand increase and global warming to create a responsible and sustainable society. Demand has been recently expanding for power semiconductors, which are a key devices of power conversion elements in various fields, such as automobiles, photovoltaic power generation, and wind power generation in addition to industrial equipment and home appliances. The power semiconductor of Fuji Electric has high energy conversion efficiency and has contributed to miniaturization and high performance of products over a long time. In 1988, we offered an insulated gate bipolar transistor (IGBT), which is used as a representative element of a power semiconductor. Furthermore, we have achieved low power loss, high heat dissipation and longer life time through many technical innovations over generations to meet the market needs, such as higher efficiency, miniaturization, and higher reliability.

The 7th-generation IGBT modules have been launched as the latest IGBT. They have a wide variety of product line-ups having a breakdown voltage of 650 to 3,300 V for various applications. The products have lower loss, smaller size, and higher guaranteed maximum junction temperature than the conventional ones while maintaining high reliability. Further, we have a line-up of small-capacity intelligent power modules (IPM) having a dual in-line structure installing a drive IC and a protection function mainly for room air conditioners. We are now developing products of 50 to 75 A to expand the product line-ups, targeting their application in industrial air conditioners.

A reverse conducting IGBT (RC-IGBT), recently developed, integrates IGBT and free wheeling diode (FWD) functions into a single chip and is expected to be higher density. We are extending product line-ups with the expanded maximum rated current in the same package by using the 7th-generation chip and its package and applying the RC-IGBT technology.

On the other hand, we are also developing products that use silicon carbide (SiC), which has been attracting attention recently as the next semiconductor material in place of silicon. We developed an All-SiC module installing SiC trench metal-oxide-semiconductor field-effect transistor (MOSFET) chips with a breakdown voltage of 1,700 V, subsequent to one with a breakdown voltage of 1,200 V.

In the automotive field, we have developed the 6.5th-generation automotive pressure sensor that contributes to high engine efficiency and clean exhaust gas to reduce the environmental load of automobiles. The sensor has a structure that can resist electro static charge due to oil mist, as well as corrosive exhaust gas contained in measuring medium. It has also been given an output voltage clamp function related to failure diagnosis. The sensor is reduced in volume (about 48% of the 6th generation) and is guaranteed to operate at 150 °C. Furthermore, regarding automotive IGBTs for driving motors used in hybrid electric vehicles and electric vehicles, we are making a product line-up that uses the above RC-IGBT and our original direct water-cooled structure.

For discrete products, we created a line-up of DFN 8×8 packages, which have small and thin surface-mount structure, to meet the requirements of industrial and communications equipment. The DFN package can be mounted on a printed circuit board at high density and delivers high-speed switching with a sub source terminal. It incorporates “Super J MOS S2 Series” or “Super J MOS S2FD Series,” which are the latest series, as switching element. LEDs are becoming increasingly used for facility lighting to save energy and reduce maintenance work. We have launched the “FA7A00Y Series” light control ICs for the power supply of facility LED lightings. The series supports input signals for various dimming and controls LED lighting with high accuracy and quick response. Furthermore, power supplies can be designed with fewer components in accordance with the revised safety standard IEC

61347-1.

We will continue developing earth-friendly power semiconductor products to create a responsible and sustainable society.

Disk Media

With the acceleration of the Internet of Things (IoT), the demand for storage capacity is increasing at a 40% annual rate. Hard disk drive (HDD) accounts for a large amount of storage capacity of hyper data centers that are operated by Amazon, Google and so on. The driving force in the HDD market is shifting to nearline HDDs. We started mass producing magnetic recording media for nearline HDDs on a full scale in FY2017. We will develop high magnetic layer design technology and reliability technology for higher recording capacity to help expand the industry of data centers, which serve as social infrastructure, contributing to the development of advanced information society.

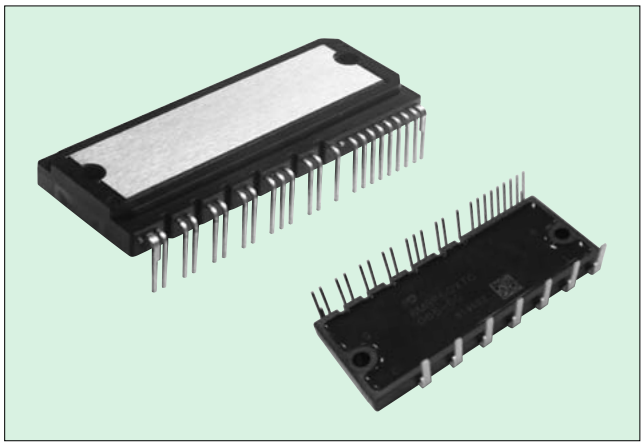
Semiconductors

1 650-V/50-A, 75-A Small-IPM

The inverter market including air conditioners, general-purpose drives, and servo drives is increasing on the basis of a highly energy-saving demand.

Fuji Electric has developed new product line-up of 650-V/50-A and 650-V/75-A Small-IPM to facilitate the construction of inverter systems that drive motors of these equipment. Small-IPM incorporates 7th-generation IGBTs to lower power loss, as well as protection circuits and drive circuits into one package. In addition, the operating junction temperature of IGBTs and FWDs is increased to 150°C with high heat resistant packaging technology. These contribute to improvement in energy-saving performance and increase in power density of inverter systems. The product employs the dual in-line package of 79 × 31 (mm).

Fig.1 650-V/50-A Small-IPM



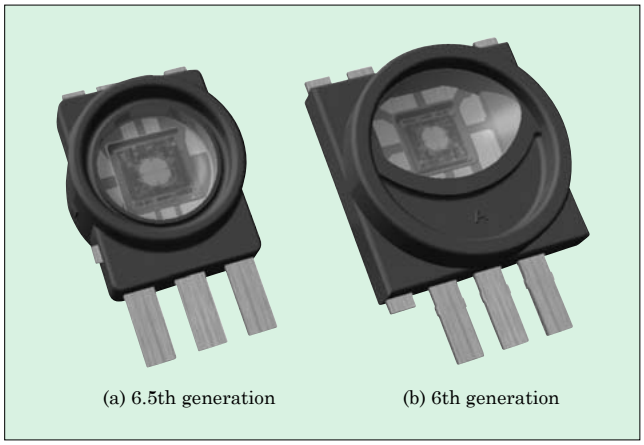
2 6.5th-Generation Automotive Pressure Sensor

Reference: FUJI ELECTRIC REVIEW 2017, vol.63, no.4, p.232

Currently, automobiles are strongly required to reduce the environmental load, and Fuji Electric has developed the 6.5th-generation automotive pressure sensor that contributes to the improvement of engine efficiency and the purifying of exhaust gas. This product achieves compact size (volume ratio of about 48%) and is guaranteed to operate at 150 °C while providing electrification resistance and corrosion resistance to measuring medium and having an output voltage clamp function. The main features are as follows:

(1) Product size (resin part): W 7.5 × H 10 × D 5.6 (mm)
(2) Operating temperature range: −40°C to +150°C
(3) Operating pressure range (intake pressure sensor): 20 to 120 kPa
(4) Output voltage (at power supply voltage of 5 V): 0.5 to 4.5 V
(5) Corrosion resistance: In accordance with JASO M611-92/B type (gasoline/diesel components)
(6) Clamp function: Clamp voltage 0.3 V/4.7 V (typ.)

Fig.2 Automotive pressure sensor



Semiconductors

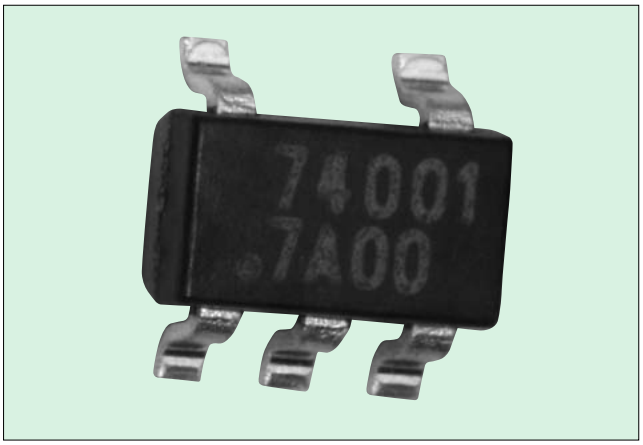
3 "FA7A00Y Series" Light Control IC for Power Supply of LED Lighting

The LED lighting market is rapidly expanding since LEDs offer energy saving and a longer service life, and the need for dimmable LED lighting equipment is especially growing. Therefore, power supplies for LED lighting are also required to offer an accurate light control function. In addition, safety standard IEC 61347-1 has been revised (insulation of light control circuit), and the power supply also needs to be compliant with this standard.

