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# FUJI ELECTRIC REVIEW

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## Technical Achievement and Outlook in FY2014

Fuji Electric

*Innovating Energy Technology*

FUJI ELECTRIC
REVIEW

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## Technical Achievement and Outlook in FY2014

Extreme weather events thought to be caused by global warming are occurring frequently all over the world and resulting in significant damage. Under these circumstances, to prevent global warming, renewable energy is increasingly being utilized and global energy technology is changing significantly. Through the pursuit of innovation in electric and thermal energy technology, Fuji Electric develops products that maximize energy efficiency and lead to a responsible and sustainable society. This special issue on "Technical Achievement and Outlook in FY2014" is a compilation of the technical achievements of FY2014 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):**
Exhaust Gas Cleaning System for Ships, Fuji Electric's Top Runner Motor "Premium Efficiency Motor," 2nd Generation IPM for Hybrid Vehicles, Inverter for elevators in European market "FRENIC-Lift LM2A," All-SiC Module for Chopper Circuit, Mega solar PCS "PVI1000AJ-3/1000"

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## Technical Achievement and Outlook in FY2014

Preface

# Fuji Electric's Contribution to the Creation of a Responsible and Sustainable Society Through Innovation in Electric and Thermal Energy Technology

Adopting a management strategy for "Expand energy-related businesses," "Globalize" and "Realize concerted strength as a team," as well as a brand statement of "Innovating Energy Technology" that represents our pursuit of innovation in electric and thermal energy technology, Fuji Electric develops products that maximize energy efficiency and lead to a responsible and sustainable society.

As an intermediate year of our "FY2015 Medium-Term Management Plan," FY2014 was positioned as a year for "Expanding Our Focus on Aggressive Management" as a next step after a "First Year for Aggressive Management" in FY2013, and focused on "bolster profitability" and "establish a growth foundation." Especially for a manufacturer such as Fuji Electric, enhancing our "manufacturing capabilities" and our "R&D capabilities" are vital for future growth. Our manufacturing-related efforts involved strengthening domestic mother factories, training production technology engineers, succeeding skills and accelerating local production and local consumption. Our R&D-related activities were centered on a core of power semiconductor and power electronics technology, including instrumentation and thermal technology, and we developed thoroughly distinctive components, and then based on those components, also developed control technology platforms and packages, and endeavored to develop products that would provide a variety of solutions to our customers. Our R&D initiatives for FY2014 also focused precisely on these areas and we achieved significant results. We also moved forward with the construction of research and development buildings at sites in Tokyo, Matsumoto and Fukiage in order to strengthen our company-wide R&D capabilities and to improve our ability to develop power semiconductors, components for power receiving and distribution, switches and control devices.

Below, I will describe the major achievements of our FY2014 R&D initiatives.

Aiming to realize technical innovation in the fields of electrical and thermal energy, we focused developing power devices that utilize silicon carbide (SiC), a promising material expected to revolutionize power devices, and developing power electronics products that incorporate those devices. We launched a 690-V line of our "FRENIC-VG Stack Series" of inverters that employ a hybrid module containing a SiC Schottky barrier diode (SiC-SBD). We also developed an All-SiC module that employs a SiC-SBD and SiC metal-oxide-semiconductor field-effect transistor (SiC-MOSFET), incorporated this module into a power conditioning sub-system (PCS) and marketed it for use in mega solar applications. This product was awarded First Prize in the FY2015 Japan Electrical Manufacturers' Association Technical Achievement Award. In addition, we also advanced development in the electrical power, industrial and transportation fields.

In the field of power electronics components, we developed distinguished products such as our "Premium Efficiency Motor" which conforms to the Top Runner Program that began in April 2015, motors with integrated invertors that realize dramatic energy savings in applications for driving air conditioning fans, and the "FRENIC-VP Series" for

the Chinese fan and pump market.

As a distinctive thermal component, we developed the "F-COOL NEO" hybrid air conditioner that aims to reduce the consumption of energy for air conditioning at data centers. This product uses approximately a third of the annual amount of electric power consumed by a typical air conditioner, and can realize significant energy savings. In FY2014, this product won the Japan Machinery Federation's President Award.

Recently, the concept of an Internet of things (IoT), in which all objects are connected to the Internet, has been attracting attention. Fuji Electric has developed "Integrated Cloud Service" that provides various services and solutions through analyzing and optimizing local data that has been uploaded to the cloud.

We are also actively developing fundamental technology that commonly supports the various technologies described above, and are carrying out leading-edge research and development with an eye toward the future.

As a tool for designing optimal structures accurately and efficiently, in FY2014, we also focused on the development of simulation technology. We designed various simulation technologies, such as for thermal fluids, structures, electromagnetism, and electromagnetic compatibility (EMC). Moreover, for materials-related simulations, we developed simulation technology for metal materials, magnetic materials, resin materials, and so on, and have also developed advanced simulation technology such as for corrosion prediction, and have applied these various technologies to materials development. In order to differentiate our IoT-based services and solutions, it is important that we differentiate the technology for analyzing collected data, and for this purpose we are also advancing high-level research.

So that products can be deployed globally, compliance with international standards is becoming increasingly important and Fuji Electric continues to strengthen its efforts in complying with international standards. In particular, for power electronics and smart communities, we are strengthening our compliance through actively participating in international committee activities, and are contributing to the enactment of standards for the EMC of PCSs and for the measurement of inverter efficiency.

Aiming to realize more efficient research and development, Fuji Electric utilizes open innovation. In China, in order to promote R&D and to create new business opportunities, we are further expanding the Zhejian University – Fuji Electric Innovation Center, and have strengthened our collaborative activities with the establishment of the Zhejiang University – Fuji Electric Cooperation Center.

By accurately assessing the needs of society and via our energy-related businesses that leverage the electric and thermal energy technology we have refined since our founding, Fuji Electric intends to contribute to the creation of a responsible and sustainable society. We sincerely request guidance and support from all concerned parties.

KITAZAWA, Michihiro
President and Representative Director

# How We Should Take Advantage of Our Power Semiconductors and Power Electronics to Proceed in Era of Networking and Standardization

## —IoT and M2M initiate titanic revolution in manufacturing—

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Today, the Internet of Things (IoT), Machine to Machine (M2M) and Industrie 4.0 are hot topics around the world. In Japan, the Electricity System Reform is also moving forward in full swing. As energy, information, and things are connected in the wake of major transitions in terms of social systems and manufacturing, it's necessary for Fuji Electric, with its core technologies of power semiconductors and power electronics, to shed light on the path ahead. Professor Dr. Shin, a pioneer in control engineering at the University of Electro-Communications, and Dr. Eguchi, Corporate General Manager of Fuji Electric at their Corporate R&D Headquarters, discussed corporate identity and the power of change.

## Power semiconductors as a competitive edge in the world

Eguchi: As a pioneer in the field of instrumentation and control technology, Professor Shin has advised Fuji Electric through various opportunities such as the Technology Research Council. We are grateful for your invaluable insights.

Fuji Electric has been active in the area of energy through technological innovations in electric and thermal energy, playing a part in creating a sustainable society. With this in mind, we have focused our development on devices that enhance energy use, such as power semiconductors and power electronics devices.

Focusing solely on components, however, will not lead us to being a big business in the future, and we may also lose our competitive edge. Our current vision is to expand our business field and to offer systematic solutions combining our components.

Today, concepts such as the Internet of Things (IoT) and Machine to Machine (M2M) are being discussed everywhere, and Industrie 4.0 is a hot topic in Europe. Meanwhile in Japan, the Electricity System Reform is moving forward. With the integration of energy, information, and things, we are facing an imminent major change in social systems and manufacturing. How should we proceed with our R&D through this tidal wave of change? We would like your opinions on the progress of instrumentation and control engineering and Fuji Electric.

Shin: I guess you and I have lived through roughly the same industrial periods as engineers. As Intel 4004 was launched in 1971, stirring a major revolution in instrumentation and control engineering, it was an interesting era for engineers.

You mentioned power semiconductors earlier, and Japan has a tremendous competitive power in that regard. Very skillful technology is necessary to ensure a robust structure that can withstand high voltage and large currents, and to manufacture it with stable quality. In my opinion, Japan has the best technology in the world. Fuji Electric has commercialized SiC semiconductors, which is also an achievement.

The mass media says that Japanese semiconductors are inferior, and so many people believe it, but in fact, that is about dynamic random access memories

(DRAM) or processors.

Technology today is moving from small to large powered systems, and Japan is also shifting its balance gradually in this direction. It's a regret that the media does not give comprehensive coverage.

My students are also losing hope for Japanese semiconductors. In fact, power semiconductor manufacturers are in need of human resources, and so a mismatch is occurring.

Eguchi: There was once an era where Japan could sell semiconductor chips well as long as we produced quality products with micro processing. It was shocking to see the end of that era. Meanwhile, power semiconductors have certain analog properties, which need some margin for adjustment. You cannot simply combine the two.

Shin: It certainly requires knowledge of physics and chemistry.

Eguchi: That's true. Semiconductor chips are products of the equipment industry that is driven by micro processing. Therefore, it may be just a matter of time before manufacturers overseas catch up with our SiC chips. As for semiconductor modules, the know-how lies in the composition of packaged components, including cooling systems, wiring, and noise reduction.

Shin: It's not only about the device technology, but also a highly sophisticated combination of technologies for operations, such as inverter circuits and algorithms, as well as the network that connects them.

You mentioned that Fuji Electric focuses on energy, and recently, the company is also working on the coffee makers and donut cases we find in convenience stores. Your enduring vending machine business is also growing into a major success. Fuji Electric is a renowned company with a long history extending its business scope to consumer products, which I think is a significant milestone in the 21st century.

Eguchi: At Fuji Electric, we have five business groups: Power and Social Infrastructure, Industrial Infrastructure, Power Electronics, Electronic Devices, and Food and Beverage Distribution. Our vending machines and coffee makers come under the Food and Beverage Distribution Business Group.

We're also expanding our business in this field to cover from upstream to downstream, namely, from plant factories to food processing, storage and logistics, and shop floors. In a way, it's the sextiary industry. However, we're fundamentally aligned for safe, secure, and efficient energy usage.

## IPv6 accelerating IoT and M2M

Shin: With hydraulic power, coal, and oil, energy sources have changed since the 18th-century industrial revolution, but electricity as an energy form has remained the same. Fuji Electric has been operating in the field of energy all along.

In the 20th century, the concept of information came into play. We understand the 20th-century world model in terms of a three-tiered structure of information, energy, and materials.

The 21st century is an era of restructuring. This is where we come to the topics mentioned earlier: IoT, M2M, and Industrie 4.0.

Eguchi: You mentioned the integration of information, energy and material—I think this is what holds the key to the future of Fuji Electric business.

Shin: Globally, Japanese manufacturers are very technologically advanced. For decades, there have been projects similar to the IoT, such as the building energy management system (BEMS) and the home energy management system (HEMS). To someone with years of experience, like yourself, it must look like a reorganization of what has been around for ages.

There is, however, one crucial difference, and that is the transition of the Internet protocol from version 4 (IPv4) to version 6 (IPv6). With IPv4, there are only 4 billion addresses available. This umber is lower than the global population, so if every person in the world had a smartphone, it wouldn't be able to allocate addresses to all one of them.

IPv6 uses a 128-bit address, which has the capacity to allocate about 10 to the power of 38 addresses. This is more than enough to allocate IP addresses wherever they are required. It would be able to handle the demand for addresses even if everyone had 100 smartphones each.

Although not yet widely known, this is the very reason why the world is getting excited about the IoT and M2M.

Eguchi: I see, that's the fundamental reason.

Previously, it was necessary to wire computers to form an individual network for remote monitoring, maintenance, and other controlling tasks and to extract necessary data at given points, in order to give feedback to work sites.

Today, data is uploaded to the network as much as possible, regardless of its relevance. This process mixes in a variety of data that is irrelevant to the on-site work, like financial data. Data used to be point-based information, but today, it is a matrix, which is completely different.

Shin: "Diversity" is an important keyword. In the 20th century, Fuji Electric, for example, was able to have an encompassing view within the networks it had developed. It was a homogenous environment, so it could pursue design and operation smoothly according to plan. Now, we are handling a variety of elements, some of which are difficult to predict. It's no longer a prescribed harmony. Designing has suddenly become very difficult.

Eguchi: It may become necessary to incorporate data

not only on things, but also on managerial index.

Shin: Factories based on the IoT would be open facilities, so it would be impossible to prepare a production plan independently. In some cases, it may be necessary to take into account what items are selling well in convenience stores, and adjust the production lines accordingly. Weather also has an impact on the sales of certain items.

Eguchi: Your research areas such as autonomous distributed systems for information appliances and wavelet diagnostics are very close to the objectives of the IoT and M2M.

Shin: We have been pursuing these for decades. But 20 years ago, telecommunication capacities were very low. Early digital cellular phones had only 9.6 kbps, so they couldn't send photographic images. In those days, there was a tremendous gap between our ideal system and the reality. Now, even smartphones are capable of communication at several hundred Mbps. This is amazing progress. You can send photos and everything.

Eguchi: Can you tell us about the possible applications of wavelet analysis?

Shin: Many parties today are interested in biosignal analyses. In this case, it goes beyond IoT into the realm of IoE (Internet of Everything). There's particularly great demand for data on body temperature, pulse, sleep, exercise, and other indicators of human health and emotional state. These things can be leveraged to ensure the safety of factory workers.

We have long contemplated ways to integrate humans into the network, but this used to be difficult to realize. In this modern age, where most people have smartphones, individuals are tagged into the network through high-speed connections.

## Will humans be consumed by machines?

Shin: I'm so fortunate to have lived in this exciting era of human-machine coexistence. But there are two regrets.

One is to do with security issues. Another is the fact that people don't have a sufficient understanding of the mechanisms.

The latest smartphones operate on 64-bit octa-core processors, which are as good as personal computers. With gigabyte memories installed, they can now communicate on the level of gigabyte per second. Now, it's possible that this is already beyond human intelligence. My students know how to use their smartphones, but they have no idea about their internal mechanism.

Eguchi: Perhaps no one understands it perfectly.

Shin: Smartphone software has over 40 million lines of code, which is almost equal to Windows XP. I'm teaching the embedded system of smartphones to students who have just finished high school.

So, this is what I always tell them; engineers who develop a product do not understand the whole mechanism because they work in specialized areas of expertise.

Eguchi: Troubleshooting methods are also different from old days.

Shin: In our day, we relied on our senses of hearing and smell. Today's engineers need computers instead. Observation doesn't work for them, so they plug their computers into a system and follow the instructions on their displays.

Eguchi: Therefore, the IoT and M2M technologies must establish methods of absorbing data on sound and smell through sensing technology, uploading them onto the Cloud, and leveraging this data for specific diagnostics or preventive measures.

Shin: That's certainly an important point. However, I want young engineers to know what it's like to work without these appliances before they become familiarized with them. If they knew how difficult it was, they would inevitably consider the benefits of information technology. Let me give you an example. Imagine a person who has never used a ruler to draw a line. He might be able to do some design using a CAD system. To my mind, however, he's missing a fundamentally important experience as a human being.

In the grand scheme of IoT and M2M, humans will be totally overwhelmed by machines without appropriate understanding of the mechanisms. As you know, Doraemon is a main character of a popular cartoon. It is a cat robot but also a friend of a boy called Nobita. This robot has many magical gadgets to get rid of troubles on Nobita. In a Doraemon analogy, the technology is Doraemon, who solves all of poor little Nobita's problems. But I believe there are some things humans have to be responsible for.

## Role to play in the Electricity System Reform

Eguchi: The Electricity System Reform is moving forward in Japan. The full retail competition will be introduced in April 2016, and in 2020, the trans-

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1980: Research Associate, Faculty of Engineering, The University of Tokyo
1988: Associate Professor, Institute of Information Sciences and Electronics, The University of Tsukuba
1992: Associate Professor, Faculty of Engineering, The University of Tokyo
2006: Professor, Faculty of Electro-Communications, The University of Electro-Communications
Fellow and 2013 President, The Society of Instrument and Control Engineers;
President, the Control System Security Center;
Paper Award and Takeda Prize and Technical Award from the Society of Instrument and Control Engineers; the Outstanding Technical Report Award from the Institute of Electrical Engineers of Japan; and the Information Security Culture Award from the Institute of Information Security

mission and distribution sector will be unbundled. Could you tell us your opinion on the future direction for Fuji Electric, from the points of view of the IoT, M2M, and information control technology?

Shin: As we've mentioned, I think the keyword is "diversity."

While an energy company regulates the entire process, it doesn't need to fully automate the power grid switching. In order to bring in natural sources of energy, such as wind power and photovoltaic generation, it's necessary to automate supply systems to monitor and command route changes and so on. This connection with natural energy is where diversity comes in, and this requires major investment.

When the sectors are divided between supply, transmission, and distribution, then different players may have different agendas. In this situation, the power voltage and frequency must be maintained to ensure a stable energy supply. This is where Fuji Electric can leverage its expertise and development capabilities.

Eguchi: We need to perform comprehensive information management.

Shin: Absolutely. Changes in the weather directly affect energy productivity. In this situation, we would need to know to what extent thermal power plants should be operated.

Eguchi: We have already begun operating supply/demand forecasting incorporating meteorological data, and we find that the cycle is very long.

Shin: Measures against spontaneous torrential rain are indispensable. Among the systems that operate for safety combining short-cycle systems with diversity, the system that survives will be one that has some flexibility for different enterprises to carry out their own businesses.

Eguchi: The safety of the system will be increasingly important. It's easy to take safety for granted. But can safety itself be an asset to add value to the system?

Shin: Companies should use risk analysis to learn the risks of withholding investments, and leave the decision to the management.

Eguchi: That's a kind of insurance scheme.

Shin: Absolutely. Insurance companies offer policies to cover damage compensation if a company is held liable due to an accident or environmental pollution. It's like car insurance which offers lower premiums for automobiles with airbags. Corporate insurance premiums are reduced by nearly 40% if the company is certified with an information security management system (ISMS) for server systems.

We are currently appealing to Japanese government to create a similar framework for control systems that allows a more advantageous insurance policy for companies with cyber security management system (CSMS) certifications.

Eguchi: Certifications will become very important. You're the President of the Control System Security Center. Does the center have any certifications?

Shin: We do, but not without credentials. We are accredited by the Japan Accreditation Board (JAB), and we also base our certification on international standards. Insurance providers can also reduce their risks through third-party certification with certain credentials.

Eguchi: There have been cases where webcam users connect their devices to the Internet without changing the default settings, and end up having their privacy invaded. In view of the coming age of the IoT and M2M, how should we view security, and what can we do to raise awareness among the general population?

Shin: Cyber security is a game of cat and mouse between attackers and countermeasures. This is not to say that there's nothing to be done, but it's important to acknowledge the situation. It's important to acknowledge that even top-range products become vulnerable over time, so it's crucial to equip updatable features.

For example, flash memories are mounted on smart meters in case a software update is required when a problem occurs. Therefore companies must figure out how much flash memory they need and how to configure their in-house systems in case updates fail and devices need replacing.

The 20th century was epitomized by mass production and consumption, but in the future, it looks like products will be maintained and cherished for long periods of time. Therefore, we should base our efforts not only on manufacturing, but also on the service-oriented industry.

## Integration of physics and statistics—indispensable for big data analysis

Eguchi: In the wake of the machine networks with IoT and M2M as well as big data analysis, global business is changing dramatically. I believe that Fuji Electric has resources with which it can contribute.

Shin: Sufficient resources. And you should make contributions.

**EGUCHI, Naoya**

1954: Born
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 and Director, Fuji Electric Co., Ltd. and Corporate General Manager, Corporate R&D Headquarters of the company

Eguchi: In-plant products and systems have been our forte. We have actuators and controllers as well as network technology. Big data analysis, however, is primarily a mathematical practice, at which information and communication technology (ICT) companies are adept. We are a company that's adept at handling physical phenomena, so where do you think we can make contributions?

Shin: Big data analysis is basically statistical analysis. I think there will be a highly reliable conclusion if integration is successfully executed between physical approaches, at which Fuji Electric excels, and statistical approaches.

Analyses without physical principles can be dangerous. Finance is a good example. There is a differential equation in probability called the Black-Scholes formula, which is often employed in investment, but the company founded by Mr. Scholes went bankrupt.

Eguchi: At present, ICT companies lead the IoT business. To be honest, we have the know-how based on on-site experience, and our pride will not allow us to simply be swallowed up in the big-data system. As you suggest, ideal integration may make it possible to gain more than what we can offer.

Shin: There must be so much to gain.

Take cars, for example. It wouldn't be so much fun if absolutely everything was put under computerized control. There are some things a driver wants to control. Without computers, on the other hand, the risk of accidents would be higher. Therefore, we need to delineate the domains of autonomous human control and computerized safety assurance.

As you know, many corporations today have business continuity plans (BCP) in place to prepare for eventualities such as accidents and natural disasters. But if the plan had to be very rigid, there would be very little room for innovative ideas.

I would question the value of uploading the company's on-site know-how straight into the Cloud. As you can imagine, parents wouldn't be able to resist the temptation to interfere if they knew all about what their children were up to. That wouldn't be good for the children's development.

Eguchi: That's a very good analogy.

## Live independently, live better connected

Eguchi: Admittedly, there is a gray area in terms of the directions IoT and M2M are going to take, but in any case, Fuji Electric hopes to strive in maximizing our component business, and offer new solutions by combining them with instrumentation and control technology.

Shin: What you just said provides a conclusion for today's discussion. It's important to be connected, but it's equally important to polish ourselves. If you connect with others without having any particular identity to assert, you will simply be absorbed.

Eguchi: It reminds me of when I was involved in the smart-grid project. It's no longer possible for a single company to handle all IoT-related requirements. So open innovation and lateral collaborations are becoming increasingly important. Distribution of responsibilities will be a difficult task. But I also feel that as Japanese manufacturers, we must compete as a team, with concerted efforts, in the world arena.

Shin: I agree.

Eguchi: You're involved in the Technology Research Council. In a sense, you're leading Team Japan. How do you think Japan would fare today compared to the traditional convoy system?

Shin: Some time ago, when Fuji Electric developed an autonomous decentralized network and brought it to an international standard, I was given the task of explaining the concept of autonomous decentralized systems at the ISO committee. The concept of decentralization is pretty self-explanatory, but autonomous control was not so easy to explain. The situation may be similar to the open innovation of today.

At the committee, I explained that while you can live independently, you can live better if you're connected with others.

First of all, we need engineers who can survive without information devices. We need to train engineers so that they can design things with a pencil. Then they can leverage useful tools in order to perform better.

This is the idea I have long held in education at the university.

The same goes for collaboration. Fuji Electric can survive on its own. If it keeps that core part intact, it can deliver better results by collaborating with other contributors.

## Excellent technology to sell for high prices

Eguchi: There was a time when the scope of Fuji Electric's business was over-extended, but today, it has a clear vision about its business direction.

Shin: I think it's a regret that you don't brag about your excellent technology enough. This is typical of Japanese engineers. However, you cannot have this attitude in open innovation. I want good technology to be appreciated for its value so that it benefits consumers across the world.

Eguchi: The international market brings in the issue of pricing. Cheaper products cost as little as a half of prices in Japan.

Shin: Price wars are a result of the unskillfulness to promote your own core technology properly. Given the high cost of labor, Japanese firms will lose in price wars.

Instead, you need to explain what justifies the high prices. As we know, there are so many users who opt for cheaper products and end up in a cul-de-sac.

Eguchi: Cheaply made products often have short lifecycles.

In this sense, Fuji Electric's product development is different, as it focuses on the company's strong core technology with added value. For example, we make a pressure sensor that withstands super-deep-sea pressure. There are many unique products like this one. There is great demand for this sensor in African countries.

We have also co-developed a domestic gas detector with Osaka Gas Co., Ltd.. This is the world's first battery-powered gas detector with a micro gas sensor, and we applied our unique micro electro mechanical systems (MEMS) technology to the device, reducing its power consumption to less than a thousandth.

We also have a range of controllers, from a distributed control system (DCS) to a programmable logic controller (PLC). As for wireless networks, we have developed an ad-hoc transmission module jointly with Tokyo Gas Co., Ltd. and other firms.

We are seeking ways to develop further by combining this high technology with our components, power electronics and actuators.

There is great potential, but we are not quite in tune with world trends. Sometimes, we have been so far ahead of the times that when the times finally caught up with us, we had reached the point of exhaustion.

## Asia to become the third power in international standards

Eguchi: It's very disturbing that international standards are so Euro-centric. We Japanese manufacturers always have to be on the defensive.

Shin: Technology is very advanced in the U.S.A., and Europe is adept at systematization. It's true that in the 20th century Japan had to assimilate to either Europe or America in terms of standardization. But as we know, Asia is showing remarkable growth. It may well become the third major power in terms of international standards. This puts Japan in a different situation. In this sense, Japan has gained a third approach; that is, to propose new standards from the Asian perspective.

Eguchi: Is movement from Asia going strong?

Shin: Yes, it is. The OLE for Process Control (OPC) Foundation is pursuing activities at King Mongkut's Institute of Technology Ladkrabang in Thailand. ISO/IEC requires support from five countries in order to make a new work item proposal. Therefore, we are currently using our university connections to network and gain five affiliates among the ASEAN member countries.

Because the current Japanese government is proactive in infrastructure exports, there have been notable changes in the international climate.

Eguchi: Another point of concern regarding standardization is differentiation. In your writing, you use the phrase "a module, but a module with a margin for adjustment." What do you mean by this?

Shin: As there are many different approaches to Industrie 4.0, I see it as applying 3D technology to information. For example, one automotive manufacturer is pursuing their development using a 3D CAD system. In the 3D domain, they input everything from the production system to people, machines, and PLC, and execute the whole program in the virtual realm to generate a manual. This manual is then distributed to plants across the world, and they launch the new car simultaneously. Here, the 3D CAD acts as the mother plant. What I mean by "a module with a margin for adjustment" is a module equipped with a variety of know-how.

Suppose you have certain models, and you know that some combination of patterns thereof will produce a car. The systematic technology that brings about these combinations embodies a certain type of know-how. Other than this, the components themselves are important. Some models may be gold, and others copper. These differ in terms of energy consumption, durability, and so on.

Recently, wearable devices in the form of wristwatches have been released. The cheapest one is made of aluminum. Then there is stainless steel one, and the top of the range is 18 karat gold, costing more than a million yen. So, you can also make distinctions according to the materials. In the future, differentiations according to component combinations and make-up will be an area of competition.

Eguchi: So, Japan must retain some areas of competition in this way.

Shin: Fuji Electric's deep-sea pressure sensor is a winner. You can't measure deep-sea pressure with a sensor mounted on a smartphone.

## Open/close strategies of technology

Eguchi: How do you envision the factories and society of the future?

Shin: I hear that President Obama is also very inter-

ested in 3D printers. I think we are leaving behind the era when products are produced by professional manufacturers. The time is coming when customers will be able to make products with a CAD system and a 3D printer at hand. If none of the cars in a catalog appeal to you, you will be able to design a car with a CAD and print it out. You will also be able to modify the car's design according to the growth or changes in your family members.

This means that there will be a variety of laypersons entering into manufacturing. That's why our task will be to systematically ensure that such products are safe and secure even when they are made by laypersons.

In the 19th century, factories and houses were located together. It was the Ford production system that initiated a new trend, and then industrial and residential areas became separate. In the future, this boundary will once again become ambiguous. Factories will appear in downtown areas. A 3D printer is a handy thing to have in a household. If you want to give your wife a nice ring, you can make one on the spot. While there is the issue of printing materials, the machines are available at mass retailers for 100,000 yen.

Eguchi: That will be the ultimate initiative in local production for local consumption. Then what will become of manufacturers?

Shin: I think that manufacturers will actually become more important. There must be someone pulling the strings in the background so that unskilled laypersons can produce proper products. Models are what set the basis for that.

