Whole Number 253, ISSN 0429-8284

FUJI ELECTRIC REVIEW

2016
Vol.62 No. 2

Technical Achievement and Outlook in FY2015

Fuji Electric

Innovating Energy Technology

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REVIEW

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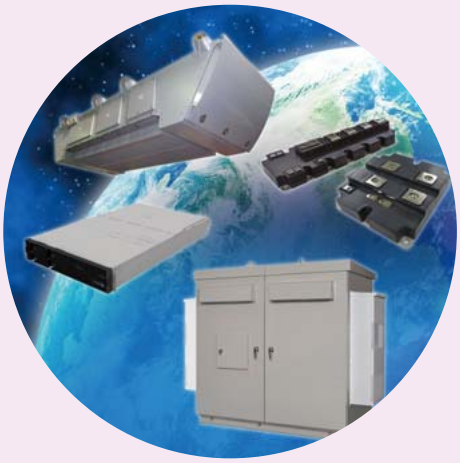
The world is facing various energy and environmental problems as a result of the sharp increase in population and the rapid development of industrialization. Under these circumstances, the world's energy technologies have been drastically changing with the advance of renewable energies developed to mitigate global warming. Fuji Electric is striving to achieve a safe, secure and sustainable society through the innovation of energy and environmental technologies. This special issue on "Technical Achievement and Outlook in FY2015" is a compilation of the technical achievements of FY2015 and summarizes the outlook for the future. We hope that this special issue will be helpful in the creation of a new society.

Cover Photo (clockwise from the upper left):
Traction converter for Tokaido Shinkansen trains, 7th-generation "X Series" IGBT module, SiC power module, Outdoor 555-kVA power conditioning sub-system "PVI600BJ-3/555," High-efficiency backup power supply for servers "F-DC POWER"



FUJI ELECTRIC REVIEW vol.62 no.2 2016
date of issue: June 30, 2016

editor-in-chief and publisher **EGUCHI Naoya**
Corporate R & D Headquarters
Fuji Electric Co., Ltd.
Gate City Ohsaki, East Tower,
11-2, Osaki 1-chome, Shinagawa-ku,
Tokyo 141-0032, Japan
http://www.fujielectric.co.jp

editorial office Fuji Electric Journal Editorial Office
c/o Fuji Office & Life Service Co., Ltd.
1, Fujimachi, Hino-shi, Tokyo 191-8502,
Japan

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Preface

Through Innovation in Energy and Environment Technology, We Contribute to the Creation of Sustainable Societies.

Since its inception in 1923, Fuji Electric has been making contributions to society in the fields of industrial and social infrastructure.

As a result of unprecedented rapid increases in population growth and industrialization, the earth is now faced with energy and environmental problems. With its brand statement of "Innovating Energy Technology," Fuji Electric is determined to contribute to the creation of a responsible and sustainable society through our pursuit of innovation in energy and environment technology. Going forward, Fuji Electric will continue to improve its energy and environment technology and manufacturing capabilities in order to supply environmentally friendly products that provide high added-value and that are able to use energy as efficiently as possible.

With our core technologies of power semiconductors and power electronics, and also including instrumentation and thermal technology, Fuji Electric's research and development initiatives are resulting in the development of thoroughly distinctive components. Moreover, by establishing and packaging a platform for control technology that is centered on these distinctive components, Fuji Electric is also focused on the development of products that will provide various solutions to our customers. For the Internet of Things (IoT), which is currently attracting much attention, Fuji Electric is leveraging its expertise in sensing and other technologies to focus on the development of distinctive devices and platforms. To accelerate these developments and strengthen the development structure, in FY2015, Fuji Electric completed construction of the Development Center at its Matsumoto Factory, which is our central base for power semiconductors, and also completed construction of the Core R&D Center that will be used as a company-wide technical development base at its Tokyo Factory, and in addition, Fuji Electric is currently constructing the Power Electronics Technical Center at its Suzuka Factory to be used as a central base for power electronics.

Fuji Electric has been pursuing synergy with power semiconductor technology and power electronics technology, and is focusing on the development of power devices based on silicon carbide (SiC), which is expected to revolutionize power devices, and on the development of power electronics products that incorporate these devices. At the Matsumoto Factory, which is our production base for power semiconductors, the industry's first 6-inch wafer process line is running as a production facility for SiC devices, and Fuji Electric is mass-producing 600- to 1,700-V Schottky barrier diodes (SBDs) and 1,200-V metal-oxide-semiconductor field-effect transistors (MOSFETs). At the same time, Fuji Electric is also developing various ultra-small and high-reliability modules capable of extracting the maximum performance from SiC devices. In addition, we have developed a 3,300-V hybrid module using a SiC-SBD that was developed in collaboration with the Tsukuba Power-Electronics Constellations (TPEC), a joint research consortium. Employing this module, we have developed a traction converter for Central Japan Railway Company. High-speed railway testing of systems that use SiC modules are being conducted for the first time in the world with Series N700 Shinkansen trains. For inverter applications, we have developed high reliability SiC-MOSFETs, and All-SiC

modules that incorporate SiC-SBDs. Leveraging the low-loss performance of these modules, we have developed a dustproof and waterproof inverter in a fully-enclosed self-cooling structure suitable for installation in adverse environments, where installation had been difficult previously. Going forward, Fuji Electric will continue to leverage the advantages of SiC devices to develop products that provide new value. Moreover, while maintaining synchronicity with the development process for power semiconductors, we also intend to develop a power electronics platform so that products can be developed efficiently within a short period of time.

As solutions to create customer value, we have combined our distinctive sensing technology with our vast experience in control technology and our strength in power electronics to develop a boiler combustion solution package that helps to reduce the cost of boiler fuel and a harbor crane solution control package that realizes the industry's highest level of steadying accuracy and energy savings. Furthermore, we have developed a supply and demand management system that supports the liberalization of the electricity retail market which has been underway since April 2016, and in collaboration with NTT Data Corporation and Kyowa Exeo Corporation, have begun selling this as a cloud service for power producers and suppliers.

Fuji Electric has a comprehensive line-up of products and technologies, ranging from onsite data sensing to gateway and network technology, and data analysis technology, and is preparing a variety solutions that will put the IoT to practical use.

As one example, we have developed a cloud-based comprehensive facilities management system, and have begun offering this service. This service allows customer equipment to be managed throughout its lifecycle, from installation of the equipment to its operation and replacing, thereby maximizing the management efficiency for customer equipment and minimizing energy cost. Fuji Electric will continue to develop distinctive devices and technology platforms to realize solutions that create customer value through the practical use of the IoT.

Fuji Electric will continue to create electromagnetic noise simulation technology, to develop resins for devices that operate at high temperatures, to develop bonding technology for dissimilar metals, to investigate the physical properties of magnetic materials, to create technology for analyzing resin and metal adhesion, and so on, as fundamental technologies and leading-edge research and development with an eye to the future.

Fuji Electric has adopted the slogan of "To be enthusiastic, ambitious and sensitive" to express its corporate philosophy. "Enthusiastic" means our creative passion and motivation, "ambitious" means our aim for advancing our high goals, and "sensitive" means the richness of the human spirit. With these concepts in mind, Fuji Electric intends to continue to accurately assess the needs of society and to realize innovations in energy and environment technology so as to contribute to the creation of a responsible and sustainable society. We are truly grateful for the guidance and encouragement received from everyone.

KITAZAWA, Michihiro
President and Representative Director

IoT and M2M — The Transformation of Social and Industrial Infrastructure

— Giving tacit knowledge an explicit form to bring new value to customers —

MORIKAWA, Hiroyuki Professor, Research Center for Advanced Science and Technology, The University of Tokyo
EGUCHI, Naoya Corporate General Manager, Corporate R&D Headquarters, Executive Officer, Fuji Electric Co., Ltd.

The Internet of Things (IoT) and machine-to-machine (M2M) technologies have become diffused and now influence the whole of society. What does the future hold for industrial systems as the IoT and M2M continue to advance? It is crucial for Fuji Electric to identify its fortes in order to take a plunge into this unknown territory with its strengths in industrial infrastructure and power electronics. Professor Hiroyuki Morikawa, a leading IoT specialist from the University of Tokyo's Research Center for Advanced Science and Technology, talks with Naoya Eguchi, Fuji Electric's Corporate General Manager from the Corporate R&D Headquarters, on the importance of having a customer-centered approach in creating new value.

The IoT and M2M are realities

Eguchi: I'd like to take this opportunity to thank you for your ongoing dedication that we are fortunate to witness on various occasions. We appreciate your input in the subject of energy conservation for network devices, and also the interaction we have with your laboratory.

Fuji Electric came into being 93 years ago as a joint venture between Siemens AG and Furukawa Electric Co., Ltd. The company has since developed mainly in the area of heavy electric equipment. We often see the Internet of Things (IoT) and machine-to-machine (M2M) technologies being mentioned today, but Fuji Electric has already been engaging in something close to them for a long time in relation to industrial plants, such as remote facility maintenance systems.

Today, I would like us to discuss this major transformation in industrial systems brought by the IoT, and explore the possibilities of leveraging our resources in this area.

Morikawa: At my laboratory, we also set our ultimate goal as the creation of new value from data-oriented technologies such as the IoT, M2M and big data. We mainly focus on gathering and analyzing data to identify what value we can offer to customers. For example, we are researching data mining in agriculture and the early detection of incipient faults for wind turbine systems. Our endeavor is a combination of two major themes: telecommunications as an infrastructure, and the applied areas such as agriculture and wind power generation.

Eguchi: At Fuji Electric, we have a rich resource of sensors, controllers, actuators and other field devices, but we still need to improve on how we leverage the collected data.

Morikawa: Sensors and actuators give Fuji Electric the means to gather data. It represents a great advantage for the company. As promoted by the OECD, a data-driven economy is the concept of creating value with data as a starting point to enhance productivity.

To the question of what the IoT is about, I say it is about turning analog into digital. Take wind power generation, for example; we rely on the experience and intuition of skilled engineers to detect abnormalities. The IoT can replace those with digital data.

Eguchi: It is about converting tacit knowledge and know-how into digital data.

Morikawa: That's right. There is a case in which a bus service operator successfully turned their unprofitable routes into profitable ones through digitization. They equipped their buses with GPS and sensors, and collected data on service execution and passenger statistics from every bus stop. Based on such data, they modified the time table and repositioned their bus stops. This is all they did, and they succeeded in turning operational loss into profit. They gathered data, which had helped them to visualize their operational status, elucidating where the problems were.

Here is another interesting example of digitization that relates to a comedy theater in Barcelona, Spain. They installed cameras on the back of each seat to capture the faces of the audience and generate digital data on how many times a particular audience

MORIKAWA, Hiroyuki

1992: Research Associate, The University of Tokyo
1993: Assistant Professor, The University of Tokyo
1997: Associate professor, The University of Tokyo
2006: Professor, The University of Tokyo
2007: Present post
2002-2007: Concurrently served as a group leader of NICT Mobile Network Group.
Concurrent posts include President of the New Generation M2M Consortium; vice-chair of the OECD Committee on Digital Economy Policy (CDEP); fellow of the Institute of Electronics, Information and Communication Engineers; member of the Information and Communications Council, the Ministry of Internal Affairs and Communications; member of the National Research and Development Agency Council, the Ministry of Land, Infrastructure, Transport and Tourism; and expert advisor of the Council for Science and Technology, the Ministry of Education, Culture, Sports, Science and Technology.

member laughed. This allowed them to introduce a new pricing system. They abolished the admission fee, and instead, they started charging audience members 30 cents every time they laughed. To our amazement, this system has improved the audience satisfaction, and the revenue increased as a result.

As these examples suggest, in the IoT, it is important to do it anyway.

Eguchi: We tend to prioritize the cost, and this often prevents us from going further to focus on value creation. We find it difficult to always keep customer-centered perspectives in formulating a new value to offer. On learning that your research starts from thinking about what to offer customers, I see great significance in this approach.

Morikawa: In the past, research at universities typically took a linear approach, starting with basic research, followed by studies for practical applications, then deployment in society. Today, however, it is more often the case that we first find issues in the field.

Eguchi: It is similar to what we do in the industrial sector.

Morikawa: That's right. Universities also need someone like an analyst who scrutinizes what customers need most.

Eguchi: What is the method of your teaching at the research center?

Morikawa: Given an increasing awareness of the IoT in agriculture and many other sectors, I sometimes send my students out into the field to find potential needs. Identifying customer needs and then implementing ideas before presenting them to customers; this is the concept of what is called design thinking.

Eguchi: We often encourage members of our laboratory to go out into the field with customers more instead of locking themselves in the lab, but it takes a great effort to do just that.

Morikawa: I would say it is ideal if about 10% of researchers and engineers were up and about in the field. Even if it does not lead to success, they can simply try again.

Eguchi: Our plant factory may be a good example of this approach. We have a 2-hectare strawberry production plant in Tomakomai, Hokkaido, Japan where we experiment with Fuji Electric products and technologies in the agricultural industry. We currently have engineers stationed there to learn from farmers, acquiring their tacit knowledge, aiming to convert it into explicit knowledge. There is also a bell-pepper plant under construction in Kushiro at the moment.

Morikawa: Speaking from the viewpoint of the data-driven economy that we spoke about earlier, it sounds like a viable business prospect. It should be possible to roll out greenhouses throughout Asia, and aggregate the data from them in Japan to formulate know-how on greenhouse management.

Eguchi: That is exactly the IoT in practice.

Will hardware be empty in value?

Eguchi: It is very inspiring to learn about new-value creation deriving from findings based on clusters of voluminous data. Meanwhile, it would be unlikely for an enterprise to decide to gather data without specific purposes.

Morikawa: There may have to be certain assumptions for data collection. Nonetheless, insights may also be gained from the data outside such assumptions. For this reason, it is advisable not to eliminate apparently irrelevant data segments.

Eguchi: Does that mean that we should upload all the data from sensors straight to the cloud? Alternatively, we could pre-process the sensor data before uploading it to the cloud for further in-depth analyses.

Morikawa: One point for consideration is whether the network and storage space can cope with the entire data volume. Monitoring camera data is a good example. Another point is the timeliness of the data. If it takes time to upload all the data, it may adversely affect the immediate decision-making and control execution. If this is the case, it would be necessary to prepare the data in a local environment.

Eguchi: Today, many global giants are putting their fingers in the IoT pie. Fuji Electric is a small competitor compared to them, and our greatest concern is how we should proceed in the IoT business. The question is whether we go for a one-stop service option to cater to all needs, or opt for a more organic, collaboration with several enterprises, forming an ecosystem where Fuji Electric is one contributor. In either case, we will need to be aware of our playing field. Otherwise, if in the future the time comes that all there is to do is to upload data, then what we do will lose its value. We must avoid falling into such a situation.

Morikawa: It is very important to be prepared for future risks such as this. As we know, a very well-known US electrical manufacturer decided to call itself a software company. They did so because hardware was losing its value in business. This is a global trend. We will need to have a bilateral approach between hardware and software. Differentiation in hardware will

EGUCHI, Naoya

1980: Joined Fuji Electric Manufacturing Co., Ltd. (now Fuji Electric Co., Ltd.)
2006: Director, Fuji Electric Systems Co., Ltd.
2009: President and Representative Director, Fuji Electric Advanced Technology Co., Ltd.
2010: Director and Managing Executive Officer, Fuji Electric Systems Co., Ltd.
April 2011: Executive Officer, Fuji Electric Co., Ltd. and Corporate General Manager, Corporate R&D Headquarters of the company.

also be important in the future.

Eguchi: This presents us with another concern as to whether we should introduce some level of intelligence into the field devices, ever if not AI.

Morikawa: Possibly. Fuji Electric products are widely used in clients' field devices. That means you have field-based know-how. This point should be given thorough consideration.

The value of thinking cannot be overemphasized. In Germany, Industrie 4.0 is an initiative based on government-industry-academia partnership. I hear that most of the 30 billion yen's worth of government funding is spent not on the development of technology, but on organizing meetings and community events. They allow a large portion of that money to be spent to ensure opportunities for thinking about the interfaces in order to connect devices via the Internet. Many stakeholders come together in this, including business rivals and small- and medium-sized enterprises representing the majority. In Japan, we tend to be happy to dedicate resources for technological development, but very little is done to ensure there are proper opportunities to think.

Eguchi: We think that Industrie 4.0 presents a great threat to us if they succeed in leading the standardization. Japan must show strong leadership.

Morikawa: As the IoT enhances connectivity, having an ecosystem approach is ever more important than today. It is no longer viable for a single company to tackle the whole enterprise. Teamwork is the key, including us universities.

Corporations in North America and Europe are advanced on this front. For example, the Industrial Internet Consortium (IIC) is a platform launched by a group of US companies. While the German Industrie 4.0 focuses on manufacturing, the IIC covers the areas of energy, healthcare, manufacturing, public services and transportation. They present themselves as being an open organization, with the top management recruited from outside. Today, more than 100 corporations participate in it from across the world.

I am sure that Japanese electrical manufacturers also share an awareness about the importance of collaboration. Today, we live in a demanding era where teamwork is indispensable even to develop a business ecosystem in order to fare well amid international competition.

Eguchi: When it comes to making our presence felt in a team, we need to have something that is globally outstanding.

Morikawa: I agree. If I may digress a little, Ferrari is one of the most outstanding manufacturers. They reduced production while hiking unit prices, and yet succeeded in expanding sales. In a Japanese context, a typical approach would be to lower prices to sell in large quantities while the product is in demand. Ferrari has been successful by doing the opposite. I think that engineers today must have this kind of perspective. They can no longer be indifferent to matters concerning sales and marketing.

Eguchi: I agree. Japanese firms tend to be prone to price competition. It was the case with memories, LCD and solar cells. They all lost in the price competition against overseas competitors in the end. Fuji Electric has power electronics and power semiconductors as its core technologies. Regarding power semiconductors, we are mindful of not falling into a price competition. Because power semiconductor is an analog technology with an accumulation of know-how, it cannot be easily copied as long as secrets are kept.

In the wake of industrial structure transformation

Eguchi: Are you working to develop network devices and sensors at your laboratory?

Morikawa: We use sensors, wirelessly collect data, and what follows is the area of our research. Currently, we are looking at multi-hop technology. By involving several wireless hops, it is possible to extend the reach outside the range of one-hop communication. A multi-hop configuration is rather laborious to set up, so we are trying to achieve differentiation by simplifying the system so that it is easier to adjust and use.

Eguchi: Fuji Electric is striving to enhance sensor usability. Leveraging our strengths in the areas of cordless, low-power consumption and miniaturized devices, we develop products such as gas sensors that can be installed almost anywhere.

We are also working on applying micro electro mechanical systems (MEMS) technology to develop self-power feeding sensors. As our technologies cover areas beyond sensors, such as inverters, motors and actuators, we want to create something out of a combination of these technologies that stands out in the world. I think it is crucial in order to survive.

Morikawa: It seems to me that the idea of combining something leads to success more often than not. I think it is an important point. However, we also need to develop what works for businesses, otherwise we cannot write papers that leave a strong impression.

Eguchi: Making an impression is important.

Morikawa: In the old days, there was not much that technology could do, and therefore even a performance improvement of 5% to 10% made an impression. Today, most things can be made possible with technology, as long as one can afford it. This has changed people's perception, and enhancing performance that much does not get the same amount of attention.

Eguchi: We would be grilled by the management about cost performance if we were to propose a 5% to 10% improvement in performance.

Morikawa: Exactly. And so, our ambition would be to aim for a 10-fold improvement.

I may not be accurate, but I say that the IoT is a result of IT and ICT matured as technology, and it is now beginning to extend its realm into many different

sectors such as agriculture, civil engineering and transportation. It is only the beginning.

Eguchi: So, the transformation has just begun.

Morikawa: My opinion is that the mainstream digitization will unfold over a long period in the coming decades.

Eguchi: M2M is literally communication between machines, and new values are created through that. It is possible that the future M2M will involve human behaviors and other complex interventions. There, we may find more new values.

Morikawa: IT and ICT are the future "general-purpose technology," to borrow an economics term. The industrial structure may well undergo a major transformation.

Take steam engines as an example of general-purpose technology. Peter Drucker pointed out that the invention of steam engines was significant not in that they brought locomotives into the world, but in that this infrastructure led to the rise of various industries such as banks, newspapers and postal services, transforming the industrial structure. It is also argued that the invention of the steam engine led to the rise of giant railway companies, which in turn necessitated the procurement of large funds, and gave birth to the Wall Street economy. Another aspect of this is that the major railroad companies created many middle-management positions, and the employees needed education, so business schools emerged.

In a similar sense, IT and ICT have paved the way to new infrastructure such as sensors and cloud computing. Changes will take place in various aspects of industries, and that will then lead to a transformation of industrial structure. I imagine that, in 30 years' time, we will be looking back at today and thinking that things were different in those days.

You're lucky if you can identify a transformation in the early days. If I did, then I would resign as professor. I often advise my young students to have flexible perspectives.

Eguchi: Would you say that the Japanese are not good at flexible thinking? We are somehow unable to further our imagination without having things built first.

Morikawa: I believe that the Japanese are also capable of having a creative imagination. We can if we try. I would like to see Fuji Electric also explore the frontiers with its strategic excellence.

It cannot be done if researchers are cocooned in their labs. They should venture out more to find challenges on behalf of the management, who are responsible for protecting the business. This is one of their purposes.

Eguchi: I absolutely agree.

Morikawa: I often mention RTB and CTB. These are financial terms; they stand for running the business or running the bank and changing the business or changing the bank. In the context of the IT division in the financial sector, for example, securing an IT system falls into RTB. Introducing a new financing system such as FinTech (Financial Technology) would be CTB.

In order to protect the company, it is crucial that RTB ensures a profit. If RTB takes a chance and fails, then the company loses its foundation.

In this sense, the IoT and the lab belong to CTB.

Eguchi: I agree that it is in the CTB domain. It is important to take chances.

Morikawa: In reality, however, many researchers, who should be in CTB, tend to be conservative. We need more researchers with a challenging spirit.

Silicon Valley is not an enemy

Eguchi: It has been inspiring to learn from this talk that we are at the beginning of a transformation of industrial structure through the IoT. Lastly, if you can, please tell us what you expect of Fuji Electric.

Morikawa: If I dare say, Fuji Electric is a bland company. I would like to see that this blandness is turned into the company's strength.

In my opinion, the IoT should be technology that will be made smart in shade. Since Fuji Electric has a rich resource of know-how and tacit knowledge, which many startups lack, I believe that such a resource can be transformed into an advantage by converting it into explicit knowledge.

Eguchi: We take great care to diligently follow up on our customers' requests, and that is the DNA of Fuji Electric. I understand your suggestion to be that we should compete not in terms of quantity, but in terms of agility.

Morikawa: Silicon Valley is not your rival. They will not try to encroach on your market territory because it is too bland for them.

Eguchi: This year, we have put "prioritize customer value" at the top of our R&D policies. It means that we cannot advance research without knowing our customers.

Morikawa: That is a good idea. Researchers should be constantly reminded of the significance of this.

Eguchi: It has been such an eye-opening discussion today, to learn that Fuji Electric can turn its bland nature into an advantage. Thank you for your time today, and we are looking forward to our future collaborations.

Achievements and Future Outlook

Powerful Component-Based Solutions Creating Customer Value

EGUCHI, Naoya
Corporate General Manager, Corporate R&D Headquarters
Executive Officer, Fuji Electric Co., Ltd.

1. Introduction

Fuji Electric has formulated the brand statement "Innovating Energy Technology" based on its concept of realizing a safe, secure and sustainable society through the pursuit of innovation in energy and environmental technology. With the attaining of this goal in mind, Fuji Electric has been concentrating its research resources on developing technologies for supplying and using electrical energy safely, securely and efficiently and technologies for utilizing thermal energy with no loss. It has also been working to develop a technology for optimally controlling these technologies. In our Medium-Term Management Plan for 2013, we described our research policy for providing energy solutions. This policy positions our power semiconductors and power electronics as core technologies, while also developing our thoroughly differentiated components, which include measurement and thermal components. The purpose is to create a platform and package for our control technologies based on our core technologies and components (see Fig. 1). This paper introduces our latest developments based on this policy.

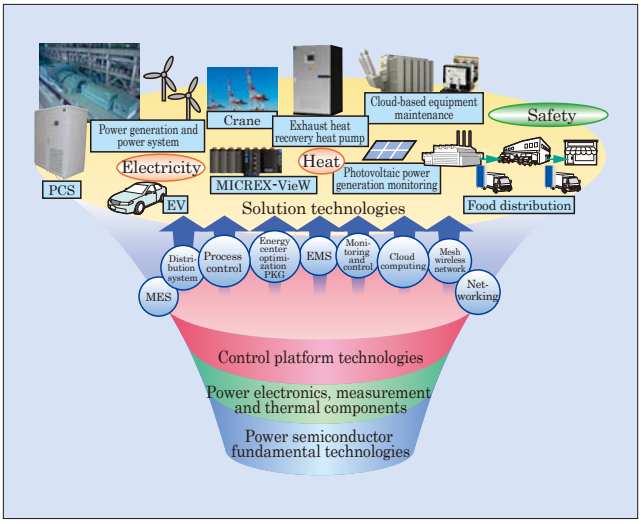

Fig.1 Fuji Electric's core technology and areas of focus

2. Synergy of Power Semiconductor and Power Electronics Technologies

The power semiconductor technology and power electronics technology are the core technologies of Fuji Electric. We aim to achieve thorough differentiation by making use of the synergy between these technologies. And we are focusing on developing silicon carbide (SiC) power semiconductors as next-generation devices capable of exceeding the physical limitations of Si devices and dramatically reducing loss. We are also making an effort to develop power electronics components that use these semiconductors.

Our Matsumoto Factory is our manufacturing base for power semiconductors, and it has a 6-inch wafer processing line launched as the first SiC manufacturing facilities in the industry. We use it to mass-produce 600- to 1,700-V withstand voltage Schottky barrier diodes (SBDs) and 1,200-V withstand voltage metal-oxide-semiconductor field-effect transistors (MOSFETs) developed jointly with the National Institute of Advanced Industrial Science and Technology. At the same time, we are also developing various ultra-small, highly reliable modules characterized by high-temperature operation, heat dissipation and low inductance. The aim is to use them for maximizing the performance of SiC devices.

By utilizing a SiC-SBD in a free wheeling diode (FWD), we have developed and are supplying the market with a hybrid module that applies Fuji Electric's 6th-generation "V Series" to the insulated-gate bipolar transistor (IGBT) chip.

In addition to the 1,200-V and 1,700-V withstand voltage products, we have commercialized a 1,700-V withstand voltage hybrid module for electric railways driven with a low carrier frequency. In order to ensure high reliability, it uses AlSiC, a composite material of aluminum and silicon carbide, as the base material and aluminum nitride (AlN) featuring high thermal conductivity for the insulating substrate material. When applied to an inverter, it achieves lower loss than Si module by 32% (with a carrier frequency of 3 kHz)[(1)]. Furthermore, we have also developed a product featuring an even higher withstand voltage:

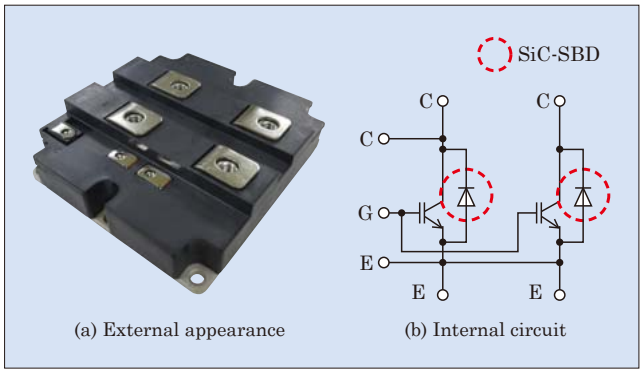

Fig.2 3,300-V withstand voltage SiC hybrid module

a 3,300-V withstand voltage hybrid module[2] (see Fig. 2). The SiC-SBD used for this module has been jointly developed with a joint research body, the Tsukuba Power-Electronics Constellations (TPEC). To enhance reliability, this module uses Sn-Sb solder under the chip, thereby improving the continuous operating temperature to 150 °C from 125 °C of Si-IGBT modules and achieving a module footprint reduction of approximately 30% from a current Si product. When employed to an inverter, it is capable of reducing the loss by 38% from a Si module (with a carrier frequency of 10 kHz).