To meet these demands, Fuji Electric has developed the "FA7A00Y Series" light control IC for the power supply of LED lighting. The main features are as follows:

(1) Supports three types of inputs (DC voltage, variable resistance, PWM), and the error of output duty is ±5% with respect to the target value
(2) Allows high-speed response within a response time of 50 ms when luminance is changed
(3) Conforms to the safety standard IEC 61347-1

Fig.3 "FA7A00Y Series"



4 "Super J MOS S2 Series" and "Super J MOS S2FD Series" for DFN 8 × 8 Packages

Fuji Electric has made a new surface mount package (DFN 8 × 8) series to meet the demand for smaller and thinner power supplies. The product has a square shape of 8 × 8 mm and is very thin at 0.85 mm. All electrode pads are arranged on the rear surface of the package, allowing higher density packaging on a printed circuit board compared with the conventional D2-PACK. A sub-source terminal is provided in the terminal arrangement; therefore, the back electromotive force that is generated in a common source inductance affecting the drive voltage is kept to the minimum. The product is also capable of high-speed switching. The product is equipped with the latest series, "Super J MOS S2 Series" or "Super J MOS S2FD Series" as a switching element. The main features are as follows:

(1) Breakdown voltage: 600 V
(2) On-state resistance: 91 to 223 mΩ

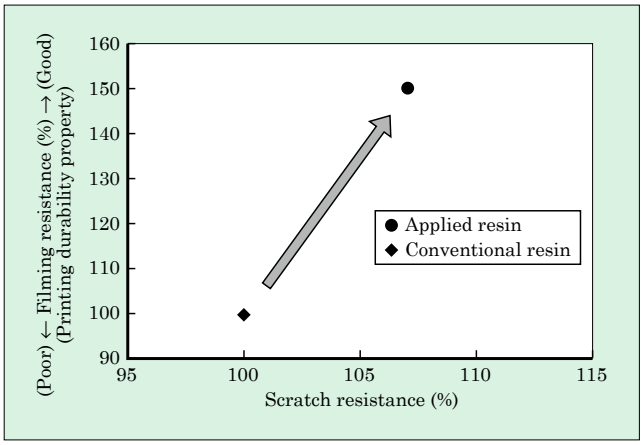
Fig.4 DFN 8 × 8 package

5 Improved Printing Durability Property of Positive Charging Organic Photoconductor

Electrophotographic printers and copying machines are becoming faster and provide higher image quality and longer service life. Photoconductors mounted on these machines are important components responsible for image quality. Photoconductors need to be very stable so that they are not affected by stress from various peripheral processes. Specifically, paper powder and components of toner that come into contact with a photoconductor adhere and accumulate on the surface of a photoconductor (a phenomenon called filming), and the service life of the photoconductor is thereby reduced. Thus, the photoconductors need to have high mechanical durability.

Fuji Electric has been developing a high-function organic photoconductor that can be used for a long time and that offers stable image quality. We have developed resin with higher scratch resistance by suppressing the sinking of paper powder and toner components, which is the starting point of filming. We thereby succeeded in improving the printing durability property by 50%.

Fig.5 Printing durability property of positive charging organic photoconductor



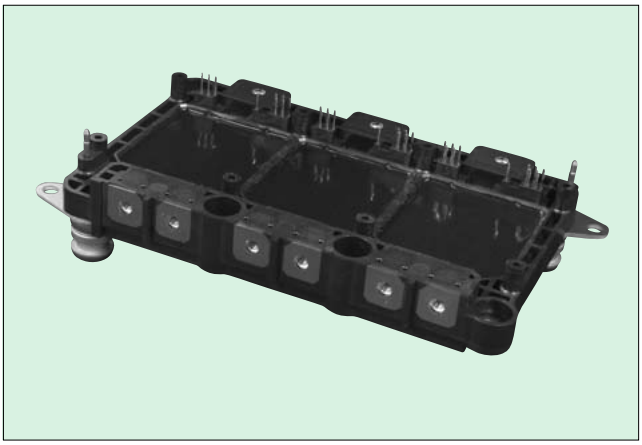
Semiconductors

6 "M660" High-Power, Direct Liquid Cooling IGBT Module for Automotive Applications

Fuji Electric is trying to expand IGBT modules used for the EV and HEV market, which are growing in Japan and overseas.

An automotive IGBT module is mounted in a limited space of an automobile and is required to be small and have large power density. Our high-power, direct liquid cooling IGBT module for automotive applications uses a cooler having a structure in which a water jacket is integrated. The cooler is made of lightweight aluminum and has excellent heat dissipation performance. Area-efficient structure and high power density have been achieved by a lead frame for the internal wiring and reverse-conducting IGBTs (RC-IGBTs) for the power elements. In this way, we have developed a general-purpose 6-in-1 IGBT module having a rating of 750 V/1,200 A, achieving one the best capacities in the world.

Fig.6 "M660"

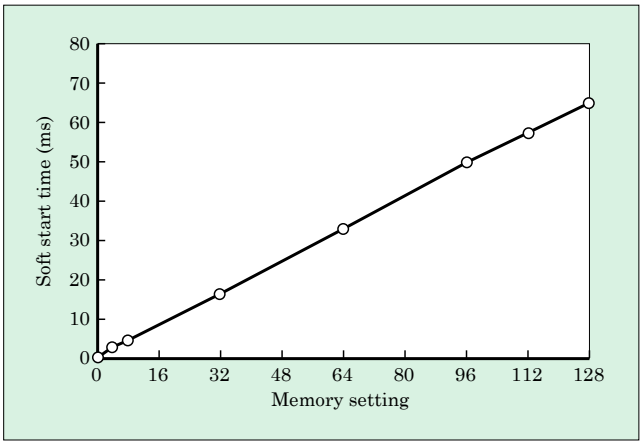


7 Digital Power Supply IC Technology Using 0.18-μm Design Rule

Fuji Electric has developed digital power supply IC technology that contributes to high stability and high efficiency of switching power supplies used in electronics. The technology also provides the benefits to customers of easy designing and part reduction.

With this technology, we can mount a rewritable memory and a digital control circuit by applying the design rule of 0.18 μm. We have added devices that have a breakdown voltage of 40 V to the device menu, allowing the products to be used in an analog circuit. The technology allows the digital power supply IC products to feature high-speed response and low power consumption, which are characteristics of an analog circuit, and modify characteristics and select functions by changing the memory settings.

Fig.7 Relationship between memory setting and soft start time of IC



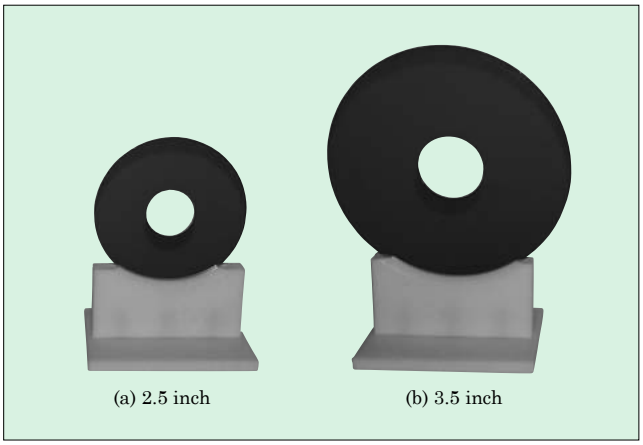
Disk Media

1 Magnetic Recording Media with Large Capacity and High Reliability for Data Centers

IoT, big data and AI are leveraged in lots of industry area currently. It is referred to as the Fourth Industrial Revolution and is shifting into high gear. This requires huge data storage capacity, and the demand for data centers is dramatically increasing. HDDs offer large-capacity inexpensively and, therefore, HDDs are expected to continue to account for more than 90% of the storage capacity in the data center market.

Fuji Electric is currently mass-producing 2.5-inch, 1-TB/platter media (industry's leading recording areal density). With utilizing this technology, 3.5-inch media have been developed for HDDs designed for data centers with capacities reaching 8 TB/unit. In FY2018, we will contribute to the advancement of information-oriented society through continuous improvements of areal density and reliability with the aim of supplying magnetic recording media for 14- to 16-TB HDDs.