Some parts manufacturers have 3D models of their screws which can be downloaded. Using this system, their clients can install the models in their CAD systems, and confirm the correct specifications for the parts before they place actual orders.

Eguchi: There are similar attempts for certain aspects of power semiconductors. It makes it possible to check switching loss and other functions using downloadable models.

Shin: Today there's great demand for data that shows whether the device works properly in a reference circuit, or to visualize the heat generation or the fluctuations in electricity currents. There's an electronics manufacturer that provides free CAD software for LCR active circuits. With this software, customers can simulate the properties of the manufacturer's capacitors in advance.

I think Fuji Electric has many advantages due to the many excellent components. So, the sensors and power semiconductors should be compatible with other manufacturer's standards for the IoT. As for protocol, it's desirable to use Application Programming Interface (API) rather than unique protocols.

Eguchi: You're suggesting that we should make part of our trade openly accessible.

Shin: I'd say that this is an open/close strategy. You may want to close off your valuable assets, but open the parts that can be utilized by other companies. From a different perspective, this means that Fuji Electric products can spread into the realms of other companies.

Eguchi: There are far more opportunities than before to speak with people from different lines of work, such as machinery manufacturers and ICT companies. In this situation, it's easy to lose sight of where we're headed if we don't maintain a clear sense of our identities.

Shin: Each member comes up with their own proposals, all of which are combined to make a successful project. That would be an ideal alliance.

## Engineering as an aspirational vocation—developing talent through industry-academia collaboration

Eguchi: Fuji Electric deals in sensors and controllers, but it needs to strengthen its control technology front. I have the impression that it's difficult to train specialists in this field. You need an object to control in order to learn how it works, so theoretical education alone is not enough. How do you teach control technology in your university?

Shin: When I was a student, it was often said that mathematics has no use in engineering. But everything that I studied at university is very useful today because in this modern age, inverters and other components are all based on formulae. Students in my class on Fourier transformation might see the lecture as no more than general knowledge, but everyone in engineering today uses this method on a daily basis. These days, even models are designed using differential equations.

Eguchi: You're suggesting that basic theories are the key to learning control engineering.

Shin: These days, an increasing number of universities are strengthening their ties with corporations. Since 2006, the University of Electro-Communications

has been running a special master's degree course—the Advanced IT Specialist Specialized Training Program—as part of a program endorsed by the Ministry of Education, Culture, Sports, Science and Technology. We have seven or eight enterprises currently taking part in this course as lecturers. They talk about the theoretical aspects of control engineering, introduce students to mathematical analysis software to handle digital signal processing, lecture on security issues, and so on. Teaching staff may introduce subjects saying, "This is used in society," but it's hard to get the students interested. On the other hand, if corporate personnel as lecturers say, "We use this in our company," then the students suddenly perk up. I would love it if Fuji Electric came to take part in our course.

Eguchi: That supports my impression that universities and corporations must work together to provide education.

Shin: In the past, it was difficult for universities to impart the practical knowledge that companies require. In our Advanced IT Specialist Specialized Training Program, the companies themselves have the opportunity to participate in training young talent.

Eguchi: The importance of education cannot be overemphasized. One of our female employees has been sent to Denmark to study at Aalborg University. I went to pay her a visit recently, and saw her confronting control theoretic study head-on. I would like to have more talented personnel like her. We must create more opportunities for education and training, maybe at your university, too.

Shin: As an educator, I am all for inspiring young people about the future. Through high school education, students learn things that have "correct" answers. But this does not cultivate aspirations. Changing their frame of mind at university is a hard task. I often tell them, "Humans don't really know very much about the world. So, you can take your own initiatives and create new products or make new discoveries. It's actually easy to create new things."

Eguchi: Younger generations are becoming increasingly conservative compared to before. Do you think this is a result of the declining birth rate?

Shin: It's because Japan is such a comfortable country to live in. Perhaps that's because Fuji Electric has made the country's infrastructure so solid. Jokes aside, I think engineers have contributed greatly to making Japan such a comfortable country.

Eguchi: I've read articles where you said that engineers were not treated well in Japan.

Shin: When you and I were younger, engineering was an esteemed career. Around the time of the economic bubble, however, many people who were talented in the sciences chose finance as their career path. Personally, as an engineer, I would like my students to experience the sense of achievement unique to engineering, that there's something they contributed in its creation, be it the development of a certain technology or plant construction. It would be unfortunate for an engineer not to have a single successful experience.

Eguchi: In this sense, engineering is an inspiring career.

Shin: As a company with a long history, Fuji Electric has overcome dramatic times of difficulties and changes, as represented by the IoT. It has survived by transforming its corporate structure, or by selecting and focusing its resources. All these experiences form the company's foundation today. The company has its sustainability and identity firmly established, and yet it maintains the ability to adapt to current global trends. These qualities must be acknowledged more widely in society as well as among students.

The same can be said about our University of Electro-Communications. We renamed ourselves after WW II. Other names proposed at the time include things like "University of Radio" and "University of Communications." I think the name "University of Electro-Communications" showed great foresight. Many other national universities are named after their regions, such as the University of Tokyo or Tohoku University. Our university is the only one without a place name in the title. It signifies that engineering is our identity.

I believe that the 21st century will be epitomized by electro-communications. Electronics and communication are crucial components of the IoT. We hope to strive hand in hand with Fuji Electric in making our contributions for the future of Japan.

Eguchi: Today, you taught us that we must be more self-assertive so that our excellent technologies will be more widely acknowledged and appreciated. We hope to continue making progress in the future by enhancing our ability to communicate our strengths, while valuing talented personnel and experts so that we can contribute to Japanese society and the world. Thank you for your time today, and we are looking forward to our future collaborations.

Achievements and Future Outlook

# Providing Powerful Component Based Energy Solutions

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

## 1. Introduction

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

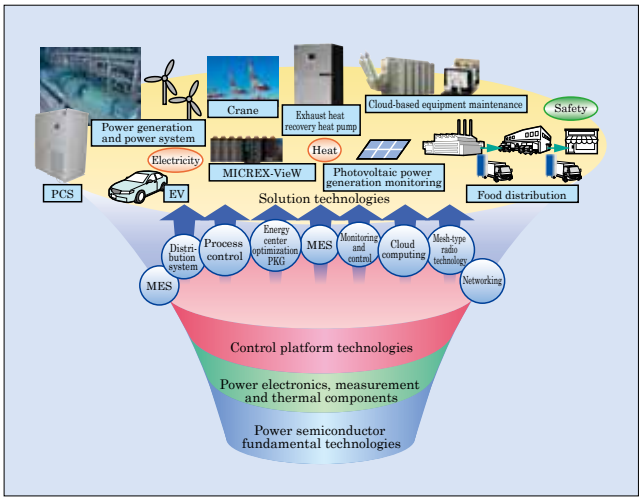


Fig.1 Fuji Electric's core technology and areas of focus

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

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

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

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

Fig.2 SiC hybrid module

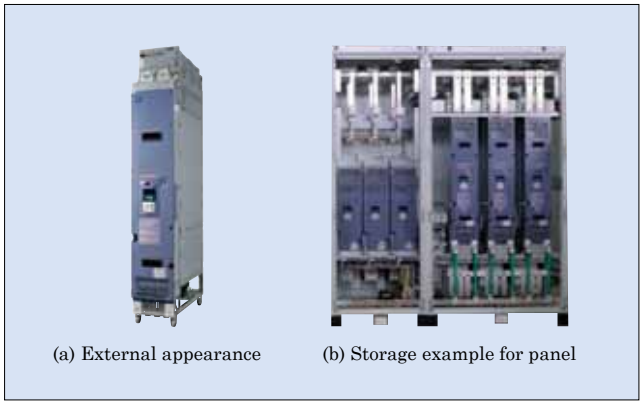


Fig.3 690-V inverter “FRENIC-VG Stack Series”

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

Furthermore, we have developed an All-SiC module that utilizes SiC-SBD and SiC-MOSFET[3], and have adopted it in our mega solar power conditioning sub-system (PCS)[4] (see Fig. 4). This module is wired using copper pins formed on the power substrate, as opposed to wire bonding, in order to accommodate high-density mounting for the SiC device. In addition,


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

by adopting a silicon nitride substrate formed by bonding a thick-copper substrate for achieving low thermal resistance, as well as utilizing technologies such as an epoxy resin sealing technology, we have created an ultra-small and highly reliable module that achieves high-temperature operation, heat dissipation and low inductance.

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

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

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

## 3. Differentiated Power Electronics Products

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

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

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

We have also developed a motor with a built-in in-

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

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

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

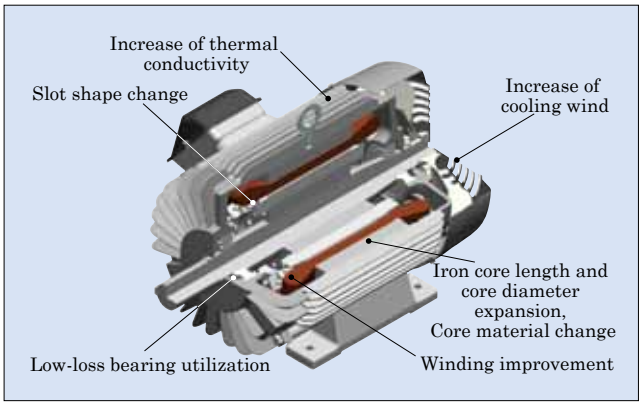


Fig.5 Motor loss reduction masures

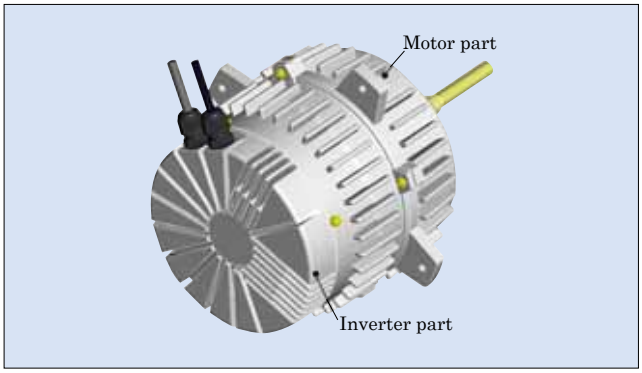


Fig.6 Motor with built-in inverter (development machine)

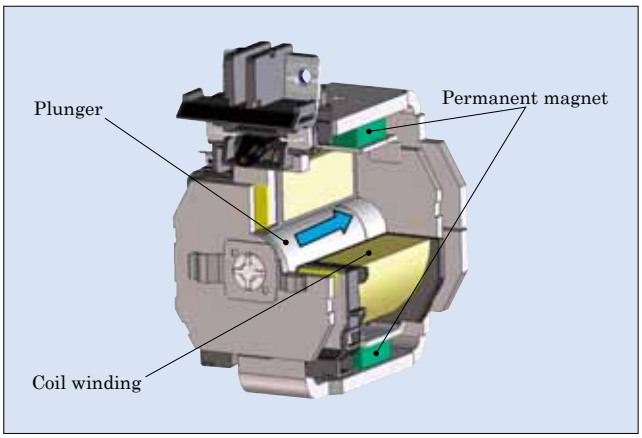


Fig.7 DC electromagnet

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

## 4. Measurement and Thermal Components

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

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


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

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

## 5. Control System Platform

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

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

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

## 6. Energy Solutions

We are continuing to advance in our supply of en-

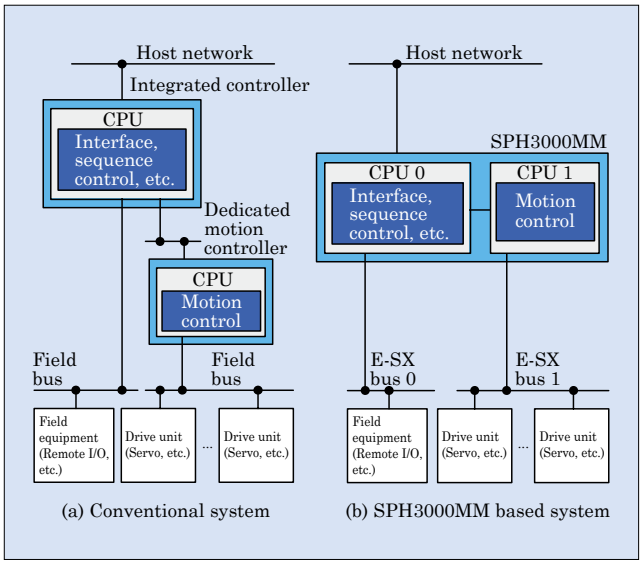


Fig.9 Conventional system and “SPH3000MM” system

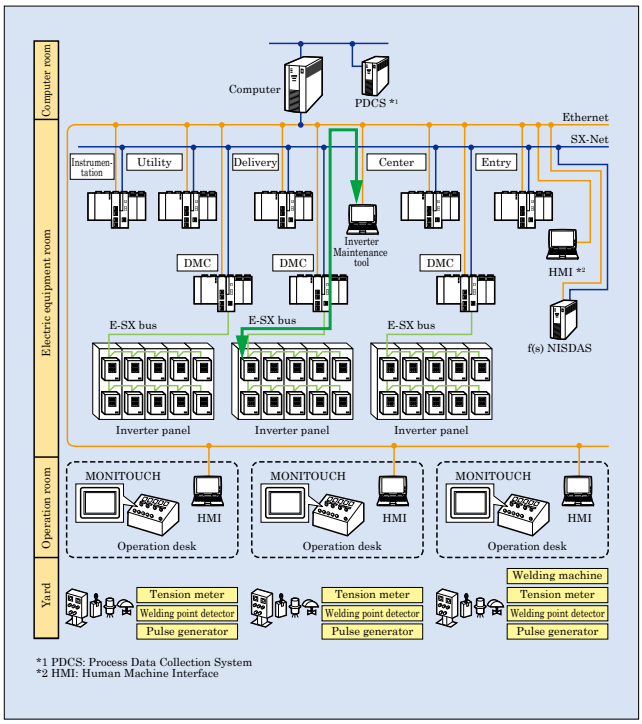


Fig.10 Conventional system and “SPH3000MM” system

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

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

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

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

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

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

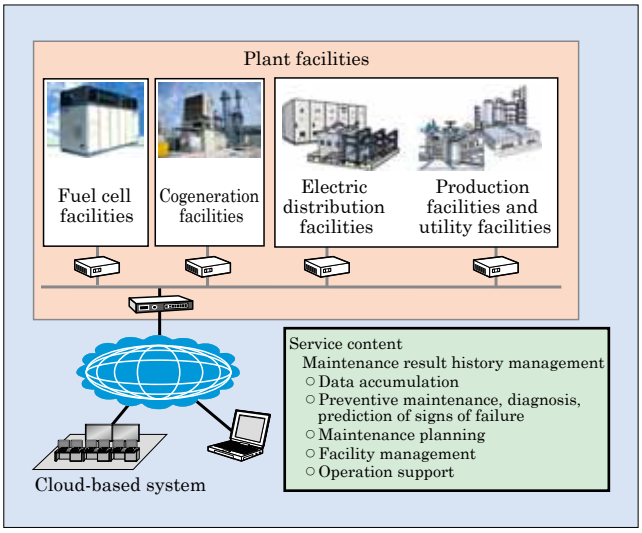


Fig.11 Integrated cloud service

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

## 7. Fundamental and Advanced Technologies

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

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

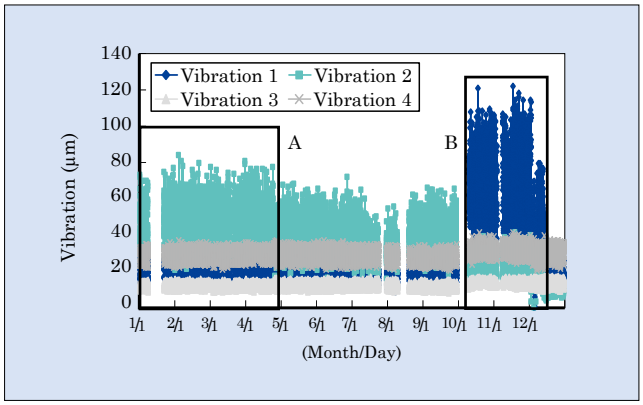


Fig.12 Turbine shaft vibration data

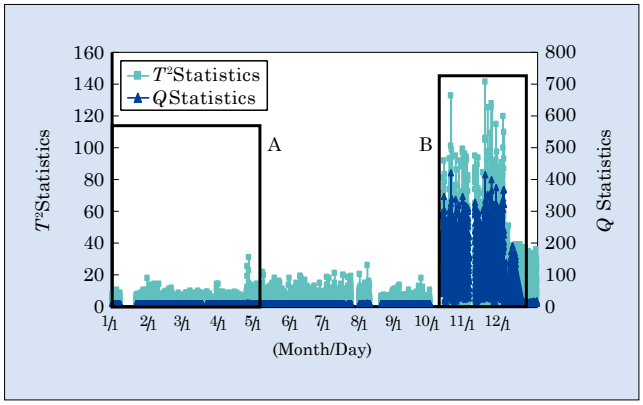


Fig.13 Vibration data analysis results

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

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

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

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

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

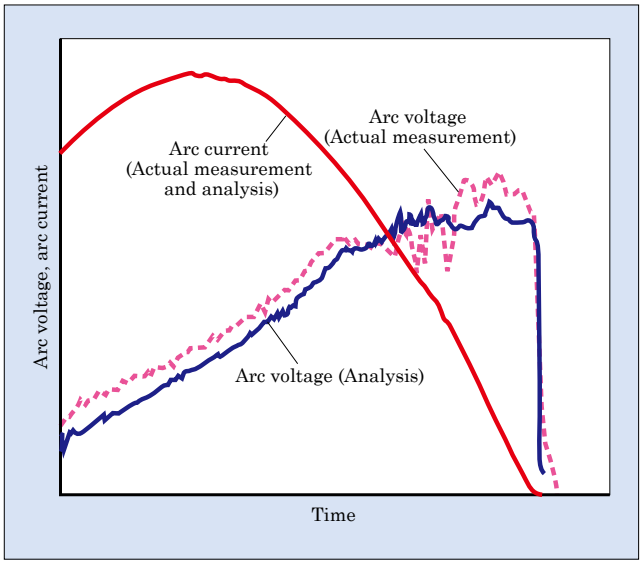


Fig.14 Arc current and arc voltage at cut-off

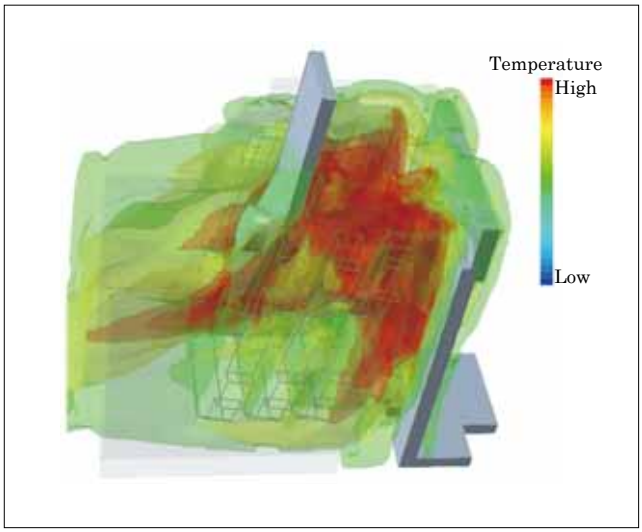


Fig.15 Circuit protector arc simulation results

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

## 8. Postscript

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

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

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

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## Mega Solar PCS Incorporating All-SiC Module "PVI1000AJ-3/1000"

In recent years, a higher degree of power generation performance and reliability has been demanded of photovoltaic power generation systems. Power conditioning sub-systems (PCS) have a central role in these systems, and are required to have a large capacity and high efficiency, as well as reliability that enables continuous operation even when disturbances occur in power supply systems. In addition to this, they must support the reduction of total costs for the systems.

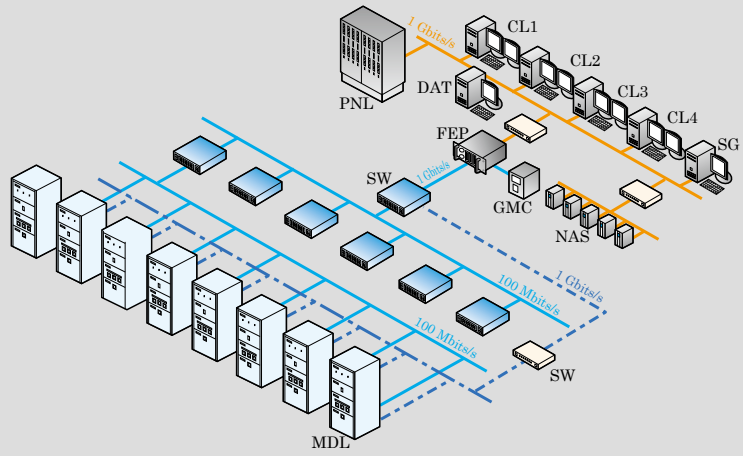
Fuji Electric has developed the mega solar PCS "PVI1000AJ-3/1000." The PCS employs an All-SiC module that consists of a silicon carbide metal-oxide-semiconductor field-effect transistor (SiC-MOSFET), as a next-generation semiconductor device, as well as an SiC Schottky barrier diode (SiC-SBD), enabling the unit to achieve a maximum efficiency of 98.8%, which is the industry's highest level. Furthermore, the unit achieves miniaturization with a footprint size approximately 60% smaller than previous products.

This product was awarded First Prize in the FY2015 (64th) Japan Electrical Manufacturers' Association Technical Achievement Award.


## All-SiC Module for Chopper Circuit

Silicon carbide (SiC) devices have attracted a lot of attention for their potential to help achieve a low-carbon society through their capability of significantly reducing power consumption. Fuji Electric has utilized the SiC metal-oxide-semiconductor field-effect transistor (SiC-MOSFET) and SiC Schottky barrier diode (SiC-SBD) devices being manufactured on the 6-inch line at the Matsumoto Factory to develop an All-SiC module for use in chopper circuits.

This module has a rated capacity of 1,200 V/100 A, and achieves miniaturization with a footprint size approximately 55% smaller than previous Si-IGBT modules. This module can be used in the booster circuits of power conditioning sub-systems (PCS) for photovoltaic power generation, and contributes to circuit miniaturization and significant reduction in power loss. These enhancements have achieved a 20% reduction in size for the PCS, and a conversion efficiency of 98.8%, which is the industry's highest level.




CL1, 2, 3, 4: Client PCs
SG : Smart grid control server
PNL : Operating & monitoring panels
DAT : Data server
FEP : Front end processor
GMC : Grand master clock
NAS : Network attached storage
SW : Ethernet switches
MDL : Simulator models

Operation system network
IEC 61850/IEC 61588 network
Off-line setting network

## Power System Analysis Simulator for Chubu Electric Power Co., Inc.

Fuji Electric has provided the Power System Analysis (PSA) Center of Chubu Electric Power Co., Inc. with a "hybrid power system analysis simulator" capable of simulating smart grids.

This facility is a power system analysis simulator that utilizes real voltage and current to perform electric power system analysis, while also enabling the simulation of a diverse range of system configurations including distributed power sources.

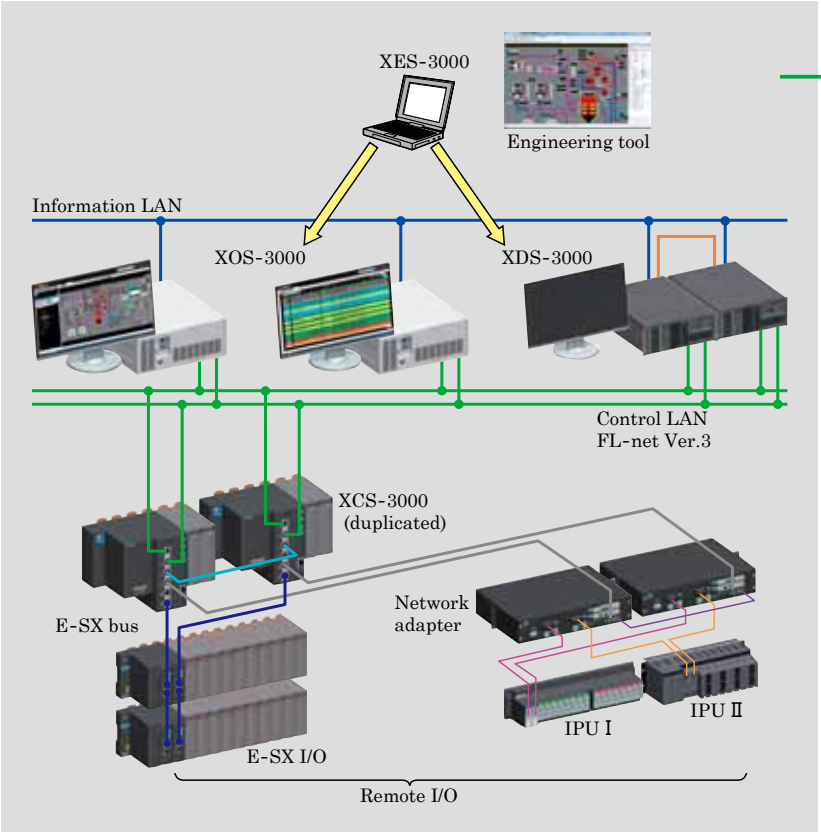
It adopts an electric power communication protocol (IEC 61850) and time synchronization system (IEC 61588) as information communication infrastructure and can also be utilized in the development and testing of control systems based on next-generation information communication technology.

The simulator is expected to contribute to the assessment of the effect of a large amount of renewable energy on systems, as well as support the testing of smart grid technology capable of utilizing renewable energy at an optimal level.

## Exhaust Gas Cleaning System for Ships (Cyclone Type $SO_x$ Scrubber)

In order to prevent air pollution from marine vessels, exhaust gas regulations have been gradually reinforced based on the International Convention (MARPOL Annex VI). Fuji Electric has developed an exhaust gas cleaning system for marine vessels ($SO_x$ removal cyclone scrubber) compliant with $SO_x$/PM regulations that have been reinforced in 2015. The unit sprays sea water on the exhaust gas and reduces $SO_x$ by dissolving it in the sprayed droplets. The main features are as follows:

(1) It achieves the industry's smallest size (diameter of 2 m, and height of 7 m) with a volume that is more than 50% smaller than previous products. It can be easily installed on both new and old ships.
(2) The cyclone system creates swirl inside the unit to secure time for the $SO_x$ absorption reaction.
(3) The high-diffusion spray nozzle increases the $SO_x$ reduction rate to over 98%, enabling the unit to meet the 2015 regulations applicable to Emission Control Area.
(4) It achieves reduction in pressure loss and the droplet dispersal rate by making use of $SO_x$ dissolution model experiments and fluid simulations.




## Small- and Medium-Scale Monitoring and Control System "MICREX-VieW XX"

Fuji Electric has developed and commenced sales of the Small- and Medium-Scale Monitoring and Control System "MICREX-VieW XX (Double X)" as a system standardizing control system architecture in order to meet the requirements of industrial and social infrastructure. This product is a system that aggregates and integrates the technologies of Fuji Electric at an advanced level by incorporating a variety of concepts including "superior visibility and operability," "integration of electric machine control and measurement control," "high reliability," "efficient engineering" and "high level of inheritability."

This product is composed of a next-generation HCI with excellent monitoring and operability, a high-speed and high-capacity controller, a highly reliable system configuration (redundancy of components including the I/O, controller, database, and network) and a high-efficiency integrated engineering tool. By connecting a multi-function network adapter, it is possible to make effective use of existing assets, as well as upgrade to high-reliability systems quickly and inexpensively.