For the Tokaido Shinkansen trains, we have developed jointly with Central Japan Railway Company a traction converter that uses SiC power semiconductor modules. The aim is to reduce its energy consumption, size and weight (see Fig. 3). SiC power semiconductor modules generate less heat than conventional Si power semiconductor modules, which allows the cooling mechanism of traction converters to be simplified. It also leads to a reduction in size and weight and energy saving for drive systems including traction converters. The running test carried out with SiC power semiconductor modules employed for a drive system of a high-speed railway is the first one in the world.

We have developed a SiC-MOSFET with even better reliability for inverters and combined it with SiC-SBD to develop an all-SiC module. By making use of the low-loss feature of this module, we have developed a dustproof and waterproof inverter with a totally enclosed self-cooled structure (see Fig. 4). This inverter can be installed in an environment where it is exposed

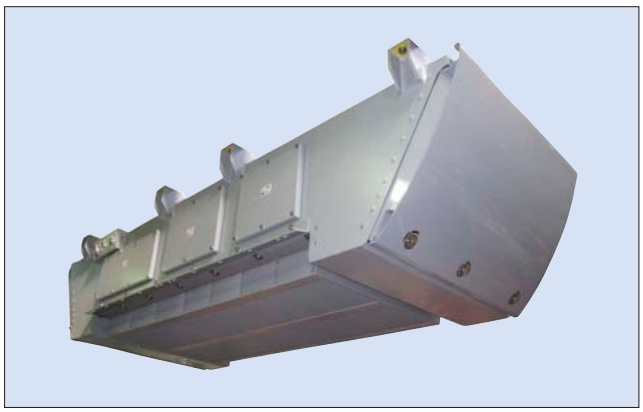

Fig. 3 Traction converter for Tokaido Shinkansen trains

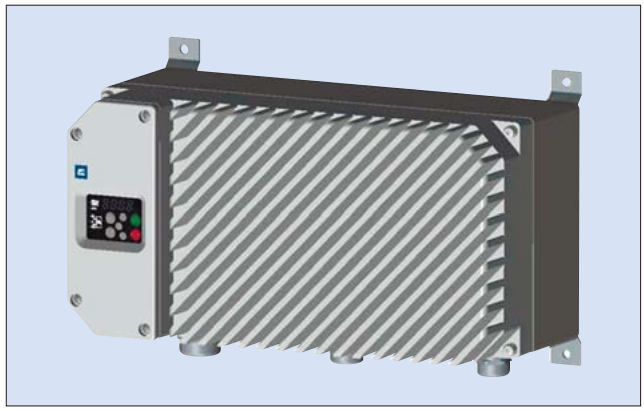

Fig.4 Dustproof and waterproof inverter with totally enclosed self-cooled structure

to dust, water, oil, etc., which was difficult to do in the past. To allow distributed installation in the vicinity of multiple motors in a production line, it is equipped with various functions including functional safety, customizable logic and open network options, and it is expected to contribute to energy saving of plants.

In addition, a backup power supply system for servers that uses SiC-SBDs has been commercialized (see Fig. 5). While power was conventionally supplied as AC to server racks, this system converts power into DC before supplying it. In addition to the loss reduction achieved by employing SiC-SBDs in the converter, the number of power conversions has been decreased from the conventional three to one. This makes it possible to improve the efficiency from the conventional 84% to 92% and reduce power loss to about half. It provides a solution to the issue of more power being consumed in data centers due to the enhanced performance and increased capacity of servers.

We are also developing a SiC trench MOSFET, which is capable of further reducing loss. With SiC, the mobility (on-state resistance) and avalanche breakdown (withstand voltage) characteristics vary depending on the crystallographic orientation and it was difficult to predict characteristics with a conventional simulation. As a project of the TPEC, we built a high-accuracy

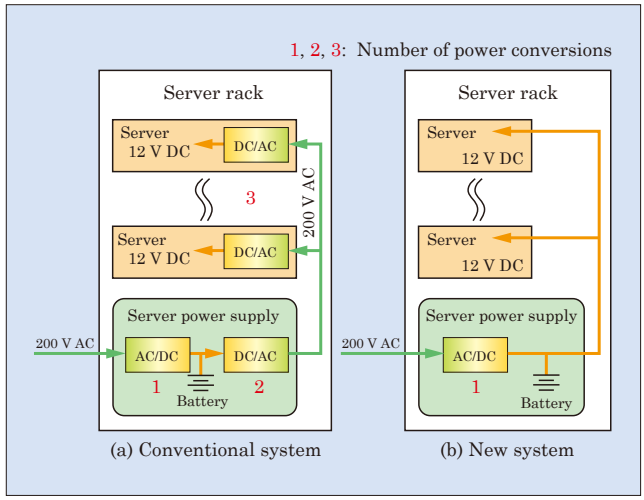

Fig.5 Backup power supply system for servers

simulation model providing results that agree well with the actual measurements for both on-state resistance and withstand voltage. This was done by introducing a model that accommodates the trench orientation, taking into account the lateral electric field and optimizing parameters[3]. By making use of this simulation technology, we have designed the optimum SiC trench MOSFET structure.

As mentioned so far, we are combining our latest SiC devices and module technologies, which maximize the performance of these devices. At the same time, we are developing compact, low-loss and differentiated power electronics products that are equipped with these devices. By doing this, we are aiming to produce the world's top level SiC devices and applicable products.

With conventional Si devices, we have developed the 7th-generation "X Series" of IGBT modules that achieve further miniaturization, loss reduction and high reliability.

With the 7th-generation IGBT chips, we have reduced the thickness of the drift layer and used smaller design rules for and optimization of the surface trench gate structure. These have significantly improved the trade-off relationship between the on-state voltage and turn-off loss. They have been used for SiC hybrid modules, where heat dissipation has been improved by developing a new slim and high-thermal-conductive AlN insulation substrate, and power cycle capability has been improved by using high-strength solder and optimizing wire bonding design. Furthermore, by employing a silicone gel with improved heat resistance, the X Series of IGBT modules have achieved a continuous operating temperature of 175 °C, where this was conventionally 150 °C. This leads to an increase of approximately 35% in output current with the same size and contributes to smaller and more efficient power electronics equipment.

We are working to develop differentiated power electronics products efficiently in a short time by maximizing the performance of these characteristic power semiconductors and bring them to the market in a timely manner; and to accomplish this, we are developing power electronics platforms synchronized with the development cycle of power semiconductors. By using the general-purpose inverter "FRENIC-Ace" marketed in FY2012 as the platform, we have developed in a short time and brought to the market the air-conditioning inverter "FRENIC-eHVAC" for the Asian market and the inverter for elevators "FRENIC-Lift" for the European market.

In a similar way, we are working on the development of a power electronics platform that uses new devices such as SiC devices and the X Series IGBT modules.

3. Electric Distribution, Switching and Control Devices and Instrumentation, Control and Thermal Components

Regarding electric distribution, switching and control devices, we have developed the "F-MPC Web unit" (UM12-10), an energy monitoring device contributing to energy saving of manufacturing facilities, office buildings and commercial facilities. It is installed in factories and buildings, and gathers and accumulates various measurements such as those related to electricity, water, gas and temperature. It is equipped with the Web server function of internally creating Web pages for monitoring the measurements on a PC or other device. It also functions as a controller that provides demand control. The sequence control function for air-conditioning, lighting and other load units has also been provided. It is equipped with a USB host function, an SD card interface and an expansion slot for an additional unit, thereby significantly enhancing scalability as compared with conventional products. For communication with instrumentation equipment, it is compatible with the MODBUS RTU protocol and Ethernet-supported devices in addition to the dedicated protocol of Fuji Electric's "F-MPC Series." This allows data to be gathered from a wide range of instrumentation equipment including the products of other companies (see Fig. 6). To simplify system construction, an automatic search function has been provided for the connected instrumentation equipment so as to automate configuration. For communication with host devices, versatility has been improved by providing compatibility with PLC loader commands and MODBUS TCP in addition to TCP/IP communication of Ethernet.

As a differentiated thermal component, we have applied heat pump technology to commercialize a steam generating heat pump with a medium capacity (30 kW), supplying saturated steam of 100 °C to 120 °C (see Fig. 7). It is capable of recovering heat from hot discharged water of 60 °C to 80 °C, which was not effectively used in the past. The heat can in turn be applied to facilities requiring steam heating in factories such as those

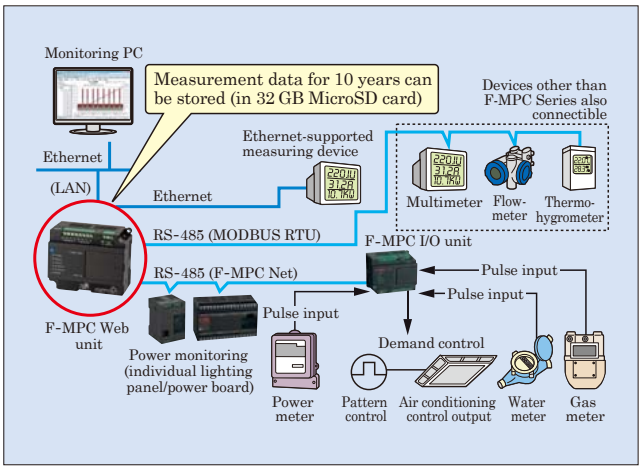

Fig. 6 Example of facility monitoring system using "F-MPC Web unit"

Fig. 7 Steam generating heat pump

for feed water preheating, washing, sterilization, air conditioning and humidification. The equipment can be installed in the vicinity of the respective facilities, which reduces heat dissipation loss due to the extension of piping. In addition, it allows multiple-unit operation with up to 10 units according to the usage of steam. In this way, it can help with energy-saving solutions for factories in areas including heat.

4. Solutions Creating Customer Value

We have combined our characteristic sensing technologies, control technologies backed by abundant experience and power electronics technologies at which we excel to develop a boiler combustion solution package that helps to reduce boiler fuel costs (see Fig. 8). It uses a proprietary laser-based CO analyzer capable of real-time measurement to control combustion with the amount of air that maximizes the boiler efficiency. At the same time, it controls the CO concentration in the boiler exhaust gas so that it is constantly within the standard value range. In this way, it reduces fuel costs. Its effect has been demonstrated with actual boilers and, with a boiler of 100 t/h, an annual cost reduction effect of over 20 million yen can be expected.

In the same way, we have developed a crane solution control package. It utilizes the synergy between instrumentation and control technology, and power electronics technology. As a solution for anti-sway control for quayside cranes, we have achieved the highest level of accuracy in the industry and effectively utilized regenerative energy to achieve an energy saving of 38%.

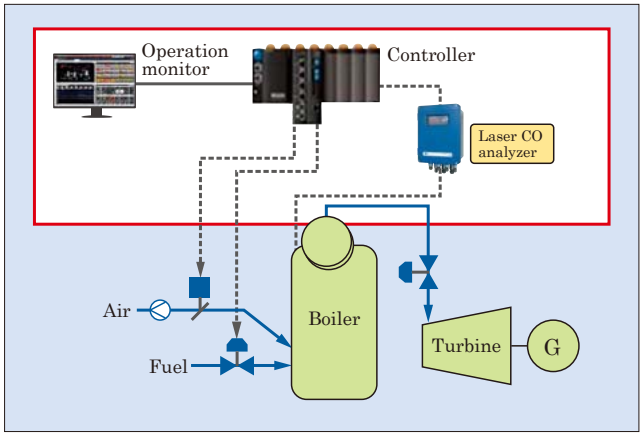

Fig. 8 Boiler combustion solution package

As a solution based on our characteristic sensor, we have, in collaboration with a construction company, developed and commercialized a vibration sensor that applies micro electro mechanical systems (MEMS) and a structure health monitoring system that makes use of it to carry out a primary diagnosis on the structural performance of buildings (see Fig. 9).

The system uses the results of measurement obtained by low-cost MEMS-applied vibration sensors to estimate the maximum acceleration and maximum story drift of the respective stories of the building. It does this based on the vibration data, and then diagnoses the soundness of the building just after the occurrence of an earthquake. This system makes it possible to diagnose whether a building has maintained sufficient strength for withstanding aftershocks, and provides a solution for safety and security.

The full liberalization of the electricity retail market started in April 2016. To deal with it, we have developed a supply-and-demand management system that supports the “planned-value balancing rules” imposed on retail electricity businesses, or power producers and suppliers (PPSs). Through cooperation with NTT DATA Corporation and Kyowa Exeo Corporation, we have released the system as a cloud service for PPSs. Applying the technology for high-speed processing of the massive amounts of data of many customers in addition to the supply and demand simulation technology, characteristic service can be provided as follows:

(a) Demand prediction for low-voltage consumers
(b) Formulation of plans in view of the balancing group (demand/power generation)
(c) Electricity market trading
(d) Automatic capturing of customer information linked with a customer information system

We intend to continue incorporating customers’ demands for improving functions while providing the

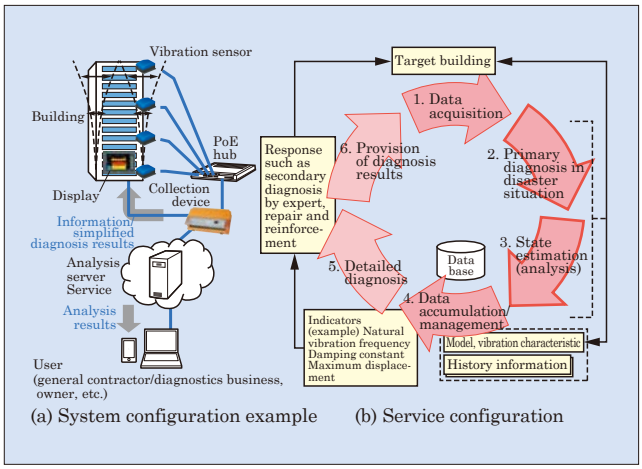

Fig. 9 Example of configuration of solution for diagnosing building soundness

service.

Recently, the concept of the Internet of Things (IoT), in which all things are connected to the Internet, has been gaining increased attention. Fuji Electric owns a complete spectrum of products and technologies ranging from on-site data sensing through gateways, network technology and data analysis technology. We offer various solutions that make use of IoT and create customer value (see Fig. 10).

As one such solution, we have developed a cloud-based comprehensive facility management system that achieves a facility life cycle management environment and started providing the service. To the "EMS service," which has already been provided, we have added new functions of facility "maintenance service" and "operation monitoring service" to achieve an integrated cloud-based service (see Fig. 11). This makes it possible to predictively diagnose equipment degradation and failure and comprehensively manage energy efficiency by grasping the operating conditions of the equipment, keeping the maintenance and inspection records and measuring energy. In this way, total life cycle management from the introduction through operation to renewal of customer facility can be achieved. This maximizes the customer facility management efficiency and minimizes the energy costs.

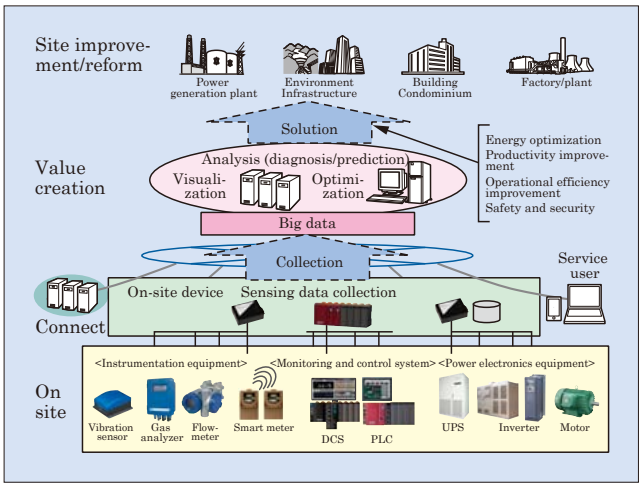

Fig.10 Fuji Electric's IoT solution

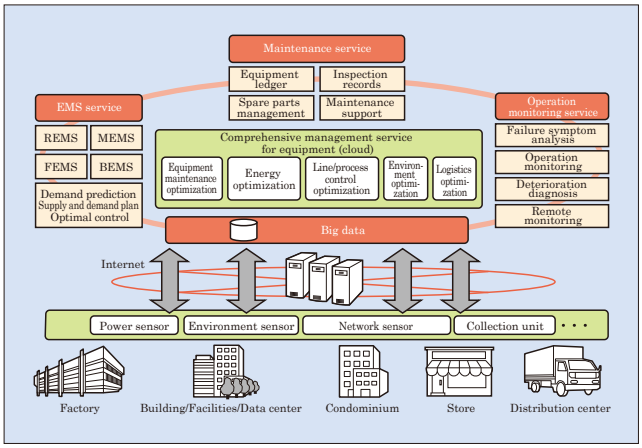

Fig.11 Cloud-based comprehensive facility management service

As a unique application, we have commercialized a wearable remote operation support package. The eyeglass-type wearable device of an operator on the work site is connected with the support site (headquarters) in a remote place in real time via the Internet. Then, proprietary software is used to give support and instructions to the operator. It allows hands-free input of image and voice data for work situations, based on which appropriate instructions can be given by an expert in a remote location.

To realize solutions that make use of IoT and create customer value, we are committed to continuous development of differentiated devices for IoT solutions and the platform technology for them.

5. Fundamental and Advanced Technologies

We have been promoting research and development to develop advanced technologies for the future, as well as fundamental technologies to support each technology that we have presented so far. We develop an array of simulation technologies that deals with thermal fluid dynamics and structures, electromagnetics, and electromagnetic compatibility (EMC: concept of not causing unintentional generation, propagation, and reception of electromagnetic interference).

Power semiconductors used in power electronics equipment may emit electromagnetic noise to the surroundings when there is high-speed switching. Conventionally, measures to deal with it were mainly trial-and-error-type approaches. At Fuji Electric, we are working on the development of technologies to simulate electromagnetic noise (conduction and radiation noise) so as to study measures to combat them from the design phase. For conduction noise, we employ a simplified model in the initial period of development and use a more detailed model at the time of detailed design to conduct accurate simulations for developing products.

For radiation noise, which is more difficult to simulate than conduction noise, we have established a specific technique: We developed a simulation technology for extracting part of a piece of equipment, which is easier to model and requires shorter computation time. Then, while repeating analysis of the part, we analyze the entire equipment[4]. This has made it possible to study a better equipment configuration in a shorter period of time (see Fig. 12).

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

We have established an analysis technique related to the adhesion between encapsulation resin and metal,

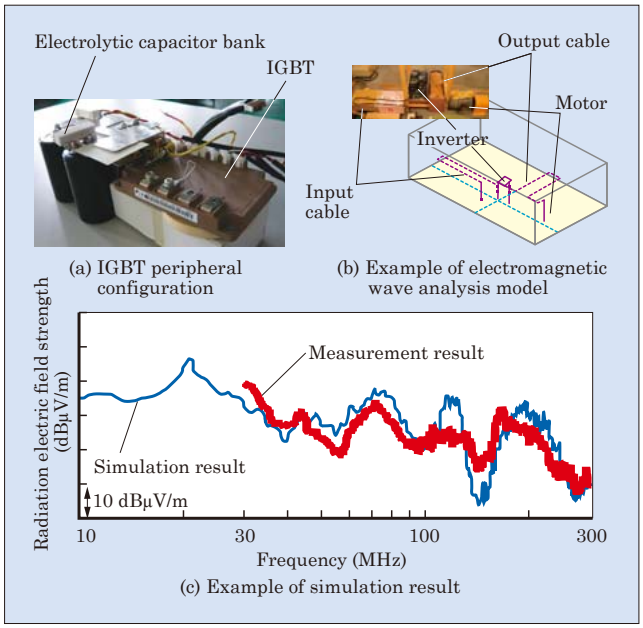

Fig.12 Example of result of radiation noise simulation

which has a significant impact on the reliability of power semiconductor modules. It utilizes simulation technologies such as the first-principles calculation and molecular dynamics calculation. We have built technology for calculating the chemical bonding force between the resin and the material to be bonded based on the molecular structure of the auxiliary agent for close adhesion with resin. With aluminum taken as an example of the component to be bonded, the results of measuring the adhesion for different auxiliary agents can be explained by the size of the chemical bonding force[5] (see Fig. 13). In addition to this chemical bonding force, external factors including the anchor effect and contamination and interface stress due to mechanical characteristics can be taken into account to estimate the actual adhesion.

As companies aim to roll out products globally, compliance with international standards is becoming increasingly important. In this situation, Fuji Electric continues to strengthen its approach to compliance with international standards. We are actively making efforts to participate in international committee activities, especially those related to power electronics. We have a successful track record of contributing to standardization activities related to the electromagnetic compatibility of power conditioning sub-systems (PCSs) and inverter efficiency measurements.

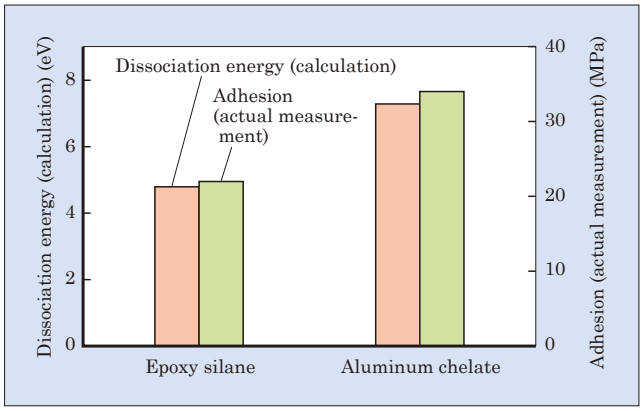

Fig.13 Comparison between chemical bonding force (dissociation energy (calculation)) and adhesion (actual measurement)

6. Postscript

We have introduced some of Fuji Electric’s efforts in developing technologies mainly for supplying and using electrical energy safely, securely and efficiently, utilizing thermal energy efficiently, and controlling energy optimally. Building a safe, secure and sustainable society in harmony with the environment will become increasingly important in the future.

To reinforce our technology development, Fuji Electric has constructed and started operation of the Core R&D Center (main building) for company-wide technology development base in the Tokyo Factory area, the Development Center for power semiconductors in the Matsumoto Factory area, and the evaluation testing building for distribution and control devices in the Fukiage Factory area. In addition, the power electronics development center in the Suzuka Factory area, which is intended to consolidate and improve the efficiency of power electronics product development, is scheduled to start operation in autumn 2016.

As we continue to passionately proceed with our research and development, Fuji Electric is committed to its brand statement that represents our pursuit of innovation in energy and environmental technology in order to contribute to the goal of realizing a responsible and sustainable society. We are moving forward in our contributions to become a greater corporate citizen in our global society so that we can achieve our ideals.

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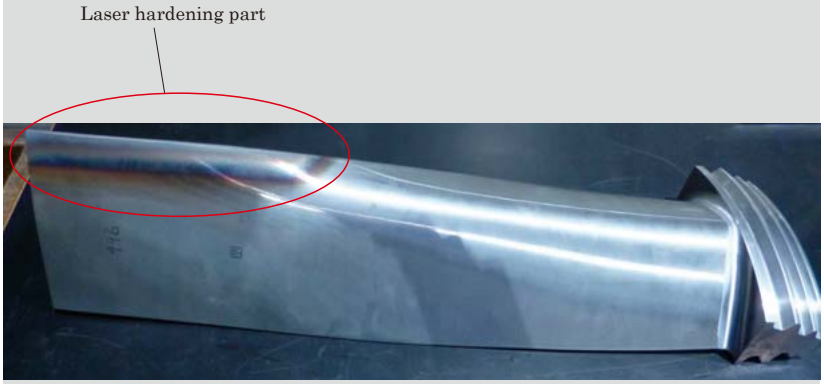
Outdoor 555-kVA Power Conditioning Sub-System "PVI600BJ-3/555"

Fuji Electric has newly released an outdoor 555-kVA power conditioning sub-system (PCS) "PVI600BJ-3/555." This equipment does not require any air conditioning equipment or container and is capable of maximizing the efficiency of a system. In addition to the well-reputed outdoor 1,000-kVA series, the outdoor high-efficiency PCS series, at which Fuji Electric excels, has been expanded.

The main features are as follows:

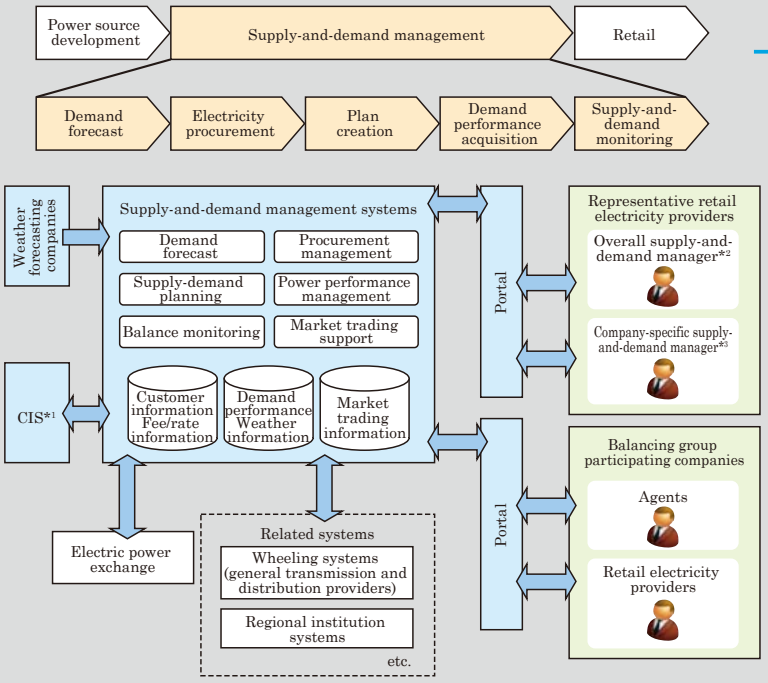
(1) Output capacity: 555 kVA (500 kW possible with 90% power factor operation)
(2) Input voltage: 600 V DC (maximum power point tracking [MPPT] range: 320 to 550 V)
(3) Output voltage: 210 V AC, 3-phase 3-wire, 50/60 Hz
(4) Equipment efficiency: 98.1% (maximum), 97.8% (EURO efficiency)
(5) Various options: Salt-tolerant model, cold weather model, fuses for a direct current branch, optical communication support, etc.



Extra-Deep Laser-Hardening Reformulation Technology for Turbine Blade

Steam turbines are required to operate on a long-term basis while maintaining power generation efficiency. In particular, turbine blades are very important components that determine the level of power generation efficiency. However, they are susceptible to wear from aging due to collision with water drops contained in steam, and this results in degraded power generation efficiency. Fuji Electric has developed an extra-deep laser-hardening reformulation technology that uses lasers to extend the service life of turbine blades by increasing wear resistance.

Lasers are suitable for hardening a turbine blade that have complex shapes owing to its excellent controllability, but they are not capable of extra-deep hardening due to the heated top surface of the blades. We thus developed an extra-deep laser-hardening reformulation technology that covers the entirety of the leading edge of the turbine blade by decreasing the temperature difference between the surface and interior of the turbine blade through application of large spot laser. By doing this, we have more than doubled the lifespan of the low-pressure blades of turbines.



*1 CIS: Customer Information System
*2 Overall supply-and-demand manager: Person who manages the supply-and-demand of the entire balancing group
*3 Company-specific supply-and-demand manager: Person who manages the supply-and-demand of retail electricity providers subsidiary to the balancing group

Supply-and-Demand Management System Responding to Electricity Deregulation

Electricity deregulation started in April 2016, and power producer and suppliers are then made it obligatory to satisfy the planned-value balancing rules. In order to respond to these changes, we have developed a supply-and-demand management system, and have launch of a cloud service jointly created with NTT DATA Corporation and Kyowa Exeo Corporation.

