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Technical Achievement and Outlook in FY2013

Fuji Electric

Innovating Energy Technology

FUJI ELECTRIC
REVIEW

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The earth, the third planet from the sun and the planet on which we live, is being subjected to global warming, abnormal weather, environmental pollution and the like. However, the citizens of the world are focusing their collective wisdom to halt these trends and to create a sustainable society. Through pursuing innovation in electrical and thermal energy technology, Fuji Electric intends to contribute to the realization of a safe, secure and sustainable society through creating products that utilize energy as efficiently as possible. This "Technical Achievement and Outlook in FY2013" issue is an updated revision of the issue format previously delivered at the beginning of the year, and is a compilation of technical achievements mainly in FY2013 and a summary of the future outlook. We will be pleased if this issue proves to be even slightly useful to all as a reference in the construction of the new society.

Cover Photo:

"Micrex-VieW XX," All-SiC module, Power conditioner for photovoltaic power generation, Aerosol particle combined analyzer

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Preface

Contribution of Fuji Electric's "Energy-Related Business" to a Safe, Secure and Sustainable Society

Fuji Electric has adopted the "expansion of energy-related business," the "pursuit of globalization" and the "Work together as a team with concerted team strength" as management policies, and "Innovating Energy Technology" as a brand statement that reflects a desire to pursue innovation in electric and thermal energy technology in order to create products that use energy with maximum efficiency and to contribute to the realization of a safe, secure and sustainable society.

In FY2013, positioned as new base year of an aggressive management initiative to expand our global energy business, we established FY2015 Medium-Term Management Plans, created a foundation for growth for future business expansion, and worked to further strengthen profitability.

In Japan, the renewable energy and energy conservation-related fields continued their strong growth, and new products in the food distribution business made good progress. Overseas, the fields of power electronics devices and power semiconductors continued strong growth, and through our acquisition of equity in a transformer manufacturer and launch of a new factory in Thailand, and establishment of a joint venture in China, and so on, we built out an infrastructure for strengthening our overseas business.

In terms of R&D, we focused on the development of distinctive global products in the energy field, and were able to achieve significant results.

Fuji Electric developed power devices that use silicon carbide (SiC), a material expected to revolutionize power devices, and accelerated the development of power electronics products that incorporate such devices. We were the first in the industry to build a SiC 6-inch wafer mass-production line, and have already started pre-mass-production. Additionally, we have utilized SiC devices in practical applications to develop power conditioner and inverters for photovoltaic power generators that realize significantly low loss and smaller size than in the past, and plan to launch products on the market in FY2014.

In addition, we have developed a number of power electronics devices based on a new 3-level power conversion circuit that uses a reverse-blocking insulated gate bipolar transistor (RB-IGBT), which is Fuji Electric's proprietary power semiconductor. All of these devices realize high efficiency and space-savings. One example is a 3-phase 4-wire high-capacity UPS developed for overseas markets, including Asia, that achieves a conversion efficiency of 96.5% and enables the installation footprint to be reduced by at 30% or more compared to conventional models.

Together with the development of components that combine power semiconductor technology and power electronics technology, Fuji Electric has also developed the "MICREX-VieW XX," a small- and medium-scale monitoring and control system for use as a platform for the control system that "connects" these devices. Featuring high reliability,

small size and high performance, this system enables the continued use of customer assets of programs and screens.

As a solution for maximizing the efficiency of energy utilization, we are developing various types of energy management systems (EMS) that realize energy-savings through optimal control of electric energy and thermal energy. In the Kitakyushu Smart Community Creation Project, which is part of the "Next-Generation Energy and Social System Demonstration Program" initiated by the Ministry of Economy, Trade and Industry in FY2010, Fuji Electric has played a central role by developing a cluster EMS (CEMS) centering on a "regional power saving station," and is continuing to demonstrate and evaluate this station. We demonstrated that dynamic pricing, which sets a high price for peak periods on summer and winter days when a power shortage is expected, is effective and confirmed that a reduction in demand of about 10% can be achieved. In addition, we have also advanced the development and demonstration of EMS for buildings (BEMS), EMS for retail (REMS), and EMS for factories (FEMS), and in response to the good results obtained, are moving forward with numerous commercial negotiations, and significant developments are expected in the future.

From the perspective of safety and security, Fuji Electric has developed systems for diagnosing the health of bridges and buildings through utilizing vibration sensors that incorporate micro electro mechanical systems (MEMS) technology to sense minute vibrations, and has begun demonstrating these systems. By utilizing MEMS technology, the sensors can be made smaller and lighter, and can easily be installed in various locations with only minimal limitations on the installation site, enabling good diagnostic accuracy to be achieved at low cost.

In addition, Fuji Electric has developed and has begun demonstrating the world's first aerosol spectrometer for performing real-time measurement of concentrations of PM2.5 mass and components, which is being scrutinized as a major environmental issue. This spectrometer is configured from an analysis unit that employs laser spectroscopic technology originally developed with gas analyzers, a particle concentrator that utilizes MEMS technology, and a mass analyzer. The spectrometer is an innovative device, and through measuring particle components in real-time, can assist in identifying the source of emissions.