(a) Front mounted (b) Side mounted

## Inverter for Elevators in European Market "FRENIC-Lift LM2A"

In Europe, elevators are being required to comply with reinforced safety standards and adopt advanced control systems. In addition, there has been increasing demand for elevators not requiring a machine room in order to install them in existing buildings. As a result, it is essential that the control panel be miniaturized and have a low profile so that it can be installed in the narrow space of the elevator shaft and side of the entrance door. Fuji Electric has developed the "FRENIC-Lift LM2A" inverter for elevators in order to meet these needs.

The main features are as follows:

(1) Has achieved the industry's smallest class size through low profile enhancements that reduce the width from 220 mm to 140 mm compared with previous products (Built-in 7.5-kW EMC filter).
(2) Has acquired third-party certification for European safety standards (EN81-20) (Compliant with contactless methods for motor output blocking).
(3) Supports major encoders in the European market.
(4) Scheduled in FY2015 to support 2 communication functions (DCP4/CiA DSP417) for elevator distance control.

## Medium-Frequency Isolation Type Auxiliary Power Supply

We have developed a compact and lightweight auxiliary power supply based on a medium frequency isolation system that is suitable for subway cars and automated people movers. Recently, lightweight enhancements have been underway for electric rolling stock in order to increase energy savings and control a number of service devices, and as a result, compact and lightweight auxiliary power supplies are in very high demand. Conventionally, it has been mainstream to use a commercial frequency transformer to isolate 3-phase AC, but recently, it is becoming more common to use a medium-frequency transformer to isolate medium-frequency voltage that has been converted by a resonance inverter. Utilization of medium frequency reduces magnetic flux in the transformer core, allowing the transformer to reduce its weight to one-tenth that of the previous product. Furthermore, we have been aiming at reducing the switching loss of power devices through the utilization of a resonance inverter.

Compared to the previous system, this auxiliary power supply has achieved a reduction by 25% in volume and 35% in mass.


(a) “CP30FI-1P”


(b) “CP30FS-2P”


(c) “CP30FM-3P”

## Lineup Enhancement for Circuit Protector “CP30F”

A circuit protector is a circuit breaker that is utilized in the protection of the control circuits and devices of various control panels. It is adopted in the circuit protection components of electronic devices. In recent years, there has been growing market demand for control panels and devices that are smaller, contribute to wire savings, improve safety and are global in scope of application. In order to meet these needs, Fuji Electric has enhanced its lineup of “CP30F” circuit protectors.

The main features are as follows:

(1) Integrates terminal cover functionality into the product and achieves a reduced setting area of 20% compared with existing models
(2) Employs a new terminal structure and contributes to reducing labor-hours related to connection electric wiring by 40% compared with existing models
(3) Adopts IP20 as the degree of protection for the main terminal
(4) Compliant with JIS, UL, IEC and GB standards

## Fuji Electric's Top Runner Motor "Premium Efficiency Motor"

In recent years, there has been growing momentum toward the reduction of global energy usage as a means of preventing global warming. Japan has also been promoting the expansion of equipment that adopts and applies Top Runner Standards based on the "Act on the Rational Use of Energy" (Energy Conservation Act). Three-phase induction motors became part of the top runner system in 2013, and Fuji Electric has been supplying the market with its "Premium Efficiency Motor" as a motor compliant with these standards.

The main features are as follows:

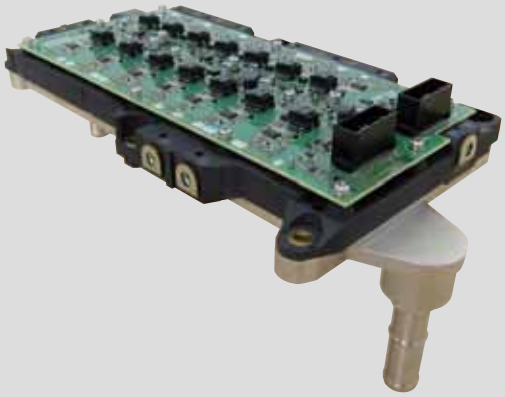
(1) Decreases loss by optimizing the groove dimensions, core material, etc., and achieves Top Runner Standard efficiency at an output between 0.75 and 375 kW.

(2) Compliant with the frame number and mating dimensions specified in JIS C 4210, while also supporting easy replacement.

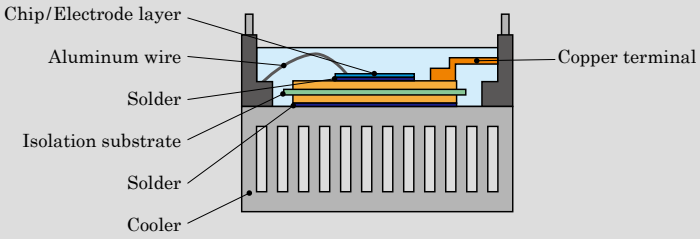
(3) Improves insulation performance while suppressing temperature rise, and also expands the range of the cast iron frame to contribute to improved corrosion resistance and reduced acoustic noise. Furthermore, it adopts IP55 as the degree of protection for the outdoor specification in compliance with global standards.

## 1,200-V Withstand Voltage SiC Hybrid Module

Fuji Electric is advancing in the development of SiC hybrid modules with a 1,200-V withstand voltage as power devices that can be utilized in inverters that contribute to energy conservation. The hybrid module utilizes an SiC Schottky barrier diode (SiC-SBD) chip that was developed in collaboration with the National Institute of Advanced Industrial Science and Technology. The chip is being manufactured on the 6-inch line at the Matsumoto Factory. The insulated gate bipolar transistor (IGBT) is equipped with Fuji Electric's latest 6th generation "V Series" IGBT chip. The package for this SiC hybrid module utilizes the same 2-in-1 package as the Si module in order to maintain compatibility. It reduces loss by about 25% compared with conventional Si modules with a rated capacity of 300 A.



(a) External appearance




(b) Cross-section view

## 2nd Generation IPM for Hybrid Vehicles

There has been an increasing demand for smaller and lighter weight intelligent power modules (IPM) for use in the motor control of hybrid electric vehicles (HEV) and electric vehicles (EV).

Fuji Electric has enhanced its 2nd generation aluminum direct water-cooled IPM by improving heat dissipation for the cooler and providing higher temperature stability for the bonding materials, as well as by reducing the footprint through the adoption of ultrasonic welding. As a result, it is much smaller than the 1 st generation model. Specifically, we have developed the following: a cooler design technology for the aluminum direct water-cooled structure that integrates the heat sink and water jacket; high temperature stability materials (aluminum wire, electrode layer and solder) capable of 175°C continuous operation; and an ultrasonic welding of copper terminal technology capable of small footprint.

The development of these technologies has enabled the 2nd generation IPM to reduce its volume by 30% and mass by 60% compared with the 1 st generation model.

## ZERO Heating Power Vending Machine

Energy-efficiency is increasingly being requested for vending machines. Inspired by the goal of significantly reducing the power consumed in actual operation over the course of a year, Fuji Electric has developed a vending machine for which a high-thermal efficiency heat pump can be used all operating conditions, without employing the electric heaters that had been used selectively in the past. An approximate 15% reduction in annual power consumption can be achieved in comparison to a conventional energy-saving vending machine.

The main features are as follows:

(1) Only heat pump heating is used inside all warehouses and in all operating conditions, and the heating efficiency in the major operating conditions has been improved by about 50% compared to conventional models.

(2) The vending machine is equipped with a high-efficiency compressor, developed in collaboration with a compressor manufacturer, and modified for vending machine use.

(3) A new of heat exchanger that uses high-density aluminum fins realizes high heat exchange efficiency.

## Donut Fixture for Seven-Eleven Japan Co., Ltd.

As a follow-up to the "Seven Café" which was introduced to Seven-Eleven Japan Co., Ltd. in 2013, Fuji Electric has developed a fixture for selling "Seven Café donuts." While maintaining the interior of the showcase at a constant cool temperature, the cooling method utilized by this product prevents donuts from drying out, and is a capable of maintaining the good taste of donuts.

The main features are as follows:

(1) Using a Peltier cooling unit as the cooler, precise cold storage performance was realized with an internal cool air circulation system.

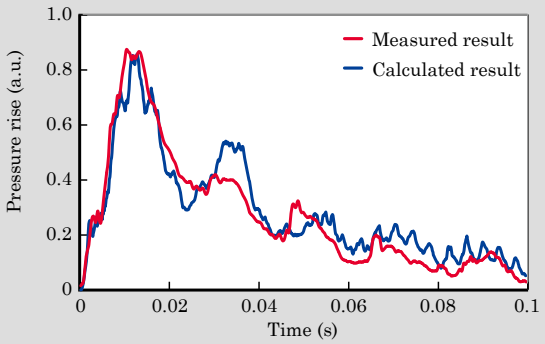
(2) Fuji Electric has developed an exterior that exhibits a sense of unity with "Seven Café" and also LED lighting tailored to round shape design that expresses ease and convenience.

(3) In consideration of the ease of cleanup, an open and closing front glass structure and a detachable shelf plate structure were used. In addition, a sliding shelf system was used so that the donuts could be removed with greater ease.

## Equipment for Greenhouse Horticulture of Tomatoh Farm Co., Ltd.

To the Tomatoh Farm Co.'s greenhouse horticulture, which was built in Tomakomai, Hokkaido, Fuji Electric has delivered a composite climate control system, substation equipment, environmental measurement equipment, refrigeration equipment, the next-generation cold storage container "D-BOX," and the like. The composite climate control system, which is of key importance to the plant, performs the centralized control of such information as temperature, humidity, and $CO_2$ concentration, and also performs high-level climate control that incorporates time periods and composite climate data. With this system, the full-year cultivation of stable and high-quality strawberries is targeted. In addition, because of the heat supplied from an energy supply center that utilizes wood biomass, a reduction in fossil fuel usage for facility operation is realized.

In the future, in addition to supplying various equipment and systems, Fuji Electric also intends to provide comprehensive engineering for greenhouse horticulture, including administrative and facilities operation know-how to the operators of greenhouse horticulture.




(a) Comparison of pressure rise inside the switchgear

(b) Internal arc test for the switchgear (third-party certification testing)

## Arc Coupled Analysis Technology Anticipating Short-Circuit Faults Inside Switchgear

International standard (IEC 62271-200) stipulate safety performance regarding short-circuit faults that occur inside switchgears. The standard requires a structure that can correspond to arc related pressure rise at the time of a fault.

To comply with these standards, Fuji Electric has developed analysis tools for implementing thermo-fluid analysis utilizing a three-dimensional simple finite volume method specialized for switchgears, as well as arc coupled analysis for anticipating the arc energy to be generated. As a result, the following has become possible:

(1) Consideration of shape and pressure discharge structure for the switchgear
(2) Significant reduction in analysis time (about 1/100th of conventional methods)
(3) High-precision prediction of pressure rise inside the switchgear (see Fig. (a))
(4) Design capable of meeting safety requirements for inside and outside the switchgear through the use of high-temperature gas convection analysis and strength analysis

The analysis tools were used to create a switchgear design that passed a third-party certification test (see Fig. (b)), and as a result, we have developed and are supplying the market with IEC standard compliant switchgear.

# Electric Power Generation Systems

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



## Outlook

In Japan, thermal power plants continued to remain in high operation in FY2014 while the year seeing continuous assessment of compliance to new regulatory standards for the restarting of nuclear power plants. At the same time, however, the study into energy mix technologies is also keeping pace as the United Nations Climate Change Conference (COP21) scheduled to be held in Paris in 2015 approaches. It is expected that aging thermal power plants will be upgraded and accelerated in usage. With regard to photovoltaic power generation, there is still big difference between facility certified capacity and construction facility capacity, and it is anticipated that construction work will continue in FY2015 and beyond. As for other types of renewable energy, small-scale geothermal binary power generation is continuing to advance, while it is expected that construction projects for large-scale geothermal power generation and wind power generation facilities will become more vibrant.

In overseas markets, the construction of large-capacity high-efficiency coal-fired power generation facilities and gas turbine combined cycle (GTCC) power generation facilities will continue, as well as projects for upgrading gas turbine power stations to combined systems. This trend is especially being supported by the long-term power demand growth in developing nations. Furthermore, the development of geothermal power generation facilities is not limited to Southeast Asia, but is also expected to take shape in other regions such as Africa.

In the field of thermal power generation, we received a large scale GTCC project. Furthermore, we also received orders (3 projects) of medium-capacity steam turbines and generator for coal and biomass-mixed thermal power facilities in Japan in FY2014. We also worked to expand and acquire projects in new markets overseas, besides those in Asian markets, and as a result, we successfully concluded receiving orders in Saudi Arabia. We continued our R&D in the development of elemental technologies for the high-temperature valves used in advanced ultra-supercritical (A-USC) steam turbines. In the field of geothermal power generation, we received an order for the first binary power generation facilities to be installed in the Takigami region in Kyushu, Japan. In addition, we also received several orders overseas, via our local partners, which included two projects in Indonesia and one project in Iceland.

As for photovoltaic power generation facilities, we completed an EPC project in December 2014 for Kisosaki Reclaimed Land Mega Solar, which included facilities with a capacity of 49.2 MW DC and 35 MW AC. We have also been pursuing increased efficiency for our power conditioning sub-systems (PCS) for photovoltaic power generation by adopting a configuration of 35 outdoor-type units with a single unit capacity of 1 MW. As for components, we have equipped chopper circuits with our SiC module and are now supplying the market with an indoor-type PCS equipped with an All-SiC module corresponding to 1,000 V DC with a single unit capacity of 1 MW and a conversion efficiency of 98.8%.

In the field of wind power generation, we are expecting to start construction and operations of large-scale wind power generation facilities, which have already completed the environmental assessment process. Fuji Electric is continuing to expand into the wind power business based on its component, system and prime contractor businesses. We are aiming to expand our market share for stabilization devices and have completed the development of a PCS for stabilization devices that has a capacity of 750 kVA and stand-alone operation functions.

In the field of fuel cells, we installed and started operations of a total of 10 fuel cells at four sewage treatment plants in FY2014. The fuel cells are compliant with the sewage digestion gas specification falling under the Feed-in Tariff (FIT) Scheme for renewable energy. In addition, we have also installed fuel cells compliant with city gas specifications in locations throughout Japan including hospitals, local heat supply businesses and universities (one fuel cell per location). In overseas markets, we have installed and started operations for fuel cells compliant with the nat-

ural gas specifications in South Korea and South Africa (one fuel cell per country).

In the field of nuclear power, four years have passed since the accident at Fukushima Daiichi Nuclear Power Plant, and in addition to gradually moving toward the maintenance phase for the site, a diverse range of technology development has begun, mostly under the efforts of the International Research Institute for Nuclear Decommissioning (IRID), which includes monitoring technology for the inside of containment vessels scheduled for decommissioning, as well as technologies for removing stagnant water and debris and methods for processing secondary waste resulting from contaminated water processing. Fuji Electric is focusing on several technologies which include the development of remote dismantling technology required in the decommissioning. We are also utilizing overseas technologies as we advance in developing applicable technologies, for example, stabilization technology for radioactive waste generated by nuclear power plants. Among efforts to be compliant with the newly enforced new regulatory standards, an enhanced standard design for various earthquake-resistant boards and function verification based on vibration tests are being promoted for nuclear power reactors. In light of these efforts, we have completed the development and are supplying nuclear power plants with medium-voltage switchgears capable of withstanding the seismic shocks required of nuclear power plants. With regard to nuclear fuel cycle related facilities, Fuji Electric is working with its customers to carry out various assessments for its installed facilities with regard to compliance with the new regulatory standards required in the restart of operations. Furthermore, we designed, manufactured and installed a piece of equipment for recovering an object that had been interfering with the reactor of the experimental fast reactor "Joyo" of the Japan Atomic Energy Agency. We successfully recovered the object while working in cooperation with members of the agency.

In addition to the efforts Fuji Electric is making to actively develop renewable energies such as geothermal, photovoltaic and wind based energies, as well as high-efficiency thermal power generation equipment and fuel cells for use in Japan and overseas, it is also contributing to society through its efforts in the field of nuclear fuel cycle and in the development of technologies required to maintain and decommission the Fukushima Daiichi Nuclear Power Plant.

## Thermal/Geothermal Power Plants

### 1 Start of Commercial Operations of Sur IPP Power Plant in Oman

Commercial operations commenced in December 2014 for the Sur IPP power plant (2,000 MW combined cycle power plant) operated by Phoenix Power Company in Oman. The main business operations of the Phoenix Power Company are being overseen by Japanese companies which include Marubeni Corporation and Chubu Electric Power Co., Inc. It is predicted that the current demand for power in Oman will increase by an average of at least 9% per year, and in light of this, the power plant is expected to play an important role in providing approximately 25% of the total domestic demand for power.

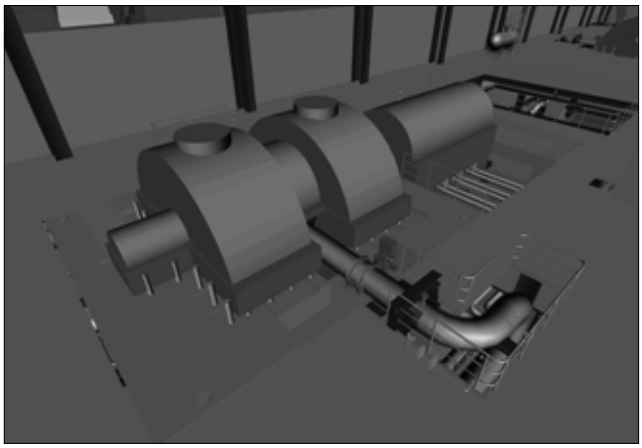
Fuji Electric has supplied the power plant, via Korean based Daewoo Engineering & Construction Co., Ltd., with a steam turbine and generator equipment set (328.2 MW×2, 161.7 MW×1). The steam turbine applies two casing reheat admission condensing double side exhaust. The condensers are located at the left and right sides of the low pressure turbine. The generator applies a hydrogen cooled type for 328.2-MW units and an air cooled type for 161.7-MW unit.

Fig. 1 Panoramic view of Sur IPP power plant

### 2 Unit 3 and Unit 4 at Ulubelu Geothermal Power Station in Indonesia

In August 2014, Sumitomo Corporation and PT Rekayasa Industri, a leading engineering company in Indonesia, contracted a full turnkey project with PT Pertamina Geothermal Energy (the Ulubelu Geothermal Power Plant Unit 3 and Unit 4 [58.8 MW×2] located in the southern Sumatra). Fuji Electric will supply main equipment such as geothermal steam turbine, generator and control units, and engineering service of the power plant as a subcontractor of Sumitomo Corporation. The completion of the power plant is scheduled in July 2016 for Unit 3 and in May 2017 for Unit 4. Fuji Electric has already installed the Ulubelu Geothermal Power Plant Unit 1 and Unit 2 (55 MW× 2), owned by an Indonesian state-owned power company, in the Ulubelu district in 2012. After the completion of the upcoming power plant construction work, Fuji Electric will have supplied main equipment of the geothermal power plant with a total output of over 220 MW in the Ulubelu district.

Fig. 2 Image of steam turbine and generator installation



### 3 Idemitsu Oita Geothermal Co., Ltd. Takigami Binary Geothermal Power Plant

Fuji Electric has received an order from Idemitsu Oita Geothermal Co., Ltd. to supply the Takigami Binary Geothermal Power Plant, which is schedule to start operations in March 2017, with the facilities and equipment at all stages of development including design, procurement, manufacturing and construction. Although high-temperature steam and hot water both gush out to the earth's surface, geothermal power generation has, up until now, only extracted high-temperature steam for utilization in power generation, but this power station will employ a binary system to make use of 130°C hot water (which, up until now, had been returned into the earth unused) in power generation. This system is planned to generate a maximum of 5.05 MW of electricity, for a yearly total of 31 million kWh. This amount of power generation, if converted in terms of general household consumption, is enough to supply approximately 8,600 households. After using the hot water in power generation, it will be restored to the earth, so the system has no more impact on geothermal resources than previous systems. This system is expected to contribute greatly to geothermal power generation in the future.

Fig. 3 Rendering of completed Takigami Binary Geothermal Power Plant

## Thermal/Geothermal Power Plants

### 4 Renovation of Power Generation Equipment with Combined Cycle Upgrade

Fuji Electric performed work for the Shinko Kakogawa Power Station of Kobe Steel, Ltd., which included the renovation of the existing CDQ Unit 1 steam turbine power generation equipment as well as a combined cycle upgrade for the existing gas turbine installation based power generation equipment.

Since the combined cycle system receives steam, which is generated from the heat recovery steam generator (HRSG), into the existing condenser during gas turbine start-up and stop, a flush box was added to the condenser. Furthermore, in order to accommodate operation that differs from the existing equipment, we improved operability and reliability by modifying the steam turbine control system and adding monitoring functionality, as well as by adding protection interlock.

We finished the work on schedule and operations for the equipment started in February 2015.

Fig. 4 CDQ unit 1 steam turbine power generation equipment

## Renewable Energy and Power Stabilization

### 1 Mega Solar Power Plant in Kisozaki Reclaimed Land (49.2 MW DC)

Fuji Electric received an order from Kisozaki MegaSolar Corporation, a subsidiary of Marubeni Corporation, to install photovoltaic power generation equipment with a capacity of 49.2 MW DC. The construction work is taking place on the reclaimed land in the town of Kisosaki, a region bordering Mie Prefecture and Aichi Prefecture. The photovoltaic power generation equipment has a total output of 35 MW AC, and 196,620 photovoltaic panels have been installed on a plot of land covering approximately 57 hectares (1,000 m×570 m). Construction started in July 2013 and was completed in December 2014. The 528 days of work were completed safely with no accidents. Fuji Electric is utilizing 35 power conditioning sub-systems (PCS) with a single unit capacity of 1,000 kW, and is performing interconnection, by means of a booster transformer, to the terminal of the 77 kV special high voltage network system of Chubu 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. 5 Panoramic view of mega solar on Kisozaki reclaimed land

### 2 Storage Battery Power Conditioning Sub-System “PVI800-3/750”

Fuji Electric has been undertaking the development and market deployment of power conditioning sub-systems (PCS) for large-capacity storage batteries in order to help solve output fluctuation problems that accompany renewable energy.

The storage battery power conditioning sub-system “PVI800-3/750” (800 V DC, 750 kW) is an indoor-only PCS with a single unit capacity of 750 kW and a maximum efficiency of 97.7%, which includes the internal power supplies (cooling fan power supply, control power supply). A system power factor compensation of 0.9 (833 kVA output) is possible when the storage battery is outputting 750 kW, and the system supports both compensation requests for the system power factor and a high operating rate for user equipment.

The PCS is distinguished by its stable waveform characteristics during stand-alone operation, and it can be utilized in micro-grid systems as a stand-alone power supply for wind farms and the like.

Fig. 6 “PVI800-3/750”

## Nuclear Power

### 1 Retrieval for Bent MARICO-2 Test Subassembly Using Remote Control Device of Experimental Fast Reactor "Joyo"

In the experimental fast reactor "Joyo", the incident that the MARICO-2 test subassembly (the irradiation rig with an instrumental line that is inserted into the core) was bent in the reactor vessel occurred in June, 2007.

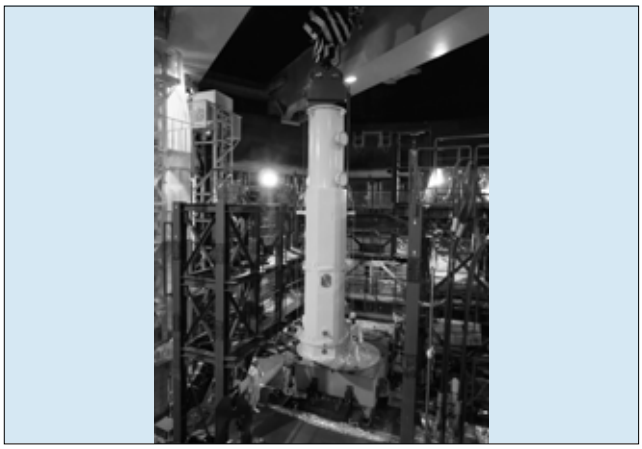
Fuji Electric has designed and manufactured the device to retrieve the bent MARICO-2 test subassembly from March, 2012 to March, 2014.

The retrieval works have had the restrictions that the work site was under the high temperature and high radiation environment that was isolated an atmosphere specific to the fast reactor, the bent test subassembly was not possible to lift straight and so on.

Therefore, the retrieval device was composed of various units which were adequately shared each function for the works.

Fuji Electric and Japan Atomic Energy Agency have jointly accomplished the retrieval works for the bent MARICO-2 test subassembly using remote control device in "Joyo" in September, 2014 after the works started in June, 2014.

Fig. 7 Retrieval works inside reactor containment vessel



### 2 Medium-Voltage Switchgear (Earthquake Resistant Specification) for Nuclear Power Plants

Fuji Electric has successfully developed and has started supplying medium-voltage switchgears that are earthquake resistant, a feature that is required by nuclear power plants. This medium-voltage switchgear was designed in consideration of the regulatory standards applied to nuclear power facilities, and can withstand a horizontal acceleration of 3 G and vertical acceleration of 2 G. This value is equivalent to an intensity of about 3 times the earthquake resistant performance required of conventional nuclear power facilities. This medium-voltage switchgear is characterized by its ability to verify function maintenance during times of vibration even when the circuit breaker is in standby mode (a state in which the circuit breaker is pulled out to the test position), as well as by its maintaining the same level of easiness as general specification switch boards even with regard to the ease of putting in and pulling out the circuit breaker. This means that the unit satisfies the seemingly contradictory requirements of being able to firmly fix the circuit breaker in place, while also allowing for easy putting in and pulling out of the circuit breaker without the use of tools.

Fig. 8 Medium-voltage switchgear (earthquake resistant specification)

# Social Infrastructure

Power System and Distribution
Energy Management
Social Environment



## Outlook

In the power system and distribution field, Fuji Electric develops and delivers supervisory control systems for various facilities related to power transmission and distribution and telecontrol (TC) equipment required for remote control. It also handles dam management systems and power generation centralized supervisory control systems required for the power generation field.

In power transmission and distribution, efficient operation of power equipment in line with the forthcoming "electricity system reform" and efficient application of water, as represented by hydroelectric power plants, will be increasingly important. In this situation, Fuji Electric has continuously delivered power system and distribution supervisory control systems and delivered new power generation centralized supervisory control systems for Miyazaki Prefecture Public Enterprise Bureau, Iwate Prefecture Public Enterprise Bureau and Arakawa Hydro Electric Power Co., Ltd., new remote monitoring consoles for Kurobe Dam and Sennindani Dam of the Kansai Electric Power Co., Inc. and new dam management systems for Kamuro Dam in Yamagata Prefecture and Yanase Dam of Shikoku Regional Development Bureau. In addition, we make use of the dam gate control technology to work on the introduction of remote supervisory control of floodgates and land sluices as measures against tsunami. We have also delivered remote supervisory control systems for seven floodgates in the harbor district of the Bureau of Port and Harbor of the Tokyo Metropolitan Government.

As part of overseas development, we have started demonstrating a distribution automation system in Asia based on our track record in Japan and intend to continue to make international contributions mainly in emerging countries.

In the energy management field, with the power system reform imminent, the time for a structural change is here. This should include the establishment of market competition such as having new players enter the electric power industry, and the selection of power companies.

As the selection-based, competitive market environment progresses, full-scale efforts are expected to be made for adjustments to the peak hour supply capacity on the assumption of demand response and negawatt trading and for energy management systems (EMSs) that support efficient use of energy.

In FY2014, which is the last year of large-scale demonstration projects (in Kitakyushu City and Keihanna Science City), Fuji Electric completed testing the demand control technology, system stabilization technology and optimum facility operation technology for introducing large amounts of renewable energy. This demonstration has enabled us to construct a new form of cluster energy management before others. We have achieved results with the cluster energy management system (CEMS) developed in the Kitakyushu Smart Community Project. Based on this, we are preparing to offer the "new power supply and demand control system" as a cloud-based service for the purpose of contributing to power retail liberalization, which starts in April 2016.