Fig.8 Magnetic recording media



Power Generation

Power Plants
New Energy

Outlook

The Japanese power market in FY2017 generally showed steady growth. However, on April 1, 2017, "Partial Revision of the Act on Special Measures Concerning Procurement of Electricity from Renewable Energy Sources by Electricity Utilities" (revised FIT scheme) was put into force, and power project development is anticipated to decrease from FY2018. Furthermore, the opportunities for new coal-fired power generation have rapidly declined under CO_2 emissions continuous reduction, and careful and close monitoring is needed along with the number of nuclear power generations that restart. On the other hand, as a renewable energy, the geothermal power generation market is expected to be more active, owing to the easier planning, for example, by faster evaluation on environment impact assessment. As for photovoltaic power generation, new project development tends to decrease, while the maintenance business opportunities are expected to increase. Wind power generation projects have completed the assessment and the projects are expected to be developed. Fuel cell growth is expected in South Korea as renewable energy.

In the overseas power market, the ratio of renewable energy will rapidly increase. This may lead power sectors in the mature countries, where the power demand growth cannot be expected, to be reorganized and accelerate the business expansion towards overseas markets.

Under mega trend in the energy field, such as distributed generation, lower carbonization, digitalization, higher efficiency and energy savings, wider introducing of flexible power generation, electricity storage technology and smart grid are anticipated.

To be aligned with market trend in thermal power and geothermal power generation, Fuji Electric is enhancing its services for higher plant efficiency, digitalization, lower carbonization, and safe and stable operation.

For the results in FY2017, thermal power generation business continuously received orders for Japan on steam turbines and generators for multi-fuel biomass power projects, and also, received orders for new projects overseas.

Geothermal power generation business completed second binary power plant in Japan at the end of FY2017, while in overseas secured an order for large scale project on engineering, procurement and construction (EPC) basis.

Service business received several rehabilitation orders for improving efficiency. Diagnosis technology services were enhanced towards slight demand increase and resulted with orders mainly for Japan. Fuji Electric will diligently continue providing higher efficiency of steam turbines and generators and strengthen its organization to comply with the needs of customers.

In the photovoltaic power generation business, outdoor stand-alone type 1,000-kW power conditioning systems (PCS) having the world's smallest footprint have reached approximately 200 units of accumulative order receipts. In addition, the construction of 7 large EPC projects received by FY2016 is progressing smoothly. The existing photovoltaic power plants are reaching their scheduled maintenance, and maintenance business opportunities are increasing.

In the fuel cell business, 5 units of phosphoric acid fuel cells were delivered to South Korea and one unit to Germany and France. South Korea has Renewable Portfolio Standard (RPS) requiring the power sectors to introduce specified ratio of renewable energy resources including fuel cells, driving the fuel cells widely in use, and the RPS is expected to accelerate the demand growth. In addition, Fuji Electric is participating in the project of New Energy and Industrial Technology Development Organization (NEDO) to commercialize solid oxide fuel cell (SOFC) system having high efficiency power generation. 50-kW class demonstrator completed 3,000 hours operation and evaluation. Field demonstrations will be progressed for the product launch in the market within FY2018.

In the nuclear power business area, Fuji Electric is offering technology and products for high earthquake resistance and fire prevention and extinguishing properties conforming to new regulatory requirements for the restart of nuclear power plants and

the construction of nuclear reprocessing plants and mixed oxide (MOX) fuel plant. Decommissioning of the prototype fast breeder reactor Monju, as a part of Japanese Government nuclear power plant decommissioning program, is steadily progressing preparation for fuel removal using Fuji Electric fuel handling systems. Further, to stabilize radioactive waste generated during operation and decommissioning of nuclear power facilities, Fuji Electric is developing waste solidification technology employing a geopolymer material for the application in Japan, collaborating with John Wood Group PLC in Scotland.

Fuji Electric will diligently and actively work on utilizing renewable energy such as geothermal, photovoltaic and wind energies towards low-carbon society. In the field of thermal power and fuel cells, Fuji Electric is developing high efficient and eco-friendly power generation equipment. Fuji Electric will also provide operation and maintenance (O&M) technology so as to provide stable power safely and continuously to contribute to society with comprehensive power supply technology.

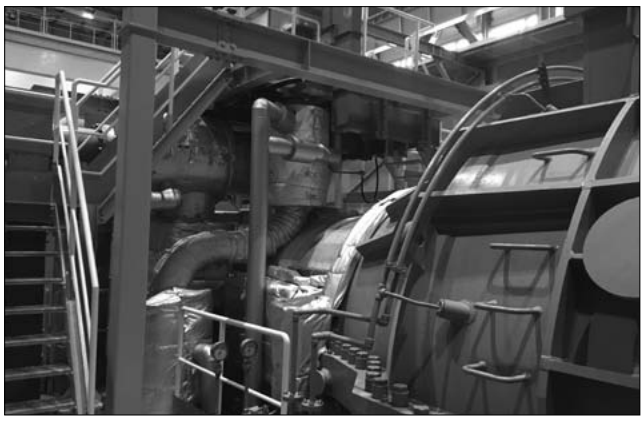
Power Plants

1 Start of Commercial Operation of Power Generation Facility No. 1 at Ishinomaki Hibarino Power Plant of Nippon Paper Ishinomaki Energy Center Ltd.

Fuji Electric has received an order from IHI Corporation, the main contractor,and made a turnkey contract for a reheat steam turbine power generation facility of the Ishinomaki Hibarino Power Plant of Nippon Paper Ishinomaki Energy Center Ltd. We completed designing, manufacturing, procuring, installing, and commissioning, of the steam turbine generator, condensing and feed water system, main circuit and house electrical equipment. In this power generation facility, a single-cylinder reheat steam turbine with axial flow exhaust and an air-cooled generator with upper arrangement of the main terminal are employed. It has high efficiency and saves space by suppressing installation height compared with that of conventional power generation equipment, contributing to the reduction of the construction costs.

Ishinomaki Hibarino Power Plant, which started commercial operation in March 2018, can carry out multi-fuel firing of woody biomass. The power plant can utilize unused materials in the Tohoku region especially in Miyagi Prefecture, and it is expected to prevent the destruction of forests, which has become a problem in Japan recently.

Fig.1 Steam turbine and generator of Power Generation Facility No. 1 at Ishinomaki Hibarino Power Plant

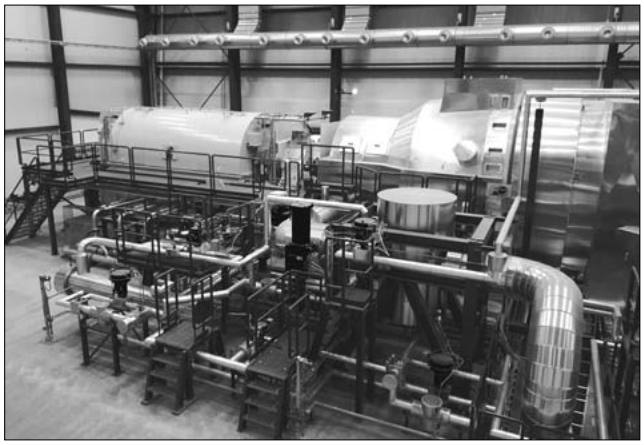


2 Start of Commercial Operation of Þeistareykir Geothermal Power Plant in Republic of Iceland

Fuji Electric has received an order for steam turbines, generators and cooling system equipment for Þeistareykir Geothermal Power Plant (2 × 45 MW) from National Power Company of Iceland (Landsvirkjun) in cooperation with Balcke-Dürr GmbH of Germany. We designed, manufactured, and delivered steam turbines, auxiliary systems, generators and spare parts, and conducted on-site installation and commissioning. The commercial operation started in December 2017 for Unit 1, and April 2018 for Unit 2. The system is expected to help meet power demand and stabilize the power transmission system of north-east Iceland. Renewable energy power generation accounts for 99% of the annual power generation amount in Iceland.

The steam turbine facility, which needs to be highly efficient, uses an axial exhaust flow type. This steam turbine has low pressure blades of 6.3m^2, the largest size for a geothermal steam turbine. In addition, corrosion-resistant (corrosion resistance and erosion resistance) technology unique to geothermal power generation were also adopted to resist corrosive geothermal fluid.