Through accurately assessing the needs of society and innovating electric and thermal energy technology, Fuji Electric intends to continue to create products that use energy with maximum efficiency and to contribute to the realization of a safe, secure and sustainable society. We sincerely request guidance and support from everyone.

KITAZAWA, Michihiro
President and Representative Director

Special Conversation

A Challenge to Energy Innovation Through Power Electronics

Expanding Applications of Power Electronics via Device Innovation

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Graduate School of Science and Engineering
Tokyo Institute of Technology

EGUCHI, Naoya
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Director, Executive Officer, Fuji Electric Co., Ltd.

The emergence of SiC power devices has enabled power electronics to be applied to fields that were difficult in the past. Where will the future of power electronics lead us? What can we expect from Fuji Electric that pursues to create a sustainable society through the use of energy technology? We had the special opportunity to meet with one of the pioneers of power electronics, Professor Dr. Akagi, Tokyo Institute of Technology. He sat down with Dr. Eguchi, Corporate General Manager of Corporate R&D Headquarters at Fuji Electric, to discuss their opinions regarding the possibilities and issues surrounding power electronics.

Power Electronics is Fuji Electric's Core Technology

Eguchi: We have worked with Professor Akagi, one of the pioneers of power electronics, on several joint research projects and received useful advice. I would first like to express my appreciation to Professor Akagi again. Today I would like to hear your broad-minded opinions so that we can discuss the development of power electronics and contribute to the future of Fuji Electric.

Fuji Electric was established 91 years ago in 1923 on the joint funding of Furukawa Electric Co., Ltd. and the German company Siemens AG (which is pronounced "Jiemens" in German). Fuji Electric was named after the "Fu" in Furukawa and "Ji" in Jiemens.

Fuji Electric had originally developed as a company that manufactured heavy electric equipment such as motors and transformers. In 1959, we started the manufacture of silicon diodes as power semiconductor devices (power devices), and then later we began manufacturing power electronics equipment such as rectifiers and inverters.

As we look back on the history of Fuji Electric, we can see that power electronics has always been a core technology of our business.

Fuji Electric will continue to manufacture environmentally-friendly and highly value-added products that make the most effective use of energy in its pursuit to realize a safe and secure sustainable society. In order to achieve this, we are aiming to provide optimal solutions integrating power devices that characterize Fuji Electric into power electronics technology that uses the power devices (e.g. power converters) as the core, combined with various surrounding technologies.

Professor Akagi, when did you first start working in the power electronics field?

Akagi: In 1957, the American company, General Electric became the first company to manufacture thyristors. I think that it would be correct to say that this was the practical start of the power electronics field.

I started doing research on power electronics in my graduation work during my fourth year as an electrical engineering student (in 1973). As an undergraduate and graduate student, I did research in the areas of a line-commutated cycloconverter and a forced commutation circuit, using thyristors. After becoming a university faculty member, I started working hands-on with nearly all types of power devices including the now obsolete static induction transistor (SIT). I have been dedicated to the power electronics field for 41 years.

When Likened to the Human Body, Power Electronics is the Muscle

Eguchi: You have always been at the cutting edge of power electronics in the long history. I have also been engaged in power electronics since my fourth year at a university in 1977 and have also devoted myself to power electronics since entering the workforce. During that time, power devices underwent dizzying changes.

Recently, the term "power electronics" is being heard more often. So, how would you respond if you were asked "What is power electronics?"

Akagi: Although it is a bit difficult to explain to non-technical people, I would say that for researchers and engineers, with various different specialties in electrical and electronic engineering, power electronics is an applied technology with power conversion technologies using power devices placed at the core, and is being practically employed in various applications such as those for motor drives, various power supplies and power system equipment. Since inverter-based air conditioners began to appear on the market in the early 1980s, the term "inverter" has been becoming more familiar to people, but power electronics covers a much larger range of technologies, which also includes inverters.

It might be easier to give an example such as that of photovoltaic power generation. Since photovoltaic cells generate DC power, connecting the output terminals to 50Hz or 60Hz power systems requires DC to AC power conversion. Power electronics is the key technology that makes this power conversion highly efficient.

Eguchi: Electronic circuits such as microcomputers and LSIs are used to control electrical signals, whereas power electronics to control electrical energy.

Akagi: Yes, that is right. If we liken the technologies to the human body, a computer is like the brain while power electronics is the muscle.

Eguchi: That is an easy way to think about it.

These days power electronics is used in many different products. Wouldn't you agree that it can be found in most home electric appliances?

Akagi: Initially, I had thought that power electronics is not needed in low-tech products such as electric fans, but the newest fans are being driven by inverters. Ten years ago, vacuum cleaners were still being powered by AC commutator motors, but are now using power electronics. Power electronics is also used in LED lighting.

Eguchi: Power electronics now have a large role in the automobile industry, too. Power electronics is actually being used in a wide range of applications. Please tell us about the basic ways of thinking about power electronics from the perspective of research in consideration of your own research results and rich experience.