In the power system reform expected to progress in the future, utilization of efficient and economical renewable energy is necessary. Fuji Electric is moving ahead with the development of new technologies and their application to operational systems.

We are actively rolling out systems overseas and have delivered a micro-grid system for the Kingdom of Tonga, photovoltaic power generation system for the Republic of Kiribati and large-capacity power conditioning sub-system (PCS) for Zhoushan marine science and technology demonstration island, a project in which we have participated from the demonstration phase.

Regarding development, we developed a hybrid power system analysis simulator for Chubu Electric Power Co., Inc. to evaluate the effect of introducing a large amount of renewable energy on the system, verify smart-grid control and study operation and control for stable power supply. For Tohoku Electric Power Co., Inc., we developed a distribution static var compensator (SVC) for overcoming the problem of voltage

rise due to introduction of a large amount of photovoltaic power generation into the distribution system.

Furthermore, we have conducted research jointly with the Institute of Physical and Chemical Research (RIKEN) and verified the possibility of reducing fuel and lighting costs by having optimum facility operation for K computer.

In the future, we intend to make use of our accumulated technology and know-how to realize stable supply of electric power and roll out new EMS capable of addressing global environmental issues not only in Japan but also overseas.

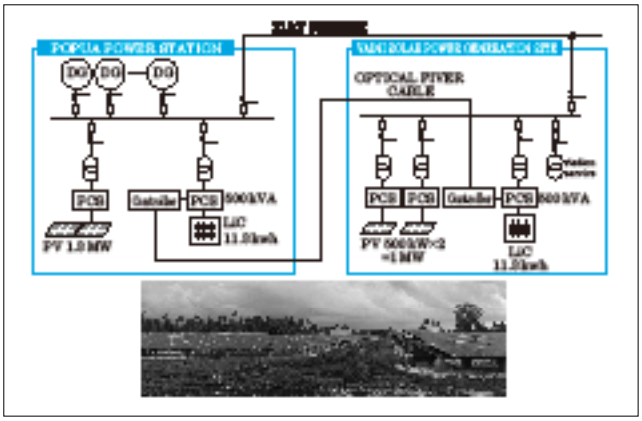
In the social environment field, there is a demand for a reduction of operation cost (life cycle cost) of factories and offices. Fuji Electric has focused on the wastewater treatment facilities, which account for a large portion of the running cost of factories and offices, and developed a technology that reduces the running costs of wastewater treatment facilities. The technology is intended for the food and beverage factories and other fields. It makes it possible to reduce the electric power cost and industrial waste disposal cost by introducing bacteria of genus Bacillus, which have a high wastewater treatment capability, and an agent (mineral) that maintains their activity as a new solution, in addition to energy-saving proposals including the introduction of conventional high-efficiency electric equipment and inverters. In the future, we intend to expand the fields of application to include persistent wastewater treatment, etc. and meet a wide range of customer needs.

## Social Infrastructure

### 1 Micro-Grid System for the Kingdom of Tonga

Fuji Electric was awarded jointly with NBK Corporation an order by Tonga Power Limited for a micro-grid system based on the "Project for Introduction of a Micro-Grid System under the Grant Aid" for the Kingdom of Tonga. It was delivered to Tongatapu Island in March 2015. This system is composed of 1 MW photovoltaic power generation facilities and two 500 kW power storage systems. It restricts output variation of unstable renewable energy by high-speed charging and discharging of the power storage devices to supply stable power to the island. The power storage systems are installed in a distributed manner in the new photovoltaic power plant and the existing diesel power plant, which are coordinated for control. Because a lithium-ion capacitor has been adopted for the power storage devices, charging and discharging of large currents and a stable cycle life of over four hundred thousand cycles can be expected.

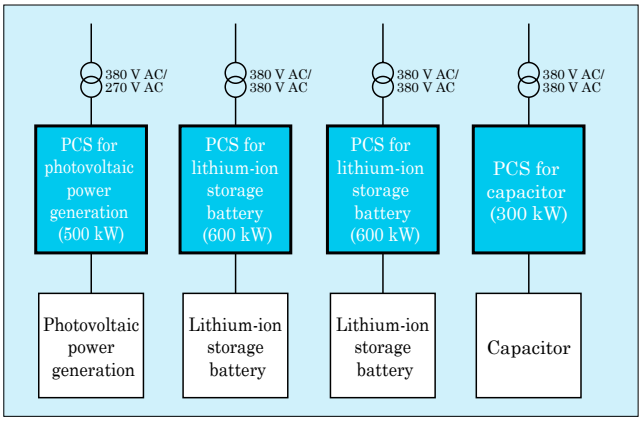
Fig. 1 System configuration and panoramic view of photovoltaic power generation station




### 2 Large-Capacity PCS for Zhoushan Marine Science and Technology Demonstration Island of Zhejiang University in China

Fuji Electric has participated with Zhejiang University in the new energy micro-grid demonstration on Zhoushan marine science and technology demonstration island of Zhejiang University in China. The project is intended to demonstrate comprehensive new energy usage that makes full use of power generation from large-scale and diverse natural energy sources (wind power, photovoltaic and ocean current) and realizes power stabilization via hybrid power storage control using storage batteries and capacitors. Fuji Electric conducted research on the system and main equipment jointly with Zhejiang University from the planning phase of the project and delivered 500 kW PCS equipment for photovoltaic power generation, 1,200 kW PCS equipment for lithium-ion batteries and 300 kW PCS equipment for capacitors. At the same time, Fuji Electric collaborated with Zhejiang University in studying and developing a PCS that meets the special needs of an isolated island and localized specification of the control system and gradually applied the results to the demonstration project.

Fig. 2 Overview of configuration of new energy micro-grid demonstration




### 3 Photovoltaic Power Generation System for the Republic of Kiribati

Fuji Electric delivered a 400 kW photovoltaic power generation system for the Republic of Kiribati as a grant aid project by the Pacific Environment Community (PEC) Fund. This system is built as a distributed system mainly including four 100 kW PCSs for photovoltaic power generation systems provided by Fuji Electric. In order to make the most of the limited land, we constructed a roof-type platform and installed photovoltaic modules over existing buildings. In this way, when maximum power is generated during the daytime, the system can supply the power of approximately 12 to 20 % of the overall demand.

In view of rapid variations in the amount of insolation, which is a characteristic of equatorial areas, output restriction control is provided to make it possible to reduce the maximum generated energy. In Kiribati, construction of additional photovoltaic power generation systems is planned and provision of an electric power storage system is being considered for power system stabilization.

For this reason, the system has been configured to make it easy to install a storage battery system.

Fig. 3 Roof-type photovoltaic modules

## Social Infrastructure

### 4 Distribution Static Var Compensator for Tohoku Electric Power Co., Inc.

There is the problem of a voltage rise caused by introducing a large amount of photovoltaic power generation into the distribution system. To solve this, Fuji Electric developed and delivered jointly with Tohoku Electric Power Co., Inc. a distribution static var compensator (SVC) that uses a magnetic flux-controlled variable inductor. The main features are as follows:

(1) The main circuit is equipped with a continuous inductance adjustment function in a simple configuration composed only of windings and iron cores.
(2) The configuration does not include a cooling fan or harmonic filter capacitor and features excellent lifespan and reliability.
(3) It allows control to be performed in view of coordination with other pieces of voltage regulating equipment such as a step voltage regulator (SVR).
(4) The controller is equipped with measuring and monitoring functions to achieve remote monitoring and control.

Fig. 4 Distribution static VAR compensator

### 5 Optimum Facility Operation for "K Computer"

Fuji Electric has collaborated with the Institute of Physical and Chemical Research (RIKEN) in research and conducted a simulation of optimum heat source operation since FY2014 for the purpose of reducing the operational cost of the "K computer." The annual power consumption of the entire facilities of RIKEN Advanced Institute for Computational Science (AICS), where the "K computer" is installed, is equivalent to that of about 25,000 general households. The cold heat demand that is high throughout the year poses a challenge of reducing the operational cost. In the joint research, Fuji Electric's optimum operation function was used to build an energy model of K to conduct a simulation and identify the minimum cost. As a result, it has been confirmed that improving the facility operations can reduce the fuel and lighting cost by 1.8% annually. In FY2015, we intend to gather field data to verify the effect in actual operation and work on further improving the operational efficiency of the K computer together with RIKEN.

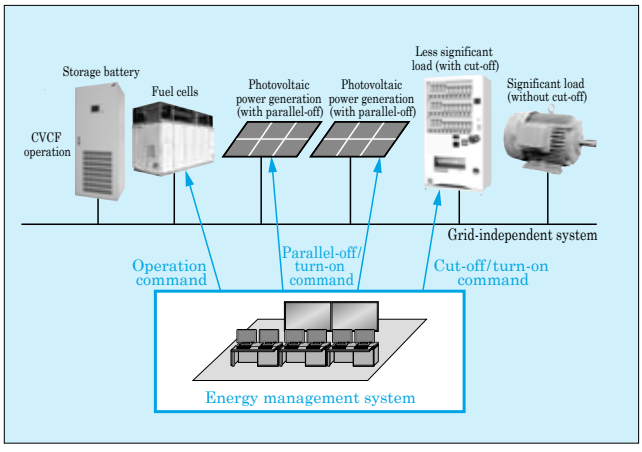
Fig. 5 "K computer," the world's first supercomputer to hit 10 petaflops


### 6 Technology for Isolated Operation in Disaster Situations Using Photovoltaic Power Generation

Fuji Electric has developed a technology that allows isolated operation even in disaster situations by combining a small-capacity storage battery with photovoltaic power generation, which has unstable output. Photovoltaic power generation is paralleled off when the photovoltaic power generation output is too large, and less significant loads are cut off when the loads are too great. In this way, the supply-and-demand balance can be adjusted to realize isolated operation even with a small-capacity storage battery. This system eliminates the need for expensive large-capacity storage batteries, and an electric power supply system can be constructed at low cost.

Electric power supply systems that make use of this technology can be combined with power generation facilities capable of stable supply such as emergency generators and fuel cells. Accordingly, isolated operation is possible even in the night-time when photovoltaic power generation output cannot be expected and electric power can be supplied continuously throughout the day and night.

Fig. 6 Example of configuration of electric power supply system



## Social Infrastructure

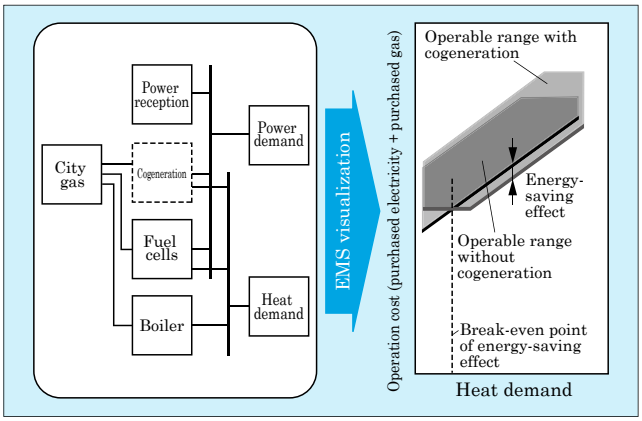
### 7 Technology to Visualize Energy Operation Optimization Based on Formula Manipulation Technology

As one energy management system (EMS) function that helps optimize energy operation, Fuji Electric has developed a technology for analyzing and visualizing rooms for energy saving from the plant device configuration information.

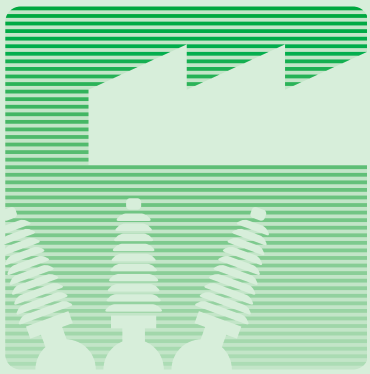
First, the power consumption characteristics of the individual devices that constitute the plant and various operation restricting conditions are given as formulae. Then, the feasible operation range of the plant can be automatically calculated by a symbolic and algebraic computation algorithm, a cutting-edge formula manipulation technology. The energy saving effect can be visualized by comparing the feasible range of operation both before and after the equipment is installed in the plant.

We intend to make use of this technology for a trial calculation of the effect of installing an EMS and to verify the operational effect of operating an EMS both in Japan and overseas.

Fig. 7 Example of visualization technology (effect of introduction of cogeneration)



# Industrial Infrastructure



Substation Systems
Industrial Plants
Industrial Measuring Instruments

## Outlook

### Substation Systems

Our substation system business makes full use of electric distribution facilities and large capacity power electronics equipment for sectors including the electrical power, industrial, factory equipment and transportation sectors, while we also continue to develop business solutions for increasing reliability and efficiency, as well as measures for the environment. We are also developing equipment and devices for overseas markets so that we can achieve our goal of expanding our overseas business.

In the field of power substations, we are developing our business in order to support the supply of stable and highly reliable electric power. These developments are characterized in our 300-MVA transformer, which we delivered utilizing a freight car loading system for transportation, and our 66-kV substation facility, which we delivered for the Bahrain Electricity and Water Authority via a turnkey system. Furthermore, we are also advancing in the development of a new gas insulated switchgear (GIS) compliant with IEC standards.

In the field of industrial and electrical equipment we have been receiving orders to perform upgrade work of existing equipment, and have been making installations to ensure the stable operation of the equipment, while we are also actively developing solutions to improve reliability by means of maintenance services for performing equipment diagnostics of aging equipment, etc.

In the field of industrial power supplies, requirements have been increasing regarding the specifications of power quality improvement systems, and against this backdrop, we have completed the delivery of our first self-commutated frequency converter with a rated capacity of 20 MVA, as a unit that aims to implement bi-directional power interchange and stabilize frequency.

In the field of fixed installations of the railroad, we have been actively supplying and installing environmentally-friendly, energy-saving (energy conservation), maintenance-saving equipment, such as our dry air utilizing 24-kV and 72-kV eco-friendly C-GIS, in order to carry out the upgrade work of existing substations for ensuring stable transportation.

### Industrial Plants

In Japan, there has been an expansion in the investment in assets to upgrade and streamline facilities, especially in the materials industry (metals, chemicals) and the assembly and machining industry (automobiles, electrical machinery). In addition, investment in equipment is expected to be continuously increased overseas in Asian markets, and expanded especially in markets in ASEAN.

Our industrial plant business is providing energy-conservation solutions centered on “electricity + heat,” as well as offering life cycle services to improve efficiency in energy usage during production processes and to stabilize the operation of equipment. We are continuing to develop total solution services packaged as problem solution systems for customers through the utilization of IoT (Internet of Things) and cloud technology developments based on core technologies including drive control technology, measurement control technology, electro-mechanics, energy management technology and AIR environmental technology.

In the field of metal industry, we have been developing products that are compliant with overseas standards, such as IEC and the CE marking, as part of our effort to increase the number of projects at high-grade steel production sites overseas. At the same time, there has been expanding demand for the upgrade of aging facilities in Japan, and we have been meeting this demand for upgrades with the launch of compatibility-friendly products such as our DC variable speed control unit “LEONIC-M Series” and AC variable speed control unit “FRENIC4000 Series,” as well as our migration-friendly products which include the small- and medium-scale monitoring and control system “MICREX-VieW XX.”

In the field of chemical industry, the trend has been to increase investment in equipment centered on new materials. We have been optimizing the batch

control package in the MICREX-VieW XX.

In the field of waste disposal industry, we have been enhancing principal facilities, while aiming to extend the operating life of 30 year-old facilities an extra 10 years. With regard to distributed control systems (DCS), we completed the upgrade of an inherited system. The upgrade work went smoothly and was completed in a short period of time. In the field of cement, we have achieved unitary management in mixed systems, while concurrently working on a similar DCS upgrade plan to extend equipment lifespan, as well as many partial upgrades as part of staged enhancements.

In the field of assembly and production industry, we have been supplying comprehensive equipment management services at all stages of the life cycle, as well as in-facility engineering that contributes to environmental optimization and line control and energy (electrical and heat) control in industrial facilities. We are aiming to expand our scope of business in light of the increase in investment in equipment in the field of assembly and machining in the Japanese and Asian markets. We have installed an optimized energy management system (EMS) and a cogeneration system utilizing a gas engine and fuel cell configuration at Fuji Electric's Yamanashi Branch Factory, and as a result, have succeeded in stabilizing electric power and minimizing energy costs. We have developed the "Integrated Cloud Service" as the foundation on which we plan to sequentially develop and offer other services, which include an EMS service, maintenance service and operation monitoring service.

In the field of AIR environmental industry, we have developed and have commenced sales of an energy-saving hybrid air conditioner utilizing indirect outside air, as well as an energy-saving module type data center that makes use of outside cold air, snow and ice.



#### Industrial Measuring Instruments

Our industrial measuring instrument business is offering a range of products including measuring equipment and sensors, controllers, industrial electric heating and radiation equipment and systems, while it is also working to create a sensor platform that can meet the requirements of customer environmental policies and safety and security standards, as well as meet the needs of an IoT generation.

We are also developing feature-rich measuring instruments and sensors for the environment and energy field. We are also the first in the industry to develop and commence sales of an aerosol compound analyzer, for use in performing atmospheric environment measurements, capable of analyzing in real-time the components of micro-sized particulate matter (PM2.5), as well as biomass gas analyzer, for use in biomass plants, capable of measuring $CH_4$, $CO_2$, $H_2S$ and $O_2$ via a single analyzer.

In the field of controllers, we have developed application-specific packages, which combine the MICREX-VieW XX, as the core component, with measuring equipment, power electronics equipment, control software and other components. In the future, we plan to expand our lineup of packages to meet the needs of various kinds of applications, such as combustion control and crane control.

We have developed and have started offering a new melting furnace for use in industrial electric heating applications. This high-efficiency and compact furnace utilizes a high-efficiency IGBT power supply and special coil. We plan to expand widely into Japanese and overseas markets.

With regard to radiation equipment and systems, we are focusing our efforts on products that can contribute to reconstructing Fukushima. We have developed and released to the market an exhaust pipe dust monitor capable of high-temperature operations at incineration facilities, as well as a high-sensitivity gamma-ray visualization Compton camera for supporting decontamination work. In addition to products that contribute to the reconstruction of Fukushima, we also plan to develop radiation measuring equipment that can help support anti-terrorism activities.

## Substation Systems

### 1 Completion of Supply and Installation of Additional "S-Former" for ALBA (Aluminum Bahrain B.S.C) Line 5.

Fuji Electric, which supplied six units of "S-FORMER" for aluminum smelting for ALBA of Bahrain in 2004, has completed full-turnkey works of installing an additional unit of S-FORMER. We surveyed an existing buried object, performed civil engineering and foundation works, installed equipment, four kinds of cooling water piping, DC bus bars and 220 kV cables, and performed commissioning tests. These tasks can be characterized as follows:

(1) Additional equipment had to be installed in a limited space. We thus designed the layout and foundation optimally and constructed them based on the results of the survey on an underground buried object at the planned site.

(2) The works for the additional installation were implemented during the continuous operation of the existing smelting facilities without causing power interruption. To connect the DC bus bar in particular, successful welding was achieved under conditions where there was a high magnetic field caused by large currents during the plant's operation. This was done while ensuring safety and confirming and managing the work procedures.

Fig.1 "S-FORMER" for aluminum smelting

### 2 Self-Commutated Frequency Changer for Minamata Factory of JNC Corporation

In January 2015, Fuji Electric delivered its first self-commutated frequency changer to the Minamata Factory of JNC Corporation. The unit interconnects a private power generation system (50 Hz) with the power system of Kyushu Electric Power Co., Inc. (60 Hz) and aims at implementing bi-directional power interchange and stabilizing frequency. The unit is configured from 3 multiplex transformers and inverter and has a rated capacity of 20 MVA. The main features are as follows:

(1) Capable of effective/reactive power control via the self-commutated inverter

(2) Capable of being operated while switching between fixed frequency control, fixed power control and autonomous-operation three-pattern high-speed control by making use of a high-performance digital control device

(3) Employs a 3-level water-cooled inverter with a low-profile compact vertical shape that has contributed to suppressing the device height to reduce the size of the panel

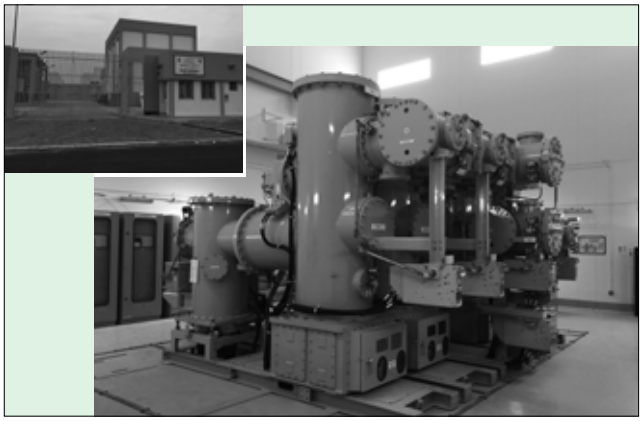
Fig. 2 Self-commutated frequency changer

### 3 Start of Operations of ESL 66-kV Substation and HYL 66-kV Substation for Bahrain Electricity and Water Authority

The Eskan Samaheej (ESL) 66-kV substation and Huneniyah (HYL) 66-kV substation have been constructed to supply electricity to the new residential area in the Kingdom of Bahrain. The substations started operations, respectively, in January and March 2015. Each substation was configured with a 66-kV gas-insulated switchgear, 11-kV metal clad switchgear, control and protection panels, auxiliary power supply equipment, neutral earth resistor, high/low voltage cables and others.

This project was contracted as a turnkey project for handing over to the customer in condition of ready for operation, and most of the work for the project was undertaken at local project offices configured by the foreign engineers of each country. The project has been highly appreciated by the customer on account of the comprehensive activities that were carried out locally, such as the basic design of the substation, confirmation of equipment specifications, acquisition of price quotes, arrangement of manpower and equipment, progress management, installation work, testing and a number of meetings with customers.

Fig. 3 ESL 66-kV substation external appearance and 66-kV gas-insulated switchgear



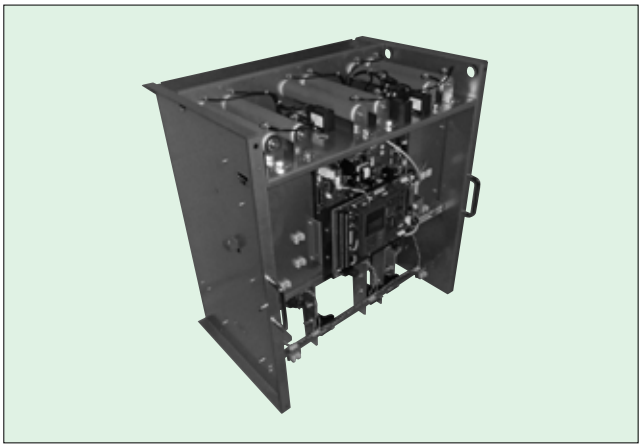
## Industrial Plants

### 1 Series Expansion for DC Motor Control Unit “LEONIC-M Compact”

We carried out additional development to enhance the performance of the “LEONIC-M Compact” DC motor control unit for use in factories, and as a result, we were able to expand the series of 150 kW units. The new armature main circuit stack has a rated voltage of 440 V DC, and comes in two models including a 320 kW, 850 A model and a 450 kW, 1,200 A model. The main features are as follows:

(1) It is significantly smaller as a result of adopting a module type thyristor in place of the previous unit type.
(2) The armature main circuit comes in a lineup of two types including a single-side type and a reversible type capable of reversible control.
(3) A variation of options are available for the field circuit including a single-phase mixed bridge.
(4) It inherits the features of previous LEONIC-M Compact units, making it easy to perform upgrade work and linking with existing facilities.

Fig. 4 Armature main circuit stack



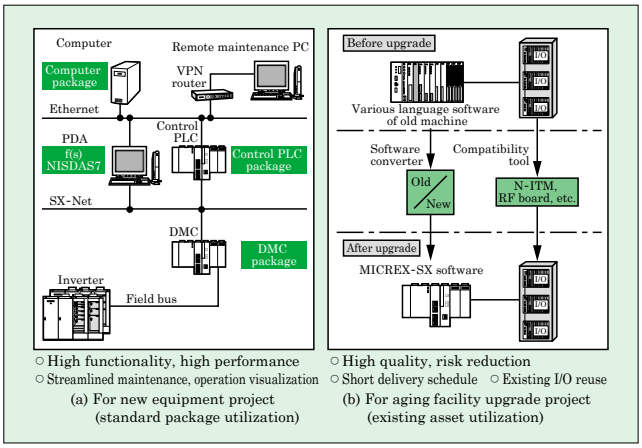


### 2 Packages and Upgrade Tools for Steel Plant Control System

The steel plant control system required a high performance and reliability, as well as enhanced functionality such as streamlined maintenance and operation visualization. Fuji Electric provided an optimized solution by developing and adopting various packages for the new equipment as well as various upgrade tools for the upgrade of the aging assets. The main features are as follows:

(1) Standardized packages for each piece of equipment used for rolling mills, processing lines, and so forth.
(2) Packaged high-speed drive control in the drive master controller (DMC)
(3) High-speed data collection and visualization at the controller level via the use of “f(s) NISDAS7”
(4) Effective use of existing system assets through use of a software converter and compatibility tools (compatible I/O series, compatible transmission board, compatible drive device)

Fig. 5 Packages and upgrade tools for steel plant control system

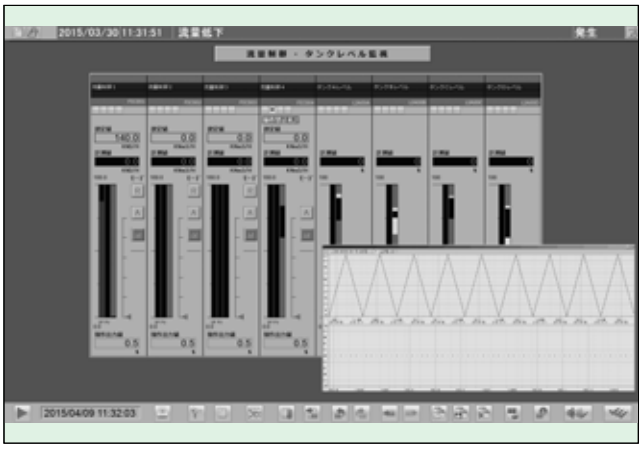



### 3 Functionality Enhancement for “MICREX-NX” Information and Process Control System

Fuji Electric is supplying the Information and Process Control System “MICREX-NX” to support “safety of production processes,” “continuation of processes” and “comfortable operations” at plants. We have recently made the following enhancements to the system’s functionality in order to better meet the needs of steel plant users.

(1) Improved visibility
We adopted a universal design for the screen layout, instrument faceplate and overview.
(2) Advanced security measures
It is now possible to suppress load increases and defend against viruses by allowing only registered programs to execute.
(3) Flexible update and expansion through a general-purpose interface
The use of a FL-net compliant LAN link device makes it possible to have a common memory interface between devices.

Fig. 6 Operation screen (universal design)



## 4 Monitoring and Control System for Chemical Plants

Fuji Electric upgraded the electrolytic cell control equipment at the Wakayama Factory of Nankai Chemical Co., Ltd. by replacing the aging monitoring and control system, initially installed by a different company, with the small- and medium-scale monitoring and control system "MICREX-VieW VX".

This was our first time installing a monitoring and control system for a caustic soda (sodium hydroxide) manufacturing plant, but we proceeded with the work after ensuring there would be no problems through carrying out in-depth discussion with the customer and inspecting the site firsthand. The construction period for replacing the equipment at the plant only took 9 days. We successfully completed the upgrade work on schedule through joint efforts with Daiso Engineering Co., Ltd. to formulate the replacement plan.