The main features are as follows:

(1) Capable of demand forecasting for low-voltage consumers
(2) Capable of planning measures in consideration of a balancing group plan for the demand side and power generation side
(3) Enables trading in the electricity market
(4) Capable of incorporating consumer information via connection with a customer information system (CIS)

This system takes into consideration future customer needs and offers services, while continuing to improve functionality.

(a) Power management system

(b) 72-kV C-GIS

(c) Transformer and rectifier

Electrical Equipment for Subway Tozai Line of Sendai City Transportation Bureau (Equipment for New Line)

Fuji Electric has delivered electrical equipment, a power management system and a power monitoring system in two substations and nine electrical rooms for Sendai city's subway Tozai Line, which started operation in December 2015.

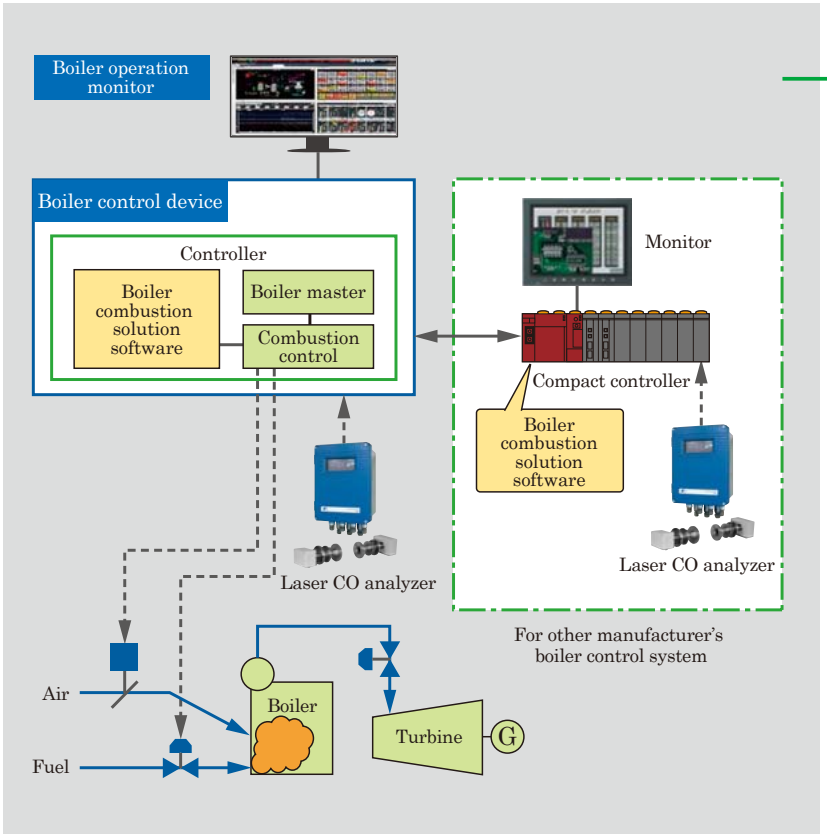
The main features are as follows:

(1) The substations receive power at 66 kV (2 lines) from Tohoku Electric Power Co, Inc. and convert it into 1,500 V DC to supply power for running trains and step it down to 6,600 V to supply power to the load for the station building's power supply. A power regeneration inverter is used to maintain the regenerative brake force of train cars and to save energy.
(2) An electrical room is installed in each station to supply power to the load for station lighting, automatic ticket gates and so on. In consideration of a blackout, redundant power supply to load and an uninterruptible power system are provided to ensure safety and reliability.
(3) The power management system allows integrated management of power systems to ensure trains can run stably. The power monitoring system allows integrated management of station power equipment to maintain a comfortable space in station premises.

Ultra-High Efficiency Data Center for Cold Regions

In recent years, an increasing number of data centers have been built due to the expansion of services such as the cloud, video streaming and IT outsourcing. As servers are designed to provide higher performance and to be high density, it has become an important challenge to reduce the air conditioning power consumption for cooling them.

In November 2015, Fuji Electric delivered an ultra-high efficiency data center for cold regions to Aoimori Cloud Base Corporation in Rokkasho Village, Aomori Prefecture. The idea is to collect snow and ice in winter, store them in a heat-insulated container, and send the cold heat of the melt water to the "F-COOL NEO" indirect outside air conditioning unit in the summertime. This improves the efficiency of the data center and can reduce annual air-conditioning power consumption by around 60% compared with the conventional data centers using general-purpose air-conditioners.



Boiler Combustion Solution Package

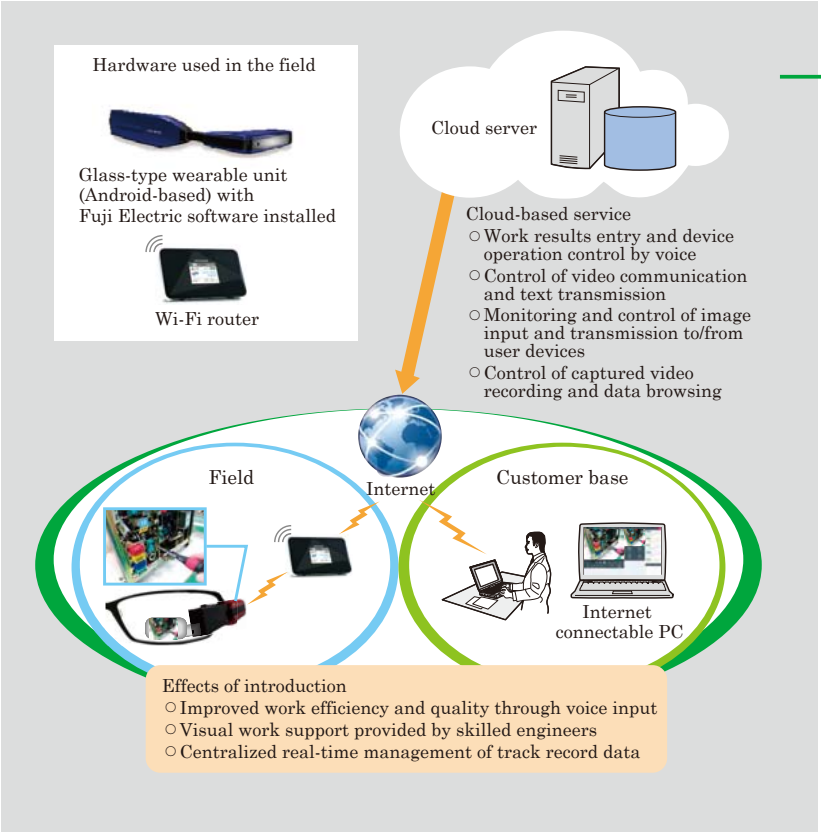
Fuji Electric has released a boiler combustion solution package that enables ultra-low excess air ratio combustion control to reduce thermal loss in exhaust gas, resulting in saving on fuel costs by about 1%. For example, it is effective to save fuel in the amount of 14 million yen annually for a 50-t/h boiler using heavy fuel oil.

The main features are as follows:

(1) Our originally developed technology has achieved high-efficiency combustion in ultra-low excess air ratio. The ultra-low excess air ratio combustion controls the oxygen concentration remaining in the exhaust gas to a value in the order of 0.8% in an actual boiler.

(2) By combining a laser CO analyzer that allows real-time measurement and boiler combustion solution software, the CO concentration in the boiler exhaust gas can be reduced to a level within the environmental reference value.

(3) The boiler combustion solution package can be installed regardless of the manufacturer of the existing boiler control system.



Wearable Remote Operation Support Package

The wearable remote operation support package is a cloud-based service intended for enhancing the quality and efficiency of field-work while supporting the handing-down and accumulation of technological know-how. It provides instruction/support features to allow bi-directional connection of audio/video data between a glass type wearable unit worn by workers (in the field) and a supporter base (at headquarters) as well as work support features to create pre-registered work procedures, to record work results and so on.

The main features are as follows:

(1) The use of a compact and lightweight unit and voice-based, hands-free operation offer a safe and efficient work environment.

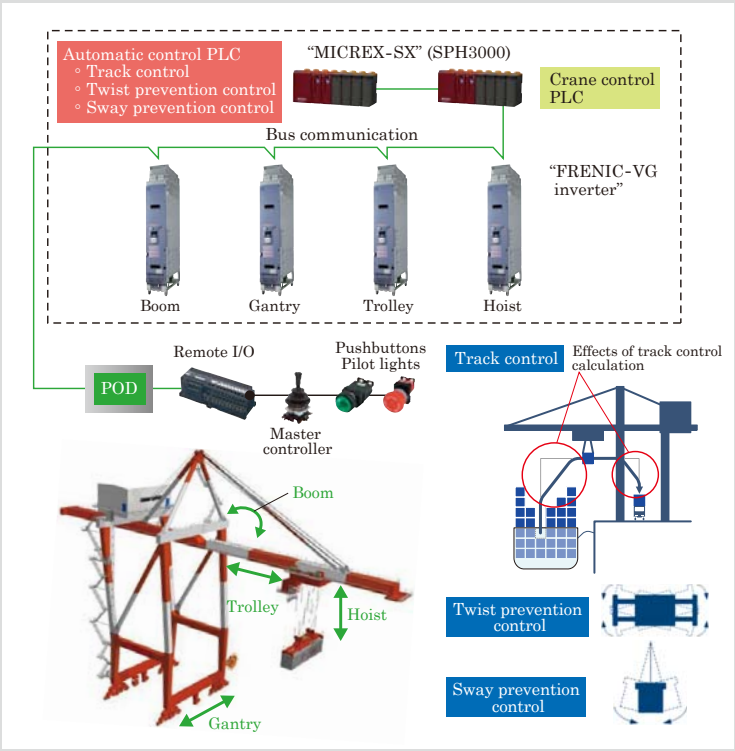
(2) The instruction/support from a skilled engineers' point of view ensures quality of work and contributes to the handing down of technologies.

(3) With the cloud-based unitary management, video/images of work instructions and work result records can be shared among involved parties or used as evidence.

High-Performance Compact IP65-Rated Inverter

Fuji Electric has developed a dustproof and waterproof compact inverter by taking advantage of low power dissipation, which is one of the features of silicon carbide (SiC) devices, and by enhancing environmental endurance.

With the degree of protection of IP65, this inverter does not need to be stored in a panel even in an environment with water splashes in which a food processing machine operates. This makes it possible to reduce the total cost thanks to saving on wiring and other factors. Since no external cooling fan is used, there is no need to worry about clogged fan filters even in a dusty environment such as a machine tool, and this eliminates the need for maintenance. In order to allow the inverter to be installed in a number of places near multiple motors in a production line, various functions are provided including functional safety, customized logic and open networks. This is a high-performance compact inverter with a totally enclosed self-cooled structure.



Control Package for Crane Solution

Fuji Electric has developed a control package for a crane solution that can support automatic operation and save on the labor required of STS cranes in today's ports and harbors, and delivered it to a port outside Japan.

This control package consists of Fuji Electric's "FRENIC-VG inverter," "MVK motor," and "MICREX-SX" (SPH3000) PLC, as well as a general-purpose sway-angle sensor manufactured by another company. In PLC software, we included the latest control theory to prevent a suspended load from swaying and twisting, and a track control theory to enable operation with the shortest travel time, achieving the highest level performance. By improving the accuracy of sway prevention control, we have reduced the time needed for stopping the crane by 25% compared with our competitors' products. As for track control, we have reduced the time needed for the crane to travel to the target position by 20% compared with conventional products under the same benchmark conditions.

High-Efficiency Backup Power Supply for Servers "F-DC POWER"

The data center market has been continuously expanding against the background of a rapid proliferation of cloud computing, and an urgent issue now is to reduce the rapidly increasing amount of power consumption.

Fuji Electric has developed "F-DC POWER," which is a high-efficiency backup power supply for servers that consume much power in data centers.

By reducing the frequency of the power conversion from 3 times for conventional products to once, we can improve the efficiency by 8 percentage points compared with existing systems. Moreover, the peak assist function makes it possible to suppress input power peak. Fuji Electric's silicon carbide (SiC) power semiconductors have been used as the power conversion device of the server power supply. These ingenuities will contribute to significant savings of energy and running cost in data centers.

(a) Traction converter

(b) SiC power module

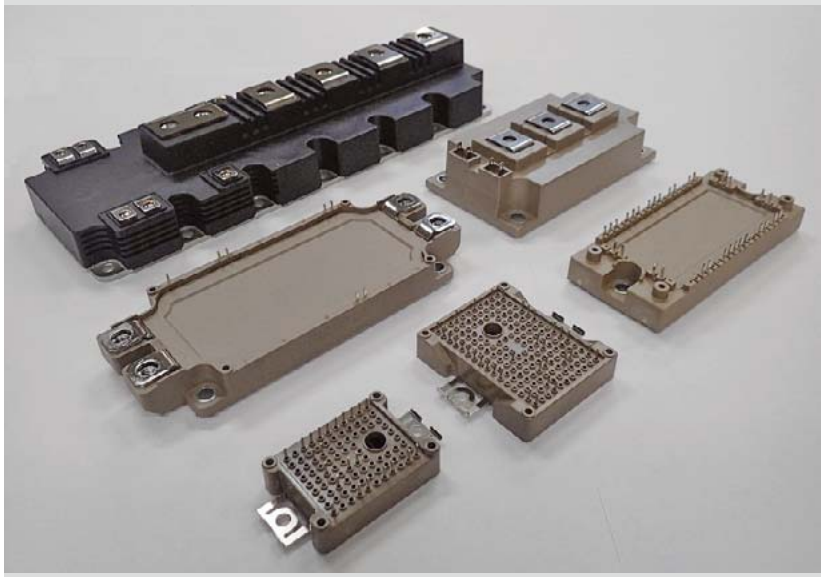
Traction Converter with SiC Power Modules for Tokaido Shinkansen Trains

Fuji Electric and Central Japan Railway Company have jointly developed a traction converter that uses a silicon carbide (SiC) power module intended for the Tokaido Shinkansen trains. The product was mounted on Series N700 trains of the Tokaido Shinkansen and is currently undergoing a running test. This is the first running test in the world of a drive system of a high-speed railway in which SiC power semiconductor modules are employed.

The main features are as follows:

(1) It is equipped with SiC power modules for electrical rolling stock developed by Fuji Electric, rated voltage of 3,300 V and rated current of 1,200 A.

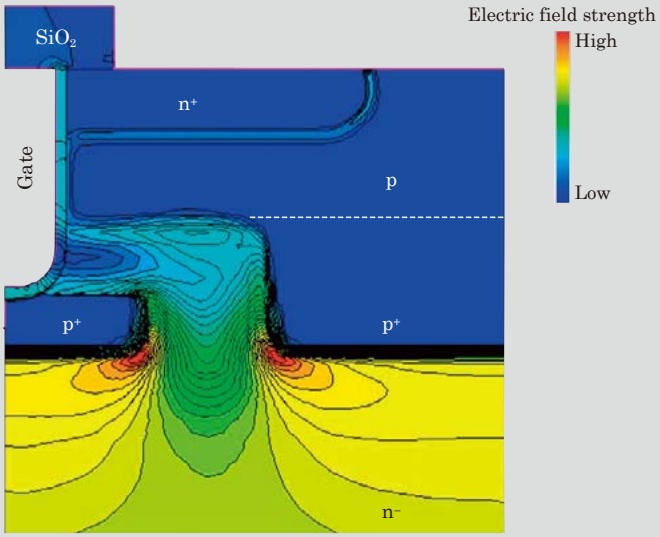
(2) The cooling mechanism of the traction converter can be simplified due to the low heat generation of SiC power modules. This allows for the creation of more compact and lightweight drive systems including traction converters.



7th-Generation "X Series" IGBT module

For power converters that use insulated-gate bipolar transistor (IGBT) modules, there have been strong demands recently for downsizing, power dissipation reduction and high reliability. In order to meet these demands, 7th-generation "X Series" IGBT modules have been developed. They have realized a further size reduction, reduced power dissipation and improved reliability of modules. This has been brought about by significantly reducing the power dissipation of IGBT and free wheeling diode (FWD) chips and developing a high-heat-dissipation, high-thermal-resistance and high-reliability package. In addition, the maximum temperature guaranteed in continuous operation has been increased from the conventional 150°C to 175°C by improving the characteristics and capability during high-temperature operation.

This has allowed for a significant increase in the output current, which contributes to a further size reduction and greater power density of power converters.



Prediction of 1.2-kV SiC Trench MOSFET Characteristics

In order to meet the demand for small size and energy saving of power electronics devices, Fuji Electric has been developing silicon carbide (SiC) trench MOSFETs that can reduce power dissipation. SiC may have different mobility (on-resistance) and avalanche breakdown (breakdown voltage) characteristics depending on the crystallographic orientation, and it was difficult to predict these characteristics by simulation.

We have introduced a Coulomb scattering model compatible with the trench face orientation, applied the Hatakeyama model that takes lateral electric field into account and optimized parameters for matching with the actual measurements. As a result, both the on-resistance and breakdown voltage have agreed well with the actual measurements, showing that we have successfully built a high-precision simulation model.

This work has been implemented under a joint research project of Tsukuba Power Electronics Constellations (TPEC).

Digital Signage Vending Machine for AEON DELIGHT Co., Ltd.

We have developed a digital signage vending machine for AEON DELIGHT Co., Ltd. This unit comes with a 46-inch LCD screen and touch panel, which displays advertisements and product images. Users can purchase products by touching the product images. The unit is capable of distributing content (advertisements, product images, etc.) during usage via the Internet connection with a server, as well as performing maintenance operations.

The main features are as follows:

(1) It comes equipped with a control unit for optimizing the specifications for the signage, and since control can be carried out on the LCD screen and touch panel, a separate personal computer for control is not required.

(2) Signal processing that only recognizes a finger image captured by infrared cameras installed in the four corners of the LCD screen enables users to choose their products without being affected by sunlight, rain, dust or other disturbances.

Electric Power Generation Systems

Thermal/Geothermal Power Plants
Nuclear Power
Renewable Energy and Power Stabilization
Fuel Cells

Outlook

In July 2015, the Ministry of Economy, Trade and Industry determined the "Long-term Energy Supply and Demand Outlook" and decided on the energy mix (power source mix) for 2030 in Japan. It also decided to fully liberalize the electricity retail market starting in April 2016. Based on these decisions, FY2015 is recognized as a turning point in the Japanese electric power industry and a year when the base for future development was made clear.

Fuji Electric, which has many eco-friendly power generation-related technologies, should be able to help bring about an energy mix with a high proportion of renewable energy in 2030.

In the overseas market, despite the low price of crude oil and new financial uncertainties, there are brisk business activities reflecting the increasing demand for power, mainly in Asia and Africa.

In the field of thermal/geothermal power plants, we received steady new orders. In the service business, in addition to receiving continued orders for maintenance and repair in Japan, we acquired the business of RTS Holdings, Inc. and its subsidiaries of the United States in the overseas market. Hence, the year was one in which we made a start to develop the service business in earnest.

Regarding the thermal power market, in Japan, we received orders from new customers for multiple steam turbines and generators together with peripheral equipment for biomass co-combustion power generation. We also received an order for 650-MW class ultra-super critical pressure large coal-fired power facilities. In the overseas market, we completed delivering many units of steam turbines and power facilities mainly in Southeast Asian countries and won new orders in South Korea.

For the geothermal market, in Japan, we made certain of an order for new geothermal binary power generation facilities and have continued providing support for achieving multiple future projects. In the overseas market, while there was a delay in an anticipated project, we successfully received orders for steam turbines and power generation equipment in Iceland, the Philippines and Mexico. In addition, we continue developing projects to win orders for them in FY2016.

In the field of nuclear power, the new regulatory standards reflecting the lessons learned from the accident in Fukushima and the method of their operation were established. Power generation was restarted with Units 1 and 2 of the Sendai Nuclear Power Plant, which passed the screening by the Nuclear Regulation Authority. It has been decided that some power plants will be decommissioned, and some entities are launching the light water reactor-related business. On the Fukushima site, design and development for taking measures against contaminated water and removing debris are being conducted mainly by the International Research Institute for Nuclear Decommissioning (IRID).

In this situation, Fuji Electric has developed and delivered ocean monitoring equipment that is capable of continuously measuring and monitoring the radioactivity concentration in the ocean for Tokyo Electric Power Company Holdings, Inc. This equipment started operation at the periphery of the Fukushima Daiichi Nuclear Power Plant. In addition, we aim to contribute to safe processing and disposal of radioactive waste generated during operation of nuclear power facilities and in the process of decommissioning and are working to apply technology that uses geopolymer materials. This technology solidifies radioactive waste stably instead of using cement.

In the field of renewable energy and power stabilization, while the Japanese mega solar market is on a declining trend after the peak in FY2014, there is still construction demand for over 4 GW and construction of equipment is expected to continue in the future. In FY2015, as an EPC project, Tomakomai Yufutsu Mega-solar Power Plant (DC output: 29.8 MW, AC output: 21 MW) was completed in October. At this plant, 21 outdoor power conditioning sub-systems (PCSs) with a single unit capacity of 1,000 kVA have been installed to improve system efficiency. In addition, we have commercialized a new outdoor 555-kVA PCS that does not require any air conditioning system or container

to expand the high-efficiency PCS series. Regarding wind power generation, commencement of large-scale wind power generation projects and construction are expected.

In the field of fuel cells, we installed 8 phosphoric acid fuel cells on sewage digestion gas, which fall the Feed-in Tariff (FIT) Scheme for renewable energy. The fuel cell installed at the Tokyo Factory of Fuji Electric has a new function of supplying the exhaust, which is clean and contains high concentration CO_2, to a nearby experimental plant factory. The experiment of using the facilities for growing strawberries is scheduled to start in October 2016. Regarding business overseas, we have financed N_2telligence GmbH, with which we had a cooperative relationship, and aim to promote sales mainly in Germany by taking advantage of the low-oxygen exhaust. Furthermore, for realizing a solid oxide fuel cell system featuring high power generation efficiency, we have been participating in a project of the New Energy and Industrial Technology Development Organization (NEDO) since FY2014 to work on the development of a system of a few tens of kW.

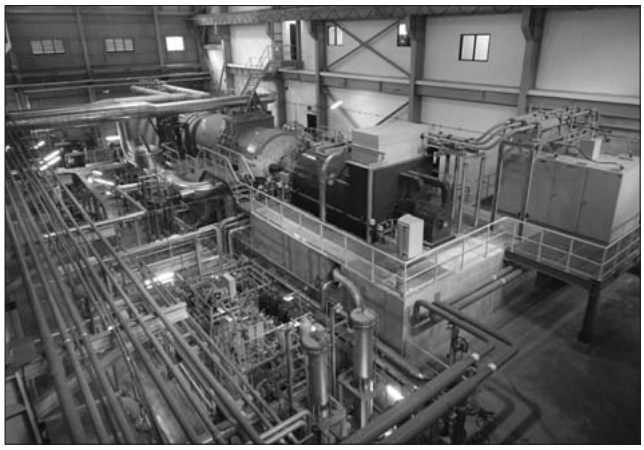
Thermal/Geothermal Power Plants

1 Steam Turbine and Generator for Kamojang Geothermal Power Plant Unit 5 of Indonesia

In 2007, Fuji Electric delivered to the Kamojang Geothermal Plant of Indonesia a steam turbine and generator for Unit 4. We received another order for providing equipment and teaching advisory service of installation and commissioning for Unit 5 (net electrical output: 35 MW) and completed the work in July 2015.

For Unit 5, we have delivered a combination of an axial exhaust flow turbine and low-level direct contact type condenser. An axial exhaust flow turbine allows the height of the turbine building to be lower than a downward exhaust flow type, and combining it with a low-level condenser eliminates the need for excavating a deep condensate pit. The delivery time was 23 months after the commencement of the contract, which is about one month shorter than the standard delivery time for similar size projects. However, this equipment configuration made it possible to reduce the period of civil and construction work, enabling us to successfully complete the work within the delivery time.

Fig.1 Steam turbine and generator

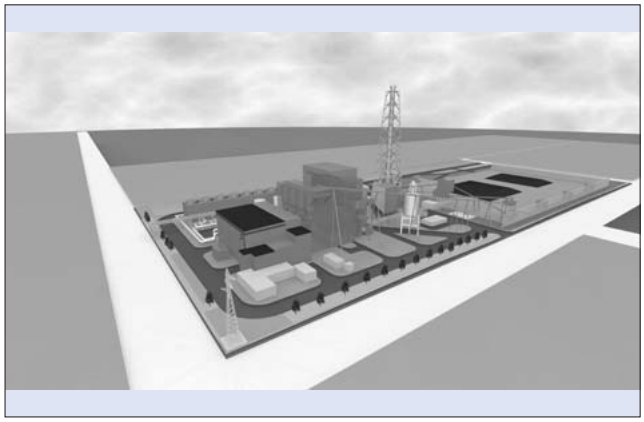


2 Power Generation Facility No.1 at Ishinomaki Hibarino Power Station of Nippon Paper Ishinomaki Energy Center Ltd.

In 2015, Fuji Electric received an order from IHI Corporation to design, procure, manufacture and install a steam turbine, generator and electric and control equipment for Power Generation Facility No. 1 at Ishinomaki Hibarino Power Station of Nippon Paper Ishinomaki Energy Center Ltd. The generator output is 149 MW and Fuji Electric will deliver a one-cylinder reheat condensing turbine (axial exhaust type) and air-cooled generator, which have good track records. This power generation facility has been planned by Nippon Paper Ishinomaki Energy Center Ltd. established by Nippon Paper Industries Co., Ltd. and Mitsubishi Corporation. Coal-biomass co-combustion boiler and power generation facility will be installed on the site to the south of Ishinomaki Mill of Nippon Paper Industries Co., Ltd.

It wil be a symbol of the reconstruction of Ishinomaki and is scheduled to start the operation in March 2018.

Fig.2 Rendering of Power Facility No.1 at Ishinomaki Hibarino Power Station



Thermal/Geothermal Power Plants

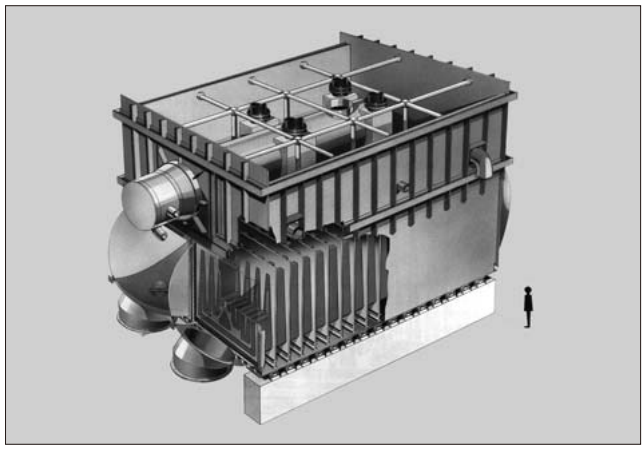
3 Seawater Leak Diagnosis System: Condenser Tube Leak Buster

A seawater leak in a condenser, which may be generated by condenser tube corrosion or collision between a foreign object and a condenser tube, causes a critical failure in power generation equipment. In recent years, seawater leaks due to aging of equipment have been on the increase.

Fuji Electric has developed "Condenser Tube Leak Buster," a seawater leak diagnosis system equipped with a function to immediately detect any seawater leak online and identify the leak in a group of condenser tubes in a short time. This system has a configuration featuring improved detection accuracy and is capable of detecting any leak within a few minutes. In addition, it can quickly identify a leak with a detection method that uses helium. This allows damage to be minimized.

The detection technology applied to this system is patent pending.