Fig.2 Delivered geothermal steam turbine and generator



Power Plants

3 Start of Commercial Operation of 2nd Nagoya Power Plant of Nakayama Nagoya Kyodo Hatsuden Co., Ltd.

Fuji Electric has received an order from IHI Corporation, the main contractor, and made a turnkey contract for a reheat steam turbine power generation facility for Second Nagoya Power Plant of Nakayama Nagoya Kyodo Hatsuden Co., Ltd. We have completed engineering, equipment design, manufacturing, procurement, installation, and commissioning of the steam turbine, generator, condenser, boiler feed water heaters, main circuit electrical equipment, and plant auxiliary power supply system. The commercial operation started in September 2017.

The steam turbine facility needs to be highly reliable and efficient, and it therefore uses a reheat turbine with one casing and an air cooling power generator of a brushless excitation type, which has high reliability and a proven track record. This configuration contributes to high reliability and a compact arrangement of a 110-MW reheat turbine and generator facility.

Fig.3 Steam turbine and generator for 2nd Nagoya Power Plant

4 Low-Pressure Turbine Replacement for Existing Power Generation Facility at Noshiro Thermal Power Station of Tohoku Electric Power Co., Inc.

Fuji Electric has replaced main components of 2 low-pressure turbines, including low-pressure turbine rotor, low-pressure inner casing and diffuser, of Noshiro Thermal Power Station of Tohoku Electric Power Co., Inc. by applying the latest technology to increase yield strength and improve efficiency.

The reaction stages have 3DS blades, which were developed using the latest analysis technology, to reduce profile loss and secondary flow loss. An optimized 3DV blade arrangement was also adopted to remove the classic distinction between reaction stages and impulse stages. Further, efficiency improves due to the use of a high-performance exhaust diffuser with reduced turbine exhaust loss.

Construction of the power generation facility was completed as planned, and the operation restarted in December 2017.

Fig.4 Low-pressure turbine rotor

5 Replacement of Generator Air Cooler Made by Another Company for Saline Water Conversion Corporation of Saudi Arabia

The Saudi Arabian Company Saline Water Conversion Corporation (SWCC) has 5 generators made by another company operating at Shoaiba Power Plant (phase 2). Fuji Electric received the order of replacing 12 air coolers (3 generators × 4 units), which are installed in 3 out of the 5 generators. We designed an air cooler on the basis of on-site investigation results. After manufacturing, we performed a hydraulic pressure test witnessed by SWCC employees, shipped the products in March 2018 and completed delivery to the plant in May.

We succeeded in receiving the order because our generators in phase one of the same plant operated well and were highly evaluated by SWCC. We will continue working on quality assurance at the plant to receive an order for replacing the 8 air coolers of the other 2 generators.

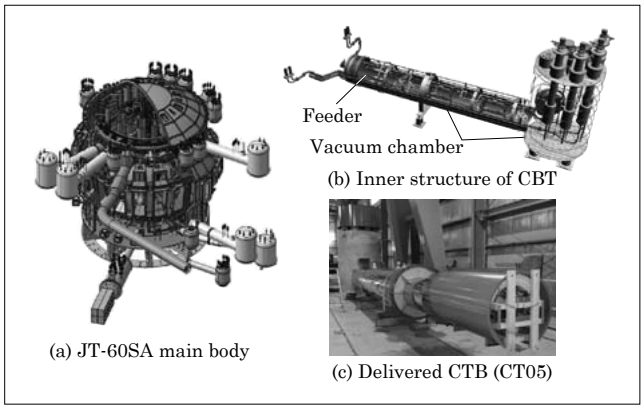
Fig.5 Hydraulic pressure test on air cooler

Power Plants

6 Production of Superconducting Power Supply Facility (Coil Terminal Boxes) for JT-60SA

JT-60SA is a large plasma test facility that the National Institutes for Quantum and Radiological Science and Technology is constructing at the Naka Fusion Institute. This project is jointly implemented by Japan and Europe in parallel with the ITER plan to realize fusion energy at an early stage. Fuji Electric received an order for 4 coil terminal boxes (CTB), which supply electricity to superconducting coils of JT-60SA. We delivered 2 CTBs in December 2017, and we are now manufacturing the remaining 2 units. The CTB consists of feeders and a vacuum chamber that houses the feeder. The CTBs receive up to 20-kA electric current at a room temperature and feed it to the coils through the feeders cooled to 4 K by liquid helium. The feeders need to have a breakdown voltage performance of 21 kV DC in a vacuum, low-temperature environment and needs to be resistant to thermal deformation due to temperature change. We have worked on the basic design, prototype and testing, contributing to the achievement of JT-60SA.

Fig.6 JT-60SA main body and CTB



Figures courtesy of National Institutes for Quantum and Radiological Science and Technology

New Energy

1 "PVI1000BT-3P/1000-F" PCS for Photovoltaic Power Generation , Completing Product Registration with Provincial Electricity Authority (PEA) of Thailand

The growth rate of commercial photovoltaic power generation are slowing down in Japan, while still being expected to increase in Southeast Asian countries, including Thailand. Thus, Fuji Electric has developed the "PVI1000 BT-3P/1000-F" PCS for photovoltaic power generation (1,000 V DC, 1 MW) and registered the product with the Provincial Electricity Authority (PEA) of Thailand. Regarding the grid connection function (protection relay and reactive power output), we clarified the difference in requirements between Japan and the PEA. We then developed software that allows functions that meet both by changing the parameter. We confirmed that its grid connection function normally operates by connecting a 1-MW unit to a large-capacity grid simulator to undergo a grid fault specified in the PEA requirements. The witness inspection attended by a PEA examiner proved that the PCS satisfies the requirements and the product registration was completed in March 2018.

Fig.7 "PVI1000BT-3P/1000-F"

2 Phosphoric Acid Fuel Cell for Youil Industry Co., Ltd. in South Korea

In South Korea, renewable energy is becoming widespread due to the government policies, such as the Renewable Portfolio Standard (RPS). The RPS obligates electricity utilities to supply a predetermined rate of electricity generated from renewable energy sources. Electricity utilities are purchasing renewable energy-derived power, and a purchase market is being formed. Fuel cells are also involved in new renewable energy, which is subjected to the new policy, and use of them is expanding rapidly.

Fuji Electric delivered five 100-kW phosphoric acid fuel cells to the South Korean company Youil Industry Co., Ltd. in FY2017. The company generates power with fuel cells and sells the electricity to electricity utilities. We will use this experience to further promote the sales of phosphoric acid fuel cells in South Korea, focusing on the small- and mid-scale power generation business and cogeneration.

Fig.8 Delivered phosphoric acid fuel cells

Food and Beverage Distribution

Vending Machines
Store Distribution

Outlook

Vending Machines

When the cap of a beverage bottle served by the subfreezing vending machine is opened, the beverage immediately start freezing in a form similar to sherbet. The refreshing sensations that these products deliver have become the source of their popularity. The subfreezing vending machine developed by Fuji Electric makes use of a supercooling phenomenon that "freezes through shocking." To reproduce this phenomenon consistently, it is necessary to cool the beverages in an undisturbed state for a certain period of time. It is the very nature of vending machines that can deliver this environment. This technique enables sales go beyond simply selling products, since consumption is encouraged as a result of the fun experience of seeing a product freeze in front of one's eye and also enjoying snow-cone like texture in one's mouth. This can truly be considered a success story in the evolution of the role of vending machines.

In this regard, cup vending machines also play a role for dramatic impact. We have often heard stories about tourists from overseas who were pleasantly surprised by the high-degree of quality and consistency of vending machines that serve a cup of fresh coffee even coming with a lid on top. It seems that those tourists have been surprisingly impressed by the care and concern given to consumers who purchase these types of products. The demand for Japanese style coffee vending machines has been rapidly increasing in China. We have thus started local production in China since 2017. We plan to gradually introduce a new series of models to meet overseas needs.

Store Distribution

The "Act on Rational Use and Proper Management of Fluorocarbons" enacted on April 1, 2015 demands the strict management of commercial refrigeration and air conditioning equipment. Vending machines and showcases are also subject to this law, and products using fluorocarbons as refrigerants have been designated as "1st category" specified products. The obligations imposed on administrators (owners) of commercial air conditioners and refrigeration equipment include the following: obligations concerning the installation of equipment, obligations concerning the use of equipment and obligations concerning the disposal of equipment. In particular, obligations concerning the use of equipment specifically stipulate conditions concerning the conduct of equipment inspection, measures for preventing leaks, prohibition on filling unrepaired equipment with refrigerants, and others.

The fluorocarbons subject to the Act on Fluorocarbon Emissions Control are those that exhibit an extremely high greenhouse effect, including those that can and cannot damage the ozone layer. Therefore, commercial refrigeration and air conditioning equipment (fluorocarbon-free equipment) that use refrigerants other than fluorocarbons, such as ammonia (NH_3), CO_2, water, air and hydrofluoroolefin (HFO) are not categorized as "1st category" specified products.