We carried out the construction work by ensuring that the upgraded system would guarantee the reliability and maintainability required for long-term, stable use of the equipment, while also emphasizing economic aspects by reusing the cabinets of the existing equipment, etc.

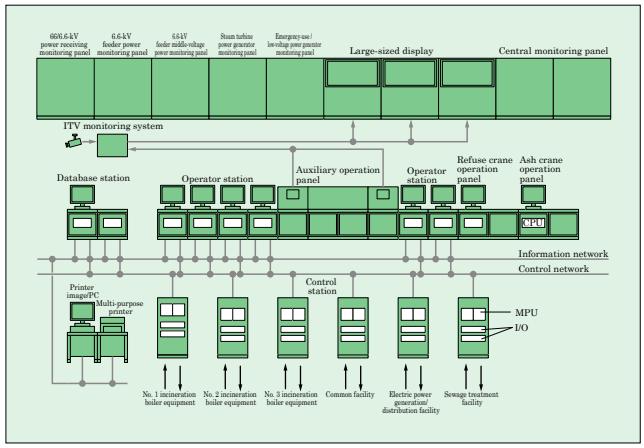
Fig. 7 Electrolytic cell control system for Wakayama Factory of Nankai Chemical Co., Ltd.

## 5 Distributed Control System for Waste Incineration Facilities

Waste incineration facilities that started operations before around 1990 are currently entering the upgrade period of their life cycle. However, the financial situation for many municipalities is quite severe, so there is increasing demand for the implementation of planned and efficient maintenance, management, and upgrading to preserve and extend the life of facilities. In order to achieve this, it is necessary to make effective use of the existing facilities (stock management) to decrease life cycle costs.

Against this backdrop, there is also an increasing need to upgrade distributed control systems (DCS), which are responsible for the main operation of the facilities. The figure shows a system for a harbor cleaning factory. The upgrade work was carried out in its entirety during the routine inspection period in September 2014. The construction period was greatly reduced by reusing existing equipment and materials such as cabinets and external line cables. The upgraded system started up without any trouble, and the upgrade work has contributed greatly to the stable operations of the facilities.

Fig. 8 Computer system for harbor cleaning factory plant control

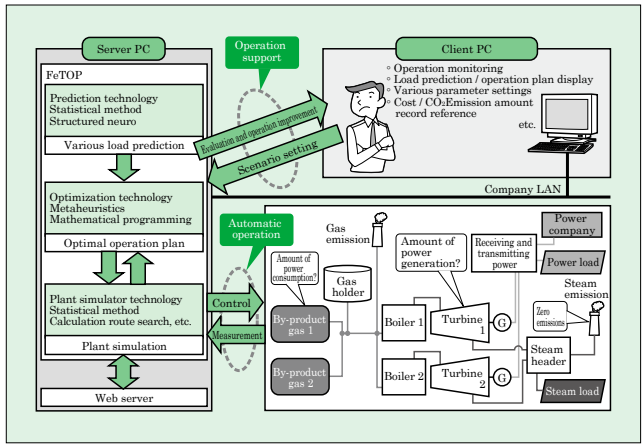



## 6 Optimal Operation System "FeTOP" for Energy Plants

Fuji Electric has developed and sold the "FeTOP" as a system that optimizes operations in order to decrease the cost and environmental burden of energy plants that supply electricity, heat and steam to factories and offices. In addition to assembly and processing factories and steel plants, the system has recently started being utilized at waste water treatment facilities and large hospitals.

(1) High-precision prediction of energy supply and demand on a continual basis.
(2) Capable of stand-alone operation in consideration of all of the various operating conditions (supply and demand, operating rules, constraints, characteristics, etc.) by means of a unique optimization technology that utilizes metaheuristics.
(3) Comes with an operation support environment including a plant simulator, and is capable of being used for degraded operation verification at the time of failure, operational training, etc. It can also be equipped to Fuji Electric's EMS platform "Energy GATE."

Fig. 9 Main functions of "FeTOP"



## Industrial Plants

### 7 Steam Generation Heat Pump

We have started the mass production design of a steam generation heat pump that recovers unused low-temperature exhaust heat (60 to 80°C) in factories, as well as regenerates steam at production sites. The main features are as follows:

(1) High efficiency

Based on our heat pump cycle technology cultivated in our vending machine business, the unit is capable of achieving a coefficient of performance (COP) of up to 3.5 by adopting a steam generation optimization method that utilizes unique two-phase heating.

(2) Small size and low cost

Cost effectiveness has been maximized by carrying out a critical design for the heat exchanger based on the use of a uniquely developed steam generation heat pump simulator. Furthermore, the unit achieves a setting area comparable to a vending machine, being within 1 m × 1 m. We have been carrying out field tests for the unit starting in FY2013 at our Mie Factory and continuing from FY2014 at our Iiyama Factory.

Fig. 10 Steam generation heat pump (field test machine)



### 8 Smart Factory System for Yamanashi Factory

Optimization EMS and cogeneration system has been installed at the Yamanashi Factory, utilizing a gas engine and a fuel cell, as part of the plan to introduce a smart factory system incorporating the ideal mix of electric power and heat. The main features are as follows:

(1) Energy creation: Supplies the factory with its full load by utilizing the cogeneration electric power.

(2) Energy conservation: Converts exhaust heat generated by the cogeneration into steam or cold water, thus supporting effective use by the factory facilities.

(3) Energy optimization: Minimizes costs by creating the optimized operation plan for the energy supplying equipment based on power and heat demand predictions.

(4) Power stabilization: Achieves stabilization by connecting the cogeneration and power company grid to create power supply redundancy, as well as by utilizing a 1-cycle VCB to compensate for power company-based interruptions and blackouts, sustaining the power supply for the factory load.

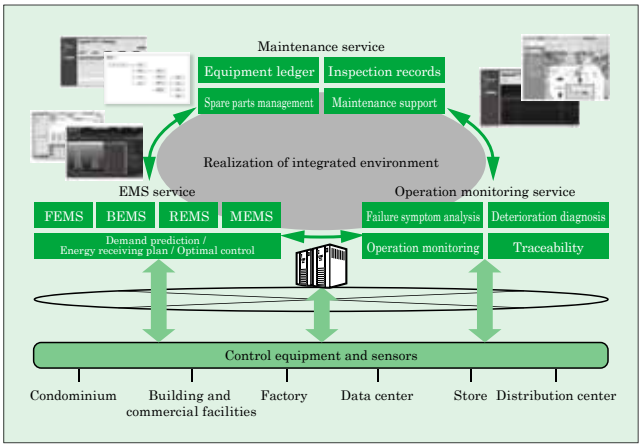
Fig. 11 External appearance of cogeneration system

### 9 "Integrated Cloud Service"

We have developed an "Integrated Cloud Service" that comprehensively supports life cycle management of equipment. We will begin sequentially supplying the service during FY2015. This is a service that integrates an energy management system (EMS) service, operation monitoring service and maintenance service by means of an integrated cloud infrastructure based on several technologies including Fuji Electric's specialized sensing technology, energy conservation analysis technology, demand prediction technology, quality trend analysis technology and equipment deterioration diagnosis technology.

It performs monitoring of operating conditions in a cloud environment, while comprehensively managing various data and information. As a result, the system contributes to achieving intelligence, safety and security of equipment at all stages of the life cycle including installation, operation and upgrade, while also supporting total optimization, including cost minimization and efficiency maximization from the viewpoint of management.

Fig. 12 "Integrated Cloud Service"



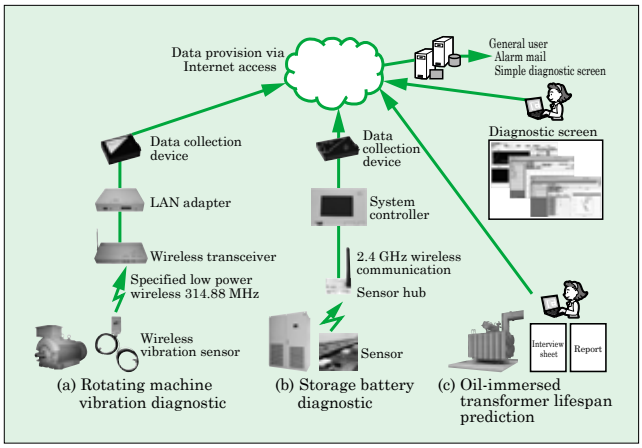
## Industrial Plants

### 10 Cloud-Based Equipment Maintenance Service

Fuji Electric have been engaged in the life cycle business in order to ensure stable and optimized operation for plant equipment at all stages of the life cycle including installation, operation and upgrading. In particular, equipment maintenance services have been facing several problems in recent years: aging of equipment, retirement of skilled maintenance engineers and maintenance of equipment in foreign countries. In order to solve these problems, we have established a cloud-based equipment maintenance service and have been enhancing its functionality. The service includes several functions such as operation monitoring, equipment diagnosis, failure symptom analysis, equipment management support and maintenance operation support. Recently, we have developed the following equipment diagnosis functions for compatibility with cloud environments.

(1) Diagnosis for detecting and notifying abnormal vibration of rotating machine bearings
(2) Diagnosis for the monitoring of storage battery degradation trends and early detection of abnormalities
(3) Diagnosis to estimate the remaining life of oil-immersed transformers

Fig. 13 Cloud-based equipment maintenance service

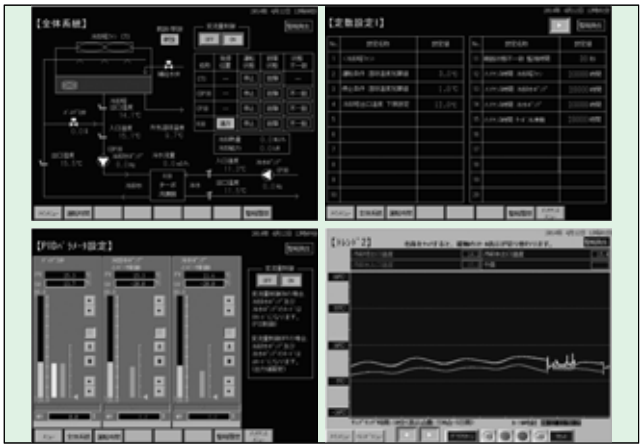



### 11 Industrial Use Air Conditioning Control Software Platform

Fuji Electric has teamed up with Fuji Furukawa Engineering & Construction Co., Ltd. to develop a software platform for sequencers characterized by its enhanced efficiency in controlling industrial-use energy-conservation equipment. Applicable equipment include air conditioners, pumps, refrigerators and cooling towers. The main features are as follows:

(1) It comes standard with a control function capable of changing the cooling water temperature based on the outside-air wet-bulb temperature, thus greatly improving the coefficient of performance for inverter refrigerators.
(2) It comes standard with a dew point calculation function, thus greatly improving humidity control accuracy. Furthermore, it is more efficient than normal platforms because it can perform reheating and humidifying at the minimum required cooling level during constant temperature and humidity control.
(3) There is no need to use a laptop PC for configuring settings. Control settings can be made easily from the touch panel.

Fig. 14 Configuration settings status screen

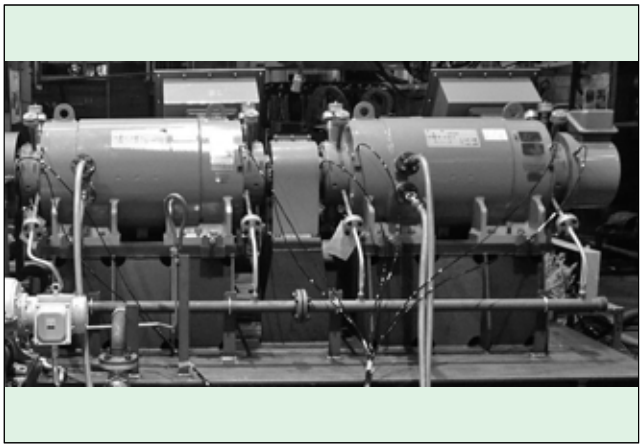


### 12 High-Speed Electric Power Generation System for Exhaust Heat Recovery Steam Turbines

We installed a high-speed electric power generation system for use with exhaust heat recovery steam turbines at a Japanese company. The generator has specifications of 350 kW, 440 V, 6 poles, 9,100 $min^{-1}$, and 455 Hz. Two units in tandem are connected to a steam turbine. This power generation system was developed to utilize exhaust heat, and it improves generation efficiency by approximately 15% compared with previous products. The main features are as follows:

(1) It directly connects the steam turbine with the generators without requiring a reducer, and this increases efficiency compared with previous methods, which suffered from a lower power generator rotational speed due to the use of a reducer.
(2) It achieves frequency conversion by utilizing a vector-control inverter and power supply regenerative operation PWM converter.
(3) It utilizes permanent magnet synchronous generators, resulting in higher efficiency than conventional winding generators.

Fig. 15 Two-unit configuration of high-speed generators



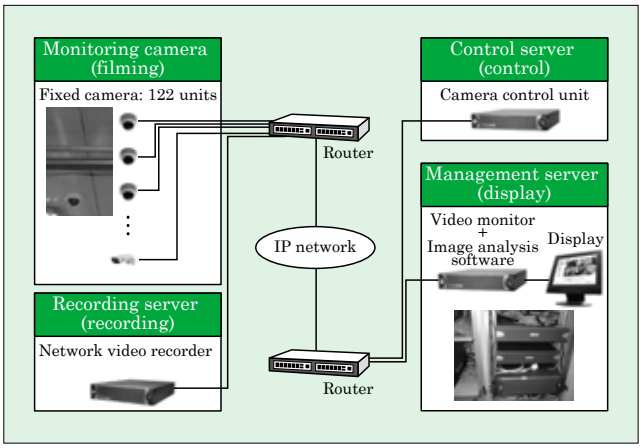
## Industrial Plants

### 13 Food Defense System for Ajinomoto General Foods, Inc.

Fuji Electric has been working on the development of an analysis system for preventing food contamination and improving productivity by means of food defense, which aims at resolving social problems related to the food industry. A food defense system is a system that automatically monitors for machinery malfunction and employee mistakes inside food factories by utilizing monitoring cameras (IP camera), recording servers and a network in combination.

We have recently installed a food defense system at Ajinomoto General Foods, Inc. The system is configured with 122 monitoring cameras, multiple management and recording servers, and a network (wired and wireless LAN). In the future, we plan to add functionality to the system so that the system can, in addition to recording monitoring states, improve convenience and provide enhanced accuracy for detecting malfunctions in the factory.

Fig. 16 Food defense system



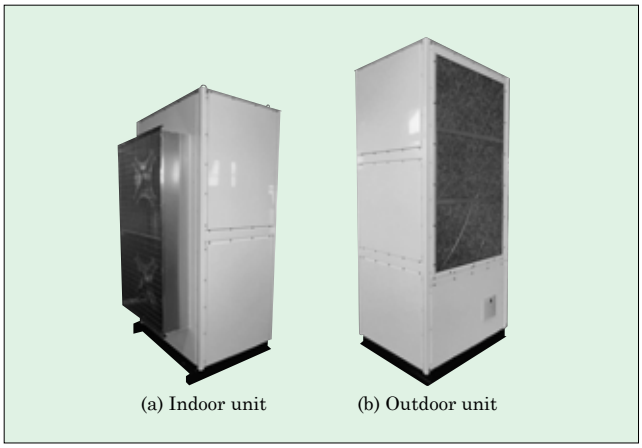



### 14 Energy-Saving Hybrid Air Conditioner "F-COOL NEO," Utilizing Indirect Outside Air

In an effort to save energy in data centers, outside air cooling systems have been increasing in usage as systems that use the natural energy of outside cold air. Fuji Electric has commenced sales of an indirect outside type air conditioner that only takes in outside cold air through the use of a heat exchanger. This air conditioner integrates both indoor and outdoor units, and more recently, we have developed a type that provides a high degree of installation flexibility by separating the indoor and outdoor units. The main features are as follows:

(1) Yearly power consumption can be reduced to approximately one-third of that of general air conditioning systems by combining the operation of an outside air conditioner and built-in refrigeration unit.
(2) Utilizing indirect outside air makes it less susceptible to corrosive substances, outside air moisture and dust such as PM2.5.
(3) A power supply is the only required utility. No cooling water or cold water is required.

Fig. 17 "F-COOL NEO"




## Industrial Measuring Instruments

### 1 Controller "XCS-3000" for "MICREX-VieW XX"

We have developed and are supplying the market with the controller "XCS-3000" for the Small- and Medium-Scale Monitoring and Control System "MICREX-VieW XX".

(1) The use of a multiprocessor configured architecture makes it possible to carry out network processing and program operation processing in parallel.
(2) It can be applied to both small- and medium-scale systems since it features a compact housing with dimensions of W145.0 × D69.8 × H113.1 (mm), super-fast high-speed processing at 8 ns per basic instruction, a large capacity memory with a 512 Ksteps for programs, etc.
(3) It achieves high-speed and large-capacity transmission of data via a control network that has a line duplex function with 1-Gbit/s Ethernet.
(4) It is possible to construct a highly reliable system by implementing an equalization protocol that transmits 512-Kword equalization data in 70 ms.

Fig. 18 "XCS-3000"

## Industrial Measuring Instruments

### 2 "MICREX-VieW XX" Network Adapter

We have developed and are supplying the market with a network adapter (NA) for connecting to the "XCS-3000" controller of the Small- and Medium-Scale Monitoring and Control System "MICREX-VieW XX". Connection with the controller is made by using a NA bus equipped with a high-speed data transfer protocol for 1-Gbit/s Ethernet. The main features are as follows:

(1) Connection can be made with not only Fuji Electric's original network, but also with open networks by mounting various communication cards in a total of six slots.
(2) It boasts of having a super-fast data refresh performance of 10 ms.
(3) It achieves highly reliable performance through a redundant configuration.
(4) In addition to improving system engineering efficiency through a standardized specification for the network adapter connection, it also makes it easy to expand and extend networks in the future.

Fig. 19 Network adapter

### 3 Programmable Display "MONITOUCH V9 Series"

In recent years, smartphones and tablets have been continuously gaining in popularity, and we have reached the point where nearly everyone has one. We have developed the programmable display "MONITOUCH V9 Series" based on the concept of maintaining the high level of quality required by manufacturers and raising the level of affinity with mobile devices used by consumers. The MONITOUCH V9 Series is very user friendly and comes with the latest network technology. It is characterized by the following features:

(1) It utilizes an electrostatic capacity type touch switch to achieve a higher level of intuitive handling and operation.
(2) It is compatible with VPN functionality and supports easy remote monitoring and operation without the need of VPN router or network skills.
(3) It comes with a wireless LAN, making wireless data communication possible with mobile devices and notebook PCs.

Fig. 20 "MONITOUCH V9 Series"

### 4 Biomass Gas Analyzer "ZPAF"

Fuji Electric has commenced sales of the biomass gas analyzer "ZPAF," which can measure generated gas at biomass plants via a single analyzer.

Biomass plants use generated gas, but the problem is that hazardous $H_2S$ (hydrogen sulphide) is also generated. Up until now, $H_2S$ measurements have been taken using continuous measurement methods, but these methods have not been able to deal with high concentrations (several hundred ppm). ZPAF utilizes a controlled potential electrolysis type sensor, making it possible to measure between 0 and 500 ppm or 0 and 2,000 ppm. Conventionally, multiple analyzers were combined to perform measurements for biomass, but ZPAF is capable of performing measurements via a single analyzer. The main features are as follows:

(1) Measures $CH_4$, $CO_2$, $H_2S$ and $O_2$ via a single analyzer.
(2) Makes it possible to replace the $H_2S$ sensor with a $O_2$ sensor directly at the work site.
(3) Comes with automatic calibration, concentration alarm and 2-range measurement functions.

Fig. 21 "ZPAF"

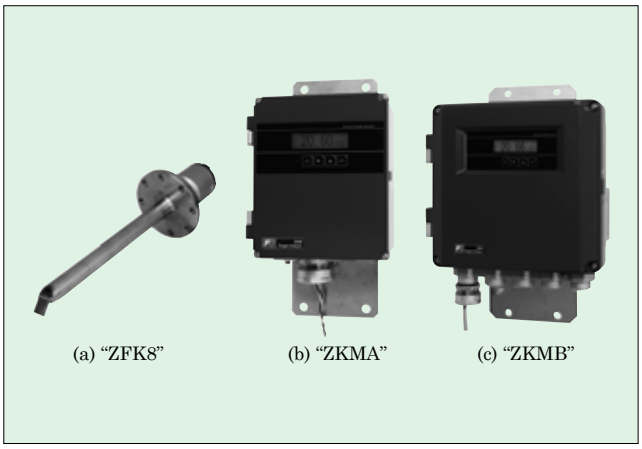
## 5 Zirconia Oxygen Analyzer "ZFK8," "ZKMA" and "ZKMB," Equipped with HART Communication Function

Fuji Electric has developed a zirconia oxygen analyzer equipped with the internationally standardized HART communication function.

Zirconia oxygen analyzers are used to increase equipment efficiency and energy conservation at various combustion management and combustion control work sites. Up until now, the work required to verify and/or change the internal parameters of instruments located throughout work sites was done at the specific areas of installation. HART communication superimposes a digital signal on an analog output (4 to 20 mA DC) to perform communication, and by providing this functionality, centralized operation can be carried out from remote locations. In addition to the HART communication function, the analyzer has the following features:

(1) Comes with a detector that makes it easy to replace sensors on site
(2) Equipped with a compact and lightweight converter not requiring the selection of an installation area
(3) Comes with safety functions including an overheat prevention function for the heater

Fig. 22 Zirconia oxygen analyzer



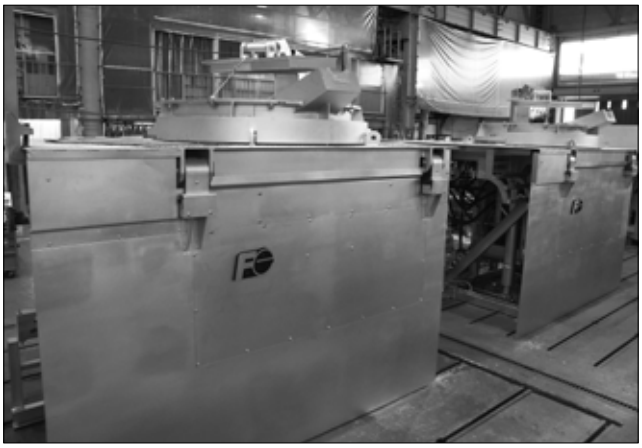



## 6 Energy Saving New Melting Furnace

There has been increasing demand for induction melting furnaces that achieve energy conservation, since they consume a large portion of the electric power energy at casting foundries. Fuji Electric has developed a new melting furnace that is characterized by its energy savings based on the adoption of a furnace body that utilizes our high-efficiency IGBT power supply and special coil. It achieves energy savings of 3 to 5% when compared with previous products. By combining an IGBT power supply with an optimally designed furnace component layout, the furnace reduces melting time and achieves energy savings efficiency, and it is expected that it will also be able to improve equipment productivity. We installed a 2-t melting furnace and a 3-t melting furnace during FY2014 after implementing field verification for the first unit.

In addition to its energy saving characteristics, the furnace reduces the coil replacement time to approximately one-third by implementing streamlining by means of a block assembly structure, as well as improves the quality and reliability of the coil by implementing cooling reinforcement to reduce the impact of vaporized zinc generated from the melting materials.

Fig. 23 Furnace body of new melting furnace (3 t, 2,250 kW)

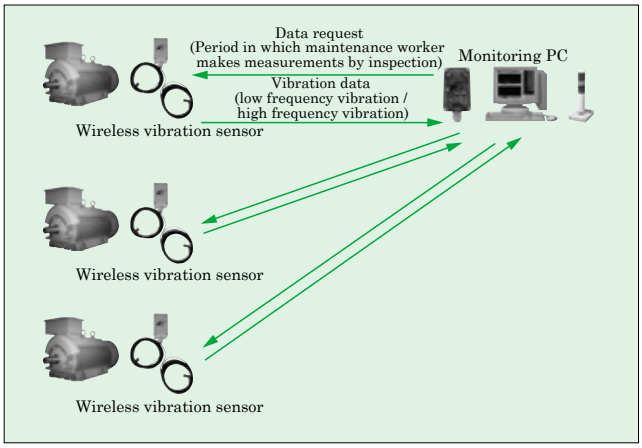


## 7 Wireless-Type Rotating-Machine Vibration Monitoring System "WISEROT" for Overseas Markets

The wireless-type rotating-machine vibration monitoring system "WISEROT" is designed to perform status monitoring for motors and machine equipment. It regularly measures the vibration and temperature of machine equipment and is capable of detecting equipment failure symptoms at an early stage by performing trend monitoring. Since it is a system that makes use of wireless communications, it can be applied to a wider range of applications and fields including applications that have been difficult to achieve for conventional wired-type online vibration monitoring systems or manual vibration measurement systems.

During FY2014, we achieved compliance for the system, meeting the requirements of overseas standards such as the CE marking and the R&TTE Directive, as well as acquired wireless certification for markets including the EU, Malaysia, Thailand, Singapore and Indonesia. In the future, we plan to gradually acquire wireless certification for other countries and increase the number of overseas services that we are providing.

Fig. 24 Configuration example for "WISEROT"



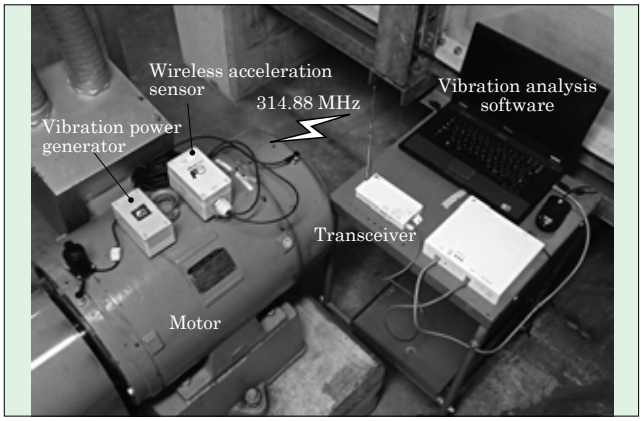
## Industrial Measuring Instruments

### 8 Energy Harvesting Technology for Wireless Sensors

We have developed an energy harvesting technology that does not require battery replacement or wiring for the power supply of wireless sensors. We have applied a vibration based power generation technology that generates power utilizing minute vibration of equipment and the installation environment to supply power to wireless sensors. We have also used a compressed sensing technology to reduce communication power, which consumes a large portion of the power used by wireless sensors.

(1) The power generation system utilizes reverse magnetostrictive properties, and achieves an average generated power of approximately 330 μW via a vibration with a vibration frequency of 100 Hz and acceleration of 0.98 m/s$^2$ (0.1 G).
(2) Communication power has been reduced by at least 50% as a result of applying a selective compressed sensing technology, which we developed in collaboration with the University of Tokyo, based on traditional compressed sensing technology.
(3) The figure shows an example of wireless vibration sensors used in a motor monitoring system that can operate without a power supply.

Fig. 25 Motor monitoring system utilizing vibration power generator

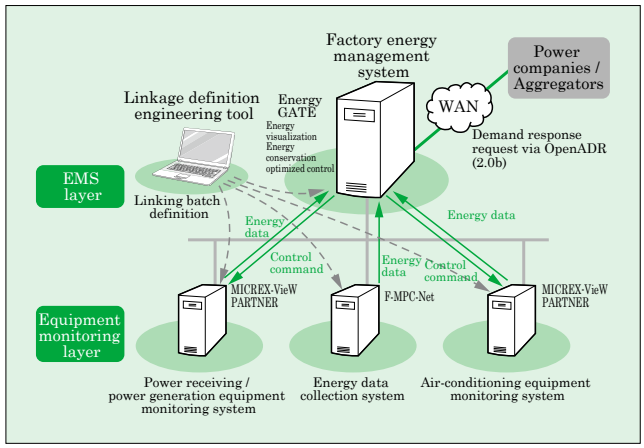



### 9 Engineering Linking Technology for EMS Layer and Equipment Monitoring Layer

We have enhanced the automatic linking function for factory energy management systems (EMS layer) and the multi-unit equipment monitoring layer. The equipment monitoring layer includes monitoring systems for power receiving, power generation and air-conditioning systems, as well as various energy data collection systems.