Fig.3 Example of surface condenser to be diagnosed



Nuclear Power

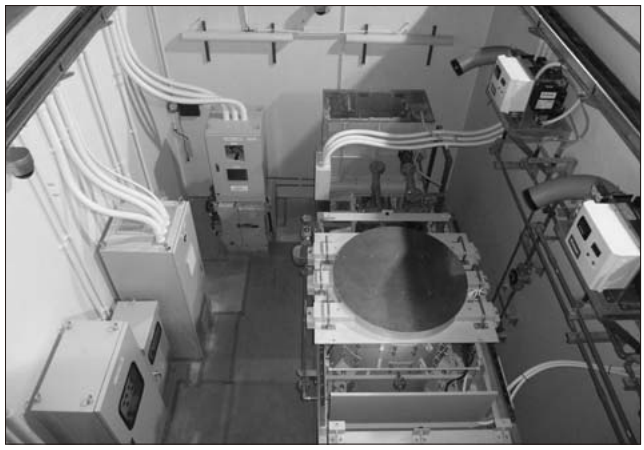
1 Seawater Radiation Monitor

Fuji Electric has developed and installed ocean monitoring equipment for seawater which is in the periphery of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.

The seawater radiation monitor is equipment capable of continuously measuring and monitoring the radioactivity concentration of cesium-134, cesium-137 and beta-ray nuclides, which are major nuclides causing seawater contamination. This equipment is composed of an intake pump that pumps up seawater, various filters to remove sand in the seawater, an UV sterilizer to restrain the growth of marine life and beta-ray and gamma-ray monitors. The equipment is characteristically installed at the tip of a breakwater and the cover that houses the equipment is provided with a structure that can withstand waves in stormy weather, not to mention being watertight.

Continuous monitoring operation was started in April 2015 and the actual measurement data are opened to public in the website of the customer.

Fig.4 Full view of inside of seawater radiation monitor

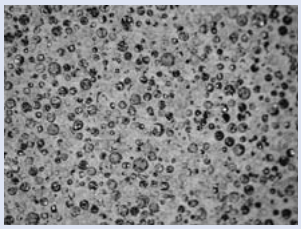


2 Technology to Solidify Radioactive Waste

As a technology for solidifying and immobilizing radioactive waste, use of geopolymers is attracting attention. Fuji Electric is working on technology for immobilizing the radioactive waste generated at nuclear plants in Japan by using a product called SIAL, made by the UK company AMEC F&W and the only commercialized geopolymer in the world. The residue resulting from using "Fuji Resin Reducer," a spent resin volume reduction and immobilization processing equipment, to process the simulated waste of an ion-exchange resin with cesium ions and cobalt ions absorbed in it was solidified with SIAL for evaluation. As a result, it has been confirmed to offer a compressive strength at least equivalent to that of a substance solidified with cement and to achieve a two-digit or more reduction in the exudation of the encapsulated cesium, cobalt, etc. into water. We are moving ahead with evaluating its applicability to various types of waste generated from nuclear power plants and other facilities.

Fig.5 Substance solidified with SIAL and its cross section

(a) Substance solidified with SIAL



(b) Cross section of substance solidified with SIAL

Renewable Energy and Power Stabilization

1 Construction of Tomakomai Yufutsu Mega-Solar Power Plant (21 MW AC)

Fuji Electric received an order from Tomakomai Yufutsu Mega-Solar Corporation, a subsidiary of Marubeni Corporation, to install a solar power plant with a capacity of 21 MW AC. The 535 days of work was completed safely with no accidents since the start of construction on site in April 2014 and commercial service was started in October 2015. The project site is located adjacent to Tomatoh Industrial Estate and is directly below the air route into New Chitose Airport. On the site of approximately 48 ha divided into three areas A, B and C, 114,440 photovoltaic cells have been installed. The output of 29.8 MW DC is converted into alternating current by using 21 power conditioning sub-systems (PCSs) with a single-unit capacity of 1,000 kW, which is boosted up with a transformer to be connected to a 66-kV power transmission line of Hokkaido Electric Power Co., Inc. This project is part of a 20-year electric power selling business, in which the customer is making use of the "Feed-in Tariff Scheme" of the Ministry of Economy, Trade and Industry.

Fig.6 Full view of areas A and B in Tomakomai Yufutsu Mega-Solar Power Plant

Fuel Cells

1 Fuel Cell for Tokyo Factory's Main Building

A fuel cell with an output of 100 kW has been installed at the main building of Fuji Electric's Tokyo Factory. The power output from this fuel cell constitutes a grid-independent system together with photovoltaic power generation and a battery, and allows power to be supplied to important loads even during a blackout. The high-temperature exhaust heat (90°C hot water) generated during power generation is cooled into cold water with an absorption refrigerator and used for the air conditioning of the main building together with medium-temperature exhaust heat (50°C hot water). The exhaust air of the fuel cell is clean and has a high concentration of CO_2, and an experiment is scheduled to start in October 2016 in which the exhaust air is sent to a nearby experimental plant factory growing strawberries.

This equipment was built with the Subsidy System for the Gas Co-Generation Promotion Program of the City Gas Promotion Center.

Fig.7 Fuel cell installed at Tokyo Factory

2 Atmospheric Pressure Solid Oxide Fuel Cell

Fuji Electric is developing an atmospheric pressure solid oxide fuel cell (SOFC) in addition to the phosphoric acid fuel cell (PAFC) with a power output of 100 kW that is currently on the market. With a commercial cogeneration system of a few tens of kW assumed, we have been participating in the "Technology Development for SOFC Commercialization Promotion," which is a project of the New Energy and Industrial Technology Development Organization (NEDO), to work on the development since FY2014. We built SOFC module verification equipment with a capacity of 10 kW by FY2015 and evaluated its performance. The results showed the equipment achieved a DC gross electrical efficiency of over 55% (equivalent to AC power generation efficiency of 50%), which is NEDO's target. In the future, we plan to design and build demonstration equipment of the 50-kW class and conduct field testing on it. We aim to launch it on the market in FY2018.

Fig.8 Solid oxide fuel cell

Social Infrastructure

Energy Management

Outlook

Since the Great East Japan Earthquake, new approaches for energy supply have been considered based on the energy mix that reexamines a medium and long-term energy balance and power source locations as well as the electricity system reform, causing several changes in the energy sector. A system with a functionality capable of solving the new challenges of energy supply systems caused by the changes is required. Since the energy market have reformed, power producers and suppliers (PPSs) and other new entrants to the industry have started offering various new services.

At the same time, the concept of national resilience began to encourage policies for pursuing comprehensive strengthening of disaster prevention, disaster mitigation and measures against system and infrastructure deterioration. As part of this effort, the maintenance of dams and sluices, as well as establishment of disaster prevention bases to be managed by local governments came into full swing.

In the field of energy management, Fuji Electric has been developing and launching the following systems and equipment.

(a) Monitoring and control systems for power system and distribution automation systems
(b) Power system protection relays
(c) Remote monitoring and control systems (telecontrol equipment)
(d) Power system analysis simulators
(e) Dam control systems
(f) Electricity storage control systems
(g) Energy management systems (EMSs)

Currently, as a means of responding to the market trends, we have been offering to retrofit the existing systems of our established customers, including general electricity utility companies and local governments. For our new customers such as PPS, we have adopted new approaches based on our cultivated system technologies. Our main achievements in FY2015 are as follows.

In the wake of the complete liberalization of electricity retailing starting in April 2016, the number of PPSs is rapidly increasing. For PPSs, we have developed a supply-and-demand management system capable of electricity supply and demand operation comply with new schemes such as "planned-value balancing rules." We have also launched a cloud service jointly created with NTT DATA Corporation and Kyowa Exeo Corporation. In the future, we plan to expand our lineup of services by offering services for the negawatt market and virtual power plants (VPPs).

Furthermore, the power generation and transmission sector will be unbundled starting in 2020, and this has given business operators an opportunity to study new lines of business. As one case in point, we delivered a reused EV battery system to Sumitomo Corporation, which intends to provide an ancillary service for ensuring the quality of power and a portion of reserve power, to perform technical verification at a remote island in Kyushu (Koshikishima). In the future, we plan to evaluate the feasibility of services using batteries and expand our business relating to an electricity storage control system.

As general electric utility companies are increasingly dealing in renewable energies, it has become evident that there is a need for system stabilization and measures for dealing with surplus power.

In order to meet this needs, we developed bank controllers for processing adjustments between banks, as well as large-scale power conditioning systems, used for large-scale battery systems (60-MWh redox flow battery) for Sumitomo Electric Industries, Ltd., so as to ensure power quality and implement measures for dealing with surplus power. We installed these facilities within a service area of Hokkaido Electric Power Co., Inc.

For Chubu Electric Power Co., Inc., we delivered a hybrid power system analysis simulator, which is capable of simulating various distributed power sources, and it can analyze system stability and evaluate smart grid control.

The increase in distributed power sources such as photovoltaic power generation has made it necessary to respond to the challenge of rising voltages coming off of distribution networks. In this regard, we have de-

veloped next-generation static var compensator (SVC) using silicon carbide (SiC) devices, as well as enhanced the functionality for optimally controlling SVC by grasping the voltage profile of entire distribution networks via a centralized voltage control system.

Storage technology is expected to play a big role in power stabilization. The world's largest facilities for evaluating storage systems has been constructed at the National Institute of Technology and Evaluation (NITE). We have installed a large-scale 500-kWh lithium-ion battery facility at the facilities as a system for evaluating batteries.

Local governments, the Ministry of Land, Infrastructure, Transport and Tourism, and the Ministry of Agriculture, Forestry and Fisheries are constructing dams and sluices based on the national resilience policy. Fuji Electric has delivered and installed dam control systems for various dams, including the Izarigawa dam managed by the Hokkaido Regional Development Bureau, the Norogawa dam in Hiroshima Prefecture, the Kinjo dam in Okinawa Prefecture, the Hinachi dam operated by the Japan Water Agency, and the Koyadaira dam operated by Kansai Electric Power Company, Incorporated.

We continue developing cutting-edge energy control technologies to contribute to stable energy supply, leading to a safe and secure society.

Energy Management

1 Izarigawa Dam Discharge Facility Control System for Hokkaido Regional Development Bureau

In March 2016, Fuji Electric delivered and installed a dam discharge facility control system for the Izarigawa Dam managed by the Sapporo Development and Construction Department, Hokkaido Regional Development Bureau. The main features are as follows:

(1) Reliability has been enhanced via redundancy of the processing unit responsible for the control functionality. Communication between units is done using the general-purpose protocol FL-net in compliance with the open network standards of the Japan Electrical Manufacturers' Association, enabling it to connect to the control panels of other company products.

(2) The water supply gate can be remotely operated from the Ariake Office in Eniwa City through a fiber optic cable.

(3) An advanced man-machine interface has been provided, such as operation support based on automatic voice guidance, group classified telephone reporting of abnormality-specific causes, and the adoption of a universal design.

Fig.1 Dam discharge facility controlling equipment for Izarigawa Dam Control Center

2 Reused EV Battery Systems in Koshikishima

We constructed a power storage system that utilizes the used batteries of electric vehicles (EVs) in Koshikishima, an island located in Satsumasendai City in Kagoshima Prefecture. Operations have begun for the purpose of demonstration after installing the system for Sumitomo Corporation, the owner of the center. Output comes from two 400-kVA units, and battery capacity is about 600 kWh (actual capacity).

To expand the capacity of the renewable energy installation in the island, we have connected several renewable energy stations with a communication network, and stabilize their output power fluctuations collectively by utilizing a single storage system. We have created a compact design for the system and are incorporating the latest technologies in order to achieve energy savings, unmanned operations and remote monitoring. This system allows for the reuse of used batteries generated by the growing popularity of EVs, and the advantage of this business model is that it is environmentally friendly and capable of solving problems related to renewable energies. We are expecting that the system will be employed by local governments that aim at local production and consumption of energy.

Fig.2 External appearance of Koshiki-shima Power Management Center

Energy Management

3 Large-Scale Lithium-Ion Battery Facility for NITE

Fuji Electric has developed and installed a large-scale 500-kW/500-kWh lithium-ion battery facility for the National Institute of Technology and Evaluation (NITE). NITE has constructed the world's largest complex facility capable of testing and evaluating megawatt class large-scale battery systems as part of the global certification infrastructure development project. The installed large-scale lithium-ion battery facility is one of the testing facilities consisting of four units. The main features are as follows:

(1) It is a container storage type supporting flexible configurations.
(2) It is possible to connect with lithium-ion batteries and power conditioning sub-systems (PCSs) of multiple manufacturers and various models.
(3) It is capable of high-speed, high-efficiency, large-capacity operation while operating independently, in parallel, or in series with other units.
(4) It achieves a high level of safety in anticipation future international standards.

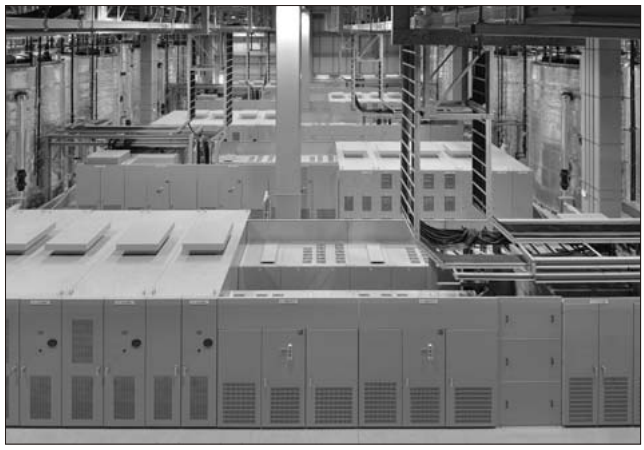
Fig.3 External appearance of large-scale lithium-ion battery facility

4 Power System Stabilizing Large-Scale Power Conditioning Systems for Minami-Hayakita Substation

The generated output of wind turbine and photovoltaic power system depends on the weather, and this leads to irregular output fluctuations. As a result, the expansion of these dispersed power supplies to utility power system has created concern regarding the impact on power quality such as frequency.

Fuji Electric received an order from Sumitomo Electric Industries, Ltd. for a bank controller and large-scale power conditioning systems for thirteen 2.5-MVA banks as a portion of the power system stabilization demonstration facility being operated by the world's largest class 60-MWh redox flow battery. We delivered and installed the equipment at Minami-Hayakita substation operated by Hokkaido Electric Power Co., Inc. in December 2015. These systems provide a governor-free corresponding operation by detecting frequency fluctuation and quickly charging and discharging batteries, a surplus power countermeasure operation in accordance with the command value received from the central load dispatching system, an optimally bank start and stop operation based on the state of batteries, and an output distribution control between banks. In the future, we are expecting that demonstration tests will produce a new and powerful means of making adjustability for generated output fluctuations.

Fig.4 Installation arrangement of large-scale power conditioning systems



Industrial Infrastructure

Substation Systems
Industrial Plants
Industrial and Instrumentation Equipment

Outlook

Substation Systems

Our substation system business makes use of electric distribution facilities and large-capacity power electronics equipment for sectors including the electrical power, industrial and transportation sectors while we also continue to develop business solutions for increasing reliability and efficiency, as well as measures for the environment. In Asia, we established Fuji Tusco Co., Ltd. and Fuji Electric Manufacturing (Thailand) Co., Ltd. in Thailand as production bases for power transformers and switching devices, in order to satisfy the expectations for infrastructure expansion. To deploy a locally self-sufficient business having sales, engineering and production bases, we also focus on the enhancement of engineering bases and promote system construction.

For the electrical power sector, we delivered 300-kV gas insulated switchgear (GIS) to a thermal power plant in Japan to support stable and reliable power supply.

As an achievement related to electrical equipment in the industrial sector, we upgraded existing equipment to ensure stable operation. We are actively developing solutions to improve reliability by means of maintenance services such as equipment diagnostics of aging equipment. We are also actively suggesting equipment developed while considering the environment, energy conservation and low maintenance. As for achievements related to power supply for industrial use, with growing requests for an improvement in power quality, we delivered a large-capacity self-commutated flicker compensator to a Japanese electric furnace manufacturer in order to suppress fluctuations in the power system voltage.

For the transportation sector, we upgraded the facility of an existing substation to ensure stable transportation and delivered power supply equipment and power management/power monitoring systems for a new subway line.

Industrial Plants

In Japan, companies have continued making solid investments from the previous fiscal year in the upgrading of aging equipment and in rationalization for strengthening competitiveness, mainly in the material industry. In addition, many companies in some sectors of the assembly and processing industry are planning to enhance facilities as part of reviewing supply chains (return to domestic production). In overseas markets, it is true that some companies are starting to rethink equipment investment due to the excessive supply and lower resource prices that have resulted from the economic slowdown in the Chinese market. Basically, however, equipment investment is tending to expand in Asia and some other regions.

Our industrial plant business has been deploying products and systems that achieve stable operation of production equipment and effective use of energies. They center on drive control, measurement control, machinery and electric, environmental and information technologies.

For the metal industry, we have developed new industrial drive control equipment that helps to enhance and informatize drive systems, and started mounting it on products on a timely basis. In order to enhance engineering efficiency and quality, we have developed a converter and various control system packages to run the existing software on the latest system and are promoting their introduction.

For the chemical and food industry, the investments in end product manufacturing equipment are increasing due to the diversified needs of end consumer products. By combining the distributed control system "MICREX-NX" or "MICREX-VieW XX" with a PC, we offer solutions that satisfy customer requests such as batch control, recipe management and a traceability function.

For the waste disposal industry, we see an increase in the installation of new equipment because customers are carrying out business integration and upgrading their existing control systems. For the upgrade work, we utilize customers' software and other existing resources as much as possible. For the installation of new equipment, we take advantage of new functions of

the latest system to optimize customers' equipment operations and life cycle costs.

For the distribution system industry, we have developed and released an energy saving system for refrigerated warehouses where freezer operation is optimized based on our original algorithm. This system can reduce annual amount power consumption by 12% or more.

For dater centers, the construction of them has been expanding in recent years, and this presents the challenge of reducing air-conditioning power consumption for cooling servers that are designed for higher performance and density. As a solution, we have developed an ultra-high efficiency data center for cold regions by adopting an indirect outside air conditioning unit "F-COOL NEO," and delivered it. The idea is to collect snow and ice in winter, store them in a heat-insulated container and use the heat of fusion from their melting as a coolant in the summertime. This can reduce annual air-conditioning power consumption by 60% compared with the case where a general-purpose air-conditioner is used.

An international convention (MARPOL) requires the reduction of CO_2 and environmentally impacting substances (NO_X, SO_X and PM). We have developed an exhaust gas cleaning system for ships (cyclonic SO_X scrubber) in conformance with SO_X/PM regulations and put it through the test for the joint research of Nippon Kaiji Kyokai and Imabari Shipbuilding Co. (Target: New ship owner institution). Our aim is to help conserve the marine environment and reduce business costs, which is a challenge in the marine industry.

Industrial and Instrumentation Equipment

Our industrial and instrumentation equipment business is offering a range of products including instrumentation equipment and sensors, radiation equipment and systems, and industrial electric heating to meet the requirements of customer environmental policies, energy-saving, and safety and security standards. We are also working to create a sensor platform and a network sensor for the IoT age.

In the sector of instrumentation equipment and sensors, we are developing feature-rich products for the environment and energy-saving field. As for liquid flow measurement, we have developed and released a spool type ultrasonic flowmeter called "FST," which provides accuracy equivalent to Coriolis flowmeters. We will add specifications according to applications such as a greater variety of diameters, explosion proof certification, and communication functionality. We will also promote the development of a gas and vapor flowmeter for energy-saving applications based on ultrasonic measurement technology as well as of application products designed for specific uses.

In the sector of radiation equipment and systems, we have been developing a new personal dosimeter intended for overseas markets and promoting the development of process monitor technologies. We will complete the production of a whole line of dosimeters for overseas markets and the product development of process monitors, and introduce them into markets. Moreover, we will promote the development of service business centered on environmental dose control and of monitoring technology related to reactor decommissioning.

In the sector of industrial electric heating, we have established a new line of high-efficiency and compact melting furnaces. We will accelerate the expansion into domestic and overseas markets. We will also add products to the line of small IH inverters of 5 kW or less mainly intended for kitchen applications and promote the expansion including new applications.

Substation Systems

1 Replacement of Electrical Equipment in Edogawa Extra-High-Voltage Power Receiving Substation for Shinjuku Line of Bureau of Transportation of Tokyo Metropolitan Government

The Edogawa Extra-high-voltage Power Receiving Substation receives 66 kV from Tokyo Electric Power Company, Incorporated in 2 lines and transmits the power to a 22-kV DC feeding substation and 6.6-kV station electrical room in 3 lines respectively. Fuji Electric delivered such equipment as 72-kV/24-kV switchgear, extra-high-voltage transformer for 15-MVA reception/4.45-MVA rectifier/5-MVA high-voltage distribution, a pure water vaporization-cooling silicon rectifier and a 1,500-V DC/7.2-kV AC enclosed switchgear.

(1) The 72-kV/24-kV switchgear has been made compact size by adopting a gas-insulated C-GIS.
(2) The extra-high-voltage transformer adopted SF_6 gas insulation, offering excellent safety and disaster prevention.
(3) It is possible to have mutual power interchange with the power transmission systems of adjacent substations at 22 kV AC/6.6 kV AC/1,500 V DC to ensure safe and stable train transportation.

Fig.1 24-kV AC C-GIS and 1,500-V DC/7.2-kV AC enclosed switchgear

Substation Systems

2 Direct Current Electric Power Converter in Maya Station of West Japan Railway Company

Fuji Electric delivered direct current electric power converter to West Japan Railway Company. This equipment converts 1,500 V DC into single-phase 200 V to achieve energy saving by using regeneration power that is generated when a train brake is applied as a power supply for lighting in the station and other purposes. This is the first introduction to West Japan Railway Company. This equipment consists of a DC high-speed circuit breaker, an inverter, a protection device, a simplified remote monitoring and control device and a storage battery control panel. The main features are as follows:

(1) The equipment has an enclosed switchgear structure intended for outdoors, and it provides excellent maintainability.
(2) Based on our know-how in regeneration power absorbing equipment accumulated over many years, the equipment is controlled without any influence on signal and communication systems.
(3) A reverse-power-flow protection function is provided.

Fig.2 Direct current electric power converter

3 300-kV GIS for Shin-Sendai Thermal Power Station No. 3 Series of Tohoku Electric Power Co., Inc.

Fuji Electric delivered 300-kV gas insulated switchgear (GIS) as extra-high-voltage electric equipment for Shin-Sendai Thermal Power Station No. 3 Series of Tohoku Electric Power Co., Inc.

As countermeasures against tsunami, the GIS is installed on a large steel platform. For this layout, we conducted in advance strength analysis including the GIS and confirmed that sufficient strength and safety could be ensured. Fuji Electric's 300-kV GIS is a lightweight model that employs aluminum enclosures and this feature is effectively applied to the seismic design.

No. 3-1 of the Shin Sendai Thermal Power Station started commercial operation in December 2015 and No. 3-2 is scheduled to start commercial operation in July 2016.

Fig.3 Shin-Sendai Thermal Power Station 300-kV GIS

4 Large-Capacity Self-Commutated Flicker Compensator for Steelmaking for Sanko Seiko Co., Ltd.

In December 2015, we delivered a large-capacity self-commutated flicker compensator for steelmaking to Sanko Seiko Co., Ltd. through JP Steel Plantech Co. Rapid fluctuation of the system voltage due to operation of an electric furnace may cause flicker disturbance. This equipment, which is intended for suppressing fluctuation of the system voltage, is composed of a 40-MVA unit including a 2-multiple transformer and inverter and 35-MVar capacitor equipment. The main features are as follows:

(1) Replacing the existing large-capacity line-commuted flicker compensator (line commutation capacity 90 MVA, filter capacity 78.5 MVar), the self-commutated flicker compensator achieved a high flicker-compensation performance with small equipment capacity.
(2) Employing a water-cooled 3-level inverter with a low-profile compact vertical shape enabled the equipment to be installed in the existing electric room with size limitations.

Fig.4 Large-capacity self-commutated flicker compensator for steelmaking

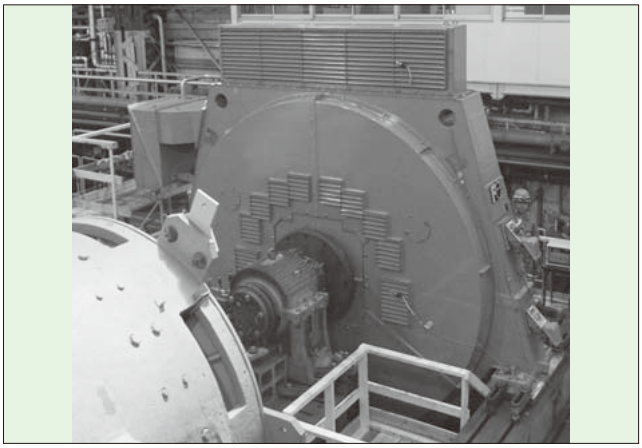
Industrial Plants

1 Synchronous Motor for Reciprocating Compressors for Sumitomo Chemical Company, Limited

Fuji Electric has replaced synchronous motor for reciprocating compressors for Sumitomo Chemical Company, Limited. The replacement motors are 3-kV, 3,040-kW, 26-pole synchronous and 3-kV, 600-kW, 14-pole induction motors. The main features of synchronous motor are as follows:

(1) Compactness has been achieved by adopting a structure with the motor rotor overhanging the compressor shaft to eliminate the bearings on the motor own.
(2) The starting current has been successfully reduced by using a part winding structure.
(3) A separate main terminal box eliminates the need for cable termination work when the stator is moved, improving maintainability.

Fig.5 3-kV, 3,040-kW, 26-pole synchronous motor (factory test)



2 CE Mark-Conforming "FRENIC-VGM" Inverter Panel

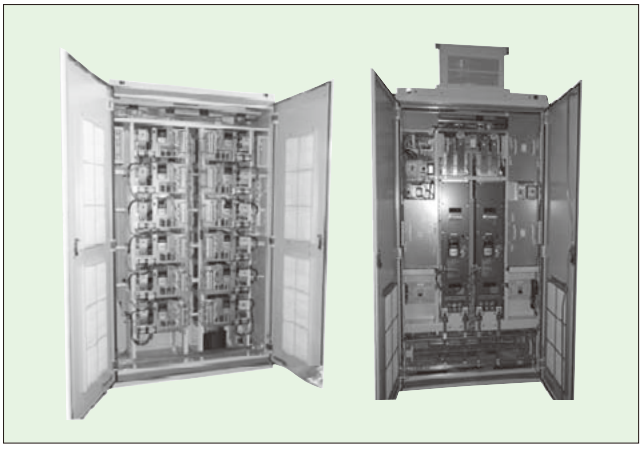
For cold-rolled steel strip processing lines outside Japan, we manufactured and delivered the "FRENIC-VGM" inverter panel that meets CE Marking.

CE Marking requires compliance with the EN Standards and IEC standards but the concept of grounding systems is significantly different from that of Japanese standards. In addition, it is necessary to use the structure of a panel and in-panel devices in accordance with CE Marking requirements, and we significantly revised the conventional basic specifications.

For this inverter panel, Fuji Electric carried out a conformity assessment based on the EC Directives and declared it to be in conformity with CE Marking.

We are contributing to the expansion of the electric power-applied plant business outside Japan by enhancing the product line-up with inverter panels conforming to EN standards and IEC standards

Fig.6 "FRENIC-VGM" inverter panel

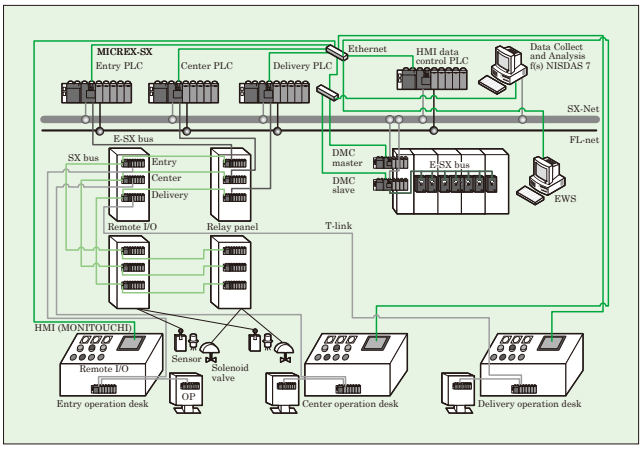


3 Continuous Galvanizing Line Electric Equipment

We delivered continuous galvanizing line electric equipment for a certain company in Indonesia. This equipment is composed of the latest control system to achieve high performance and reliability, and is provided with improved additional functions such as maintainability and operation visualization. The main features are as follows:

(1) "FRENIC-VGM" has been employed as the drive and "SPH3000MG" as the controller that controls the various sections and controls drives (DMC) to build a network with the gigabit control LAN "SX-Net."
(2) One unit of DMC is capable of controlling up to 64 drives and the maintenance tool can be used via the Ethernet to conduct overall monitoring of the DMC.
(3) "f(s) NISDAS 7" on the SX-Net can be used for high-speed collection of plant data for thousands of points (1,024 words/1 ms).