The non-leak integrated showcases that Fuji Electric manufactures and sells use HFO-1234yf as the refrigerant. This refrigerant is characterized by a global warming potential (GWP) of less than 1 and is these showcases are not categorized as "1st category" specified product. As a result, the above mentioned management and reporting obligations are not required for them. Furthermore, compared with non-integrated types, integrated types make it easy to determine leak locations and leak amounts and simplify voluntary management measures because no special skills are required. In FY2011, Fuji Electric was the first in the industry to use an HFO refrigerant in vending machines as a measure for protecting the environment (reducing GWP to about 1/1,300). Since then, we have been actively promoting the use of low GWP products. HFO-1234yf is highly compatible with R134a refrigerant used in our vending machines, thus allowing it to take full advantage of the technical innovations developed by Fuji Electric. As a result, the showcases use HFO refrigerants because they can deliver high performance at low cost. We believe that by taking the initiative to solve social problems, we are also ultimately contributing to reducing the workloads of customers who use our

products.

We recognize that labor savings are achieved by not only reducing current workloads but also creating no additional workloads, and we will continue tackling an even greater range of issues.

Labor shortages are becoming a serious issue in the distribution and retail industries in Japan. To contribute to improving the work environment of distribution and retail workplace, Fuji Electric will combine its expertise in IoT, mechatronics and cooling and heating technologies to offer new products and services based on the 3 keywords of convenience, labor savings and energy savings.

Vending Machines

1 "FAT30L6RT8IK" Subfreezing Beverage Vending Machine

Fuji Electric has partnered with Asahi Soft Drinks Co., Ltd. to develop a vending machine that makes it possible to sell beverages cooled down to subfreezing temperatures.

We have initiated this development to create the vending machine based on the concept of "providing consumers with new surprising, fun and delicious products, raise the appeal of vending machines and create business growth." The main features are as follows:

(1) The defrosting system applies hot gas defrosting method that utilizes the refrigerant's condensation heat as means of defrosting the vending machine without affecting the product's temperature.
(2) In order to cool products in vending machines to subfreezing temperatures, temperature control is implemented via 3 zones inside the vending machine: a subfreezing temperature zone (for the next product to be sold), preliminary cooling zone, and replenished products cooling zone.

Fig.1 "FAT30L6RT8IK"

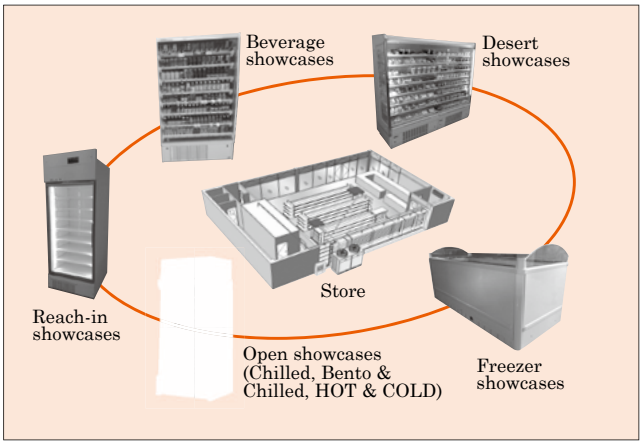
Store Distribution

1 Line-Up Expansion of Non-Leak Integrated Showcase

For the convenience store industry, in which Fuji Electric aims to expand business, we have developed and expanded a series of non-leak integrated showcases for in-house stores with restrictions of cosntructing stores. The series simplifies installation work by integrating the cooling unit directly inside store showcases. We have expanded the product line-up to 5 models. The main features are as follows:

(1) External piping and outdoor unit are not required to install.
(2) Employing the showcase facilitates flexible store layouts and easy layout changes.
(3) On-site refrigerant filling is not required, reducing the risk of refrigerant leakage.
(4) Drainage has been eliminated by utilizing a steam-based system that uses the exhaust heat of the cooling unit.

Fig.2 Product line-up



Field Services

Field Services

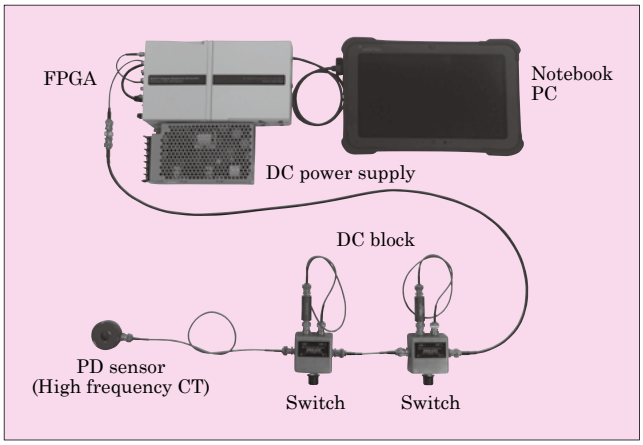
Field Services

1 Online Partial Discharge Measurement Device

Partial discharge measurement is used to check the health of medium-voltage switchboards. Although various measurement methods and measurement devices have been developed, none of them have had online capability.

Fuji Electric developed the online partial discharge measurement device as a device for constantly monitoring partial discharge to meet the need of long-term continuous operation of equipment. The prototype is composed of a PD sensor (high frequency CT) for detecting partial discharge signals, DC block and FPGA. The FPGA incorporates a logic that eliminates noise and extracts characteristic values (partial discharge phase and waveforms) from signals and then determines the existence of discharge generation. We plan to conduct prototype field verification and develop portable partial discharge detection devices, and using this technology, we will achieve IoT based partial discharge measurement systems.

Fig.1 Online partial discharge measurement device

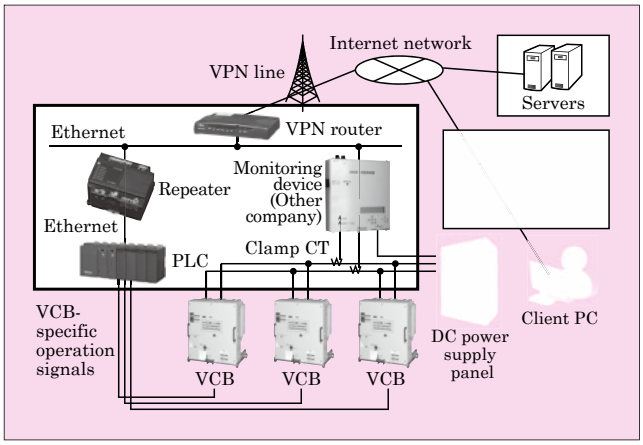


2 VCB Collective Monitoring System

The VCB collective monitoring system constantly and remotely monitors the operating current of vacuum circuit breakers (VCBs) that play an important role in power supply applications. A monitoring device is installed in the control power supply circuit of a VCB, and changes in current and time are automatically measured, transmitted and recorded to a cloud server via a VPN line. By accessing the server from a client PC, users can monitor, check and compare the current waveforms of any VCB. The main features are as follows:

(1) A single monitoring device for acquiring data can be used to monitor multiple VCBs.
(2) Capable of acquiring the operating characteristics of VCB closing and breaking.
(3) Capable of comparing characteristics by tracing the acquired data.
(4) Makes it possible to combine and identify the operating signals of individual VCB on the server.

Fig.2 Configuration of VCB collective monitoring system



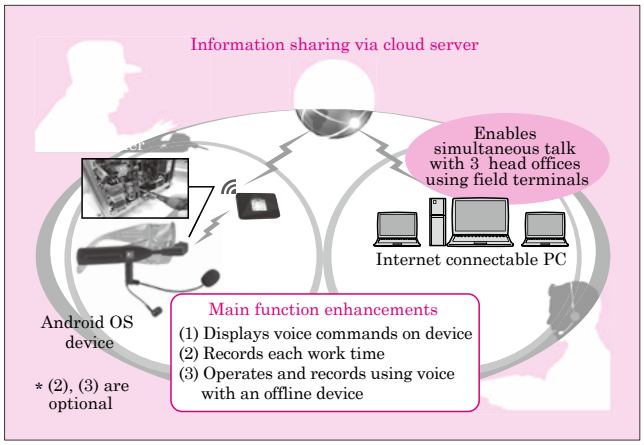
3 Functionality Expansion of “FWOSP” Wearable Remote Operation Support Package

The “FWOSP” Wearable Remote Operation Support Package is a cloud-based service that improves the quality and efficiency of work in the job field and support the transfer and accumulation of technical know-how.