By making use of a linkage definition engineering tool, it is possible to link, at regular intervals, the measurements of multiple equipment monitoring systems with the EMS layer via a simple definition operation. By linking the function that optimally calculates energy savings (energy costs and $CO_2$ reduction) for the EMS layer with multiple equipment monitoring systems, it is also possible to achieve energy supply-and-demand balance control and energy conservation control for the entire factory. Furthermore, the utilization of OpenADR (2.0 b) on the EMS layer enables automatic control to be implemented by linking the equipment monitoring systems to demand response requests received from power companies or aggregators.

Fig. 26 Entire system configuration

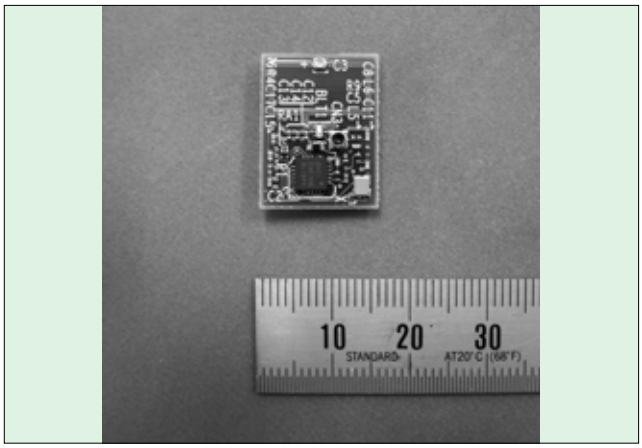



### 10 Ultra-Small Wireless Module with Built-In Antenna for Embedded Applications

Fuji Electric has successfully developed an ultra-small wireless module for the 920 MHz band. It incorporates an antenna on the substrate and has attained the industry's smallest class with dimensions of 15 × 20 (mm). Its ultra-small size makes it easy to be embedded into an existing device, and by connecting it to the serial communication interface of the existing device, it is possible to convert serial communication to a wireless configuration. In addition, it has two digital I/O interfaces and one analog input interface that enable I/O switching, and it can directly access the data on the device. Furthermore, it also comes equipped with Fuji Electric's original asynchronous communication protocol for suppressing power consumption, as well as a relay function for extending the communication range. The main features are as follows:

(1) Operating frequency band: 922.4 to 928.0 MHz
(2) Communication distance: 100 m (line-of-sight distance when using the built-in antenna)
(3) Certification (in Japan): Scheduled to acquire ARIB STD-T108

Fig. 27 Ultra-small wireless module



# Power Electronics Equipment

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

## Outlook

Present day, power electronics products have permeated in all fields ranging from social infrastructure that supports lifelines to durable consumer goods. And it is raising great expectations from the perspective of energy conservation and high-efficiency utilization of electrical energy in particular. New power devices that use silicon carbide (SiC) are now in the practical application phase and are expected to become widespread.

In the field of drive systems, to meet various needs of customers relating to variable-speed driving of motors, Fuji Electric provides products based on platform technology. We have commercialized "FRENIC-Lift LM2A" as an inverter for machine-roomless elevators. It has achieved conformity to safety standards mandatory in the European market and realized slim dimensions that are among the industry's smallest as an inverter with a built-in EMC filter. The "FRENIC-eHVAC Series" for air conditioning has a built-in EMC filter as standard model. It features the customization function, which has been received favorably in the "FRENIC-Ace Series," further enhanced to offer a variety of control and communication options. In addition, we have commercialized the "FRENIC4600FM6e Series" of medium-voltage inverters capable of directly driving a large-capacity medium-voltage motor. It covers a wide range of ratings including the input voltage of 6 kV/10 kV and output apparent power of 460 kVA to 15.6 MVA and is equipped with various operation control functions such as inverter parallel operation and synchronous motor driving.

Regarding rotating machines, Fuji Electric has commercialized "Premium Efficiency Motors" of IE3 efficiency according to the Top Runner Program based on the "Act on the Rational Use of Energy" (Energy Conservation Act). The slot structure, windings and core materials have been optimized for loss reduction to achieve the premium efficiency IE3 level of IEC 60034-30/JIS C 4034-30, and they have been standardized in the IP55 degree of protection for outdoor types.

In the field of power supply systems, Fuji Electric has commercialized 2 series of uninterruptible power systems (UPSs). One is the "6000DX Series" of 3-phase 200 V large-capacity UPS to meet the replacement demand in the Japanese market, which features an output power density improved by 10% while maintaining compatibility with the current models. And the other is the "7000HX-T3U Series" of 3-phase 400 V large-capacity UPS for the North American market, offering the world's highest level efficiency of 97.5%. In order to reduce power consumption of data centers, we have developed a rack-mounted DC UPS that integrates a UPS and switching power supply for a server. It is expected as a power supply system capable of reducing distribution losses and eliminating the need for UPS installation space. In relation to renewable energy, we have commercialized "PVI1000 AJ-3/1000," a power conditioning sub-system (PCS) for mega solar power plants, employing an All-SiC module. It has achieved miniaturization with a footprint size 60% smaller than previous products by taking full advantage of the features of SiC power devices. It has awarded First Prize in the FY2015 (64th) Japan Electrical Manufacturers' Association Technical Achievement Award.

In the transportation power electronics field, Fuji Electric has developed an auxiliary power unit with medium frequency link, combining a resonance inverter and medium frequency transformer. Compared to previous systems, the unit has achieved significant size and weight reductions. We have shipped a door system combining a rotating type permanent magnet flat motor with a rack-and-pinion mechanism to the North American market. In addition, we have started providing an auxiliary power unit and linear door system for subway cars of the Washington Metropolitan Area Transit Authority of the U.S. For both products, major parts procurement and final assembly are carried out according to the "Buy American Act," the first of such cases of Fuji Electric's products for electrical rolling stock. Furthermore, we have developed a passenger information system that uses a high-brightness, high-definition display and a train communication card with Ethernet applied.

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 sector. We have developed a non-polarity DC high-voltage breaker series of 400 to 800 AF, which is ideal for photovoltaic power generation equipment, and a 2-pole plug-in breaker of the industry's smallest size for data centers. As an energy monitoring system, we have developed a CT-based model of the "F-MPC PV Series." It adopts a current-detection system that uses a CT, supports an output voltage of 1,000 V DC as a standard feature and makes it possible to measure up to 12 strings of solar panels. Regarding magnetic starters, we have developed AC- and DC-operated 18-A, 22-A and 32-A models of the "SK Series," which is suitable as the primary switch of a drive unit, and "SC-N12/DS" which is ideal for photovoltaic power generation equipment. As for control devices, we have developed ϕ30 emergency stop pushbutton switches equipped with the Synchro Safe Contact for improved safety.

In the future, we intend to continue developing various technologies, products and solutions in power electronics equipment to ensure customer satisfaction and help realize a sustainable society.

## Drive Systems

### 1 Inverter for Air Conditioning "FRENIC-eHVAC Series"

In order to expand the offer of inverters for air conditioning, we have commercialized the "FRENIC-eHVAC Series," which meets the specification and pricing requirements of the market. The main features are as follows:

(1) The pricing requirements of the air conditioning market have been met by using the optimum design.
(2) Reinforced customizable logic is provided as a standard feature to flexibly meet the end users' need for dedicated functions.
(3) Functions required for air conditioning such as PID control, cascade operation and forced operation have been provided as standard features.
(4) The BACnet communication protocol has been supported as a standard feature and various control and communication options have been commercialized to make it easy to build systems.
(5) A multi-functional keypad panel supporting 19 languages is available as an optional feature so that the system can be used in more countries and regions.

Fig. 1 "FRENIC-eHVAC Series"


### 2 Medium-Voltage Inverter "FRENIC4600FM6e Series"

The price of medium-voltage inverters is falling at an accelerating pace in China, which is their biggest market, due to the emergence of local manufacturers. We have developed the "FRENIC4600FM6e Series" of medium-voltage inverters, which are competitive enough to cope with the business environment and equipped with differentiating and auxiliary functions suited for fields including electrical power and metallurgy.

(1) Voltage/capacity class
  ○ 6.0 kV, 450 to 9,350 kVA
  ○ 10.0 kV, 500 to 15,600 kVA
(2) Improvement of market competitiveness by simplifying the circuit configuration
(3) Large-capacity motor and synchronous motor driving by inverter parallel operation control
(4) Redundant operation by cell bypass function (auxiliary function)
(5) Conformity to IEC, GB and DL (national electric power standards of China)

Fig. 2 "FRENIC4600FM6e Series" (10.0 kV, 1,280 kVA model)

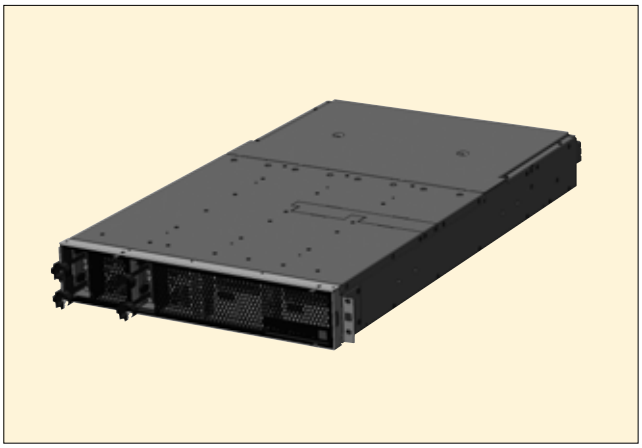
## Power Supply Systems

### 1 Rack-Mount DC UPS

Reducing the power consumption of data centers, which consume large amounts of electricity, is an important issue to deal with. Fuji Electric has developed a rack-mounted DC uninterruptible power system (UPS) that helps to save energy at data centers. This system integrates an uninterruptible power supply and switching power supply to reduce the power loss in the entire power distribution process. The main features are as follows:

(1) It has achieved a 5 to 7% reduction in power distribution losses at data centers.
(2) The need for space to install an uninterruptible power supply has been eliminated, achieving a footprint reduction of approximately 20%.
(3) The single-unit output apparent power can be increased in increments of 2.5 kW.
(4) The system has been given a power assist function, which allows server operation at a load exceeding the power limit for a certain period while imposing a power limitation on the server rack.

Fig. 3 Rack-mount DC UPS



## Transportation Systems

### 1 Door Drive System and Auxiliary Power Unit for Subway Cars of Washington Metropolitan Area Transit Authority

Fuji Electric has commercialized a door drive system (linear synchronous motor drive) and auxiliary power unit (input: 700 V DC / output: 230 V AC, 120 V AC, 37.5 V DC) for subway cars of the Washington Metropolitan Area Transit Authority and started delivering the equipment. The system links between incidental equipment such as the desktop automatic diagnostic system and on-board diagnostic PC software with the self-diagnosis function of the main unit to achieve improved maintainability.

In response to the "Buy American Act" that gives preference to U.S.-made products in purchases, we have transferred technology from our factory in Japan to a manufacturing base in the United States to procure major parts and carry out final assembly in the United States. The equipment conforms to the following standards required by the Transit Authority:

(1) Standard for electrical equipment used on rolling stock: IEC 60571
(2) EMC standard: IEC 61000-6-2, etc.
(3) Shock and vibration standard: IEC 61373

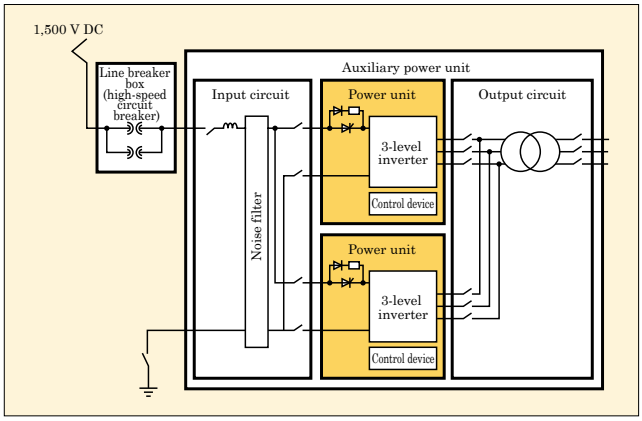
Fig. 4 New subway car (7000 Series) of Washington Metropolitan Area Transit Authority

### 2 Auxiliary Power Unit for Newly Built Trains of Sanyo Electric Railway Co., Ltd.

Auxiliary power units for train cars require high reliability, quietness and reduction of size and weight due to the severe use environment of electrical rolling stock. And the requirements placed on them are becoming increasingly sophisticated on a daily basis.

The auxiliary power unit for newly built trains of Sanyo Electric Railway Co., Ltd. has a power unit of a redundant structure composed of the regular and standby systems. In addition, the reliability has been improved by adopting a standby redundancy system, in which the regular system is switched over to the standby system in the event of failure. The three-level inverter system that supports 1,500-V DC overhead line input has been adopted as the circuit system and a 1.7-kV rated insulated-gate bipolar transistor (IGBT) device with excellent switching characteristics has been used. In this way, we have managed to reduce the generated loss due to switching, reduce noise by increasing the carrier frequency and decreasing the output voltage distortion, and reduce size and weight by reducing the output AC filter reactors.

Fig. 5 Simplified connection diagram of auxiliary power unit for newly built trains




### 3 Power Unit for Echigo TOKImeki Railway Company

Echigo TOKImeki Railway started operations on March 14, 2015 as a conventional railway line that runs parallel to the Hokuriku Shinkansen Line. To the Nihonkai Hisui Line on the former Hokuriku Main Line section, new ET122 Series diesel multiple-units were introduced, and they are based on the KiHa 122 Series diesel multiple-units of West Japan Railway Company.

Fuji Electric has made use of its experience in auxiliary power units for diesel multiple-units, which it has offered up to now, to delivered power units for the ET122 Series diesel multiple-units. The main features are as follows:

(1) The same generator control circuit as that of the KiHa 122 Series has been used and the rectifier control circuit changed from the conventional analog system to a digital system.
(2) Redundancy is provided to allow backup with multiple cars connected in the event of failure of one power unit.

Fig. 6 ET122 Series diesel multiple-unit and power unit

## Transportation Systems

### 4 Rack and Pinion Door Drive System for Railways in North America

Fuji Electric delivered a door drive system for passengers and gangways for the diesel-powered rail cars to be introduced by Sonoma-Marin Area Rail Transit. This is the second example of a rack and pinion door system in the North American market following the service test car. The main features are as follows:

(1) High reliability and safety have been realized by giving the new products the mechanism element of existing products, which is recognized for its high reliability.
(2) Motor characteristics have been improved to reduce power consumption by 52%.
(3) It is easier for the customer to make adjustments by factory adjustment.
(4) The failure diagnosis function has been provided so that it is easier to identify the cause of any failure.
(5) The detection performance for any passenger or belongings caught between doors has been improved to realize even higher safety.

Fig. 7 New car and rack and pinion door drive system


### 5 Passenger Information System for Rolling Stock

We developed a passenger information system jointly with Toyo Denki Seizo K.K., which was installed in cable cars (Cable Line) of Nankai Electric Railway Co., Ltd. and started operations on March 1, 2015. A passenger information display is installed at the top front part inside a cable car to show information about places along the cable line, station facilities and tourist spots in multiple languages (Japanese, English and French) together with images. The main features are as follows:

(1) High-brightness, high-definition display (32-inch half-cut size)
(2) Conforms to electronic equipment standard (IEC 60571) applied to electrical rolling stock
(3) Integrated unit including control power supply and computer
(4) Longer service life (60,000 hours) and lower power consumption achieved by applying long-life LED backlight

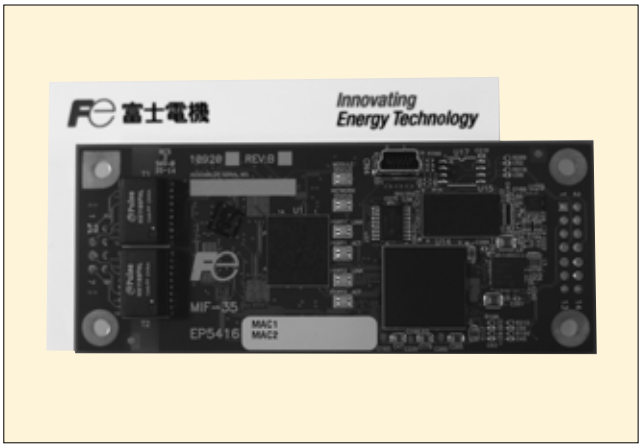
Fig. 8 Passenger information display in cable car


### 6 TRDP System Train Communication Card for Electrical Rolling Stock Conforming to IEC 61375-2-3

In the global railway industry, international standardization of communication networks for electrical rolling stock using Ethernet is in process. In line with this trend, we have developed a communication card that makes it possible to connect various types of on-board equipment of electrical rolling stock. The main features are as follows:

(1) Equipped with the TRDP protocol conforming to IEC 61375-2-3.
(2) Provided with two communication ports and the network switch function and can be integrated in devices such as propulsion equipment to configure various redundant communication topologies according to the functions of the application device.
(3) Provided with the environmental endurance, high reliability and high-speed response required in the railway industry.
(4) Allows incorporation of other communication protocols including PROFINET without a need to change the hardware.

Fig. 9 Communication card (comparison with business card)



## Electric Distribution, Switching and Control Devices

### 1 Expansion of Compact Magnetic Contactor “SK Series” (SK32 Type)

The compact magnetic contactor “SK Series,” types SK06 to 22 (5 ratings), have been received favorably since their release thanks to their smaller sizes and lower power consumption. We have developed a 32-A product (SK32 type), a larger frame size type of the series, to expand the lineup. The SK Series is specifically intended for contributing to size reduction and energy savings of machine control units and other devices. The main features are as follows:

(1) It has a slim width of 53 mm (installation area reduced by 33% from “SC-N1,” our equivalent product).
(2) A newly-designed electromagnet has been adopted to significantly reduce the electromagnet capacity (DC-operated electromagnet capacity 2.4 W, an electromagnet capacity reduction of 73% from “SC-N1/G,” our equivalent product).
(3) The DC-operated type is equipped with a coil surge suppression device as a standard feature.
(4) The terminal cover is provided as standard equipment (degree of protection: IP20).

Fig. 10 “SK32A”


### 2 Magnetic Contactor for Photovoltaic Power Generation Equipment “SC-N12/DS”

Magnetic contactors used in power conditioning sub-systems (PCSs) for photovoltaic power generation equipment need to meet various requirements including the specification and installation environment of the PCS.

Up to now, Fuji Electric has lined up the “SC-N14/DS” and “SC-N16/DS” Series of magnetic contactors with 660 and 800 A ratings for photovoltaic power generation equipment. We have expanded the lineup with the addition of 550-A rated “SC-N12/DS,” developed to meet diversifying needs. The main features are as follows:

(1) The standard-type magnetic contactor (450-A rated) has been used as the basis to develop a 550-A model, the only product with this rating offered by a Japanese manufacturer, while maintaining the same dimensions.
(2) The operating ambient temperature range has been expanded to deal with diverse use environments. (Standard type: −5 to +55°C, developed model: −10 to +60°C)

Fig. 11 “SC-N12/DS” 550-A rated model

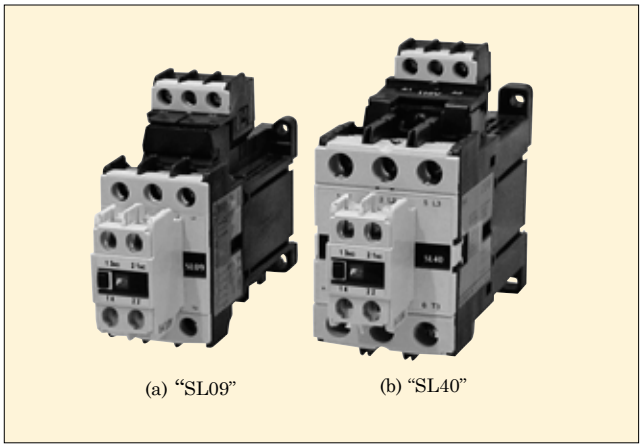

### 3 Mute Magnetic Contactor “SL Series”

In the Chinese elevator market, machine rooms have been increasingly eliminated mainly for exclusive hotels and condominiums and control panels have come to be installed near the elevator cages themselves. This has given rise to the requirement for reducing the operating noise of magnetic contactors.

With the mute magnetic contactor “SL Series,” the operating noise has been successfully reduced from that of the standard products to target the Chinese elevator market. The main features are as follows:

(1) Reduced operating noise of the magnetic contactor (by approximately over 10 dBA from the standard AC products)
(2) Operating circuit capable of both AC/DC operation
(3) Acquisition of China Compulsory Certificate (CCC)
(4) Integration of coil surge suppression function

Fig. 12 “SL Series”



(a) “SL09” (b) “SL40”

## Electric Distribution, Switching and Control Devices

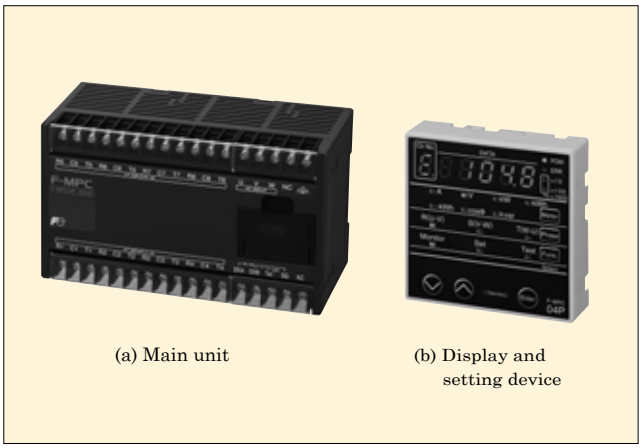
### 4 Line Expansion of Multi-Circuit Power Monitoring Unit “F-MPC04P Series”

As there are increasing needs to monitor energy, in order to contribute to miniaturization and power saving of distribution switchboards, we remodeled the 3-phase 3-wire type (8-circuit measurement) of the “F-MPC04P Series” in January 2014. We have now remodeled the single-phase 2-wire (12-circuit measurement) and 3-phase 4-wire (4-circuit measurement) types to expand the line.

The new “F-MPC04P” has been provided with a capability to measure a reverse power flow as distributed power sources have been becoming increasingly widespread in recent years. The main features are as follows:

(1) Size and weight reduced (by 60% from previous products) and power consumption decreased (by 50%)
(2) Usability improved by a larger display and setting device (□48 to □80)
(3) Replaceable without changing higher-level system software
(4) MODBUS/RTU added as an RS-485 communication protocol
(5) 100 A and 800 A products added as split CTs exclusively for combination

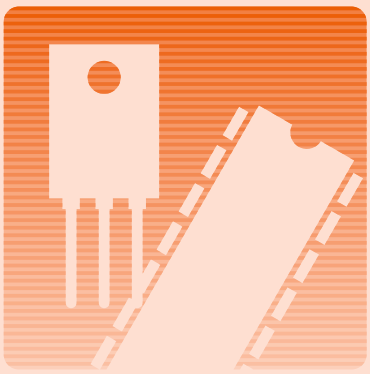
Fig. 13 “F-MPC04P”



(a) Main unit　(b) Display and setting device



# Electronic Devices



Power Semiconductors
Photoconductors
Disk Media

## Outlook

### Power Semiconductors

In an effort to prevent global warming, seek harmony with the environment and realize a safe, secure and sustainable society, power electronics technologies that support "energy creation," or proliferation of renewable energy, and "energy conservation," or efficient energy use, are raising great expectations from society. In this situation, Fuji Electric is developing power semiconductor products that feature high energy conversion efficiency, reduced noise and friendliness to the global environment. Power semiconductors are used for products in the environment/energy field, industrial machinery, automobiles and home appliances and contribute to society.

In the environment/energy field, we have expanded the lineup of insulated gate bipolar transistor (IGBT) modules for 3-level power conversion circuits to be used in power conditioning sub-systems (PCS) for photovoltaic power generation. The IGBT modules have a neutral-point bidirectional switch equipped with an advanced T-type neutral-point-clamped (AT-NPC) circuit that applies Fuji Electric's proprietary reverse-blocking (RB)-IGBT capable of withstanding a voltage of 900 V to a middle bi-directional switch in order to pursue even higher power conversion efficiency for meeting the recent need for input voltage increase.

For the industrial machinery field, we have expanded the lineup of intelligent power module (IPM) products that apply the latest "V Series" IGBT technology intended for machine tools with NC units, servomechanisms or spindles. In addition, we have commercialized "MiniSKiiP" for motor drive applications with a capacity of up to 22 kW. This can make contributions to further miniaturization of equipment. We have also developed the "High Speed W Series" of 1,200-V high-speed discrete IGBTs, which contribute to miniaturization of welding machines and uninterruptible power systems (UPS). This series allows higher-speed switching than before and contributes to miniaturization of welding machine and UPS.

In the field of automobiles, we have expanded the lineup of large-current intelligent power switches (IPS) used for controlling high-output motors and other applications. As compared with conventional products, the new IPS can reduce the on-resistance by 37.5% with the same package and realize maximum energy capability equivalent to that of the conventional products. A lineup of relative pressure sensors has been added to the 6th-generation pressure sensors. They are capable of measuring a relative pressure in the 100 kPa range with an accuracy of ±1 kPa. They are used for monitoring the internal pressure of brake boosters during idling stops to contribute to fuel efficiency improvement and exhaust gas reduction. Furthermore, in the field of in-vehicle IGBT used for motor driving of hybrid and electric vehicles, Fuji Electric is establishing a lineup of products that use its proprietary direct water cooling structure and reverse-conducting RC-IGBT chip.

In the field of power supplies for home appliances, we have expanded the lineup of 6th-generation PWM control IC for notebook PCs, printers and relatively small TVs. We have made it possible to perform miniaturization of parts such as transformers by supporting high-frequency operation at a switching frequency of up to 100 kHz in addition to the conventional 65 kHz and offer a lineup compatible with a variety of specifications of power supplies.

In the future, we intend to continue developing power semiconductor products that are friendly to the global environment so as to realize a safe, secure and sustainable society.

### Photoconductors

The photoconductor market is undergoing polarization between price-oriented customers and quality-oriented customers, along with the growth of Chinese manufacturers. Fuji Electric is working to enhance the performance of photoconductors to accommodate higher-speed operation and longer service life of equipment.

In FY2014, we developed and mass-produced positively charged organic photoconductors with the improved print quality. We achieved this by applying a new layer design technology, and high-durability or-

ganic photoconductors with the durability doubled by applying materials with excellent storage stability and wear resistance. We will further help to conserve energy, reduce cost and improve the efficiency of the office environment through the provision of photoconductors that meet customer needs.

### Disk Media

With the proliferation of big data analytics and cloud computing, perpendicular magnetic recording media for hard disk drives (HDDs) is required to provide with larger capacity and lower cost.

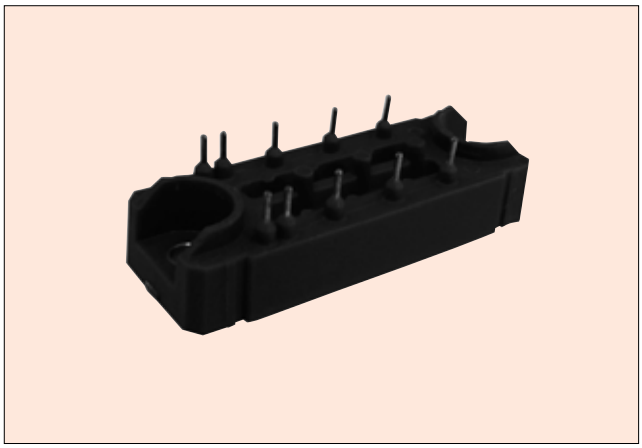
In FY2014, Fuji Electric developed and mass-produced characteristics-improved models of 3.5-inch aluminum substrate media with a capacity of 1 TB per disk and new models of 2.5-inch aluminum substrate media with a capacity of 500 GB per disk. The aim is to contribute to cost reduction and improvement of the manufacturing yield of customers. In order to contribute to the advancement of IT society, we are committed to making continued development of large-capacity media suited for shingled magnetic recording (SMR), a new technology.