Fig.7 System configuration

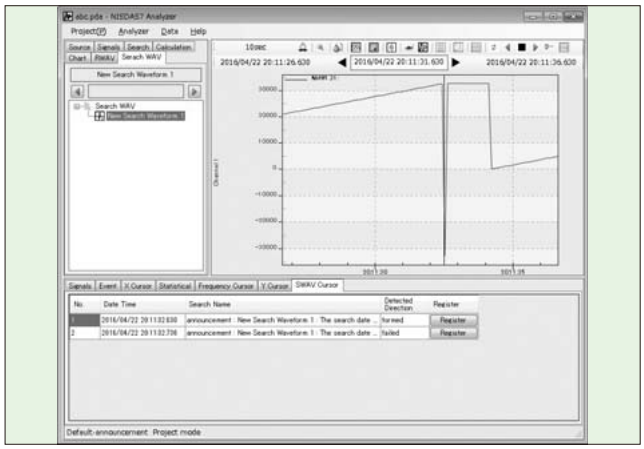


Industrial Plants

4 New Functions of Data Collection and Analysis Support Package Software "f(s) NISDAS 7"

Fuji Electric offers "f(s) NISDAS 7," data collection and analysis support package software for stable operation and preventive maintenance of equipment. A function of collecting common memory values of FL-net (OPCN-2) has now been added. FL-net is a controller level network that achieves communication between controllers, such as PLCs, robot controllers (RCs) and computer numerical control (CNC) units, and PCs. Signals can be registered simply by registering the variable name of each communication node. The variable names correspond to the notations of "SX-Programmer Expert" and "SX-Programmer Standard" of the "MICREX-SX Series." In addition, a waveform search function has been added to the analysis function. This makes it easy to search for specific events on the equipment and contributes to stable operation.

Fig.8 Waveform detection result screen

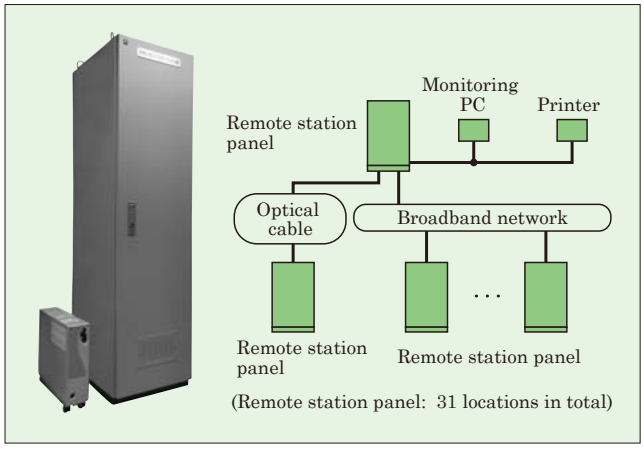


5 Elevating Machine Monitoring System for Terminal 1 of Narita International Airport

Fuji Electric delivered an elevating machine monitoring system for Terminal 2 of Narita International Airport, and it has earned customer's trust with many years of stable operation. We have won an order for work to replace the elevating machine monitoring system for Terminal 1 of the airport and completed the work without any problem by closely examining in advance the existing system provided by another company.

The system collects status signals of 79 elevators, 88 escalators and 33 moving walkways around the terminal building with the remote station panels newly installed in the vicinity (in 31 locations) to provide centralized monitoring with a monitoring PC installed at the center via LAN. The communication system used for the elevating machines was the manufacturer's proprietary one, and we have dealt with this by devising the interface. This system employs "FOCUS-SX."

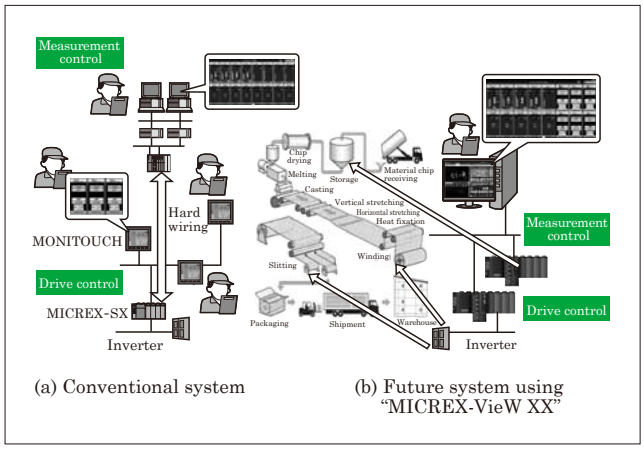
Fig.9 Remote station panel and system configuration



6 Monitoring and Control System Package for Chemical Plants

One feature of Fuji Electric's monitoring and control system is EIC integration. To roll out the product into the chemical industry and further into the pharmaceutical industry and the food/beverage industry, we have developed the functions required for the respective fields from the perspective of integration of drive control and measurement control on "MICREX-VieW XX," the common platform. The functions are integrated management of the electric equipment faceplate and measuring instrument faceplate as an integrated solution, batch control package conforming to international standard S88 and electronic recording and electronic authentication package compatible with international standard Part 11. Based on these 3 functions, we offer to the market a compact system that seamlessly integrates drive control with measurement control. In addition, we have reduced the management cost by having integrated management of drive and measurement data and unitary management of equipment.

Fig.10 Integration of drive control and measurement control



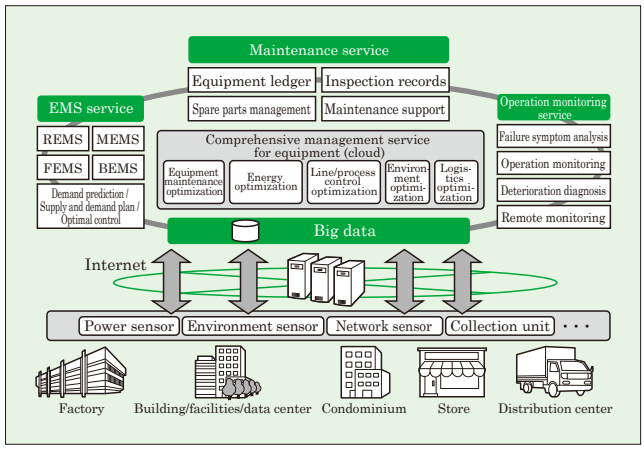
Industrial Plants

7 Functionality Enhancement for Comprehensive Equipment Management Service

Fuji Electric has developed a cloud-based comprehensive equipment management system that realizes an equipment life cycle management environment and started providing the service.

In FY2015, to the "EMS service" already provided, we newly added "operation monitoring service" and "maintenance service" functions for equipment to realize an integrated cloud-based service. Utilization of this cloud-based service has made it possible to predictively diagnose equipment degradation and failure and comprehensively manage energy efficiency. This can be done by grasping the operating conditions of the equipment, keeping maintenance and inspection records and measuring energy. Fuji Electric realizes total life cycle management from the introduction through operation and replacement of equipment. It also gives strong support to customers so that they can maximize the efficiency of equipment management and minimize their energy costs.

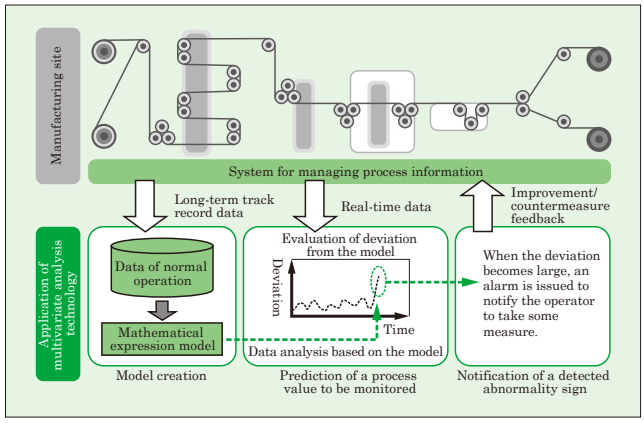
Fig.11 Comprehensive equipment management service



8 Abnormality Sign Analysis and Deterioration Diagnostic Technology by Multivariate Analysis

This technology uses enormous amounts of data generated on a daily basis by equipment and sensors. It applies multivariate analysis to detect signs of abnormality and equipment deterioration to help ensure stable operation of a plant. Generally, periodic inspections are conducted in a plant and daily checks are carried out for important equipment. However, failures may occur. One reason why signs of failures cannot be caught is that in some cases an overall change takes place gradually and cannot be detected by seeing instantaneous data. To deal with this issue, Fuji Electric has developed a technique in which a mathematical model is created from multivariate data obtained during normal operation on a monthly or yearly basis. This realizes accurate prediction and detection of signs of abnormality from a long-term perspective. As a result of applying this technique to measurement data of an actual plant, we were able to catch signs of abnormality a few hours or days before failures occurs.

Fig.12 Outline of abnormality sign analysis and deterioration diagnosis technology



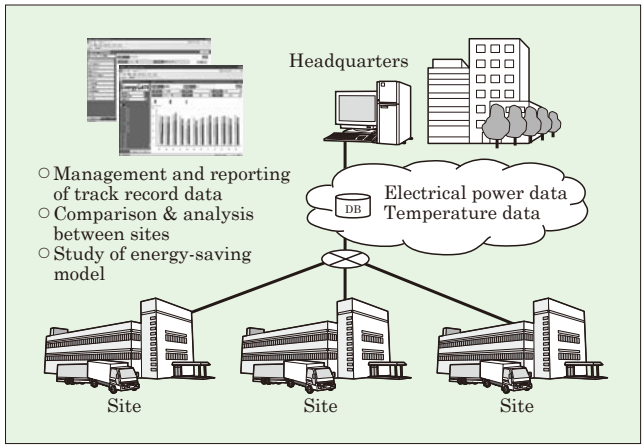
9 Integrated EMS for Refrigerated Distribution Centers

Refrigerated distribution centers that handle chilled and frozen foods require higher energy costs than dry distribution centers. This is because they must maintain the specified temperature in large spaces, and so an effective way to reduce the costs is desired. Fuji Electric has developed an integrated energy management system (EMS) for refrigerated distribution centers and started providing support services for visualization of energy usage and saving of energy as follows:

(1) The initial cost and management cost can be reduced by making use of the cloud system.
(2) Multiple sites can be managed in a centralized manner which helps accumulate and share energy-saving know-how by making comparisons between sites.
(3) Making a comparison with temperature information inside the refrigerator allows for energy saving analysis in view of the actual conditions of the center operation.
(4) The scope of visualization can be configured according to the scale of a site.

Reference: FUJI ELECTRIC REVIEW 2015, vol.61, no.3, p.182

Fig.13 Outline of integrated EMS for refrigerated distribution centers



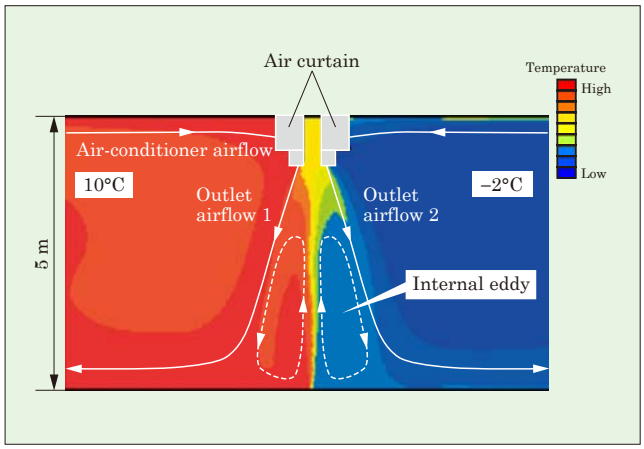
Industrial Plants

10 Air Flow Control System "Zoning Air Curtains"

For air-conditioning systems for large spaces such as refrigeration centers and plant factories, Fuji Electric has developed an air flow control system called "zoning air curtains." It provides temperature zoning for indoor space using air flows only. This system is characterized by two air curtains installed at a specified interval. Internal eddies are induced between the air curtains by making use of the balance between the air flows out of the respective air curtains. This provides an air shutoff with two air flows that blow out and internal eddies that cause little heat transfer. Hence we have achieved a high thermal insulation effect with an improvement of 45% from the conventional system, allowing temperature zoning for indoor space.

We conducted simulation analysis of the zoning air curtains in an environment assuming a refrigerated warehouse of a refrigeration center. As a result of this, we confirmed that temperature zoning of the indoor space was realized with the targeted temperature difference of 10 K only by using air flows instead of a thermal insulation wall.

Fig.14 Result of analysis of temperature zoning simulation



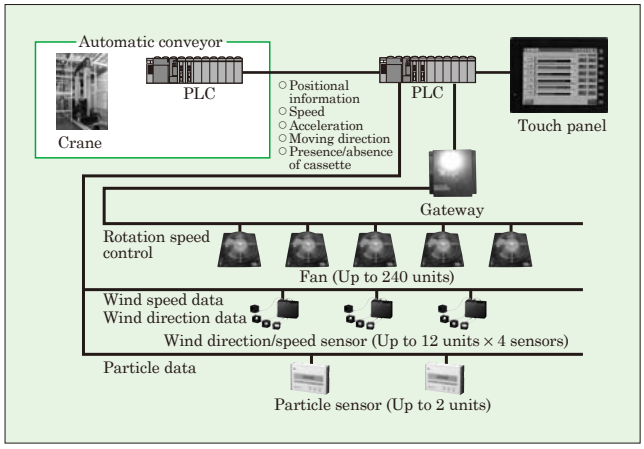
11 Air Flow Improvement Control System for Clean Rooms

The major source of dust in clean rooms is the drives of automatic conveyors, and maintaining cleanliness near automatic conveyors has a significant effect on the yield of products. Fuji Electric has developed a control system to improve air flow that reduces dust swirling and quickly removes dust by combining the conventional clean technology with sensing and control technologies. This system can be used to provide clean space with low energy consumption. The main features are as follows:

(1) The positional information and speed value of an automatic conveyor are collected and applied to automatically control the rotation speed of a fan installed near a drive for reducing the swirling of dust.

(2) The wind speed in the vertical direction is constantly monitored to determine whether there is any swirling and optimize the number of revolutions of the fan. This helps to reduce the running costs.

Fig.15 Outline of air flow improvement control system

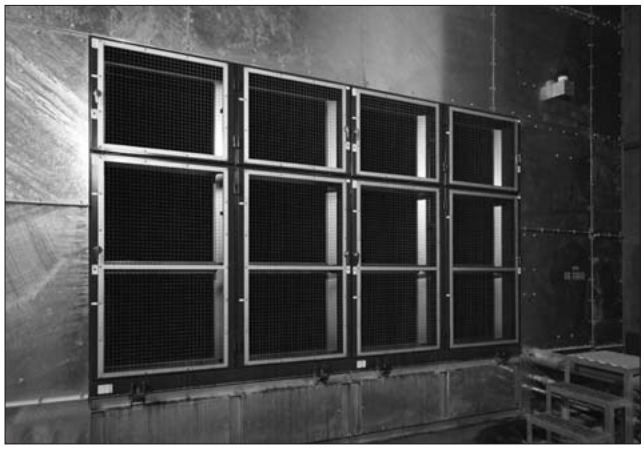


12 Air Cleaning System for Urban Expressway Central Circular Route Shinagawa Line

At city centers, loop roads are constructed to handle concentrated vehicle traffic and more expressways are being constructed as underground tunnels. For underground tunnels, electrostatic precipitators remove more than 80% of SPM in the air in tunnels, and denitrification equipment removes over 90% of NO_2. The air is blown out high at the top of ventilation towers to be diffused. In this way, the environment in underground tunnels and around ventilation towers is maintained so that road users and local residents can be kept safe and secure.

Fuji Electric cooperated with Nishimatsu Construction Co., Ltd. to deliver the first air purification system composed of electrostatic precipitators and denitrification equipment for the Central Circular Route Shinjuku Line in 2009. Based on the results of its operation, the air cleaning system was integrated and streamlined so that it could be installed in a narrow underground tunnel. In 2015, the system was delivered for the Central Circular Road Shinagawa Line, and it helps to ensure safety and security.

Fig.16 Electric dust collector at Naka-meguro Ventilation Station



Industrial Plants

13 Exhaust Gas Cleaning System for Marine Vessels (Cyclone Type SO_X Scrubber)

In order to prevent air pollution resulting from marine vessels, exhaust gas regulations have been gradually reinforced based on the International Convention (MARPOL 73/78). Fuji Electric has developed an exhaust gas cleaning system for marine vessels (cyclone type SO_X scrubber) compliant with SO_X/PM regulations. The unit sprays alkaline water on the exhaust gas and reduces SO_X by dissolving it in the sprayed droplets. The main features are as follows:

(1) The system has the smallest size in the industry with a volume reduction of over 50% from conventional products, and was offered for testing in the joint research of Nippon Kaiji Kyokai and Imabari Shipbuilding Co., Ltd. (intended for the main engine of a new ship).
(2) The cyclone system creates a swirl inside the unit to improve the SO_X reduction rate to over 98%.
(3) It achieves a reduction in pressure loss and the droplet dispersal rate by making use of SO_X dissolution model experiments and fluid simulations.

Fig.17 SO_X scrubber for 9-MW main engine (diameter 2 m, height 6 m)

14 Equipment for Greenhouse Horticulture of Salad Paprika Co.,Ltd.

The greenhouse horticulture of Salad paprika Co.,Ltd. is under construction in Kushiro City, Hokkaido. It is one of the largest paprika production sites in Japan with an area under cultivation of approximately 2.2 ha. Fuji Electric will deliver to the plant equipment and materials including a composite climate control system, incident light diffusing greenhouse covering material for improving the plant insolation efficiency and double-parallel-row cultivation equipment capable of improving the production efficiency. The plant aims to achieve the highest crop yield per unit area in Japan by ensuring the optimum cultivation environment, using these types of equipment. In terms of operation, a high unit price transaction can be achieved by making use of the cool climate of the area to offer stable shipping in warm seasons, in which other areas of production are having difficulty in supplying produce, and year-round supply.

In the future, we aim to expand the greenhouse horticulture business based on the cultivation environment technology, know-how on cultivation business operation and EPC experience with a large-scale greenhouse horticulture, to be acquired at this plant.

Fig.18 Greenhouse horticulture (under construction)

15 Air-Conditioning System for Complete Artificial Light Plant Factory

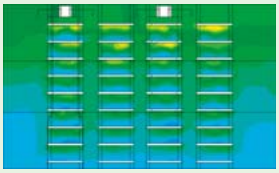
As the stable supply of food has come to be regarded as important recently, complete artificial light plant factories, which do not depend on the season or climate and allow multi-tier cultivation, are attracting attention.

Fuji Electric has taken advantage of its thermo-fluid analysis technology and delivered to a certain customer an air-conditioning system for a complete artificial light plant factory. It homogenizes temperature in a facility, which is especially important for stable production of crops. The main features are as follows:

(1) Optimum device capacity has been specified in a thermal load calculation with the transpiration of plants and heat generation load of lighting taken into account.
(2) Thermo-fluid simulation based on the physical conditions such as the passage width and aperture ratio of vents has been conducted. This has determined the temperature distribution and wind speed distribution in the facility so that an air-conditioning system with appropriate capacity and layout can be provided.

Fig.19 Inside of plant factory and results of thermo-fluid simulation

(a) Inside of plant factory



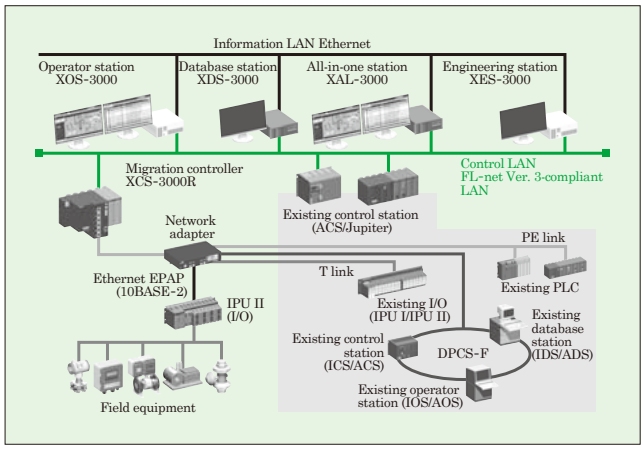
(b) Results of thermo-fluid simulation

Industrial Plants

16 Product Line Expansion of Small- and Medium-Scale Monitoring and Control System "MICREX-VieW XX"

Fuji Electric has developed the "MICREX-VieW XX migration system" with ensured compatibility with the conventional "MICREX Series" and the all-in-one station "XAL-3000." The MICREX-VieW XX migration system can connect to existing networks and I/O through a network adapter, saving the labor of wiring work. In addition, making use of the existing system screens and controller applications means an existing system can be updated to a highly reliable one in a short time. XAL-3000 integrates the operator station "XOS-3000" and database station "XDS-3000" into one unit. It can be used to construct a small system capable of reducing the initial introduction and maintenance costs in total while ensuring high reliability by redundancy.

Fig.20 "MICREX-VieW XX migration system"

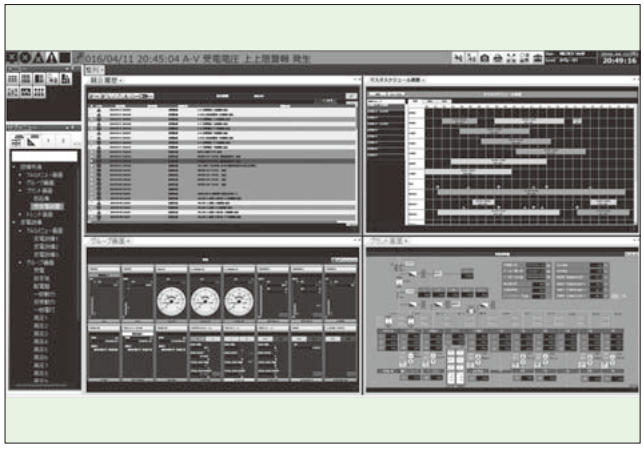


17 Equipment Monitoring System "MICREX-VieW PARTNER"

Fuji Electric has developed equipment monitoring system "MICREX-VieW PARTNER." It is at the core of level II of the ISO energy management hierarchy that connects level III (EMS) and level I (collection device). The main features are as follows:

(1) Energy management systems can be seamlessly built in the equipment alone, line or entire factory or between factories due to the strengthened vertical and horizontal integration.
(2) Addition or renovation of systems is easy and the monitoring points can be simply configured from either the upper or lower level.
(3) The operator access control function based on the latest ICT has achieved improved operability and reinforced security.
(4) The same operation as that for the small- and medium-scale monitoring and control system "MICREX-VieW XX" can be used, which mitigates the burden of operater training by employer.

Fig.21 Example of operation screen

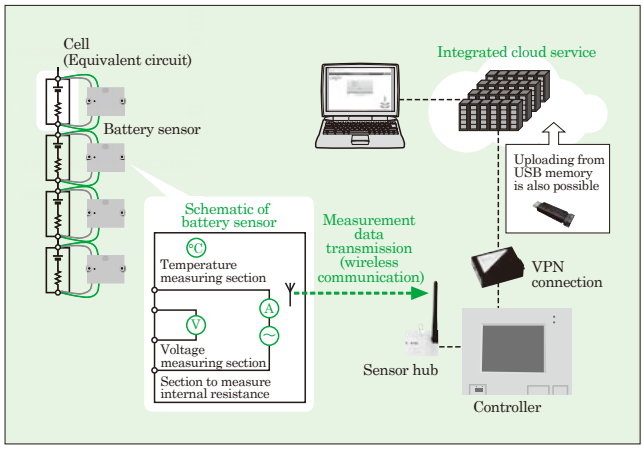


18 Cloud-Based Battery Diagnosis Service

Fuji Electric offers "Integrated Cloud Service" in the field of equipment maintenance, utilizing the IoT and M2M. The cloud-based battery diagnosis service ensures the stable operation of equipment that requires batteries. Measurement for each electric cell is possible and the voltage, internal resistance and temperature of valve-regulated batteries are continuously monitored to detect any characteristic change of the batteries, which allows abnormalities or aging degradation to be grasped. The main features are as follows:

(1) Loss resulting from unexpected failure can be avoided.
(2) Signs of degradation can be detected to make repair and replacement plans.
(3) Prediction management through an annual or biannual inspection can be changed to maintenance management by constant monitoring.
(4) The replacement time can be predicted with numerical trend management to reduce risks and costs.

Fig.22 Outline of cloud-based battery diagnosis service



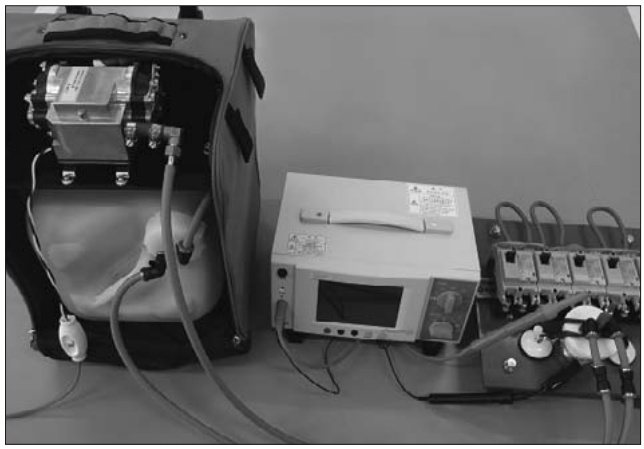
Industrial Plants

19 Insulation Diagnosis Service by Surface Resistance Measuring Device

For distribution equipment that has been in use for a long time, identifying appropriate replacement time is important and insulation diagnosis technology is desired for that purpose. With existing diagnosis techniques, surface resistance at high humidity is estimated based on the usage environment and analysis of deposits. Problems with this technique includes that the accuracy of the surface resistance cannot be assured, lab analysis is required and the cleaning effect cannot be applied.

Fuji Electric has developed a surface resistance measuring device capable of on-site direct measurement of the surface resistance of the insulator of the distribution equipment installed under arbitrary humidity conditions. The accuracy of the surface resistance can be assured and the surface resistance restoration effect by cleaning in periodic inspections and degradation characteristic (remaining life) of the insulator can be grasped. We will offer a new insulation diagnosis service by using this device.

Fig.23 Surface resistance measuring device



Industrial and Instrumentation Equipment

1 New Electronic Personal Dosimeter "NRF50"

Fuji Electric has developed a new electronic personal dosimeter "NRF50," which reflects market needs. NRF50 has characteristics that conventional products do not have, such as a large dot LCD, radio communication module and emergency call button. In addition, it is compliant with IEC 61526 Ed3.0 and ANSI N42.20, which are international standards for dosimeters, and combines the electromagnetic compatibility (EMC) performance that satisfies MIL-STD-461F, waterproof performance of IP65/67 and high robustness. For radio communication, either 900-MHz radio or Wi-Fi can be selected and the real-time remote monitoring system can reduce exposure of workers to radiation. In addition to use in nuclear facilities, this dosimeter is expected to use for decontamination and measures against radiation terrorism.