Fuji Electric has expanded following operation and management functions by bidirectionally connecting the glass-type wearable device worn by workers to a PC located at the head office using voice and video: instructions, work support, voice input for recording pre-registered work procedures and work results. The main features are as follows:

(1) Voice input commands are displayed as a list on the glass-type device to improve convenience at the job field and to achieve reliable voice operation.
(2) FWOSP can be used for work time management by recording the work time on the server and confirming and downloading it via a PC in the head office.
(3) The package comes equipped with a standalone function capable of recording results and displaying procedures by voice operation even when not connected to the Internet.

Fig.3 “FWOSP”



Fundamental and Advanced Technologies

Fundamental Technology
Advanced Technology

Outlook

Fuji Electric is working on developing competitive components that are excellent in creating customer value and solutions using the components. At the same time, we are energetically committed to research and development of fundamental technology that supports product development and advanced technology that can differentiate our products for those of competitors.

In material technology, we have developed simulation technology for predicting the progress of corrosion of geothermal turbines with a multi-phase field method. The technology uniformly deals with ion diffusion in corrosive liquids and metal melting, and it supports various corrosive environments and corrosion modes. We will apply this technology to product design in the future.

We are proceeding with the development of silicon carbide (SiC) devices aiming at overwhelming differentiation and power electronics equipment using SiC devices. We are promoting research by using leading analytic technology and computational science to clarify the mechanism to achieve SiC devices with low resistance and high reliability. In addition, we have made the relation between discharge voltage and electric field distribution of insulation surface into a mathematical expression by using discharge theory. Combining the mathematical expression with a simulation of the chip's internal structure, we developed breakdown voltage prediction technology for accurately predicting breakdown voltage (difference with the measured value within 5%) and optimized the insulating structure of SiC devices.

To maximize the performance of a SiC-MOSFET (metal-oxide-semiconductor field-effect transistor), we have developed unique active gate drive technology to achieve both high-speed switching operation and surge voltage suppression. Surge voltage jumping was reduced by about 20% with this technology.

As thermal energy technology, we developed advanced technology aiming at effective use of unused low-temperature exhaust, and we are applying the technology to products. We have developed the technology to achieve two-stage compression with the same compressor and are now developing a 150 °C high-temperature steam generator that can operate efficiently. In addition, we have succeeded in developing adsorbent employing a new concept and it has overwhelming adsorption performance. We are now developing an adsorption freezing machine using this adsorbent.

We also established laser display technology with high visibility and the ability to project focus-free images that are in focus regardless of the distance with and the angle of the projection plane. This breakthrough technology can achieve both safety and visibility by utilizing visual effects. We will work to have it implemented in digital signage in the fields of factory automation and food distribution.

As system technology, we developed crane control technology that can resist disturbance such as wind and requires no adjustment of control parameters with respect to fluctuations of the suspended load weight and rope length. Robust control for reinforcing the existing controls can reduce the introduction cost.

The Internet of Things (IoT) is attracting attention as a solution for creating customer value. We are expanding the solution using various field devices and a sophisticated, characteristic analytic technology with the key phrase "Small, Quick Start & Spiral-Up." We developed an IoT platform having a communication function and security function of a cloud and an edge controller, as well as the service interfaces for easily constructing services based on general-purpose cloud technology. We are going to start operating the IoT platform in FY2018.

We also developed device authentication technology for IoT systems that prevents the connection of unauthorized devices. IoT devices mutually authenticate with the cloud before transmitting data and transmit a token (license) with the data to the cloud when transmitting data.

To meet the rising demand for abnormality diagnosis technology for equipment, we developed diagnostic visualization technology that determines the diagnosability of an abnormality using the acquired data in

one-tenth of the time of the conventional type. We have also developed non-linear diagnosis technology to diagnose complicated object that had been difficult with the conventional technology.

We aim to apply deep learning technology, which allows accurate inference, to an industrial field. To this end, we are developing deep learning technology that enables automatic learning and inference basis explanation via automatic parameter learning with model structure optimization and inference basis explanation with input and output relation quantification.

We are developing a method that optimizes purposes in a large-scale calculation to reduce the number of prototypes. We established a multi-purpose optimization method for temperature and noise of power electronics equipment by automating 3D-CAD shapes and analysis settings with respect to a parametric design factors, and we verified the improved performance. We will promote the product development by front loading.

Fuji Electric will strive to develop advanced technology that contributes to innovating electric and thermal energy and environmental technology. We are also improving the fundamental technology that supports product development. Thus, we will continue providing components and solutions that allow excellent differentiation of products and create customer value.

Fundamental Technology

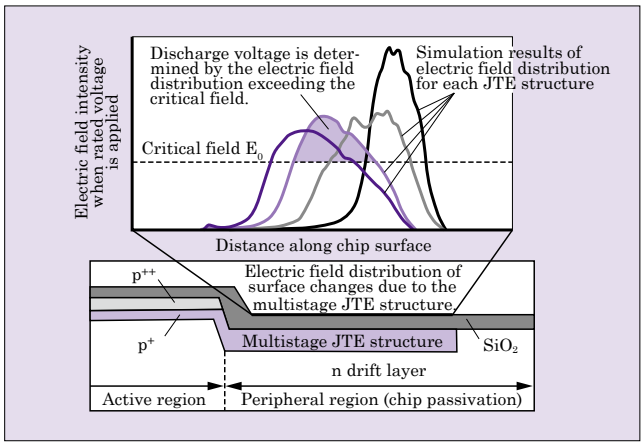
1 Optimization of Surface Insulation Design of Semiconductor Chip Based on Discharge Theory

Fuji Electric has established design technology for preventing the breakdown of surface insulation in the peripheral region (chip passivation) of SiC semiconductor chips.

In the conventional chip design process, the breakdown voltage was calculated from the carrier density and mobility of the inner junction termination extension (JTE) structure of a peripheral region. Meanwhile, an estimation based on the maximum electric field was used for the surface structure part. To improve the power density of a chip, it was necessary to maintain the breakdown voltage with a shorter insulation width; however, it had been difficult to accurately determine the insulation breakdown of the surface.

We have made the relation between the discharge voltage and the electric field distribution of the surface into a mathematical expression applying the discharge theory of a gas space. With the mathematical expression, we developed technology for predicting the breakdown voltage of chip surface from the simulation result of the JTE structure at a high accuracy of 5% or less compared with the measured value.

Fig.1 Passivation schematic diagram of SiC chip and its electric field distribution



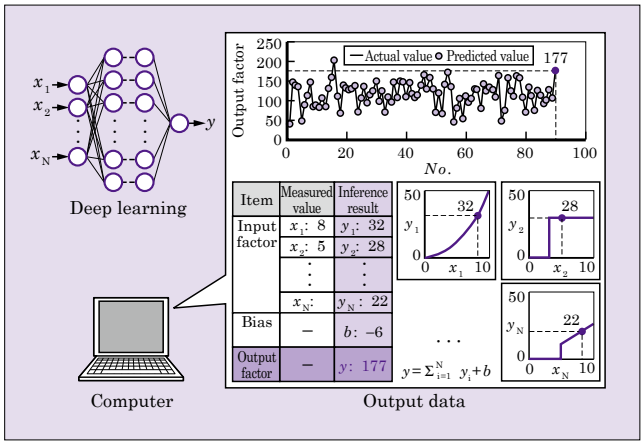
2 Deep Learning Technology That Allows Automatic Learning and Inference Basis Explanation

Deep learning is attracting attention in the image processing field as technology that allows accurate inference (classification and regression). However, deep learning requires manual parameters and maintenance tuning, and it is difficult to interpret the inference results. Therefore, deep learning had been only applied to limited applications in the industrial field, which require long-term operation and reliability. Fuji Electric has been developing deep learning technology that allows automatic learning and inference basis explanation. The main features are as follows:

(1) Automatic parameter learning using model structure optimization
(2) Automatic maintenance learning using close learning
(3) Inference basis explanation using quantification of input and output relation

Introducing this technology will expand applications in the industrial field.