## Power Semiconductors

### 1 Industrial RC-IGBT Module Technology Using a New Package

For industrial IGBT modules, the market for which has been rapidly expanding in recent years, we have developed a reverse-conducting IGBT (RC-IGBT) integrating an IGBT and diode. We have combined it with a new package that achieves excellent heat dissipation and high reliability at the same time, and thereby realized significant miniaturization and improvement in the power density of an IGBT module. The RC-IGBT has accomplished a low power dissipation equivalent to that of the conventional IGBTs and diodes and achieved a 27% reduction in the chip area at the 1,200 V and 100 A rating. In addition, combining the RC-IGBT and the new package has made it possible to achieve low inverter losses equivalent to, and a significant IGBT chip temperature decrease from, the conventional 2-in-1 modules, with the footprint reduced to 42%. A comparison based on the same IGBT chip temperature shows that it can operate with a 58% larger output current. This helps to reduce the size and cost of power converters.

Fig. 1 RC-IGBT module in new package



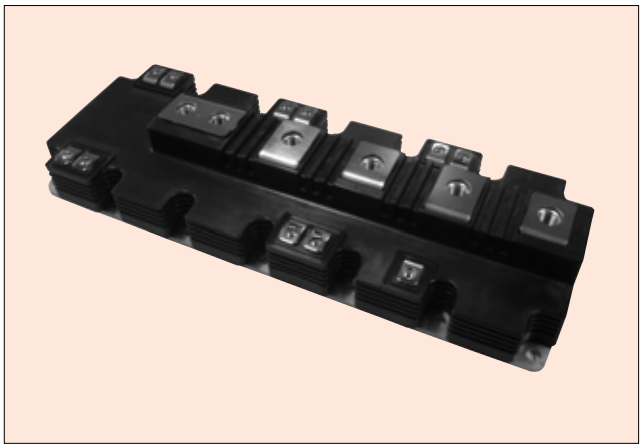
### 2 High-Power 3-Level IGBT Module

Fuji Electric is committed to developing high-power 3-level insulated gate bipolar transistor (IGBT) modules applied to 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 and the ratings available are 1,200 V/450 A, 600 A and 900 A. It realizes 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 future photovoltaic power generation systems with higher voltage levels, we will commercialize an I-type module (1,200 V/600 A) capable of accommodating 1,500 V DC. The main features are as follows:

(1) T-type: RB-IGBT applied to realize efficiency improvement
(2) I-type: terminal compatibility with T-type for easy replacement

Fig. 2 High-power 3-level module common to T-type and I-type

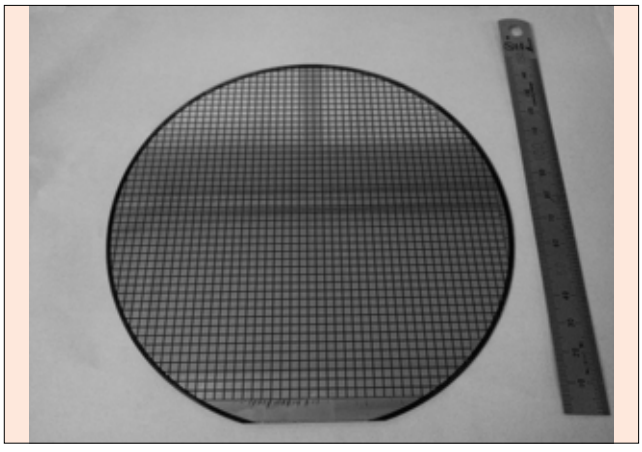


### 3 6-Inch SiC-MOSFET

Fuji Electric is working on the development of a silicon carbide metal-oxide-semiconductor field-effect transistor (SiC-MOSFET) that uses a 6-inch SiC substrate. As compared with conventional Si devices, SiC-MOSFETs are characterized by having more electron and hole traps in the gate oxide film formed on an SiC substrate. These traps may cause poor long-term stability of the gate threshold voltage under gate bias conditions. We have figured out suitable conditions for manufacturing a gate oxide film to successfully develop an SiC-MOSFET with excellent threshold stability.

We are continuing to move forward with the development of an All-SiC module equipped with a 1,200-V rated SiC-MOSFET and SiC-Schottky barrier diode (SiC-SBD). In addition, we plan to develop high blocking voltage SiC-MOSFETs with ratings of 1,700 V and up to 3,300 V.

Fig. 3 6-inch SiC wafer



## Power Semiconductors

### 4 High-Power In-Vehicle Standard Module for Electric and Hybrid Electric Vehicles

As electric vehicles have been undergoing power increase recently, power modules are also required to offer larger capacity. We have developed a high-power in-vehicle standard module for electric and hybrid electric vehicles.

This product is a power module with a built-in inverter circuit for driving a motor. It features a high power class of 750 V/800 A, which is among the largest of general-purpose modules. As the device, a reverse-conducting IGBT (RC-IGBT) that applies the 7th-generation chip technology is used. This device integrates an IGBT and free wheeling diode (FWD) on the same chip and contributes to miniaturization of the module. The cooling unit uses an aluminum water jacket and realizes an improvement of approximate 40% in cooling performance from Fuji Electric's conventional aluminum heat sink.

Fig. 4 High-power in-vehicle standard module

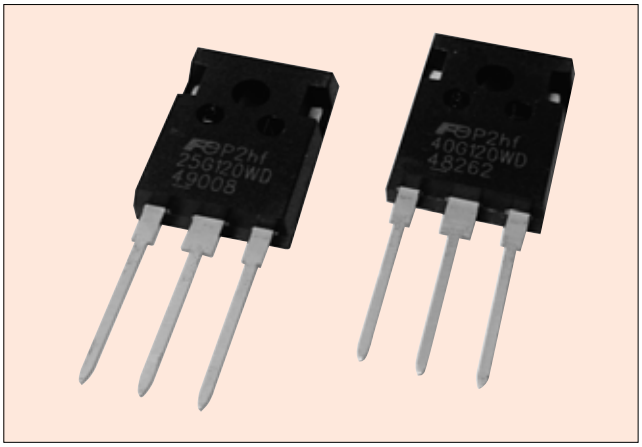

### 5 1,200-V High-Speed Discrete IGBT "High-Speed W Series"

Recently, there has been a strong demand relating to welding machines and uninterruptible power systems (UPS) for frequency and efficiency increase in order to achieve miniaturization of the devices. For these devices, we have developed the "High-Speed W Series," a series of 1,200 V high-speed discrete IGBTs.

The conventional "High-Speed V Series" has been optimized for high-frequency applications to significantly reduce the switching loss. The main features are as follows:

(1) High-frequency drive (20 to 100 kHz)
(2) Turn-off loss reduced by approximately 40% (from previous products)
(3) Rated voltage/current: 1,200 V/25 A, 40 A
(4) $T_{jmax}$ = 175°C guaranteed
(5) Package: TO-247 (all lead-free)

Fig. 5 "High-Speed W Series"



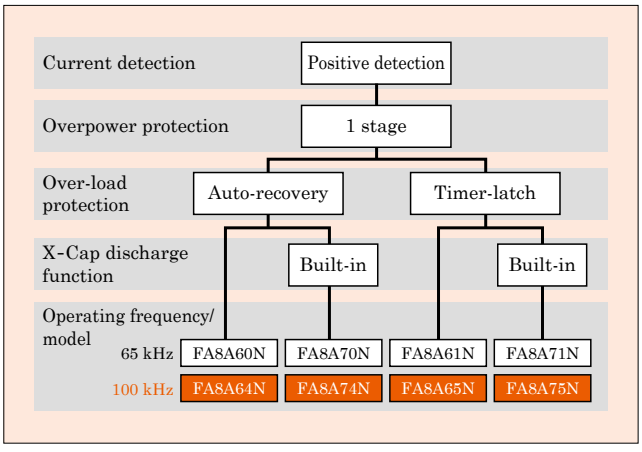
### 6 Expansion of the 6th-Generation PWM Control IC Lineup

Recently, an increasing number of electronic devices such as home appliances and servers have become always-on systems and the demand for reducing the standby power is ever increasing. Fuji Electric has already commercialized the 6th-generation PWM control IC "FA8A60 Series," which have many state setting functions and various protective functions. However, in addition, there is a growing need for miniaturization.

In order to meet this need, we have developed the "FA8A64 Series" with the operating frequency changed from 65 kHz to 100 kHz for miniaturization of the transformer, which is a major factor of the power supply volume, as an addition to the product lineup.

It is compatible with the FA8A60 Series in terms of the terminals, functions and characteristics. This means the design assets of the conventional power supplies can be used and the new power supply design elements can be simplified.

Fig. 6 6th-generation PWM control IC series table



## Power Semiconductors

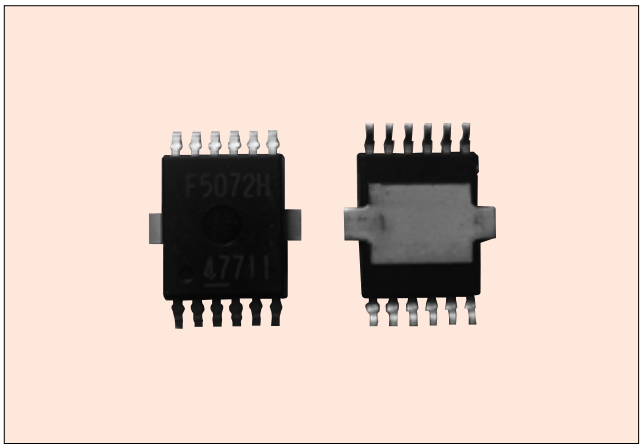
### 7 High-Current IPS for Vehicles

In the field of automotive electrical components, there is growing demand for miniaturization, reliability improvement and functional enhancement of systems. In order to meet these requirements, we have developed a high-current intelligent power switch (IPS) used for controlling high-output motors and other applications.

This IPS uses a power metal-oxide-semiconductor field-effect transistor (MOSFET) with a trench structure and a control IC built into a chip-on-chip structure to realize a low on-resistance (5 mΩ max.) within a small package. In order to achieve high reliability, protective functions including overcurrent and overheat detection and low voltage detection have been provided. In addition, a package featuring excellent heat dissipation is used and a good energy sharing balance in parallel connections is realized to deal with any temperature rise due to a current increase arising from the lower on-resistance.

Reference: FUJI ELECTRIC REVIEW 2014, vol.60, no.4, p.243

Fig. 7 Hig-current IPS for vehicles



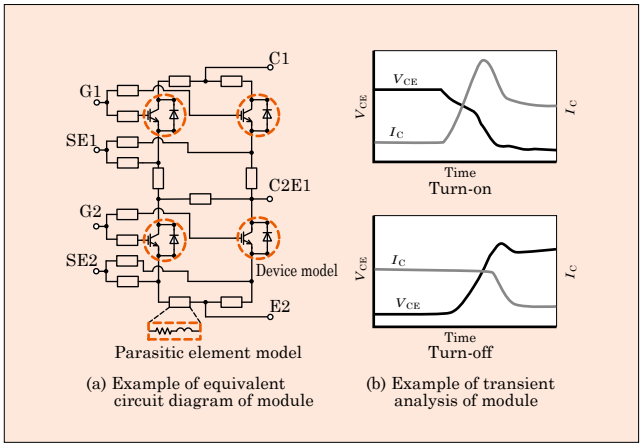
### 8 Power Semiconductor Simulation Technologies

As there is growing demand for reduced power dissipation and larger capacity of power semiconductors, simulation technologies are gaining importance.

Fuji Electric is working on the development of simulation technologies not only for device and package design but for analyzing the behavior of entire modules, which are increasingly complicated by SiC and other devices. We verify a switching operation of the module utilizing the transient analysis with an equivalent circuit of the module, which is combination of device model and parasitic element model inherent in the package structure as shown in Fig. 8. We are also engaged in the development of electromagnetic field analysis technologies for noise reduction.

These simulation technologies contribute to functionality and higher quality of Fuji Electric's power semiconductors.

Fig. 8 Example of simulation of module switching characteristics

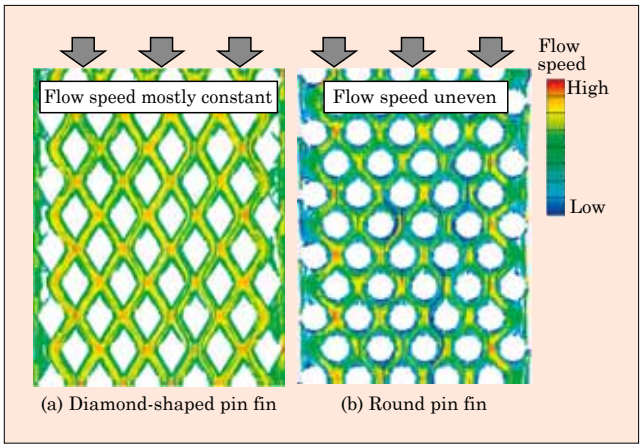



### 9 Fluid Simulation Technology for Next-Generation Power Semiconductors

For power semiconductor modules, which are used in power converters and motor controllers, studies are recently being conducted for water cooling in order to improve the efficiency of cooling systems.

A thermal-fluid dynamics simulation is used to analyze the cooling performance of a cooler. We have developed a fluid simulation technology that allows integrated analysis of the flow speed and pressure loss of the coolant that flows in a cooler. The figure shows the result of analysis of the coolant flow of a cooler. This simulation technology has made it possible to optimize the coolant flow speed and pressure loss in a short term. We have also attempted to improve the efficiency of customer-specific cooling systems by designing an entire system in view of the pump performance. As a result, coolers can now be built that are capable of cooling approximately three times as much loss (heat) as that of air-cooling systems.

Fig. 9 Result of analysis of coolant flow speed of a cooler



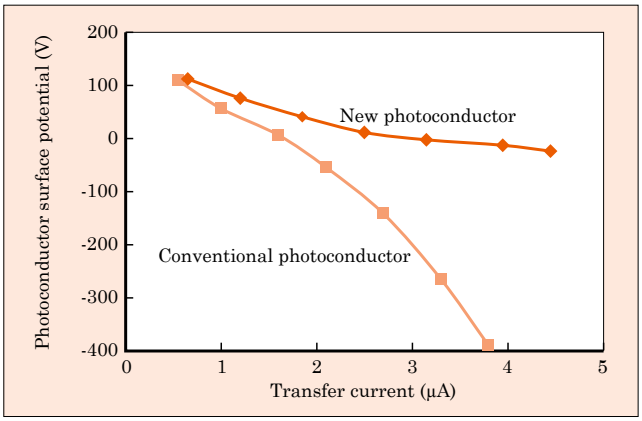
## Photoconductors

### 1 High-Quality Positively Charged Organic Photoconductors

Electrophotographic printers and photocopiers are becoming increasingly high-speed and offering higher image quality. The photoconductors provided in these devices are key components that determine the image quality, and they need to have high stability against stress from various peripheral processes. In the transfer process by positive charging, a negative polarity bias is applied to transfer the toner attached to the surface of the photoconductor to the paper to form an image. It is known that, if the applied bias is too high, the history by the presence of toner on the surface of the photoconductor may vary, causing degradation of image quality.

Fuji Electric has established a new layer design technology for controlling electron injection in the transfer process. By applying this technology, we have developed a photoconductor that suppresses negative charging of the surface of the photoconductor after transfer to provide a stable image quality.

Fig. 10 Transfer characteristic of positively charged organic photoconductors

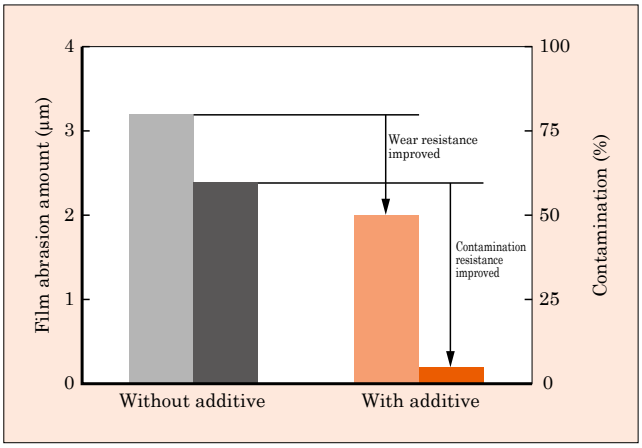



### 2 High-Durability Organic Photoconductors

Recently, image forming devices such as photocopiers, printers and facsimiles have been undergoing evolution in terms of miniaturization, speed-up and service life extension. Regarding peripheral members that come in contact with photoconductors such as charging and transfer rollers, a variety of products are offered. And the surface of photoconductors is required to have durability against eluting components from various peripheral members.

Fuji Electric has designed an additive molecule in a size appropriate for voids formed in the photosensitive layer on the surface to have the voids filled with the additive, and thereby made it possible to form a more robust film. In addition, we have improved the contamination resistance and wear resistance by preventing components eluting out of the peripheral members from infiltrating into the surface of the photoconductor. And we have realized a high-durability organic photoconductor with electrical characteristics stable against repetitive use and changing use environment conditions.

Fig. 11 Improvement of durability with additive



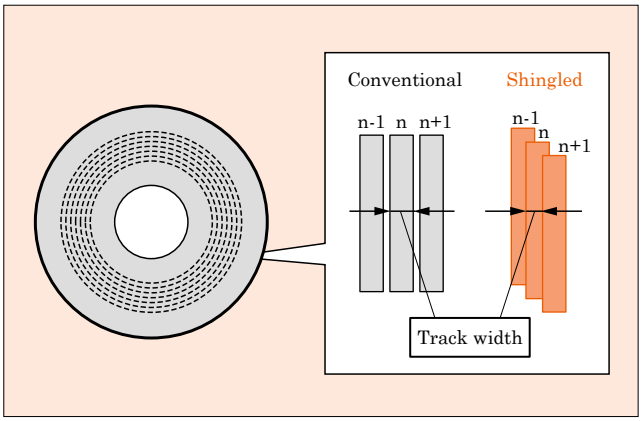

## Disk Media

### 1 Perpendicular Magnetic Recording Medium for Shingled Magnetic Recording (SMR)

To further increase the recording capacity of HDDs, adoption of shingled magnetic recording (SMR), a new magnetic recording system, is about to start. With SMR, data tracks, which have conventionally been arranged at regular intervals, are overlapped like shingles for recording. This makes it possible to narrow the effective track width and in turn improve the recording density.

Fuji Electric is working to develop technology for an SMR-enabled perpendicular magnetic recording medium. By ingenuities such as multi-layering of the magnetic layer, we have successfully suppressed mutual magnetic interference between data tracks while maintaining ease of recording. Furthermore, we have optimized the carbon protective film and lubricant to achieve a lower head flying height without affecting the durability, and improved the recording and reproduction performance. We plan to apply this technology to the medium (recording density: 1,500 Gbits/in$^2$, 1 TB per 2.5-inch medium) for HDDs to be commercialized in FY2016.

Fig. 12 Schematic depiction of data track recording method in shingled magnetic recording



# Food Distribution

Vending Machines
Stores
Distribution Systems

## Outlook

A shrinking population coupled with a declining birthrate and an aging population, together with an increase in single-person households and an increase in the number of women entering the workforce is causing changes in the manner of consumption and the retail environment in the food distribution market. Consumers have a particularly strong tendency to demand convenience and food safety and security, and the manufacturers who handle food products and beverages show a strong interest in meeting consumer demands and also in conserving energy for environmental reasons. In the food distribution field in which Fuji Electric participates, we are expanding the areas of our business that are proximate to the final consumer, such as at supermarkets and with vending machines, and are also entering into business opportunities in the food processing and storage fields with refrigerated warehouses and so on, and with refrigeration-related business for food processing plants. In the future, we plan to expand our business further to plant factories, and to enlarge our domain upstream to extend from production through consumption.

Research and development-related keywords in the food distribution field include "energy savings," "convenience," "global responsiveness," and "safety and security." The cooling and heating control technology that is driving the reduction in energy consumption by cooling and heating equipment is being used in vending machines that heat and refrigerated beverages, store showcases used to display an array of beverages, and so on. This technology is also being applied to products and systems that contribute to the distribution process for food.

For vending machines that sell beverages in cans and PET bottles, we have developed Fuji Electric's proprietary hybrid heat pump vending machine that utilizes ambient air, in addition to internal exhaust heat, as a heat source. We improved the energy-saving performance further in FY2014, and introduced to the market the 2015 model of the "Hybrid ZERO," the industry's first heaterless vending machine. This vending machine heats products using only a hybrid heat pump, and employs a heating method developed without using any of the heaters that had been used in part in the past. As a result, a 50% increase in heating efficiency was obtained. In addition, we developed a cooling circuit in collaboration with an automotive parts manufacturer, and employed a component called an "ejector," which makes effective use of the energy loss when a liquid expands, for the first time in a vending machine. As a result, efficiency was improved greatly and the annual power consumption was reduced by 25%.

For vending machines that sell beverages in cups, we have developed an ultra-small cup type vending machine that is specialized for use in offices and provides easy access to delicious coffee. This product has a single-cup drip-type coffee extraction system and a hygienic and easy-to-clean cup mixing mechanism, and we developed and installed mechanical components for miniaturization. This product also features the industry's top class performance in terms of power consumption.

For global expansion, Fuji Electric has developed the multipurpose vending machines named "Twistar" for the purpose of overseas production, started mass production in Thailand in July, and began selling to China and Southeast Asian countries.

For products to be used in stores, as a follow-up to the coffee machines that have been installed on convenience store counters since 2013, we developed a fixture for selling donuts. Focusing on the internal environment in which donuts are stored to maintain their particular deliciousness, we realized a fixture that is able to supply a delicious product at all times by cooling the donuts to a constant temperature while preventing them from drying out. Moreover, in order to meet the growing demand for frozen food and ice cream products, we developed a horizontal ice cream case having a built-in freezer. As a result of an improved air curtain, the required refrigeration capacity is reduced, thus making it possible to achieve a smaller size and improved energy-saving performance.

In the cold storage market that exists for the purpose of storing and sorting food during the food distri-

bution process, many of the refrigerators and refrigerated warehouses in existence were constructed more than 30 years ago. For this reason, administrative costs often have frequently increased significantly as a result of higher maintenance costs due to stricter regulations for Freon refrigerant and higher electricity costs due to deterioration in the thermal insulation performance of walls. In response to these environmental changes, we have developed an energy-saving control system for optimizing the operation of the refrigeration equipment. Through performing capacity control for the refrigeration unit and airflow control in accordance with the load on the fan for the unit cooler, and so on, we have realized a 12% reduction in annual power consumption by refrigerated warehouses.

In addition, as a new initiative for sunlight-based plant factories, we have delivered complex environmental control systems, substation equipment, refrigeration equipment, etc., and have promoted demonstration testing, promoted the construction of an optimal environment for growing plants and energy savings, and we plan to provide comprehensive engineering for plant factories.

Based on the societal needs for convenience, food safety and security, and energy savings, Fuji Electric will expand its development of products that fully incorporate "cooling/heating technology," "mechatronics technology," and "embedded software technology," and intends to apply new technology to develop new markets.

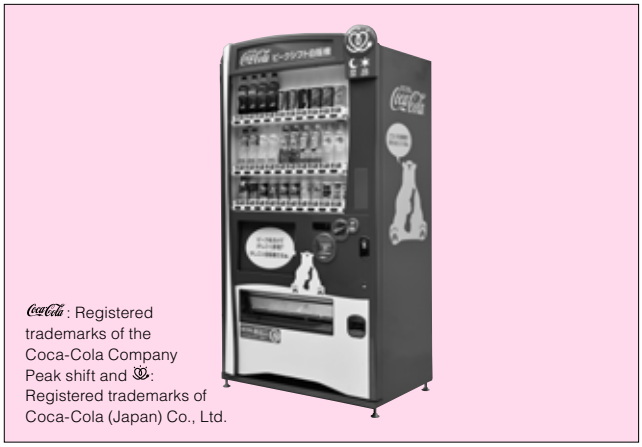
## Vending Machines

### 1 Peak Shift Vending Machine Equipped with Ejector

Fuji Electric has introduced a peak shift $CO_2$ refrigerant vending machine capable of supplying cool drinks all day long, without using power for cooling for up to 16 hours maximum. In order to improve energy savings and energy conservation further, an ejector is installed in the cooling circuit to establish an energy-saving system with enhanced cooling efficiency. The compressor power is reduced by approximately 30%, and the annual power consumption can also be reduced by approximately 25%. Main features are listed below.

(1) By using an ejector, the compressor loss due to the driving force and the expansion process could be reduced.
(2) Precise, energy-saving operation was realized by constructing a pressure optimization control that boosts the pressure in according to the ambient environment and the load.
(3) The gas-liquid separator was optimized, and the amount of refrigerator oil returned while maintaining the gas-liquid separator function is ensured.

Fig. 1 Peak shift vending machine equipped with ejector



Coca-Cola: Registered trademarks of the Coca-Cola Company
Peak shift and ®: Registered trademarks of Coca-Cola (Japan) Co., Ltd.

### 2 Ultra-Compact Cup-Type Vending Machine for Japan Beverage Holdings Inc.

In collaboration with Japan Beverage Holdings Inc., a leading cup beverage company, Fuji Electric has developed an ultra-compact cup-type vending machine. Featuring a compact size, low power consumption and so on, the vending machine has specifications that are well suited for installation in an office environment, and is able to provide familiar delicious, full-fledged coffee. The main features are as follows:

(1) Based on the image of a menu board at a coffee shop, this vending machine is equipped with an integrated sheet key that shows selection buttons and summarizes the products on display.
(2) The vending machine is equipped with a single-cup drip-type coffee extraction system and, as a compact cup mixing system having excellent sanitation and cleanliness, the industry's first transverse uniaxial transport system.
(3) Realized industry-leading low power consumption of 849 kWh/y.

Fig. 2 Ultra-compact cup-type vending machine

## Stores

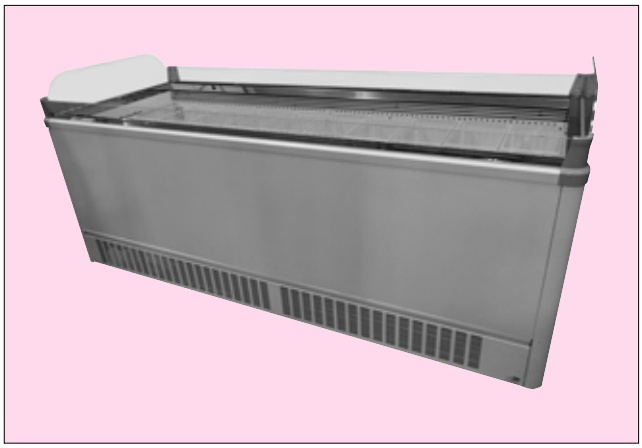
### 1 7.5-Shaku Horizontal Ice Cream Case

In the convenience store industry, there is a growing need for large-capacity open-type horizontal ice cream cases that will be of considerable assistance in the sales of frozen food and ice cream. Fuji Electric has developed a 7.5-shaku*-wide horizontal ice cream case that has a built-in freezer with enhanced energy efficiency. The main features are as follows:

(1) With a high-performance air curtain that controls the amount of external air heat intrusion, the amount of frost formation is reduced and the amount of power consumed is reduced by 20% compared to models from other companies.
(2) By optimizing the heat exhaust structure inside the machine room, condensation capacity was increased and the condensing unit attained higher efficiency.
(3) From the beginning of the development process, the design was standardized and was constructed as the base model of a horizontal showcase. This allows the series to be expanded to freezer and refrigeration showcases.