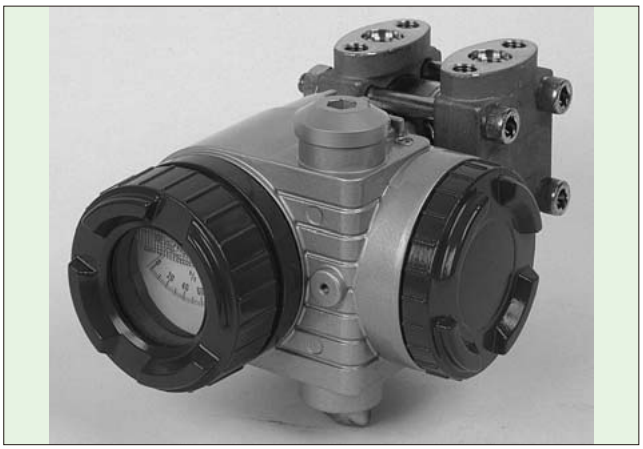
Fig.24 "NRF50"

2 Analog Circuit Pressure Transmitter for Special Applications

Fuji Electric has developed an analog circuit pressure transmitter with excellent radiation resistance for nuclear power plants. Currently, for control and monitoring, petroleum, chemical, steel and power generation and other industry plants mostly employ digital circuit transmitters equipped with a microcomputer. However, highly-integrated semiconductors are easily affected by radiation, and at nuclear power plants, they are only used in low-radiation areas. Analog circuit transmitters are capable of meeting requirements that cannot be satisfied by digital circuit transmitters. The main features are as follows:

(1) Radiation resistance: Adopting electronic components with a high radiation resistance and circuit structure have achieved a radiation resistance of 50-kGy irradiation.
(2) High temperature resistant characteristic: A high temperature resistant characteristic of 125°C has been provided assuming a coolant leak accident.
(3) Seismic vibration: The structural design ensures resistance to an acceleration of 5 G.

Fig.25 Analog circuit pressure transmitter



3 High-Accuracy Spool Piece Ultrasonic Flowmeter "FST"

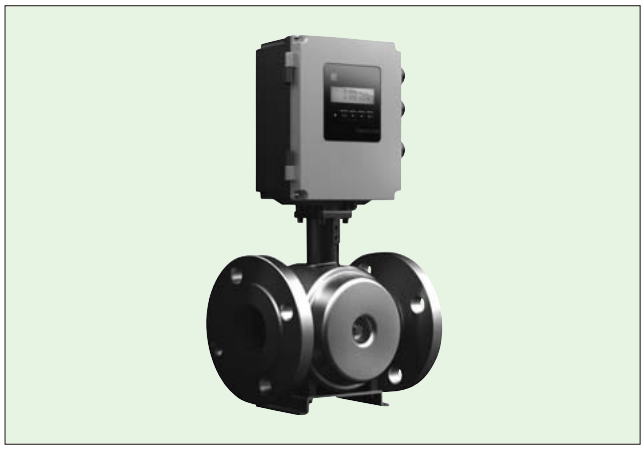
The high-accuracy spool piece ultrasonic flowmeter "FST" contributes to energy saving and quality improvement by accurately measuring various liquids with multipath (3 paths) and its scope of application is expected to expand. The main features are as follows:

(1) It can measure fluids with very high accuracy by using three pairs of ultrasonic sensors installed facing each other in piping together with our proprietary digital signal processing technology and arithmetic algorithm.
Accuracy: ±0.2% of rate (flow velocity: 1 to 10 m/s)

(2) It can measure oil, deionized water and other low-conductivity liquids which are difficult to measure with electromagnetic flowmeters.

(3) Measurable fluid temperature of FST is higher than that of an electromagnetic flowmeter.
Fluid temperature: −40°C to +150°C

Fig.26 "FST"



Power Electronics Equipment

Drive Systems
Power Supply Systems
Transportation Systems
Electric Distribution, Switching and Control Devices

Outlook

Power electronics products form the basis of daily life and production activities in a wide range of fields from lifeline services to industrial/social infrastructures. In terms of energy saving, there are strong expectations for high-efficiency conversion technology. There are calls for the proliferation of products featuring silicon carbide (SiC) power devices as well as products conforming to regulations regarding efficiency and safety.

In the field of drive systems, we have developed a high-performance compact IP65-rated inverter. We reduced power dissipation in the main circuit by 44% through using an SiC power device and achieved compactness and a totally enclosed self-cooled structure for the inverter. This is a dustproof and waterproof inverter that can be installed without a panel even in an environment with dust or water/oil splashes, and that does not need an external cooling fan. As for the "RHC Series" of PWM converters with an SiC hybrid module (stack type), we added a new 690-V model to the line-up intended for cranes and iron/steel applications for which demand is increasing overseas. We employed SiC power devices to products with a capacity of 355 kW or higher to achieve miniaturization through reducing the generated loss.

In the field of power supply systems, we delivered uninterruptible power systems (UPSs) for data centers. The amount of equipment investment made in data centers is increasing year by year due to the proliferation of cloud services and the utilization of big data. Amid an acceleration in efficiency improvement and systematization, we have commercialized high-efficiency large-capacity UPSs intended for North America and Asia that conform to the standards in the respective countries. We have also commercialized a rack-mounted direct current UPS that integrates a UPS and a server's internal power supply in order to reduce the conversion loss during power distribution. We will increase the variety of high-efficiency products to which SiC power devices are used.

In the field of transportation systems, we have developed jointly with Central Japan Railway Company a traction converter that uses SiC power devices, for Tokaido Shinkansen trains. We mounted a prototype on Series N700 train cars and are conducting the first running test in the world using a drive system of a high-speed railway in which an SiC power devices are employed. We are also working to commercialize a compact and lightweight auxiliary power unit that does not use a commercial frequency transformer by applying insulation technology through high-frequency switching. Drive systems for train car doors were delivered for new cars of the Nippori-Toneri Liner of the Bureau of Transportation, Tokyo Metropolitan Government and New Shuttle of Saitama New Urban Transit Co., Ltd. Instead of conventional products using a pneumatic door drive system, they are equipped with rack-and-pinion type electrical operated door drive system that offers high reliability and improved maintainability. These cars are currently being used for commercial operations. For rotating machines, we have developed motors that conform to overseas efficiency regulations, one for GB2 in China and the other for EISA in the United States (both classified as efficiency class IE3). The motor conforming to EISA in the United States also conforms to UL standards. Furthermore, we have developed low-inertia, high-speed motors that are required due to the proliferation of electric vehicles and faster rotation of mounted motors.

In the field of electric distribution, switching and control devices, there is growing demand for space-saving and highly reliable distribution equipment and control systems for production equipment, office buildings and commercial facilities in addition to the renewable energy-related businesses. In line with the proliferation of Top Runner motors (IE3) following the revision of the "Act on the Rational Use of Energy" (Energy Conservation Act), we have developed the "G-TWIN Series" of circuit breakers supporting 100 to 250 AF and "SW-N03" to "SW-N5-1" of compact magnetic switches combined with new thermal overload relays. The low-voltage distribution equipment market is demanding improved added value of lighting distribution panels.

In response, we have developed a breaker providing single-phase 3-wire neutral line phase loss protection and earth leakage alarm by adding an earth leakage alarm function to a neutral line phase loss protection breaker. As for high-voltage vacuum circuit breakers, we have developed a 24-kV vacuum circuit breaker (VCB) for the Southeast Asian market that conforms to IEC 62271-200 by itself. With it, we have achieved significant compactness through the use of a solid-insulated vacuum valve. As an energy monitoring system, we have developed "F-MPC Web Unit" (UM12-10) featuring enhanced support functions for energy-saving measures and a simplified user interface. With regard to switchgears, we started producing switchgears at Fuji Electric Manufacturing (Thailand) Co., Ltd. and are planning to transfer MV switchgears to Fuji SMBE Pte. Ltd. (Singapore) as a move toward globalization. We have completed the development of 24-kV/25-kA IEC-compliant switchgear following the development and commercialization of the 7.2-kV/31.5-kA model. Compared with JEM-compliant products designed for the Japanese market, human safety has been improved through measures against internal arc accident and such like.

We will continue to working to develop new technologies and products, pursue customer satisfaction and contribute to the achievement of a sustainable society.

Drive Systems

1 Servo System "ALPHA5 Smart Series" (Multi-Axis Integrated Type)

For the "ALPHA5 Smart Series," a product that mainly targets China and other Asian markets, we developed a new, multi-axis integrated type (Max. connectable axis: 5). The main features are as follows:

(1) By employing a common converter section, we have managed to reduce the amount of power supply wiring and lower the price.
(2) By using common direct-current intermediate capacitors and supplying DC power to each inverter, we have saved power by making effective use of regeneration power.
(3) The line-up of three types of inverters, 0.2 kW, 0.4 kW and 0.75 kW, offers higher flexibility in the combination of capacities.
(4) The configuration allows a single axis to be replaced, which improves maintainability.

Fig.1 "ALPHA5 Smart Series" (multi-axis integrated type)

2 SiC Hybrid Module-Mounted PWM Converter "RHC Series"

PWM converters have been used to save energy, improve the power factor and suppress harmonics through regenerative operation of a power supply. In recent years, they have also come to require a larger capacity due to their increasing applications in large-scale systems. Fuji Electric has developed the "RHC Series" of PWM converters designed to provide larger capacity. The main features are as follows:

(1) SiC hybrid module using SiC for FWD and Si for IGBT is employed to increase capacity by about 43% compared with products using a conventional Si module of the same appearance (stack type).
(2) A direct parallel connection method allows an output of 450 kW and parallel connection of up to four units (1,700-kW/690-V line).
(3) It can use spare parts of the "FRENIC-VG" inverter that are in common when only the software, terminal block board and touch panel are changed.

Fig.2 "RHC Series" (stack type)

Drive Systems

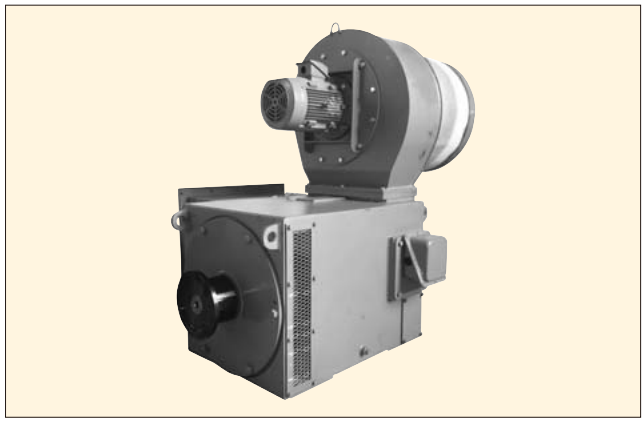
3 Low-Inertia, High-Speed Motor for Automotive Testing Machines

Fuji Electric has developed a low-inertia, high-speed motor with 500-kW rated output. It is to be used as driving power or a load of testing machines for such automotive components as engines, transmissions, differential gears. The main features are as follows:

(1) Since this is an induction motor, it rotates smoothly especially when no current is applied, without generating torque ripples or core loss.
(2) The design of the rotor has been innovated as driving power for testing machines, resulting in lower inertia, faster rotation and higher torque compared with conventional motors.
(3) Use of an air-cooling system eliminates the need for water-cooling equipment and piping work.
(4) The adoption of grease-lubricated sealed bearings eliminates the need for forced lubricating equipment.

We plan to continue the development of 220-kW and 370-kW models to expand model variations.

Fig.3 Low-inertia, high-speed motor for automotive testing machines



Power Supply Systems

1 High-Efficiency UPS for North America "UPS7000HX-T3U"

Products for data centers, which are expected to increase in particular in the UPS market, have been requiring high-quality and high-efficiency UPSs and it has become important to obtain various certifications to prove such ability.

The high-efficiency UPS for North America "UPS7000HX-T3U" provides an input/output voltage of 480 V AC and equipment capacity of 500 kVA. It has achieved equipment efficiency of 97.5% which is the industry's highest level for a UPS double conversion. To sell it in the market in North America, we have obtained the following third-party certifications for the product:

(1) U.S. safety standard UL 1778 and Canada's safety standard CSA C22.2 No. 107.3-14
(2) Energy Star
(3) California's seismic standards (OSHPD)

Fig.4 "UPS7000HX-T3U"

2 Expanding Product Line of 3-Phase 400-V Large-Capacity UPS "UPS7000HX Series"

In order to increase the variety of products outside Japan, Fuji Electric has developed "UPS7000HX-T4C" (300/400/500 kVA) as models to be added to the "UPS7000HX Series" product line of large-capacity UPS products that have been released in advance. To provide safety and security, these products have been evaluated by a third-party certification body and approved for their conformance to the following safety standards of the respective regions:

(1) The products have obtained conformance certifications for European safety standard EN 62040-1 and EMC standard EN 62040-2 and declared the conformance to CE Marking.
(2) The products have satisfied the requirements of the international standard IEC 62040-3 regarding the performance and test requirements of UPS.
(3) We have had a safety test conducted by the TLC Certification Center, which is a Chinese official certification body, and acquired TLC certification.

Fig.5 "UPS7000HX-T4C"

Transportation Systems

1 Rack-and-Pinion Door Drive System for Nippori-Toneri Liner of Bureau of Transportation, Tokyo Metropolitan Government

Model 330 cars of Nippori-Toneri Liner, which started being operated on October 10, 2015 by Bureau of Transportation, Tokyo Metropolitan Government, have adopted an electrical operated door drive system instead of a conventional pneumatic door drive system. Fuji Electric has delivered a rack-and-pinion door drive system. The main features are as follows:

(1) It achieves high reliability and safety by adopting the latest power electronics technology while inheriting the mechanism of Fuji Electric's conventional products.
(2) The standardized adjusting method of the locking mechanism facilitates the door installation and lock adjustment work during the manufacturing and maintenance of rolling stock.
(3) A failure diagnosis function reduces maintenance time.
(4) Adoption of the latest sensing technology has improved the detection performance in the case of a passenger or belongings being caught between doors.

Fig.6 Model 330 cars and rack-and-pinion door drive system

2 Rack-and-Pinion Door Drive System for New Shuttle of Saitama New Urban Transit Co., Ltd.

Series 2020 cars of New Shuttle, which started being operated on November 4, 2015 by Saitama New Urban Transit Co., Ltd., have adopted an electrical operated door drive system instead of a conventional pneumatic door drive system. Fuji Electric has delivered a rack-and-pinion door drive system. The main features are as follows:

(1) In order to install the door system to the train car at a slant due to the limited mounting space, we improved the methods of hanging the system equipment and of connecting it to the door panel for higher flexibility.
(2) The standardized adjusting method of the locking mechanism facilitates the door installation and lock adjustment work during the manufacturing and maintenance of rolling stock.
(3) A failure diagnosis function reduces maintenance time.
(4) Adoption of the latest sensing technology has improved the detection performance in the case of a passenger or belongings being caught between doors.

Fig.7 Series 2020 cars and rack-and-pinion door drive system

Electric Distribution, Switching and Control Devices

1 24-kV Vacuum Circuit Breaker (VCB) for Southeast Asian Market

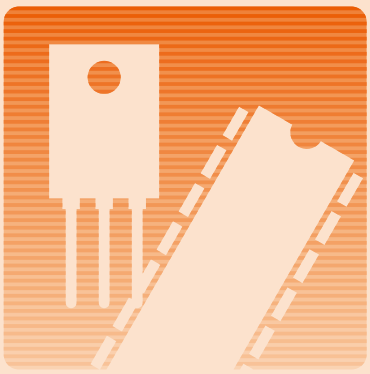
Fuji Electric has developed a vacuum circuit breaker (VCB) to be mounted on IEC standard-compliant switchgears intended mainly for the electric distribution market in Southeast Asia.

The specifications include a rated voltage of 24 kV, rated breaking current of 25 kA, and rated current of 1,250 A. The main features are as follows:

(1) Safety mechanism conforming to IEC 62271-200
  ○ The external operation mechanism unit allows the VCB to be inserted into or drawn out from the outside of the panel with the door closed.
  ○ The interlock mechanism prohibits the insertion/drawing out operation when the power is on and opens the front door only at the test position.
(2) Compactness through the adoption of a solid-insulated valve to the main circuit
  Pitch between phases: Shortened from 230 to 210 mm
  Pitch between poles: Shortened from 470 to 310 mm
  External height: Lowered from 1,125 to 788 mm

Fig.8 "HS2520F-12Mf-A"

Electronic Devices



Power Semiconductors
Photoconductors
Disk Media

Outlook

Power Semiconductors

To conserve the global environment and stably supply energy, power electronics technologies that support energy creation, or the spread of renewable energy, and energy saving, or efficient energy use, are raising great expectations from society. In this situation, Fuji Electric is developing power semiconductor products featuring high energy conversion efficiency, low noise and environmental friendliness. They are being used to products in the field of the environment and energy, industrial machinery, automobiles and home appliances and making contributions to society.

Insulated gate bipolar transistors (IGBTs), which are widely in use for power semiconductors, were developed in the 1980s and the current mainstream is the 6th generation. Fuji Electric has established technologies to further reduce power dissipation, heat dissipation and thermal resistance and developed the 7th-generation IGBTs. We have also worked on developing silicon carbide (SiC), which has recently been attracting attention as a new material, and developed a hybrid product combining Si-IGBT with SiC-SBD and the 1st-generation all-SiC module employing SiC-MOSFET.

In the field of the environment and energy, we have further expanded the product line-up of IGBT modules for 3-level conversion circuits for power conditioning sub-systems (PCSs) of photovoltaic power system. We have mass-produced a module product with an AT-NPC circuit configuration. It applies our proprietary 1,200-V rated voltage RB-IGBT for the neutral point switch, allowing systems to use higher voltages. In addition, we have added to the line-up an NPC 3-level module compatible with 1,500-V DC systems.

In the field of industrial machinery, we have developed IPM products suited for supporting multiple axes of servo amplifiers. Optimizing the thermal design makes it possible to reduce the IPM dimensions, contributing to the miniaturization of multi-axis servo amplifiers.

For home appliances and small industrial motor drives, we have commercialized the 2nd-generation small IPMs that meet the requirements for miniaturization and energy saving of systems. By applying the 7th-generation IGBT technology, we have achieved a reduction in power dissipation of over 20% from the 1st-generation products in the rated and maximum load region.

In the field of automobiles, we have added to the 6th-generation pressure sensor line-up a relative pressure sensor for fuel gas. Pressures in the range of -80 to +5 kPa can be measured with accuracy of ±1.5% F.S. or less (25 °C). This helps to reduce emissions of hazardous fuel gas by monitoring the internal pressure of fuel supply systems. Furthermore, in the field of in-vehicle IGBTs used for motor driving of electric and hybrid vehicles, Fuji Electric is establishing a line-up of products that use its proprietary direct liquid cooling structure and reverse-conducting IGBT (RC-IGBT) chip.

In the field of power supply systems, we have commercialized the 2nd-generation low power dissipation SJ-MOSFET "Super J MOS S2 Series." They achieve high-efficiency power conversion for various applications including those in the field of communication and energy. With the 2nd-generation products, the on-state resistance normalized by unit area has been further reduced and the trade-off between the switching loss and voltage surge at turn-off has been improved. In this way, we have improved the power conversion efficiency and ease of use at the same time. We have also commercialized the high-voltage input PWM control IC "FA8A80 Series." They can withstand surges from a power supply line, and they integrate the low standby power function and are suited for home appliances to be used in developing countries with unstable power supply conditions.

In the future, we intend to continue developing ecological power semiconductor products so as to realize a safe, secure and sustainable society.

Photoconductors

Photoconductors used for electrographic devices such as printers and photocopiers are required to offer

higher speed and durability for the purpose of reducing printing costs.

In FY2015, we made use of the development of new additives to develop and mass-produce a high-speed organic photoconductor. It eliminates any degradation in image quality caused by optical fatigue. We also completed making the basic design of the next-generation high-durability organic photoconductors. We will further help to save energy, reduce cost and improve work efficiency in the office through the provision of photoconductors that meet customer needs including mass production of these high-durability photoconductors.

Disk Media

There has continued to be strong demand for magnetic recording media for hard disk drives (HDDs) for use in cloud servers, and a capacity increase and cost reduction have been becoming more and more important.

In FY2015, Fuji Electric established the basic layer configuration of media suited for shingled magnetic recording, which allows a capacity increase. In FY2016, we plan to start mass producing 2.5-inch media with a recording capacity of 1 TB/disk. We intend to continue developing high-capacity recording media and providing high-reliability storage, which is at the core of IT infrastructure.

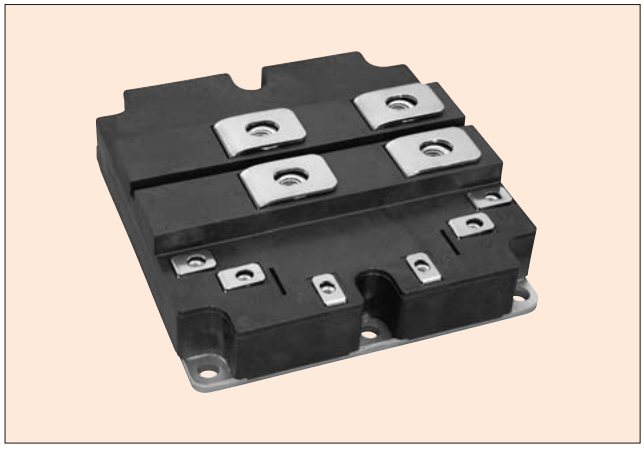
Power Semiconductors

1 1,700-V Withstand Voltage SiC Hybrid Module

Recently, silicon carbide (SiC) devices characterized by high thermal resistance and high breakdown electric field tolerance have been raising expectations for a dramatic reduction in power dissipation, which is difficult to realize with Si devices. Up to now, Fuji Electric has commercialized SiC hybrid modules, which combine the SiC-Schottky barrier diode (SiC-SBD) chips and silicon insulated gate bipolar transistor (Si-IGBT) chips. We have recently developed a new 1,700-V withstand voltage SiC hybrid module intended for the main power supply of electric railways. This product is available in two series including a low $V_{CE\ (sat)}$ model that focuses on steady-state loss and low turn-off surge voltage in addition to a standard model featuring low power dissipation. The standard model has achieved a 32% reduction in the loss generated in inverter operation (carrier frequency 3 kHz) as compared with a conventional Si module.

Reference: FUJI ELECTRIC REVIEW 2015, vol.61, no.4, p.228

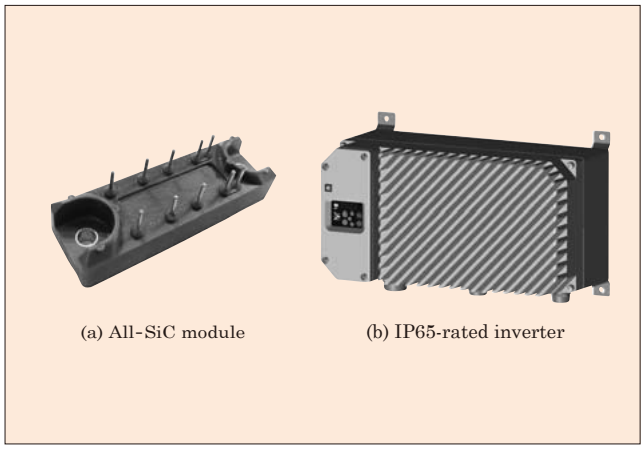
Fig.1 1,700-V withstand voltage SiC hybrid module



2 Small-Capacity All-SiC Module

To bring about a low-carbon society, Fuji Electric commercialized in 2014 a power conditioning sub-system (PCS) for photovoltaic power generation equipped with all-SiC modules with a 1,200-V/100-A rating. In view of uses in various applications, we have recently developed a small-capacity all-SiC module with a rating of up to 50 A. The package structure has been optimized according to the rated capacity to reduce the footprint size by 30% from that of the 100-A rated product. A 44% reduction in power dissipation has also been realized as compared with the conventional Si product. The features of this package include high-temperature operation guarantee, high reliability and low thermal resistance. By utilizing them, the module has been employed in an enclosed space with a self-cooling structure. It has helped develop a high-performance compact IP65-rated inverter with improved environmental endurance to achieve dustproof and waterproof properties.

Fig.2 All-SiC module and IP65-rated inverter



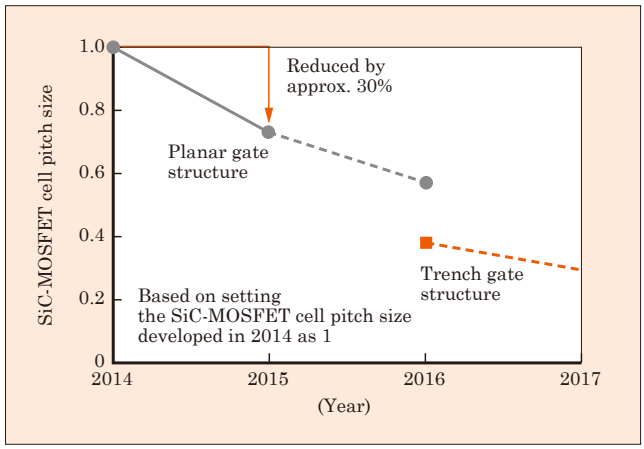
Power Semiconductors

3 6-Inch SiC-MOSFET

Fuji Electric has used a 6-inch silicon carbide (SiC) substrate to develop an SiC metal-oxide-semiconductor field-effect transistor (SiC-MOSFET) with a planar gate structure having the on-state resistance in operation further reduced. To improve the characteristics, the cell pitch size and channel length have been reduced by approximately 30% from a conventional device. In this way, we have offered a line-up of planar SiC-MOSFETs with ratings of 600 V, 1,200 V and 1,700 V.

In FY2016, we plan to commercialize an all-SiC module equipped with an SiC-MOSFET and SiC-Schottky barrier diode (SiC-SBD) and a discrete SiC-MOSFET. To further lower on-state resistance, we are working on even smaller design rules with a planar gate structure and technology development for an SiC-MOSFET with a trench gate structure.

Fig.3 Road map for small design rule on SiC-MOSFET



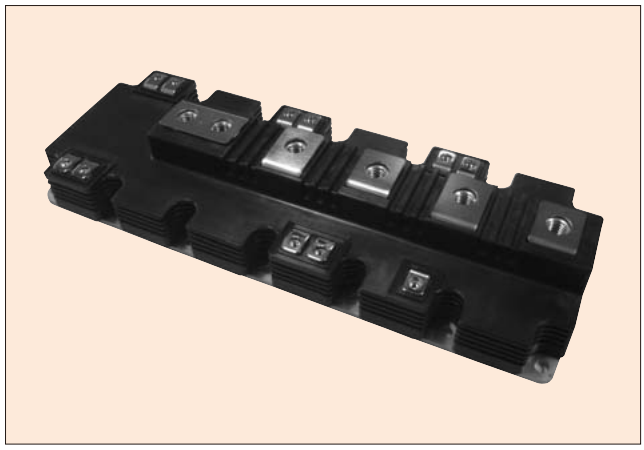
4 Expansion of the High-Power 3-Level IGBT Module Line-Up

Fuji Electric is committed to developing high-power 3-level IGBT modules used in the renewable energy field including wind and photovoltaic power generation, and has been highly rated by the market.

The high-power 3-level IGBT module integrates a 3-level power conversion circuit in one package. 1,700-V/450-A and 600-A ratings were expanded as new line-up. It achieves improved power conversion efficiency and miniaturization of equipment and also makes it easier to increase the capacity of equipment by making parallel connections. Furthermore, in preparation for photovoltaic power generation output with higher voltage levels, we will commercialize an I-type module with a rating of 1,200 V/600 A capable of using at 1,500 V DC. The main features are as follows:

(1) T-type: Employing RB-IGBT to improve efficiency
(2) I-type: Equipped with terminals compatible with T-type to ensure easy replacement

Fig.4 High-power 3-level module common to T-type and I-type



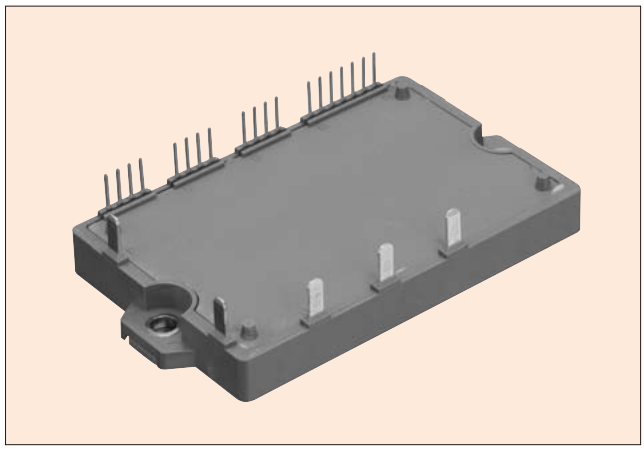
5 "V Series" of IPM High Heat Dissipation "P626 Package"

Recently, servo amplifiers have been required to be compact, support multiple axes and offer higher performance via increased carrier frequency. For that reason, IPMs for them have faced big challenges: compactness, chip temperature reduction, and power cycle lifetime.