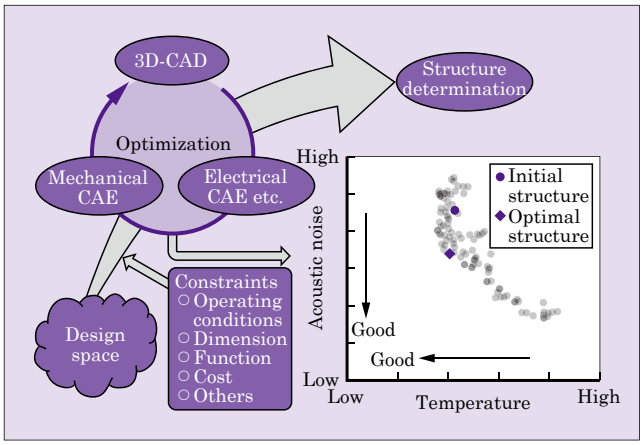
Fig.2 Example of inference basis explanation using deep learning technology



3 Approach of Computer Aided Engineering in Product Designing (Multi-Purpose Optimization)

Improvement of computing speed has enabled us to find out the mechanism of physical phenomena with large-scale calculation and shorten the calculation time. In addition to calculating representative conditions, optimal execution environment that involves hundreds of calculations are being created to improve functions and quality. Optimization in the mechanical simulation field requires automation of analysis condition settings such as the creation of a computational grid associated with changes in 3D-CAD shapes. Fuji Electric has used computer aided engineering for multi-purpose optimization with respect to the contradictory temperature and acoustic noise requirements for the cooling structure of power electronics equipment. We derived an optimal structure for parametric design factors by estimating noise in a short time in addition to automating 3D-CAD shapes and applying analysis condition settings. We have verified the derived structure on an actual equipment and confirmed the performance improvement. We will apply this front loading approach to product development.

Fig.3 Practical example of multi-purpose optimization

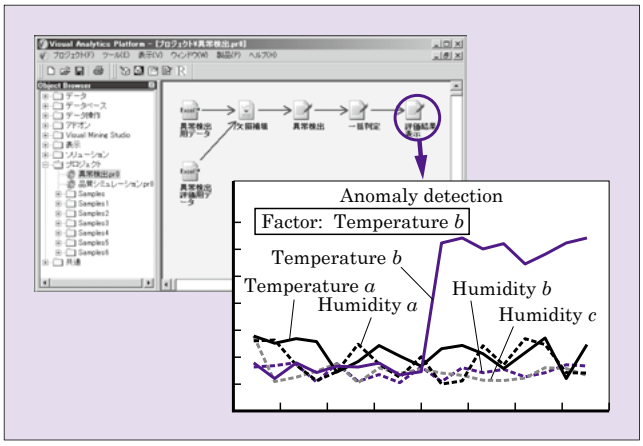


4 Data Analysis Platform Technology

Various types of data from each industrial classification are gathered through the cloud service that Fuji Electric is commercializing. To exploit these data as valuable information for new business, it is needed to create an environment for many engineers to easily analyze data. We have developed a data analysis platform using "Visual Mining Studio," which is a data mining product of NTT DATA Mathematical Systems Inc. The main features of the platform are as follows:

(1) Allow various types of analyses, such as correlation calculation, anomaly detection and quality simulation, by using Fuji Electric's unique data analysis engine.
(2) Provide analysis templates and standard procedure manuals to facilitate data analysis without any expertise.

Fig.4 Example of analysis template (Anomaly detection)

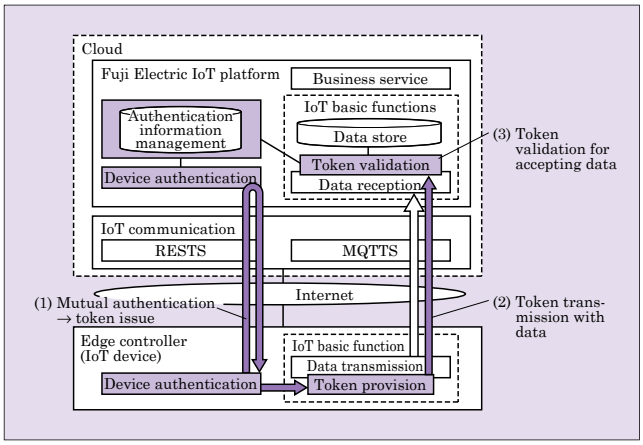


5 Device Authentication Mechanism for IoT System

In IoT systems, services on a cloud collect data from IoT devices via the Internet. Therefore, there is a risk of unauthorized device connection to the services.

Fuji Electric has developed an authentication mechanism for the IoT devices. In advance of transmitting data, an IoT device interacts with the cloud for mutual authentication and receives a token [see Fig. 5 (1)]. When the IoT device transmits data to the cloud, the token is also sent as an attachment [see Fig. 5 (2)]. The data receiving function in the cloud only accepts data with a valid token [see Fig. 5 (3)]. As a result, data from unauthorized devices are excluded. We will apply this mechanism to IoT devices such as edge devices, which are connected to our IoT platform, to keep our IoT systems safe and secure.

Fig.5 IoT system configuration applying device authentication



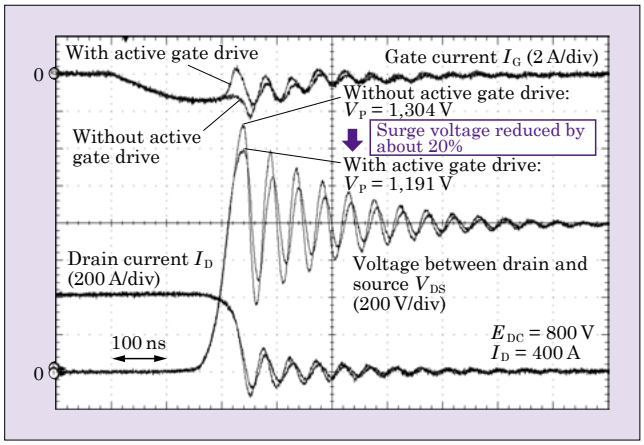
Advanced Technology

1 Active Gate Driving Technology for SiC-MOSFET

SiC-MOSFETs, which operate at high speed with low loss, are expected to help reduce the size and improve the efficiency of power electronics equipment. However, the application of SiC-MOSFETs has been restricted because of their excessive switching surge voltage, therefore their performance has not been fully used.

Fuji Electric has developed an active gate driving technology to maximize the performance of SiC-MOSFETs. As shown in Fig. 6, the device can switch at high speed with its surge voltage suppressed by the unique control method that stops the flow of the gate current for a certain period when the drain current is reduced. We confirmed that this method reduced turn-off surge voltages by about 20%, and the turn-off loss had similar switching characteristics compared with those during normal driving.

Fig.6 Surge voltage suppression with active gate driving technology



2 Solid Oxide Fuel Cell for Commercial Use

Fuji Electric is now developing solid oxide fuel cells (SOFC) in addition to 100-kW phosphoric acid fuel cells (PAFC), which are available now. We have been participating in "Technical development for promoting practical realization of SOFC" of New Energy and Industrial Technology Development Organization (NEDO) since FY2014, presuming a cogeneration system for commercial use of dozens of kilowatts. In FY2017, we conducted the electricity generation test of a 50-kW class prototype systems at the Chiba Factory and verified its continuous rating operation for 3,000 hours or longer. As the result, we have achieved the target performance, which is an AC power generation efficiency of 50% or more and exhaust heat recovery efficiency of 30% or more. In FY2018, we are conducting a field demonstration and plan to develop a commercial product to be launched at the end of FY2018.

Fig.7 Solid oxide fuel cell for commercial use (prototype system)

3 Robust Design of Anti-Sway Control System for Cranes

Fuji Electric has developed the anti-sway control system for cranes used in the factory automation field. We have developed a control design method that can resist disturbance such as wind that swings suspended loads. The main features are as follows:

(1) Readjustment of control parameters is unnecessary.

The control parameters do not need to be readjusted when the weight of the suspended load or rope length is changed.

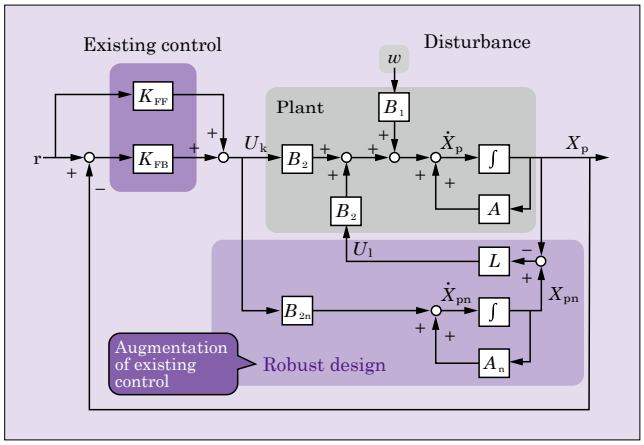
(2) The introduction cost is reduced.