* Shaku: an old Japanese unit of length equivalent to approximately 30.3 cm

Fig. 3 Horizontal ice cream case



## Distribution Systems

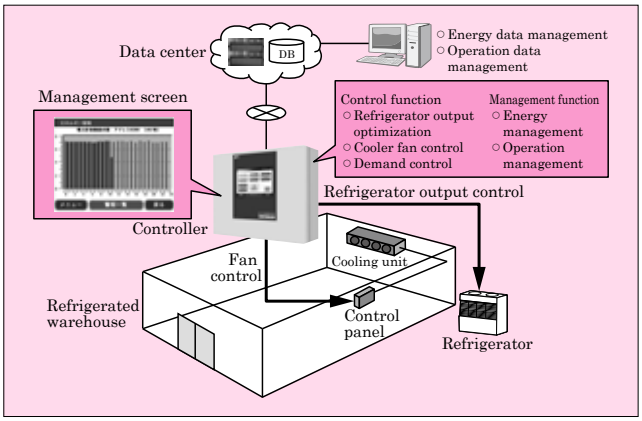
### 1 Energy Saving Control System for Refrigerated Warehouse

In these days, a refrigerated warehouse for the purpose of food storing and sorting in a distribution process has a big problem of reducing energy usage due to increased electricity costs. Fuji Electric has developed an energy-saving control system that optimizes the operation of refrigeration equipment (cooler, refrigerator) in a warehouse. The main features are as follows:

(1) Energy-saving function: Owing to a refrigerator output control function based on a proprietary algorithm that operates according to the internal load status and by controlling the cooler with intermittent operation, the annual power consumption in the warehouse can be reduced by 12%.

(2) Management function: A display function having high visibility and operability allows energy management and operation management to be implemented with ease.

Fig. 4 Configuration of energy-saving control system for refrigerated warehouse



# Fundamental and Advanced Technologies

Fundamental Technology
Advanced Technology

## Outlook

Energy-related fields including power electronics are raising expectations as areas that will grow in the future. For this reason, large-scale projects involving collaboration between industry, government and academia are being continuously carried out. These projects are facilitating the establishment of an environment that makes it possible to develop wide-band gap semiconductor materials such as silicon carbide (SiC) and gallium nitride (GaN). These are next-generation power semiconductors that follow Si power semiconductors, in which Japan has maintained its competitiveness. The environment also allows for research and development relating to power electronics equipment using such materials.

Commercialization of power semiconductors and power electronics equipment requires specialized elemental technologies and coordinating technologies that integrate them. Elemental technologies of power semiconductors include technology to produce high-quality semiconductors that provide the base and technology to form an epitaxial layer on the substrate. They also include technology for p/n control by ion implantation to dope impurities, photo-etching technology, trench forming technology, insulating film forming technology, semiconductor-metal junction technologies to form Schottky and ohmic junctions and other process-related technologies. Further, they include common fundamental technologies for the individual processes. Power semiconductor devices can be completed by integrating these elemental technologies to design and build devices and processes that satisfy the intended performance and cost requirements. In research and development of wide-band gap semiconductors, improving the level of the respective elemental technologies is required to develop advanced technologies, a task that is important and difficult. In order to ultimately make power semiconductor devices into competitive products, coordinating the elemental technologies to improve competitiveness in terms of cost and performance is essential. Technologies required include technology to electrically connect power semiconductor devices to terminals and package technology to give them an insulation property and durability. Various types of power electronics equipment that use the completed power semiconductor modules and power systems that use them as key components are also necessary to meet similar demand, as device performance is improved.

Fuji Electric has positioned power semiconductors and power electronics at the center of our core technologies to move forward with research and development of fundamental and advanced technologies required. And we have systematized these core technologies through measurement and control technologies to reinforce our efforts in electrical and thermal energy-related solutions. To acquire advanced technologies we do not own ourselves, we actively take part in industry-government-academia collaboration projects and joint research.

Regarding SiC, we have developed a simulation technology that makes it possible to estimate the epitaxial film growth rate in a vertical CVD furnace capable of high growth rate, which is used by the R&D Partnership for Future Power Electronics Technology. In addition, we have developed an SiC trench metal-oxide semiconductor field-effect transistor (MOSFET) jointly with the National Institute of Advanced Industrial Science and Technology and achieved on-resistance that is 20% lower than the conventional planar type in the 3.3-kV class. We have also developed an SiC-Schottky barrier diode (SiC-SBD) and made use of its characteristic small reverse-recovery loss to realize a 25% reduction in inverter generated loss. To develop these semiconductor devices, we have made the most use of various analysis technologies including synchrotron radiation topography and spectroscopic analysis. We have also conducted follow-up evaluations on the types and locations of defects, substrate stress and deformation for each process, and this contributes to the building of process technologies that generate fewer stacking faults.

For power electronics equipment, we have achieved miniaturization and a density increase while also establishing an analysis technique that makes it possible to predict temperature with higher accuracy than the

conventional method. We have done this by linking electromagnetic field analysis with thermo-fluid analysis to apply the loss distribution as a heat generation condition. In addition, as many international standards are established by the International Electrotechnical Commission (IEC), Fuji Electric actively engages in committee activities, and has received recognition for this.

We have also worked on various development activities for improving the performance and safety of electrical and thermal systems and the components that support them. Concerning technologies for protecting photovoltaic power generation systems, we have developed power system protection equipment and its installation technology for estimating an overcurrent due to lightning strikes. In the field of high-temperature-resistant solder bonding materials, we have developed a lead-free solder alloy featuring a continuous operation lifetime that is about 2.6 times longer than the previous products. The aim is to realize smaller power converters with a higher output by improving their power density. Regarding the arc interaction analysis technology anticipating short-circuit faults inside switchboards, we have developed analysis tools for implementing thermo-fluid analysis utilizing a three-dimensional simple finite volume method as well as arc interaction analysis. This allows designers to consider the shape and pressure discharge structure for the switchboard and significantly reduce the analysis time (about 1/100 of the conventional method).

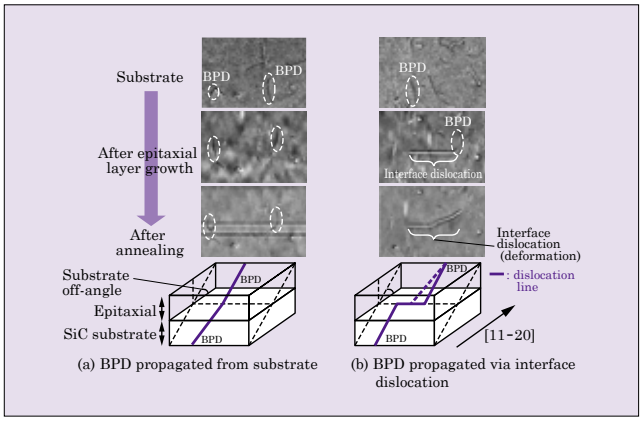
Fuji Electric will continue working to improve the quality of research and development. It will do this by striving to develop advanced technologies leading to innovation of electrical and thermal energy technologies, and making the most of fundamental technologies that support these development activities.

## Fundamental Technology

### 1 Analysis Technology Supporting the Development of Next-Generation Power Devices

To improve the reliability of SiC-metal-oxide semiconductor field-effect transistor (SiC-MOSFET), it is essential to control crystal defects in the device structure. In particular, the key is to use technology for transforming crystal dislocations inherent in a substrate into a harmless form, eventually eliminating stacking faults generated in the epitaxial layer. Crystal dislocations are transformed by thermal and mechanical stress generated in the respective stages of the process but the course of transformation has been unknown up to now. Fuji Electric has made the most use of various analysis technologies including synchrotron radiation topography and spectroscopic analysis for analytical study. It has also conducted follow-up evaluations on the types and locations of defects, substrate stress and deformation for each process for a range of items from a substrate to a device. Based on this, we have successfully suppressed the generation of defects in the device manufacturing process to realize a high-reliability SiC-MOSFET that features characteristic changes of the MOSFET during operation that are less than one-fifth, compared with that of conventional devices.

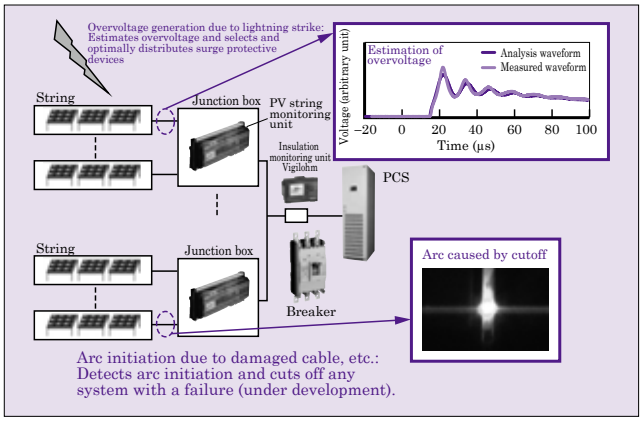
Fig. 1 Synchrotron radiation topograph of SiC basal plane dislocations (BPD)




### 2 Protection Technologies of Photovoltaic Power Generation Systems

As photovoltaic power generation systems become increasingly widespread, the need is also increasing for safe operation of distributed power generation facilities. In addition to the development of equipment required to protect power systems, Fuji Electric is working on the development of technologies for appropriate selection and installation of these facilities. We have developed technology to analyze the system voltage and current behavior associated with short circuits, which is required for selecting circuit breakers, and analysis technology for estimating an overvoltage due to lightning strikes, which is required for selecting surge protective devices (SPDs). At present, we are engaged in the development of technology for quickly detecting arc faults resulting from incomplete circuit connections or dameged cables. In the future, we intend to propose even safer systems by combining a string monitoring unit, insulation monitoring unit, etc.

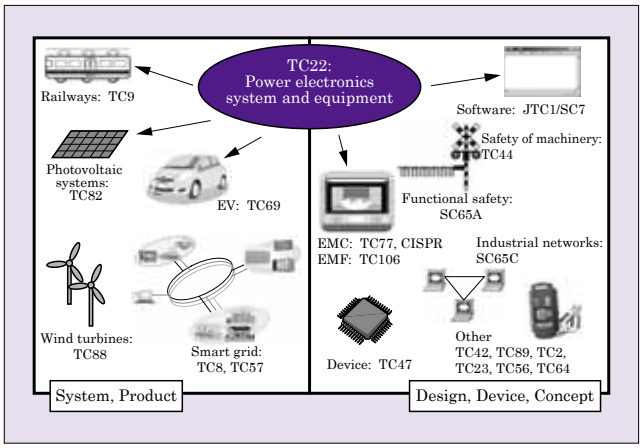
Fig. 2 Products and technologies relating to safe operation of photovoltaic power generation systems




### 3 Conformance to International Standards Related to Power Electronics

In the field of power electronics, a number of international standards are established by the International Electrotechnical Commission (IEC). Recently, the number of deliberations on standards has been increasing. This makes it necessary for manufacturers to participate in the deliberations and develop conforming technologies in order to expand into the global market, and Fuji Electric has been actively engaged in these activities. Regarding the drive efficiency standard, we have submitted a measuring method and sequence from Japan to international deliberations based on the results of testing jointly conducted with the Japan Electrical Manufacturers' Association (JEMA). We have also acted as the leader to reflect this standard in a draft of the IEC standard. Fuji Electric received recognition for its revision activities for Edition 5.1 of CISPR 11, an international standard for radio frequency emission, and won an IEC 1906 Award. In addition, our achievement of the inclusion in CISPR 11 of EMC requirements for system interconnection power converters for photovoltaic power generation equipment was acknowledged. This led to us winning an award at the Electrical Industry Technology Achievement Awards as a member of the JEMA Distributed Power Supply EMC Study Committee team.

Fig. 3 International standards surrounding power electronics



## 4 Gas Analysis Technology Conforming to MARPOL Annex VI "Regulations for Prevention of Air Pollution from Ships"

In order to prevent air pollution from ships, exhaust gas regulations are gradually being reinforced based on the International Convention (MARPOL Annex VI). To meet the requirement for continuous monitoring of exhaust gas from ship engines, Fuji Electric has developed a gas analysis technology that conforms to the "Regulations for the Prevention of Air Pollution from Ships." The main features are as follows:

(1) A laser-based method allows wet basis measurement that reduces the effect of moisture interference. This has eliminated the need for a moisture-removing device, leading to the successful miniaturization of the entire equipment.
(2) One unit incorporates two laser elements to allow simultaneous measurement of $SO_2$ (sulfur dioxide) and $CO_2$.
(3) Sensitivity of $SO_2$ measurement is improved by applying a quantum cascade laser.

Fig. 4 Laser-based $SO_2/CO_2$ gas analyzer

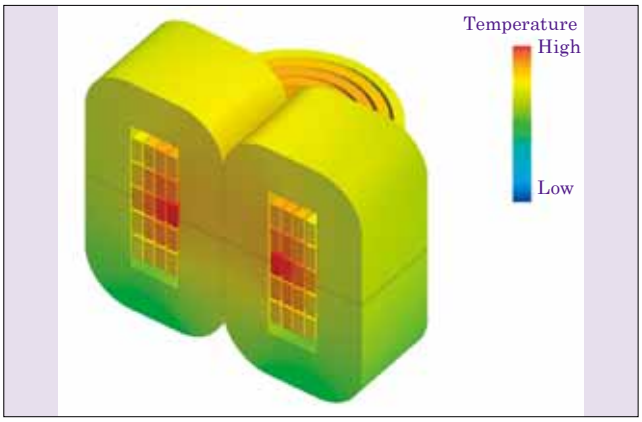
## 5 Thermal Simulation Technology in Reactor Design

Recently, power electronics devices have been getting increasingly smaller in size and higher in density and, in terms of thermal design of equipment, improved temperature prediction accuracy is required for magnetic components such as reactors and transformers.

To determine the temperature with high accuracy, it is key to be able to perform accurate loss calculations. Accordingly, we have attempted to improve accuracy in electromagnetic field analysis by modeling that gives consideration to magnetic characteristics and eddy current loss due to leakage flux. Furthermore, we have established an analysis technique capable of predicting temperature with higher accuracy than the conventional method by linking electromagnetic field analysis with thermo-fluid analysis to apply the loss distribution as a heat generation condition. This provides detailed temperature distribution including hot spots by analysis and improves the design accuracy of a reactor cooling structure.

In the future, we intend to apply this technique to equipment design so as to reduce the number of prototyping cycles and development period.

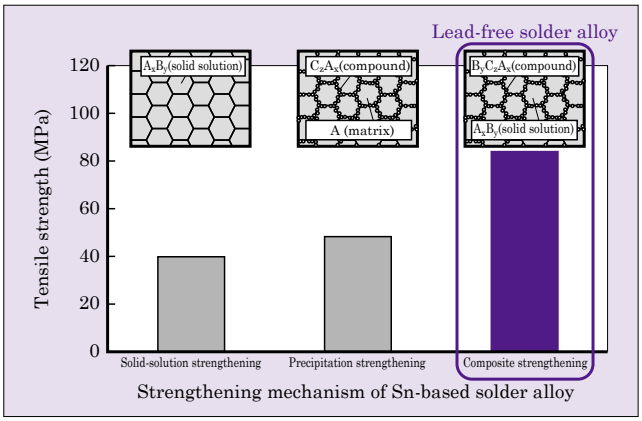
Fig. 5 Example of reactor temperature analysis by linking electromagnetic field analysis with thermo-fluid analysis




## 6 Solder Joining Materials with High-Temperature Operations

Solder joining materials for power semiconductors are required to offer characteristics of high thermal resistance and fatigue lifetime resistant in order to achieve the high-temperature operation and improved reliability demanded. Fuji Electric has been working independently on the development of solder joining materials since 1990 and making contributions to society by realizing environmentally friendly and highly reliable power converters. To meet the need for power converters with better performances, we have developed a new lead-free solder alloy that withstands high-temperature operation. This lead-free solder alloy is a result of identifying the degradation mechanism by conducting detailed failure analysis of materials respectively from solid-solution strengthening and precipitation strengthening, which are strengthening mechanisms for metal materials, and compensating for their weaknesses to achieve composite strengthening. This has enabled us to accomplish a high-temperature continuous operation lifetime ($T_{jmax}$ = 175°C) improved by approximately 2.6 times compared with that of conventional solders. This makes it possible to achieve a higher output and reduce the size of power converters by having an improved power density.

Fig. 6 Relationship between solder alloy strengthening mechanism and mechanical characteristic

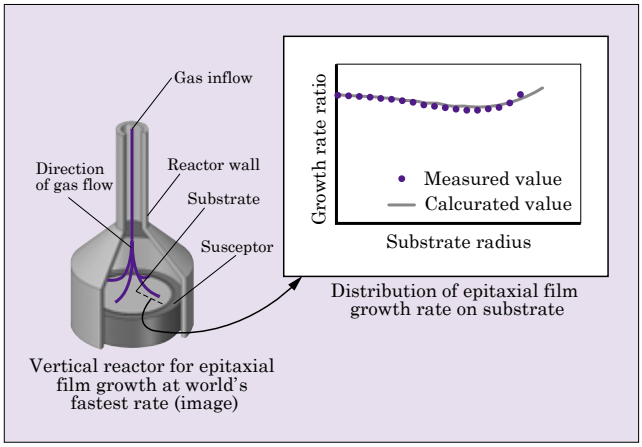


## Advanced Technology

### 1 SiC Epitaxial Film Growth Simulation Technology

In an epitaxial film growth process by using chemical vapor deposition (CVD), high growth rate and uniformity film thickness are required in order to improve productivity. In this research, we have developed a simulation technology that makes it possible to estimate the growth rate of epitaxial film in a vertical CVD reactor which can provide high growth rate used in the R&D Partnership for Future Power Electronics Technology. In the simulation, the epitaxial film growth rate in a substrate can be estimated under the various kind of process conditions, such as temperature and gas flow rate. This research is a result of the "Novel Semiconductor Power Electronics Project Realizing Low Carbon Emission Society" entrusted by the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO).

Fig. 7 Distribution of epitaxial film growth rate on substrate

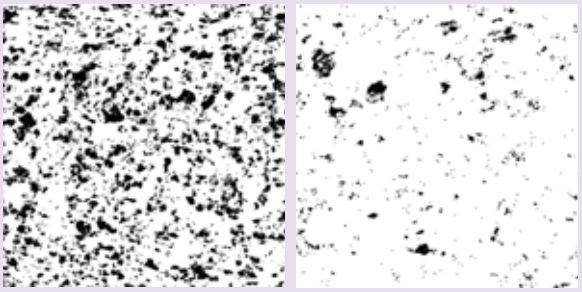



### 2 Crystal Orientation Control Technology for Heat-Assisted Magnetic Recording

For the magnetic layer of heat-assisted magnetic recording media, ordered FePt alloy with high magnetic anisotropy energy is used. A magnetic film of FePt, which is a cubical crystalline system, is more prone to crystal orientation defects than a magnetic film of CoPt, which is a hexagonal-crystal used in the magnetic layer of the current perpendicular magnetic recording media. As a result, low-frequency noise at reading will be large.

In order to reduce crystal orientation defects, Fuji Electric worked on developing the seed layer directly beneath the magnetic layer. By introducing the newly developed seed layer, we have successfully reduced orientation defects of magnetic grains that grow directly on the layer by 25% as compared with the current seed layer. We now plan to verify the effectiveness of the medium with this seed layer.

Fig. 8 Crystal orientation mapping of FePt film formed on seed layer

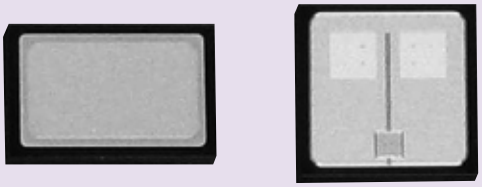



*White: Perpendicular orientation (non-defective orientation),
Black: In-plane or oblique orientation (defective orientation)

### 3 3,300-V SiC-SBD and SiC-MOSFET

An SiC-Schottky barrier diode (SiC-SBD) is characterized by the extremely small reverse recovery loss. By replacing the silicon diode used in a 3,300-V insulated-gate bipolar transistor (IGBT) module with an SiC-SBD to make a hybrid module, the inverter generated loss can be reduced by 25%. In addition, an SiC-metal-oxide semiconductor field-effect transistor (SiC-MOSFET) can be combined with an SiC-SBD for use in an inverter circuit as an All-SiC module, which makes it possible to further reduce generated loss. For the SiC-MOSFET, an implantation and epitaxial metal oxide semiconductor (IEMOS) structure has been used to achieve the characteristic on-resistance at room temperature of 14 $m\Omega cm^2$. These 3,300-V SiC modules are expected to be applied to electrical rolling stock and transmission and distribution devices. This research or part of this research has been conducted as a project of the "Tsukuba Power-Electronics Constellations (TPEC)," a joint research entity.

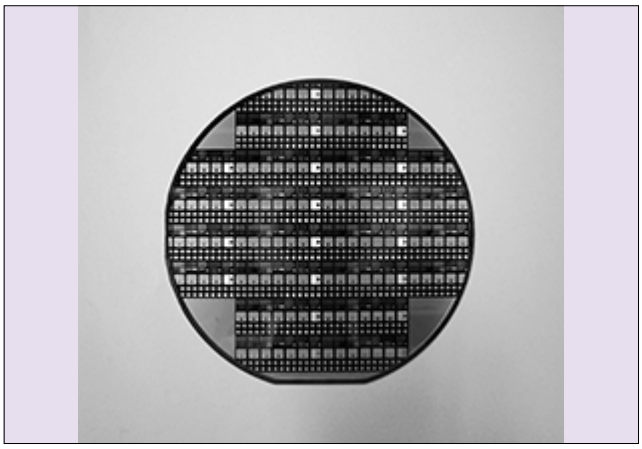
Fig. 9 Chip external appearance



## 4 SiC Trench MOSFET

Recently, practical application of SiC-metal-oxide-semiconductor field-effect transistors (SiC-MOSFETs), which are capable of dissipating less power, has been progressing in order to meet the demand for efficiency improvement and miniaturization of power converters. Because of the planar structure, there is a limit to the amount that on-resistance can be reduced by having smaller design rules. Accordingly, to further reduce on-resistance, Fuji Electric is engaged in the development of a trench MOSFET, which is advantageous for smaller design rules, jointly with the National Institute of Advanced Industrial Science and Technology. The trench MOSFET under development is not only aimed at achieving low on-resistance but also intended for mitigation of an electric field in the gate oxide film at the trench bottom. It achieves this by using the p-well structure deeper than a trench gate in order to ensure high reliability. The trench MOSFET of 3.3-kV class experimentally produced with this structure has achieved 20% lower on-resistance than a planar type.

Fig. 10 Wafer after processing of 3.3-kV SiC trench MOSFETs

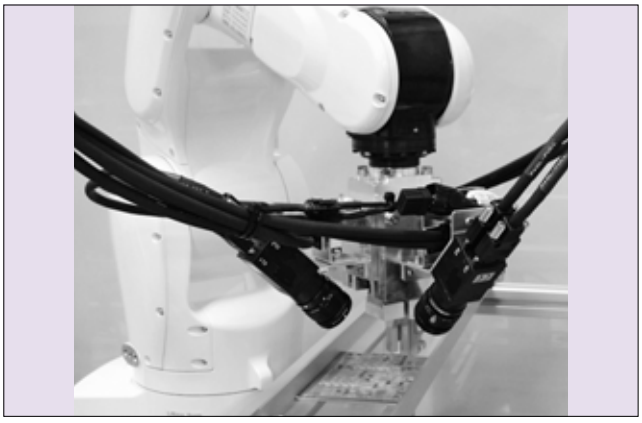


## 5 Visual Feedback Control in Robot Operation

Recently, automation by using robots has been advanced but operations dependent on human perception (vision, kinesthetic sense, tactile sense, etc.) have not reached a level of practical use. To realize robot behavior that fits the situation in the same way as a human, we are moving ahead with the development of autonomous control technology of robots. Our system gives real-time feedback of visual and kinesthetic sense information to control the arm trajectory and force of operational movements.

We have recently developed a technology for automatic mounting of electronic components that uses visual information for feedback control of a robot. When an electronic component is inserted in the printed circuit board, two cameras are used to capture the lead end and the center of the through-hole. Then, the arm trajectory is successively adjusted so that the two coincide on each camera image, and this has made it possible to insert a component with high accuracy and without any insertion failure due to displacement.

Fig. 11 Electronic component mounting using visual feedback control





# FUJI ELECTRIC REVIEW vol.61 no.2 2015 Detailed Contents

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* Non-consolidated subsidiaries

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### Fuji Electric Brazil-Equipamentos de Energia Ltda *
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## Asia

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URL http://www.sg.fujielectric.com/

### Fuji SMBE Pte. Ltd. *
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URL http://smbe.fujielectric.com/

### Fuji Electric (Thailand) Co., Ltd. *
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### Fuji Electric Manufacturing (Thailand) Co., Ltd.
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### Fuji Electric France S.A.S
Manufacture and sales of measurement and control devices
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## China

### Fuji Electric (China) Co., Ltd.
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URL http://www.fujielectric.com.cn/

### Shanghai Fuji Electric Switchgear Co., Ltd.
Manufacture and sales of switching equipment, monitoring control appliances, and related facilities and products
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URL http://www.fujielectric.com.cn/sfswgr/

### Shanghai Fuji Electric Transformer Co., Ltd.
Manufacture and sales of molded case transformers
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### Wuxi Fuji Electric FA Co., Ltd.
Manufacture and sales of low/high-voltage inverters, temperature controllers, gas analyzers, and UPS
Tel +86-510-8815-2088

### Fuji Electric (Changshu) Co., Ltd.
Manufacture and sales of electromagnetic contactors and thermal relays
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URL http://www.csfe.com.cn/

### Fuji Electric (Zhuhai) Co., Ltd.
Manufacture and sales of industrial electric heating devices
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### Fuji Electric (Shenzhen) Co., Ltd.
Manufacture and sales of photoconductors, semiconductor devices and currency handling equipment
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URL http://www.szfujielectric.com.cn/FUJIWebSite/index.html

### Fuji Electric Dalian Co., Ltd.
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### Fuji Electric Motor (Dalian) Co., Ltd.
Manufacture of industrial motors
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### Dailan Fuji Bingshan Vending Machine Co.,Ltd.
Development, manufacture, sales, servicing, overhauling, and installation of vending machines, and related consulting
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### Fuji Electric (Hangzhou) Software Co., Ltd.
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### Zhejiang Innovation Fuji Technology Co., Ltd. *
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### Fuji Electric FA (Asia) Co., Ltd.
Sales of electrical distribution and control equipments
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### Fuji Electric Hong Kong Co., Ltd.
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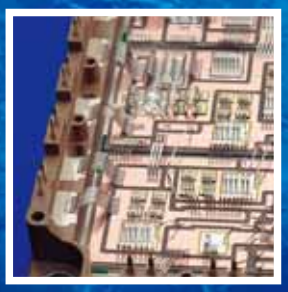
### Hoei Hong Kong Co., Ltd.
Sales of electrical/electronic components
Tel +852-2369-8186
URL http://www.hoei.com.hk/

# *Innovating* Energy Technology

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

Corrosion Resistant, Material, and Hot Water Utilization Technology

Geothermal Power Plants



Device Technology

Power Devices (IGBT)

Power Electronics Technology

Power Conditioning Systems (PCS) for Megasolar Plants

Power Electronics Technology

Inverters

Power Electronics Technology

Uninterruptible Power Supply Systems (UPS)

Heat Excange and Refrigerant Control Technology

Hybrid Heat Pump Vending Machines

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