New "P626 package," is a high heat dissipation type that uses an aluminum-nitride-insulating substrate featuring high thermal conductivity to expand the "V Series" IPM line-up. Chip temperature rise has been decreased by achieving a 30% reduction in the thermal resistance, and a significant improvement in the power cycle lifetime has also been realized. The main features are as follows:

(1) Rated voltage/current: 600 V/75 A (6 in1)
(2) Dimensions: W87 × D50 × H12 (mm)
(3) Thermal resistance $R_{th(j\text{-}c)max}$: 0.43°C/W (IGBT), 0.65°C/W (FWD)

Fig.5 "P626 package"



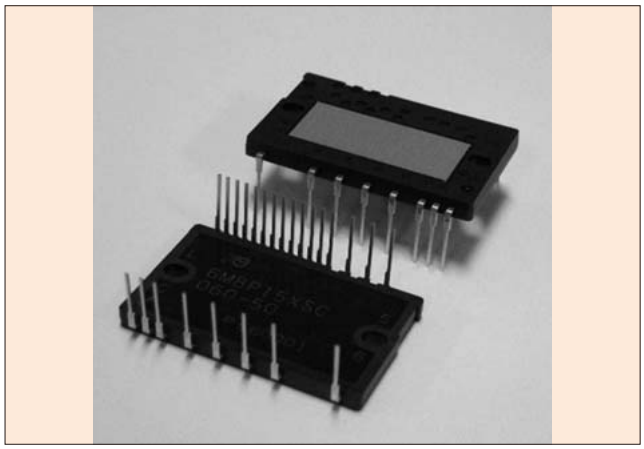
Power Semiconductors

6 2nd-Generation Small IPM

Fuji Electric has developed 2nd-generation small IPMs that integrate into a single package the power devices and control IC needed in inverter system construction. They are intended for the markets for home appliances such as air conditioners and washing machines and for industrial motor drives, in which there is a high demand for energy saving. The 2nd-generation small IPMs have achieved a reduction in power dissipation by using the 7th-generation IGBT technology as the basis. As the effect of its application, it achieves lower power dissipation than conventional products in the entire load range during operation of an air conditioner, and especially in the intermediate load range that has a major impact on the energy saving performance, it lowers power dissipation by 10%. The guaranteed operation temperature range has been expanded from 125°C to 150°C. This has increased the allowable output current by approximately 25%, achieving energy saving, increased output current and improved degree of freedom in system design.

Reference: FUJI ELECTRIC REVIEW 2015, vol.61, no.4, p.242

Fig.6 2nd-generation small IPM



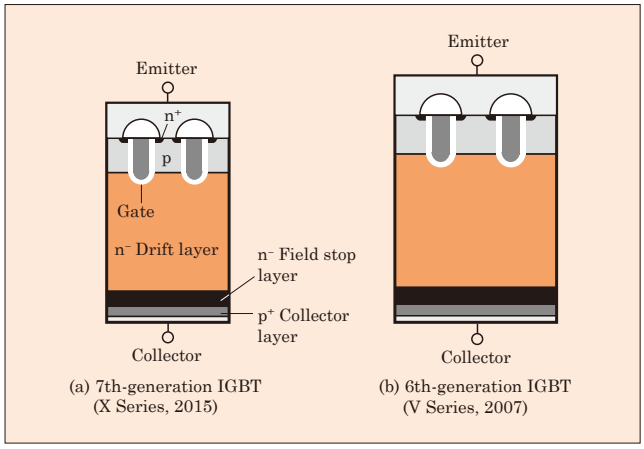
7 7th-Generation IGBT Chip

The scale of the market for insulated gate bipolar transistor (IGBT) modules is expected to continue expanding in the future. In the field of the environment and energy in particular, there is increasing demand for reduced power dissipation of power converters. To meet this demand, Fuji Electric has developed the 7th-generation IGBT and freewheeling diode (FWD) chips.

The IGBT chip has a surface structure based on smaller design rules and the drift layer has been made thinner. This significantly improves the characteristics including a reduction of the on-state voltage by 25% (0.5 V) and the turn-off loss by 10% from the 6th-generation IGBT. For the FWD chip, the silicon has been made thinner and the carrier distribution optimized by a new lifetime control method. As a result, reduced power dissipation and soft recovery have been achieved at the same time, and a reverse recovery loss has been reduced by 30% with the same surge voltage.

Reference: FUJI ELECTRIC REVIEW 2015, vol.61, no.4, p.237

Fig.7 7th-generation IGBT chip cross sectional structure

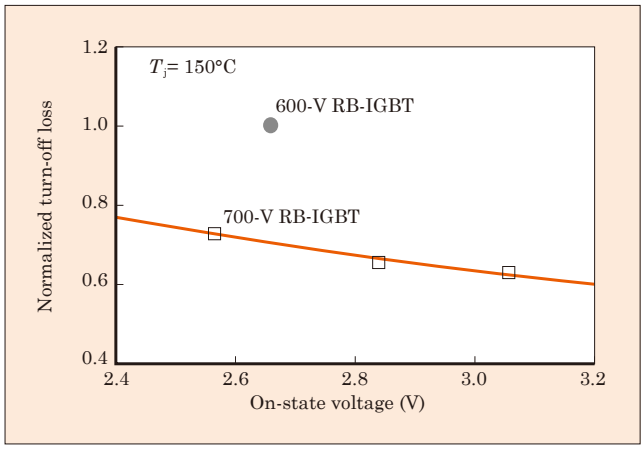


8 700-V RB-IGBT for Large Capacity Power Supply

To improve the efficiency of power converters, an advanced T-type neutral-point-clamped (AT-NPC) power conversion circuit that uses reverse-blocking insulated gate bipolar transistors (RB-IGBTs), which have both forward- and reverse-biased breakdown voltages, as the neutral point clamped switch is attracting attention. By using RB-IGBTs, conduction loss as well as the number of devices can be reduced.

For areas where the input voltage is high and equipment with a larger capacity, Fuji Electric has commercialized a 700-V RB-IGBT based on a 600-V RB-IGBT. Application of 700-V RB-IGBTs allows for high-speed switching to increase capacity and improves the efficiency of the equipment owing to the improvement of the trade-off relationships between the switching loss and on-state voltage of a device. The leakage current in the reverse direction is also reduced to approximately 1/10 that of a 600-V IGBT, which contributes to greater reliability and a higher degree of freedom in equipment design.

Fig.8 Trade-off relationships between turn-off loss and on-state voltage

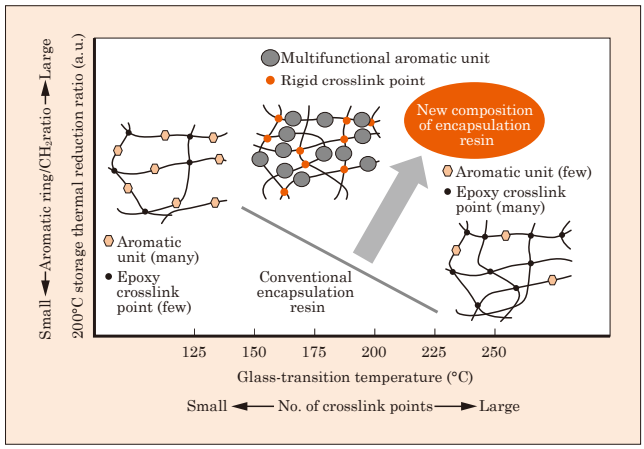


Power Semiconductors

9 High-Thermal-Resistance High-Adhesion Encapsulation Resin

Fuji Electric has been developing power devices that use silicon carbide (SiC), which allows operation at high temperatures of over 200°C, whereas the conventional Si devices has an operating temperature limitation of 175°C, and spreading their applications to the industrial and automotive fields. With the conventional encapsulation resin composition, increasing the glass-transition temperature T_g, which is an indicator of thermal resistance, causes pyrolysis to be accelerated and decrease of the strength, adhesion and insulation had to be dealt with. Accordingly, we have developed high-thermal-resistance high-adhesion encapsulation resin that satisfies the insulation requirements of power devices. We have employed a high-thermal-resistance high-adhesion resin structure that causes less decrease in physical properties due to pyrolysis while improving T_g. In a high-temperature storage test (equivalent to an acceleration test at 225°C for 6,663 h conforming to UL 1557) for guaranteeing high-temperature operation at 200°C, no peeling between the encapsulation resin and structural components such as the insulating substrate and devices or encapsulation resin cracking occur.

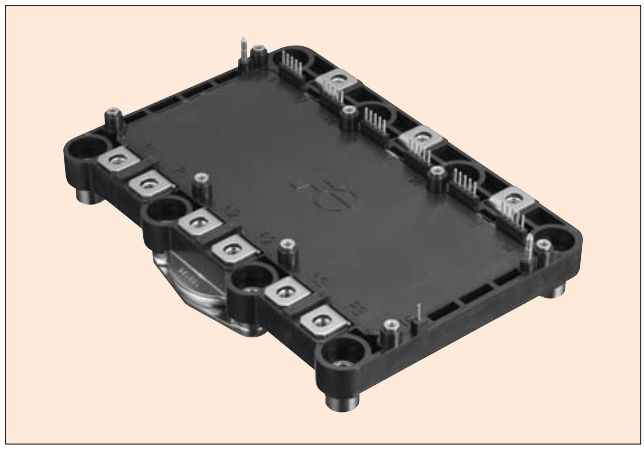
Fig.9 Conceptual diagram of high thermal resistance and high adhesion of encapsulation resin



10 High-Power Standard Module for Electric and Hybrid Electric Vehicles

Recently, inverters used for electric vehicles and hybrid electric vehicles have been required to offer high power and low loss. Power modules, which are the major parts of inverters, are required to be compact and have high power. Fuji Electric has developed a next generation high-power standard module for automotive application. This module has direct liquid cooling system with aluminium. This cooling system, which uses an optimized flow channel design, has improved the cooling performance by approximately 40% as compared with the conventional cooling system. A reverse-conducting insulated gate bipolar transistor (RC-IGBT), in which IGBT and freewheeling diode (FWD) are integrated on the same chip, is used as a power device in the module. In this way, it achieves the largest capacity of a general-purpose 6-in-1 module: 750-V/800-A rating for automotive application.

Fig.10 High-power in-vehicle standard module

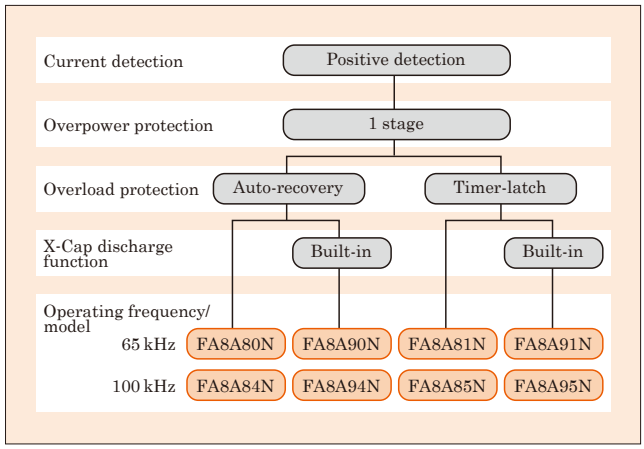


11 High-Voltage Input PWM Control IC "FA8A80 Series"

Recently, electronic devices such as home appliances and servers have been increasingly becoming always-on, and the demand for reducing the standby power is ever increasing. In addition, in developing countries, which are expected to grow in the future, power conditions are often unstable and instantaneous power failures occur frequently. For this reason, a high-reliability power supply is required that is resistant to any overvoltage generated when the power is restored after an instantaneous power failure and that withstands external surges.

Fuji Electric has used as the basis the "FA8A60 Series" 6th-generation PWM power control IC equipped with many state setting functions and various protective functions to develop high-reliability "FA8A80 Series," which has the high-voltage input terminal to be connected to AC featuring guaranteed ESD immunity of 2 kV and guaranteed withstand voltage of 650 V. It is compatible with the FA8A60 Series in terms of the terminals, functions and characteristics. This means the design assets of the conventional products can be used and the new power supply design elements can be simplified.

Fig.11 "FA8A80 Series" line-up



Power Semiconductors

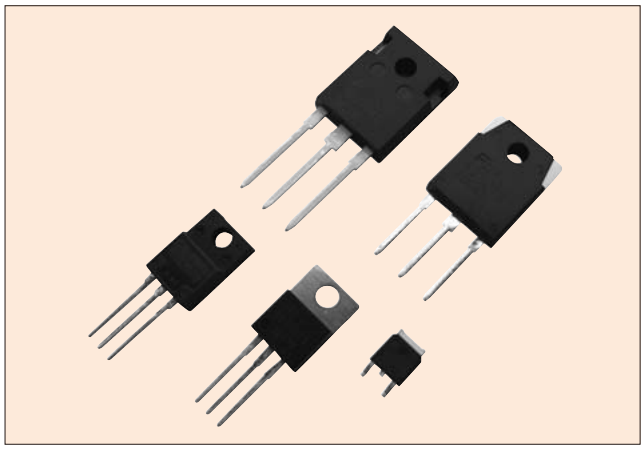
12 "Super J MOS S2 Series"

Fuji Electric has developed the "Super J MOS S2 Series" that applies the superjunction technology as a power device capable of contributing to improved efficiency and miniaturization of switching power supply. This product has achieved 25% lower on-state resistance per unit area and 30% lower charge and discharge energy of parasitic capacitance (output capacitance: C_{oss}) than conventional products. The surge voltage at turn-off is also lower than that of conventional products, and this series provides ease of use with a low power dissipation. The main specifications of the product are as follows:

(1) Withstand voltage: 600 V
(2) On-state resistance: 25 to 380 mΩ
(3) Package: TO-247, TO-3P, TO-220F, TO-220, TO-252

Reference: FUJI ELECTRIC REVIEW 2015, vol.61, no.4, p.276

Fig.12 "Super J MOS S2 Series"



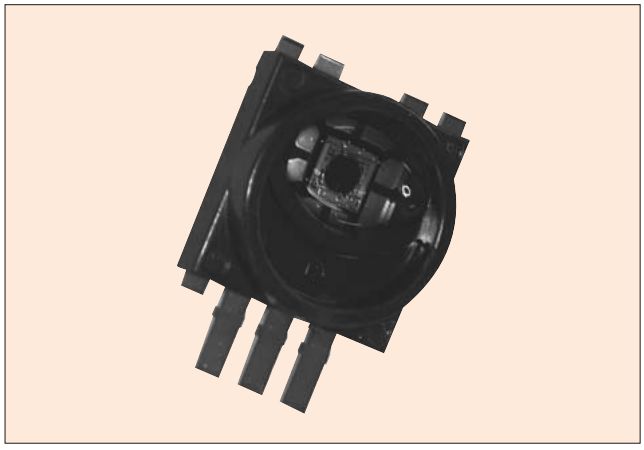
13 Relative Pressure Sensor for Automobile Fuel Tanks

Recently, automobiles have been required to reduce their environmental impact in addition to providing safety and comfort. The relative pressure sensor for automobile fuel tanks is intended for controlling emission control units for fuel evaporative gas, which is an environmentally hazardous substance, and achieves both ensured durability and high-precision detection by improving resistance to vaporized fuel, reinforcing electromagnetic compatibility (EMC) and enhancing the protective functions based on the 6th-generation compact pressure sensor technology. The main features are as follows:

(1) Pressure / Output voltage range: +5 to -80 kPa / 0.5 to 4.5 V
(2) Temperature range: -40 °C to +135 °C
(3) Pressure error: ±1.5% F.S. or less (25 °C)
(4) Temperature error: 2.0 times (max.)
(5) Applicable fuel: gasoline, diesel oil, E10, E25, E85, M15, M100, biodiesel

Reference: FUJI ELECTRIC REVIEW 2015, vol.61, no.4, p.267

Fig.13 Relative pressure sensor for automobile fuel tanks



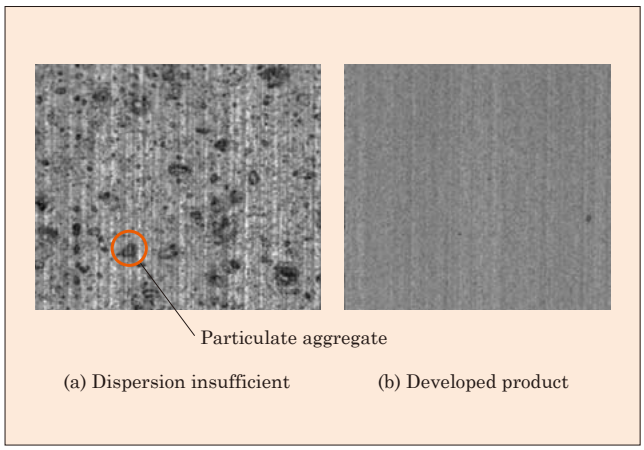
Photoconductors

1 High-Durability Organic Photoconductors

For printers and photocopiers, which are equipped with photoconductors, service life extension, speed-up, resource saving and compactness are required. Photoconductors may be worn by contact with cleaning mechanisms or peripheral materials such as toner, and improvement of durability by increasing the wear resistance of the surface is desired.

Fuji Electric is working to improve durability by developing functional materials of photoconductors. For improving durability of the surface layer of photoconductors, adding particulates to the surface layer is effective. By dispersing particulate in the surface layer, interaction between the particulate surface and photoconductor material improves the binding force of the photoconductor material, which improves durability of the surface layer. We are working on the development for realizing organic photoconductors with high durability by making use of the additive particulates and technology for dispersion in the surface layer.

Fig.14 Surface condition of particulate-dispersed photoconductor



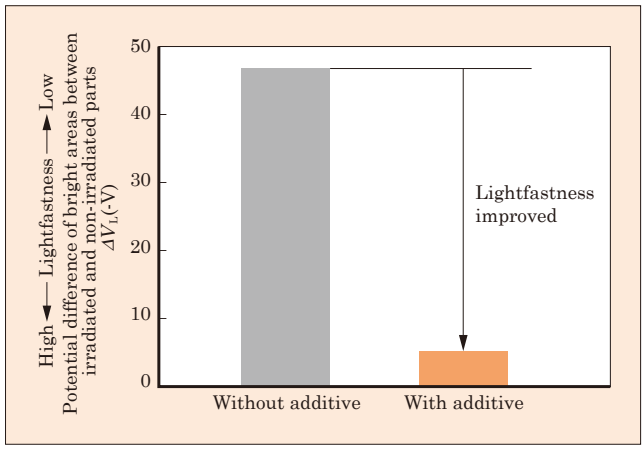
Photoconductors

2 High-Speed Negatively Charged Organic Photoconductor

With printers and photocopiers used in offices, high-speed printing and printing cost reduction are being promoted. Photoconductors mounted in them are required to offer high durability and high-speed response. In order to meet the high-speed response requirement, a high-mobility charge transport agent is used in the charge transport layer. The charge transport agent is, however, vulnerable to optical fatigue, and it needs to be imparted with lightfastness by some means.

Fuji Electric is working on developing additives that can effectively impart lightfastness to develop a high-speed negatively charged organic photoconductor capable of solving these problems. We have focused on the molecular structure and absorption spectrum of the electron transport agent. We have selected materials in view of the impact on the maximum light-absorbing wavelength and electrical characteristics and optimized the additive amount. In this way, we have successfully minimized the adverse effect on the electrical characteristics to develop an improved photoconductor with greater lightfastness than conventional products.

Fig.15 Improvement of lightfastness with additive



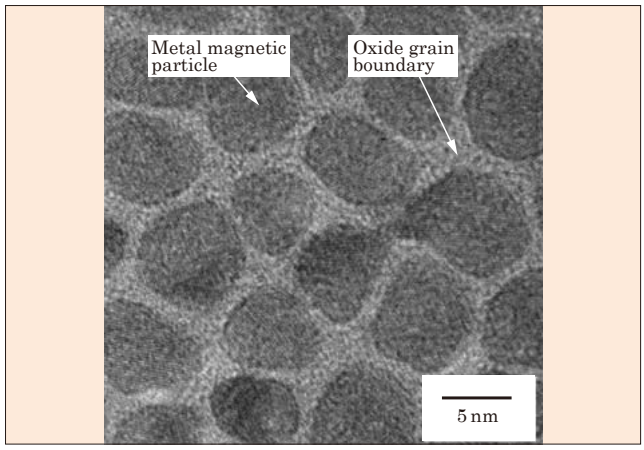
Disk Media

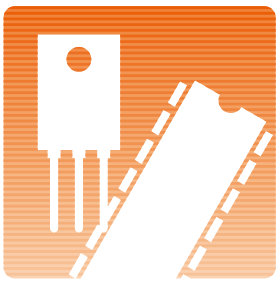
1 Recording Density Improvement of Shingled Magnetic Recording (SMR)-Based Magnetic Recording Medium

In the HDD market, the shifting of driver application from PC to data center had causes the increase of demand for high recording capacity. For that reason, HDDs that employ shingled magnetic recording (SMR), a new recording system, are being commercialized.

In Fuji Electric, a recording medium best suited for SMR is being developed by optimizing compositions and thin film fabrication process of the multi magnetic granular layer. This is to reduce the size and homogenize magnetic grains, as well as appropriately control the magnetic interaction between magnetic layers. As a result, we have achieved a high recording density of 1,235 Gbits/in^2 by realizing clear magnetization reversal while maintaining ease of recording. We have also minimized the erase band width at the same time. This technology is planned to be applied to the HDD recording medium for data centers scheduled for commercialization in FY2016.

Fig.16 Planar TEM image of magnetic recording medium





Food Distribution

Vending Machines
Stores
Distribution Systems

Outlook

At the International Media Center of the Ise-Shima Summit 2016, Fuji Electric exhibited a digital signage vending machin equipped with a large-screen and various type of sensors. The vending machine provided a complimentary bottle of mineral water to people who smiled in front of the vending machine. In addition to smiling, the machine also provided the mineral water to people who gave it a "thumbs up." Furthermore, the vending machine attempted to provide a stress-free experience for users via its multi-language functionality, which includes Japanese, German, Italian, English and French. We attempted to provide Journalists from around the world with a smile.

Vending Machines

Smart vending machines are gaining in popularity in China and Europe for their ability to provide product information and advertisements via image distribution although they have not expanded much in Japan yet. In addition, cloud-based settlement is quickly gaining popularity as a method of electronic payment, and a connection to a smartphone is becoming an essential.

Fuji Electric has developed large-sized displays, various sensing technologies, and touch panels resistant to sunlight, dust, snow and rain to propel the development of futuristic outdoor vending machines. As one type of modern vending machine, we have been pursuing the development of a next-generation vending machine that does not merely sell products like conventional machines, but comes equipped with interactive functions that promote participation in events and campaigns. As one of the examples of such vending machines, we started to deliver digital signage vending machines to AEON DELIGHT Co., Ltd., In FY2015. The vending machines are expected to be utilized as a tool for attracting customers to stores.

Stores

As settlement function is a important element in the food distribution sector, Fuji Electric has offered various types of products for settlement depending on the settlement conditions that are changing in Japan and abroad. Various types of electronic money are continuing to gain popularity in Japan, and one of the challenges that business operators face is how they should offer users a charging method before starting operation of prepaid electronic money. There are several methods available such as point-of-sale charging and online charging via mobile phones. For supermarkets, of which customer age and average customer spend is relatively high, easy-to-use cash chargers facilitate customers to use electronic money. Since the media for storing electronic money has been changing from cards to mobile phones, and now, usability of a card reading component needs to be improved.

Along with expanding the market of vending machines and automatic change dispensers to the worldwide, we have developed an increasing number of algorithms for identifying the paper currency of different countries. However, one technology that is desperately and immediately needed is an algorithm for discriminating between counterfeit bills. To meet this need, we have developed an automatic generation technique for a discrimination algorithm. We are able to provide customers with a higher quality service since our futuristic automatic change dispensers are capable of undergoing continuous algorithm updates via the Internet connection. At the same time, we are utilizing mechatronics technology to increase the money processing speed and overall reliability.

Distribution Systems

Production of frozen foods for home use has been increasing every year, and the production is higher than that 10 years ago by 10% or more. In addition to more convenience stores and supermarkets carrying frozen foods, the increase in delivery services is also expected to contribute to this trend in the future. Furthermore, as the demand for frozen foods has been increasing in Asia in recent years, there has been a growing need for constant temperature distribution of these foods. In order to meet these needs, we have offered the "WALKOOL" portable frozen storage container. This product makes it possible to seamlessly

transport low-temperature foods from food production sites to store sales floors.

Being relatively close to the consumers in the food distribution business, we needs to be more sensitivity to the changes in lifestyles of people. We are working actively to develop one-of-a-kind products that anticipate the needs of customers by imagining the types of products that correspond to changes in preferences and lifestyles.

Stores

1 Compact Edy Charger "RBCT16-E01" for Rakuten, Inc.

Fuji Electric has been deploying compact Edy chargers to the electronic money market since 2004. We developed the "RBCT16-E01" as a new type of compact Edy charger for Rakuten, Inc. The unit is not only compatible with conventional cards and mobile phones, but also modern larger-sized smartphones. The main features are as follows:

(1) A newly designed card settlement processing component has achieved advanced security and enhanced scalability for the unit.
(2) The unit comes equipped with a function for connecting to Fuji Electric's maintenance server, making it possible to perform remote maintenance.
(3) A newly designed shape for the card reading component makes the unit compatible with large-sized smartphones.

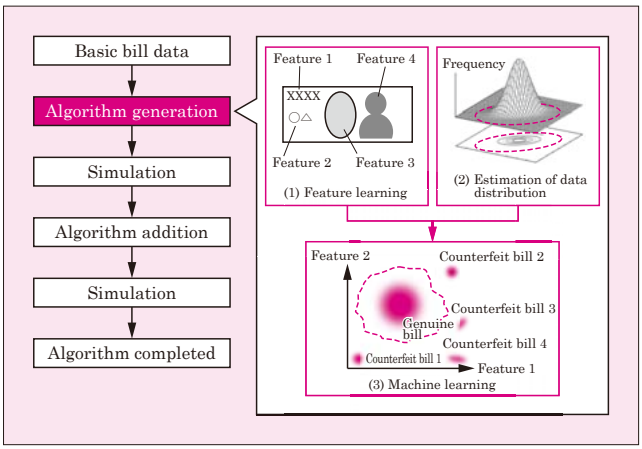
Fig.1 "RBCT16-E01"

2 Bill Validation Algorithm Generation Using Machine Learning Technique

Identification algorithms for bill validation have up until now required repeated upgrading every time applicable currency change. The reason is that algorithms for bill validation are constructed on the basis of size, pattern and security information peculiar to each applicable currency. However, we have recently developed a computer-based technique for automatically generating identification algorithms based on basic bill data. The main features are as follows:

(1) Automatic feature extraction of newly issued bills makes it possible to upgrade algorithms quickly.
(2) Distribution is statistically estimated, thus improving the acceptance rate of genuine bills.
(3) Identification algorithms using machine learning technique drastically improve the rejection rate of counterfeit bills.