The introduction cost can be reduced because the robust design for augmenting the existing control requires little system modification (see Fig. 8).

(3) The robustness is improved.

A simulation of a harbor crane showed that the anti-swing control performance of the suspended load with respect to disturbance improved by 32.9%.

Fig.8 Block diagram of robust design

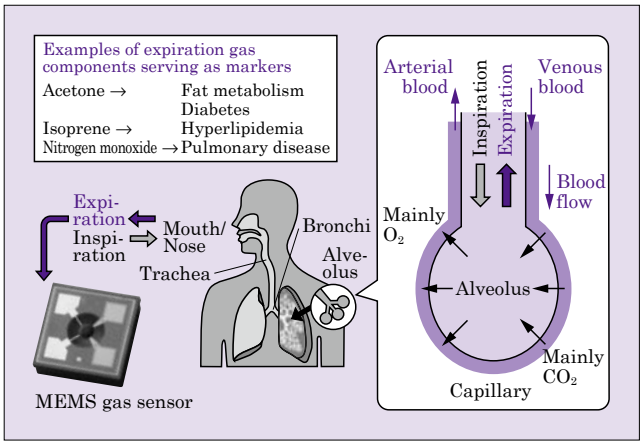


Advanced Technology

4 Breath Measurement Technology Using MEMS Gas Sensors

Fuji Electric has been studying breath measurement using a MEMS gas sensor as an application of the world's first battery-powered methane sensors for a utility gas alarm. Human breath contains volatile gases that were in the blood, and our study is based on the concept that measuring them in the breath is an effective way to provide health care. Recently, breath acetone produced during the metabolism of fat has been attracting attention as an index for training and dieting, and a diabetic marker. Against the backdrop, we have developed a breath acetone sensor. The catalyst technology optimized for detecting acetone can distinguish breath acetone from breath alcohol, which had been impossible with the conventional technology. Furthermore, the accuracy of detecting breath acetone has been improved by reducing the detection sensitivity of breath alcohol. The MEMS gas sensor allows high-sensitivity detection with sensor drive technology and can detect breath acetone concentration in the range of 0.1 to 20 ppm.

Fig.9 Breath measurement using MEMS gas sensor

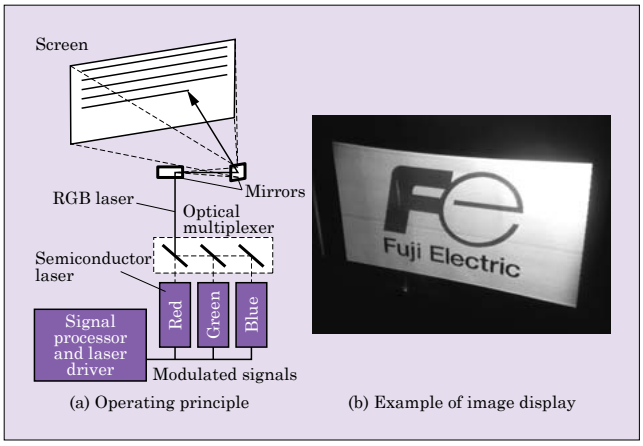


5 Laser Display Technology with High Visibility

Recently, digital signage for interactive advertisements and worker support that use videos has come to be used in various fields. There is increasing demand for a video display device that can project images at various places. Fuji Electric has established laser display technology with high visibility for projecting focus-free images that are in focus regardless of the distance with and the angle of the projection plane. The conventional laser display has a problem of low visibility in bright places.

We thus use the characteristics of human vision to develop laser beam technology that improves visibility while suppressing the laser beam output, achieving safe and highly visible lasers. We will consider how to apply this technology to digital signage in the fields of factory automation and food distribution.

Fig.10 Operation principle of laser display prototype and example of image display

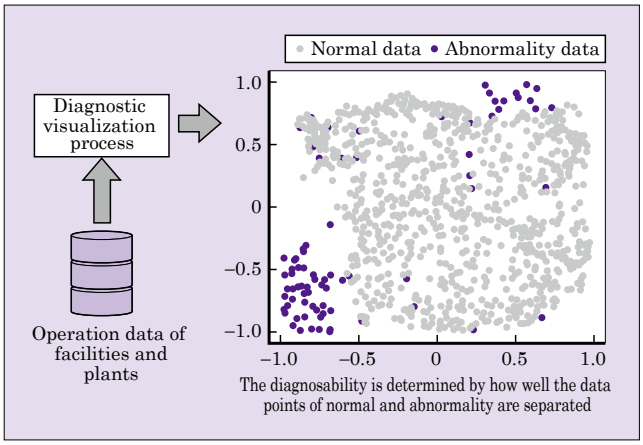


6 Diagnostic Visualization Technology and Non-Linear Diagnosis Technology

There in an increasing demand for abnormality diagnosis technology of facilities and plants using data, and more complicated targets than before are required to diagnose. In abnormality diagnosis, it is important to quickly determine diagnosability with the obtained data, present it to the customer, and construct a high performance model.

Fuji Electric has been developing diagnostic visualization technology for determining abnormality diagnosability on the basis of operation data of the diagnostic target and non-linear diagnosis technology that can diagnose complicated abnormalities of facilities and plants. We have applied the diagnostic visualization technology to an actual project and verified that the determination of diagnosability, a process that has taken more than one week, can be completed in half a day. In addition, the non-linear diagnosis technology improved by more than 20% the diagnostic performance of objects that had been difficult to diagnose with conventional technology.

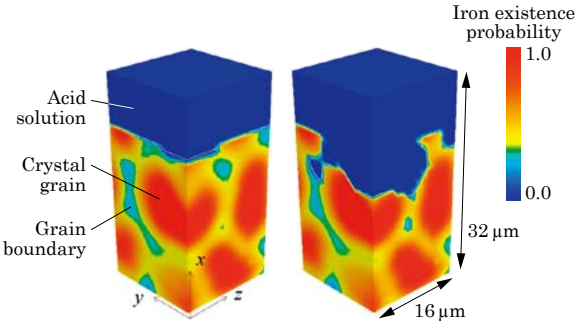
Fig.11 Example of diagnostic visualization technology



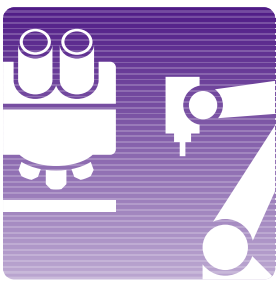
7 Corrosion Simulation Technology

Fuji Electric develops products that can operate under severe corrosive environments, such as a geothermal turbine and a cleaning system for marine exhaust gas. To ensure long and stable operation of products, technology is required for accurately predicting the progress of corrosion over time. Corrosive environment differs depending on product, and corrosion includes various modes; the corrosion prediction technology needs to deal with all the conditions. We have thus developed corrosion simulation technology that supports each corrosive environment and corrosion mode using a multi-phase field method. The technology can uniformly deal with ion diffusion in corrosive liquids and metal melting on the surface of products, and so can be used for various corrosion environments of products. The technology also deals with various corrosion modes including pitting corrosion by incorporating the unevenness of metal structures into the calculation model. We will apply this technology to product design.

Fig.12 Simulation result of pitting progress of corrosion of iron



(a) Before corrosion (b) After corrosion



FUJI ELECTRIC REVIEW vol.64 no.2 2018 Detailed Contents

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Contributing to the Creation of Sustainable Societies through Our Energy and Environment Businesses

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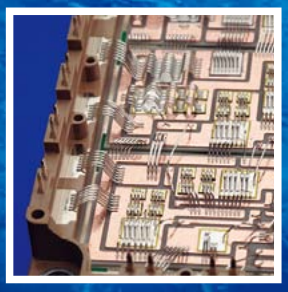
Innovating Energy Technology

Through our pursuit of innovation in electric and thermal energy technology, we develop products that maximize energy efficiency and lead to a responsible and sustainable society.

Corrosion Resistant, Material, and Hot Water Utilization Technology

Geothermal Power Plants



Device Technology

Power Devices (IGBT)

Power Electronics Technology

Power Conditioning Systems (PCS) for Megasolar Plants

Power Electronics Technology

Inverters

Power Electronics Technology

Uninterruptible Power Supply Systems (UPS)

Heat Excange and Refrigerant Control Technology

Hybrid Heat Pump Vending Machines

Fuji Electric