Fig.2 Automatic generation flow of identification algorithm



Distribution Systems

1 Frozen Storage Container “WALKOOL”

We have utilized the heating and cooling technology that we cultivated in our vending machines to develop and produce the “WALKOOL” portable frozen storage container for use in the logistics and distribution industry. The main features are as follows:

(1) The unit utilizes cold storage materials and vacuum insulated panels (VIPs), making it possible to store goods at a temperature of –20°C or below for 8 hours without an electrical power source.
(2) The unit secures a volume of 400 L with dimensions that are compliant with the standard size of a cart used in the logistics industry.
(3) The unit has been made completely of stainless steel in consideration of the exterior design.

In the future, we intend to acquire international standard certification so that we can expand to the global market.

Fig.3 “WALKOOL”

Fundamental and Advanced Technologies

Fundamental Technology
Advanced Technology

Outlook

The year 2015 was filled with indications of volatility and change, including collapsing prices in crude oil, signs of structural change in the Chinese economy and increase in demand for energy in India.

Energy saving and natural resource saving technologies have been advancing in the United States, Japan and the European Union, and this has brought about reduction in energy consumption. On the other hand, it is mostly recognized that energy consumption is increasing in India, Southeast Asia and China. Against this backdrop, it is expected that there will be greater demand for electric power infrastructure, power electronics equipment and power semiconductors that can contribute to energy savings.

Extensive efforts are taking place with regard to the IoT and M2M technologies in various sectors such as the energy, health care, transportation and industrial sectors.

Fuji Electric has been working to meet the needs of the market and its customers by developing a diverse line-up of products in the fields of electric power generation systems, social infrastructure, industrial infrastructure, power electronics equipment, electronic devices and food distribution. Furthermore, we have been working to promote the development of fundamental and advanced technologies for supporting these fields so as to provide our customers with products that are higher quality, safer and more secure.

In particular, we have established a simulation technology based on the phase field model utilizing thermodynamics in order to develop a highly precise technology for predicting changes in the aged metal structures of power generation turbines. The use of this technology makes it possible to predict the long-term degradation of high-temperature materials. In addition, we have also developed a technology for improving wear resistance by means of ultra-deep laser hardening of turbine blades.

We have been able to reduce pressure loss by a new shape optimization technology based on the adjoint method for optimizing the shape of fluidic devices such as cooling water flow paths and steam turbine exhaust chambers.

In order to respond to electricity system reforms, we have developed automation technologies for power generation and interconnected line planning that has 3 features: minimizing power source procurement costs, meeting various power source restrictions such as successive starting/stopping restrictions, and meeting capacity restrictions on interconnected lines. We have also been working to develop a technology for supporting electricity market trading in order to improve operational efficiency and profitability for the electricity business. Furthermore, in order to facilitate the design of substation systems, we have developed a technology for analyzing the optimum capacity of a STATCOM and harmonics filter even when system impedance fluctuates irregularly.

In order to safely and efficiently operate factories and plants, we developed a system for detecting at early stages signs of abnormalities at plants based on a predictive model we constructed utilizing past data on plant operations. In addition, we also developed a technology applicable to batch processes (which account for approximately half of all production processes) for preventing the production of defective products via the use of early abnormality diagnosis.

In recent years, there has been much expectation regarding the IoT and M2M, and as such, we have developed a multi-OS applicable technology for operating different operating systems, including real-time OS and general-purpose OS such as Linux, in parallel with a single CPU, making it now possible to quickly and easily achieve multi-functionality in embedded devices. Moreover, in embedded devices where network connection has become commonplace, we have been developing an obfuscation technology to support long-term storage of encryption key, while also successfully reducing the amount of required ROM by more than 70% and hardening the system against conventional types of attacks. In the field of sensors, we have developed a multi-element gas detection technology utilizing ultra-low power MEMS gas sensors based on MEMS methane sensors, and we have confirmed that highly sensitive

and selective detection is possible for LP gas (mainly consisting of isobutane and propane) and hydrogen.

As a way of responding to the compactness and increased density of power electronics equipment, we have established a simulation technology capable of highly precise prediction of temperatures utilizing detailed modeling of heat transfer paths. Furthermore, by incorporating our uniquely developed high-precision device models and technologies for analyzing the parasitic inductance of wiring structures, we have developed a technology capable of implementing switching tests on circuit simulations, and this has made it possible to improve the design accuracy of circuits while also reducing the number of trial productions.

In the field of electronic devices, we have been participating in the Cross-ministerial Strategic Innovation Promotion Program (SIP) implemented by the National Institute of Advanced Industrial Science and Technology (AIST), and have developed a 20-kV class ultra-high withstand voltage SiC-PiN diode. In addition, we have been working on improving the orientation of a magnetic film of ordered FePt alloy as a means of facilitating the development of a heat-assisted magnetic recording method, which is considered to be a strong candidate as a next-generation recording method for hard disk media. The characteristics of these elements are influenced by minute defects in semiconductors and the atomic arrangement at device interfaces. For this reason, we have utilized various cutting-edge analysis technologies and the first-principles calculation in our analysis projects.

In the future, we will continue utilizing fundamental technologies in the pursuit of advanced technologies leading to innovation of electrical and thermal energy technologies and environmental technologies, as well as in the development of products that earn the trust of our customers through safety and security.

Fundamental Technology

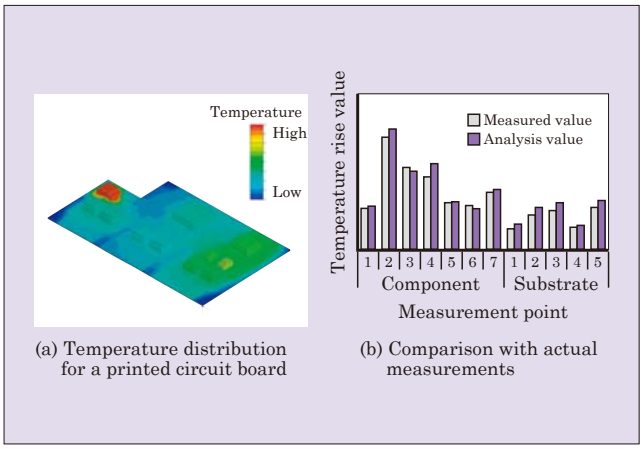
1 Cooling Design Technology for Power Electronics Equipment

In recent years, power electronics equipment has seen advances in miniaturization and density, and as a result, simulations have become increasingly important in the thermal design of equipment.

Fuji Electric has been working to develop a simulation technology that corresponds to the design stage. We have established a simulation technology capable of more accurate temperature prediction for detailed design than conventional one by precisely modeling the heat transfer path, such as wiring patterns on a printed circuit board, according to the heat transfer characteristics derived from the structure of mounted components.

As a result, it is now possible to analyze and determine the temperature distributions of printed circuit boards and parts mounted in equipment, thus improving the precision of designs. Utilizing this technology in equipment design will reduce the number of trial productions and shorten the development period.

Fig.1 Example of temperature simulation for a printed circuit board



(a) Temperature distribution for a printed circuit board

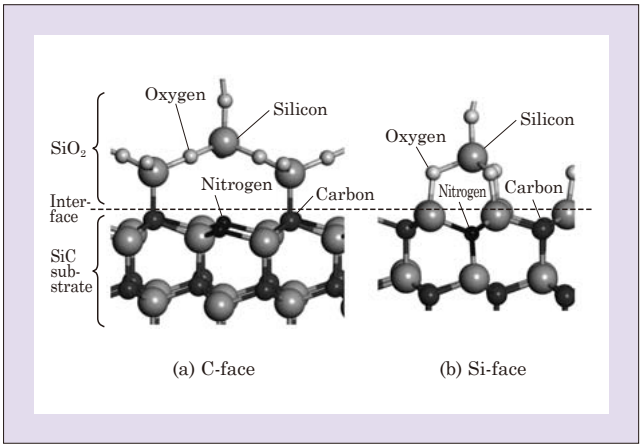
(b) Comparison with actual measurements

Fundamental Technology

2 Analysis Technology Supporting Development of Next-Generation Power Devices

Fuji Electric has been carrying out research and development of next-generation power devices such as SiC metal-oxide-semiconductor field-effect transistors (SiC-MOSFETs) utilizing the silicon carbide (SiC), a wide band-gap semiconductors, in order to meet the increasing need for low loss power electronics equipment. The electrical characteristics of SiC-MOSFETs are influenced by the atomic arrangement at the interface between SiC and gate oxide (SiC/SiO_2 interface). We are currently making efforts to analyze this atomic arrangement by utilizing various analysis techniques including X-ray photoelectron spectroscopy as well as simulation techniques that adopt first-principles calculations. By utilizing these techniques, we can now estimate differences in terminated structures, due to the varieties of SiC substrates (surface orientation), that occur based on the presence of nitrogen introduced to the SiC/SiO_2 interface (see Figure). In the future, we plan to analyze the mechanisms for introducing nitrogen atoms, thereby contributing to process development.

Fig.2 SiC/SiO_2 interface structure derived by analysis

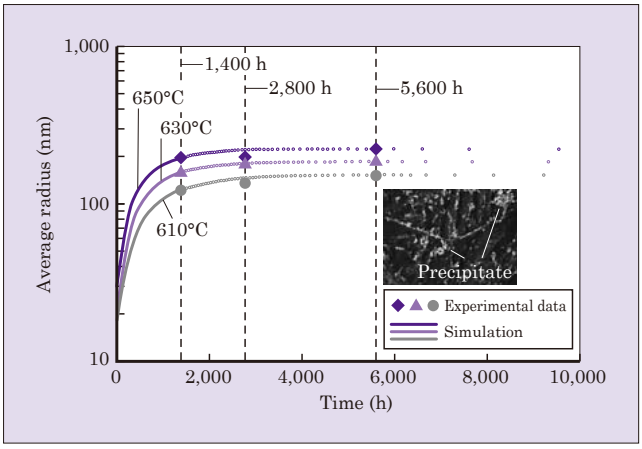


3 Simulation Technology of Metal Composition for Degradation Assessment Technologies

Much of the metal used in turbines suffers from deformity in metal structure due to various types of damage such as creep, fatigue or embrittlement resulting from long-term use at high temperatures. In order to ensure the safe and stable long-term use of products, a technology capable of accurately predicting deformity in aged structure is highly needed.

Fuji Electric has established a simulation technology in consideration of the passage of time by utilizing the phase field model that applies thermodynamics. The figure shows a simulation of the change in particle size of precipitates in steel resulting from heat aging after the passage of 10,000 hours. The simulation results matched up very well with the actual results. The use of this technology has made it possible to predict long-term degradation of high-temperature materials. In the future, we plan to make use of this simulation technology as our product degradation assessment technology while developing simulation technologies for other types of degradation such as corrosion.

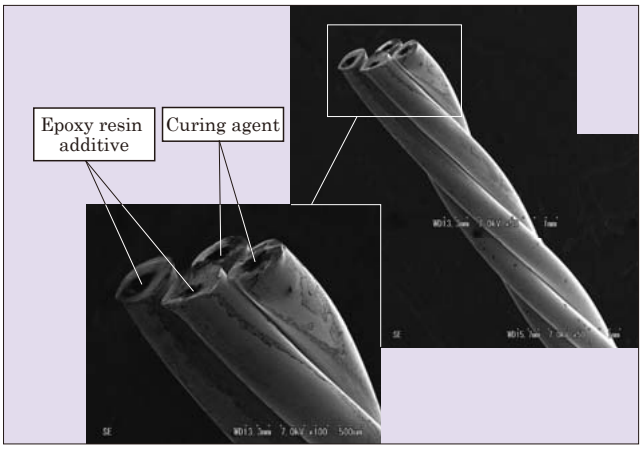
Fig.3 Evolution of precipitates in steels during thermal aging



4 Wire Solder Containing Epoxy Flux

Fuji Electric has developed cream solder containing epoxy flux capable of being used in the soldering of small chip components utilized in high-density mounting. The cream solder is characterized by its ability to reinforce minute solder bonds with a thermosetting epoxy flux. When defects occur in soldering, repair work using wire solder is essential, and it is also necessary to carry out the repair utilizing epoxy flux. However, since heat is applied in the production process of wire solder, the epoxy flux ends up being thermally cured. As a result, wire solder is separately classified according to epoxy resin and curing agents. We have, therefore, developed wire solder containing epoxy flux capable of being used in soldering by bundling and twisting a wire solder containing epoxy resin and one containing curing agent. By adding an appropriate activator, the solder exhibits the performance equivalent to conventional products. In the future, we plan to use these types of wire solder in products.

Fig.4 Composition of wire solder containing epoxy flux



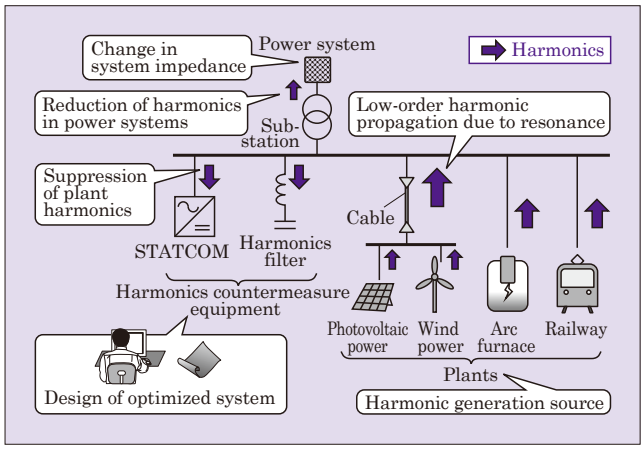
Fundamental Technology

5 Automated Harmonic Analysis for Substation Facility Design

When plants that generate harmonics (photovoltaic, wind power, arc furnaces, railways, etc.) are connected to relatively weak power systems, the phenomenon of resonance amplifies low-order harmonics, and this sometimes makes it difficult to mitigate harmonics within a specified range. Furthermore, since the system impedance of power systems varies depending on operating conditions, it became necessary to construct an optimized substation system capable of mitigating harmonics under varying states of impedance.

Fuji Electric has developed a technology for analyzing optimum capacity for STATCOM, as well as a harmonics filter effective even when there is complex variation in system impedance. The system implements automation of repetitive work by utilizing a general purpose analysis software in conjunction with a search method for solutions to reduce the number of extensive parameter combinations. We plan to continue working to improve the quality of substation systems while reducing the time required to design them.

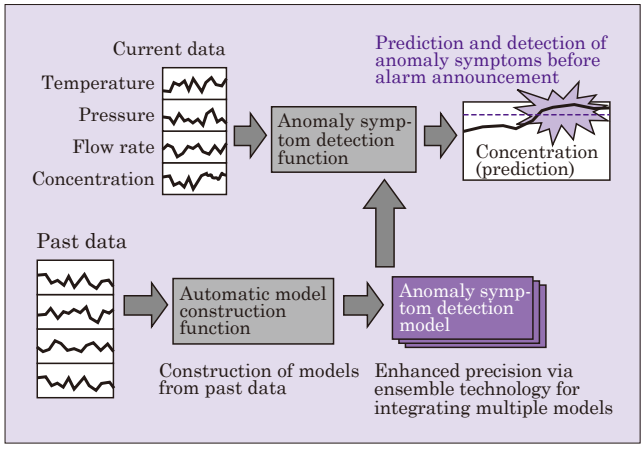
Fig.5 Substation system for mitigating harmonics



6 System for Detecting Symptoms of Anomalies Utilizing Automatic Model Generation Technology

In recent years, there has been growing need for operational support to ensure the safe and efficient operation of factories and plants. To meet this need, we have developed a system for detecting at early stages symptoms of anomalies at plants. We have constructed a predictive model that utilizes accumulated past data on plant operations. The predictive model enables us to predict plant conditions and detect anomalies at early stages. The system is capable of both predicting the occurrence of anomalies and automatically constructing predictive models. The predictions are highly precise since they are based on an ensemble technology that comprehensively evaluates the prediction results of multiple models. The results of the developed system have been verified by referencing actual plant data. Based on an experiment that used one year data, the system was able to predict beforehand approximately 90% of certain types of actual alarm occurrences.

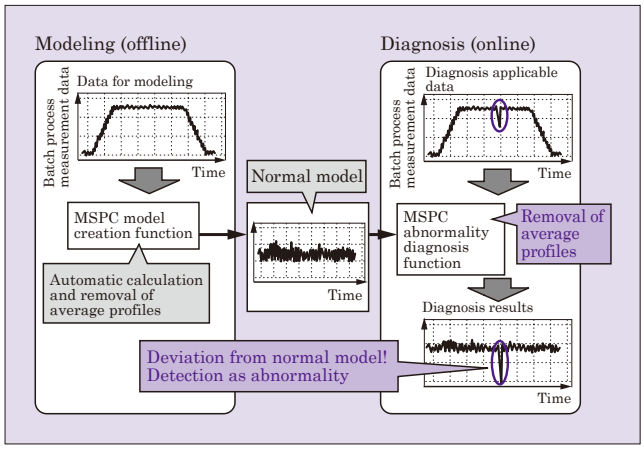
Fig.6 Overview of automatic model generation technology



7 MSPC Technology for Batch Processes

Fuji Electric has developed a technology applicable to batch processes, which account for approximately half of all production processes, for preventing the production of defective products by early abnormality diagnosis. Conventional technologies are unable to prevent the production of defective products since they only support abnormality diagnosis after the completion of batch processing. In contrast to this, the newly developed multivariate statistical process control (MSPC) technology for batch processes is capable of implementing abnormality diagnosis during batch processing. This is a uniquely developed technology that does not simply handle measured data from batch processes, but rather detects deviation from normal models after removing average profiles automatically calculated from the data. We have confirmed that the technology is capable of detecting symptoms that lead to abnormalities (failure) based on deviations from normal models by applying it to actual measured data of refrigerated open showcases, of which the data behaves similarly to that of batch processes.

Fig.7 Concept of MSPC technology for batch processes

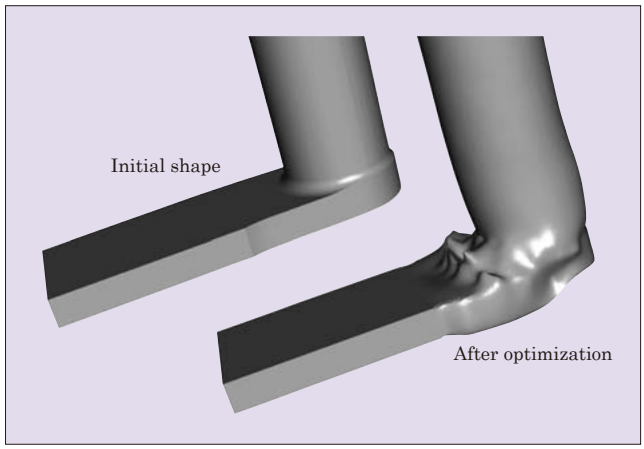


Fundamental Technology

8 Technology for Optimizing Flow Paths via Adjoint Method

Fuji Electric has constructed a shape optimization technology based on the adjoint method as a new method for optimizing the shape of fluidic devices. An adjoint solution (sensitivity distribution) shows the orientation of shape correction for improving objective functions. An optimized shape is obtained by repeatedly changing the shape based on the adjoint solution. This method derives complex shapes that are unimagined by designers, bringing significant improvement. Compared to conventional parameter optimization techniques, this method exhibited superior results such as a pressure loss reduction rate of 1.5 times and a calculation time of 1/10 in validation models for simple wind tunnels. It can also be applied on a trial basis to the cooling water flow paths of motors and the exhaust chambers of steam turbines. It achieved lower pressure loss by 33% in cooling water flow paths of motors via experimentation and by 30% in the exhaust chambers of steam turbines via analysis than conventional methods.

Fig.8 Change in cooling water flow path via optimization

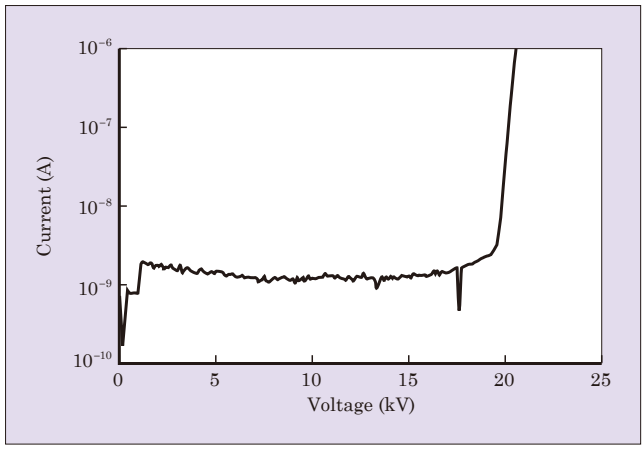


Advanced Technology

1 20-kV Class Ultra-High Breakdown Voltage SiC-PiN Diode

We have been participating in the Cross-ministerial Strategic Innovation Promotion Program (SIP) implemented by the National Institute of Advanced Industrial Science and Technology (AIST), and have developed a 20-kV class ultra-high breakdown voltage SiC-PiN diode. This diode can be used in combination with an SiC-IGBT in the field of ultra-high voltage applications including power transmission and distribution equipment. It has a higher breakdown voltage and lower dissipation loss than conventional silicon diodes, and it is expected to contribute to energy savings, miniaturization and weight reduction in equipment. We optimally designed the multi-step junction termination extension (JTE) structure to achieve a high breakdown voltage. In addition, by employing a high-quality epitaxial film with a thickness of at least 200 µm, and by suppressing the doping concentration inside the epitaxial film to an extremely low value of 3×10^{14} cm^{-3}, the diode is able to achieve the world's highest class breakdown voltage characteristic of 20 kV or higher.

Fig.9 Reverse voltage characteristics of 20-kV class SiC-PiN diode

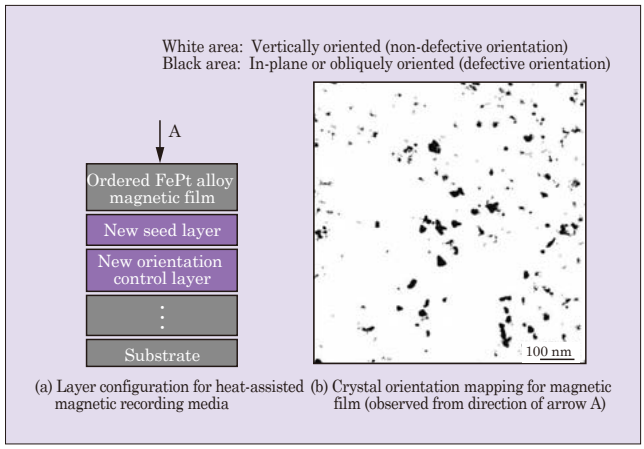


2 Orientation Control Technology for Heat-Assisted Magnetic Recording Media

Hard disk drives are requiring even larger storage capacity for data centers and personal use. The heat-assisted magnetic recording method is considered to be a strong candidate as a next-generation recording method supporting increases in capacity. Magnetic recording media that meet this need make use of an ordered FePt alloy magnetic film that has a high coercive force. Compared to conventional CoPt magnetic film, ordered FePt alloy magnetic film has a greater tendency to produce orientation defects, and noise during recording and reproduction is a problem.

Fuji Electric has newly developed an orientation control layer for promoting a vertical orientation for the seed layer. By introducing this control layer beneath the seed layer, we have confirmed that the orientation defects produced by the ordered FePt alloy magnetic film have been suppressed from a previous level of 30% to a level of 2.4%. In the future, we plan to continue using this technology as we study the practical application of magnetic recording media.

Fig.10 Crystal orientation mapping for magnetic film



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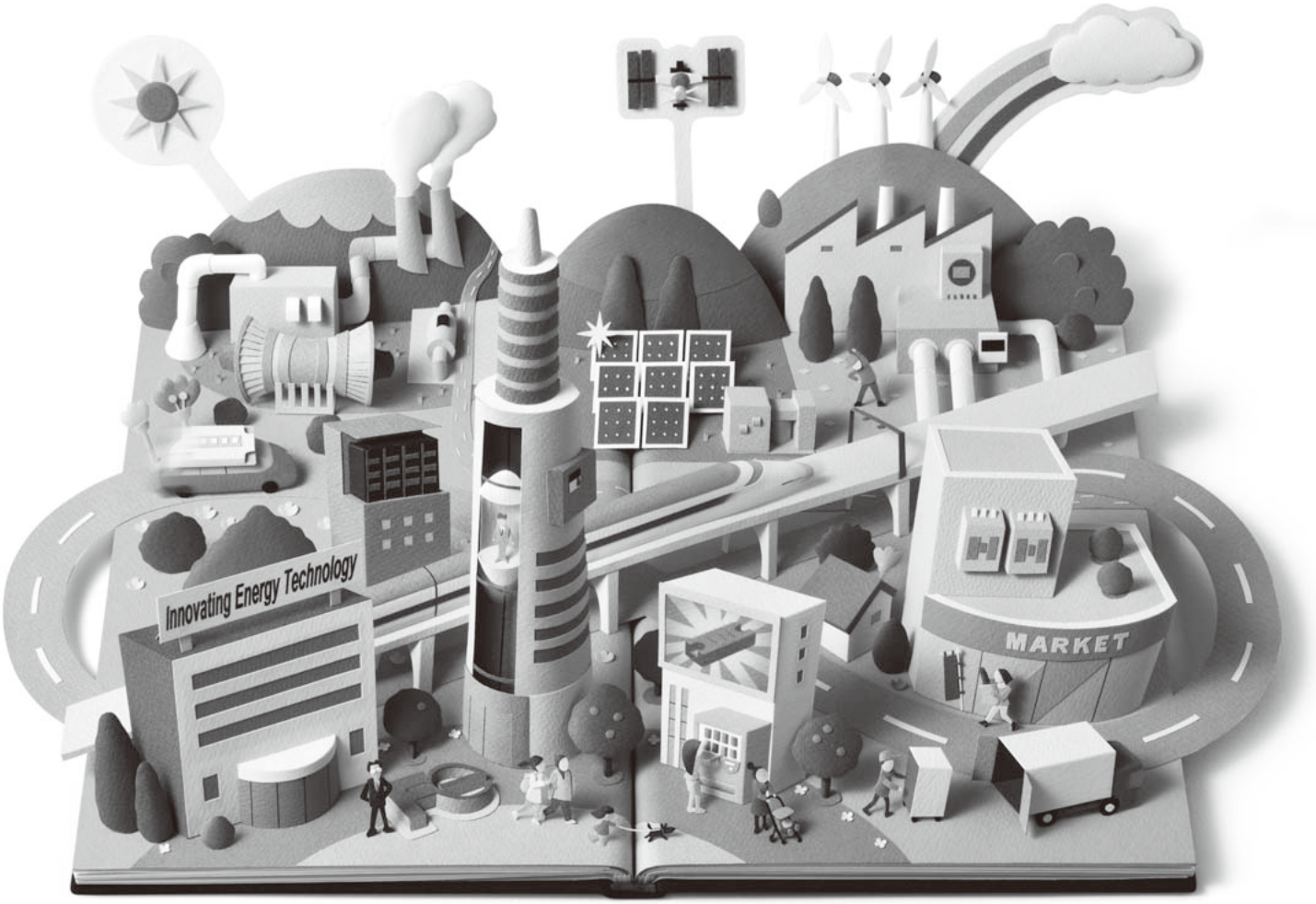
Innovating Energy Technology



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Tel +1-732-560-9410
URL http://www.americas.fujielectric.com/

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Tel +55-11-2283-5991
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Fuji Electric Philippines, Inc.
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Tel +60-3-4297-5322

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Tel +886-2-2511-1820

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Representative office of Fujielectric Co., Ltd. (Cambodia)
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Tel +855-(0)23-964-070

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Fuji Electric Europe GmbH
Sales of electrical/electronic machinery and components
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Fuji Electric FA (Asia) Co., Ltd.
Sales of electrical distribution and control equipments
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URL http://www.fea.hk/

Fuji Electric Hong Kong Co., Ltd.
Sales of semiconductor devices and photoconductors
Tel +852-2664-8699

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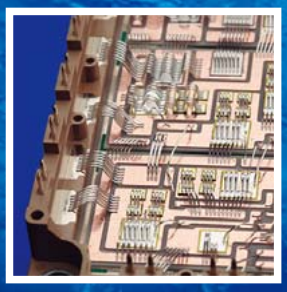

Device Technology

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

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