Three-Level Inverters and Patents

Akagi: University-level research and corporate-level research and development are slightly different. Research efforts at universities seek novelty and pursue challenges with the expectation that today's high cost technologies will become affordable in the future. Alternatively, when attempting to research subjects that are already in practical usage, professors and graduate students have to find and research something new in analysis, control, design, or other technical aspects.

Eguchi: You have published various types of new theories and technologies such as the instantaneous reactive power theory, or the p-q theory and active filters. You have also researched three-level inverters.

Akagi: During my tenure at Nagaoka University of Technology, I worked in the Power Electronics Laboratory (Power Lab) with Professor Akira Nabae and Associate Professor Isao Takahashi, and we published our results on three-level inverters. Since it was a new university that was established in 1978, there were no graduate students on campus. As a result, I was in charge of the laboratory experiments. It was around November of 1979, I still vividly remember being able to verify our experiment on the adjustable-speed control of an induction motor driven by a three-level inverter.

Eguchi: You never got the three-level inverters patented, didn't you?

Akagi: No, we didn't apply for a patent. At a national convention of the Institute of Electrical Engineers of Japan in March 1980, we published our research paper on the circuit structure of three-level inverters and the adjustable-speed control of an induction motor driven by this new inverter. It is inter-

EGUCHI, Naoya

Born in 1954. Joined Fuji Electric Manufacturing Co., Ltd. in 1980 (now Fuji Electric Co., Ltd.). Fuji Electric Systems Co., Ltd. Board of Directors in 2006. President of Fuji Electric Advanced Technology Co., Ltd. in 2009. Director and Managing Executive Officer of Fuji Electric Systems Co., Ltd. in 2010. Director and Executive Officer of Fuji Electric Co., Ltd. in April 2011, and concurrently serving as General Manager of Corporate R&D Headquarters.

esting to note, but a researcher in the United States was carrying out the same research as ours at the same exact time. This person applied for a patent in Japan. However, since we had published our paper, his patent application was not approved by the Japan Patent Office.

Eguchi: It was fortunate that no patent on the three-level inverter was granted in Japan. After this, the three-level inverter became widely used in industrial fields such as railways and plants. I feel deeply that you are the one who pioneered the development of power electronics in Japan.

Akagi: While I was staying at the University of Wisconsin-Madison as a visiting professor in 1996, I heard from a doctoral student that since the three-level inverter was patented in the United States, it would not be used practically until the patent expired. This resulted in a delay in its adoption.

Eguchi: This is one of the aspects related to patents, and therefore what is a preferable way to obtain a patent is really a sensitive issue.

Akagi: In my opinion, ideas for which a basic patent can be granted should be filed from universities and in other cases, it is best to publish a paper to make the technology public. This is because ideas that can grant a basic patent are not easily generated.

SiC Brings a New Generation to Power Electronics

Eguchi: At first, insulated gate bipolar transistors (IGBTs) as power devices became widespread, and then three-level inverters as circuits. Recently, reverse-blocking (RB)-IGBT power devices have appeared on the market. The technology still doesn't need to take on a new form since there is still plenty of room for evolution based on the fundamentals. You are now also involved in new multi-level converter research, so it seems that you still have a lot of different projects to work on, right?

Recently, Fuji Electric has been focused on development of silicon carbide (SiC) devices. Theoretically, power loss is only one-tenth of silicon devices. We have been making big moves from thyristors to transistors and IGBTs, and now I believe that a new generation is emerging. What are your thoughts on SiC?

Akagi: Our laboratory is actually working on experiments with SiC metal-oxide-semiconductor field-effect transistors (MOSFETs) and SiC Schottky barrier diodes (SBDs), so I know first-hand the advantages of the SiC power devices. The on-resistance of an SiC-MOSFET and the on-voltage of an SiC-SBD are smaller than those of an IGBT, in spite of much better switching characteristics. For example, in a bidirectional isolated DC-DC converter of about 100kW, an IGBT needs to suppress the switching frequency to about 4kHz, but SiC has a low power loss and can be operated at 20kHz, which exceeds the audio frequency. As a result, no acoustic noise is generated.

This can only be due to the fact that it is a different material. When mercury-arc rectifiers were replaced by thyristors, material was changed completely, and I think that the change from Si to SiC is equivalent to that change. The switch from bipolar junction transistors, which were called power transistors in Japan, to IGBTs was a big jump, and I think that the current change to SiC is even bigger.

Eguchi: The research done at Fuji Electric is widely divided into corporate research and business division research. Corporate research is currently dedicating about one-third of its resources to SiC. The Matsumoto Factory has also implemented a manufacturing line that uses SiC six-inch wafers. In addition, it has shifted its operations to support the mass production of SBDs. We are also starting to handle MOSFETs, so I think we can make some considerable achievements within the next two or three years.

Akagi: We had the same experience when power transistors were switched to IGBTs. The first-generation IGBTs that were put into practical use in 1986 were said to have a high on-voltage while also being expensive, but since they possessed good characteristics, a major shift to IGBTs occurred within two or three years. After power electronics engineers recognized their superiority, the trend to adopt them could not be stopped. Then came the 1990s when power transistors were no longer used except for special purposes only. Currently, papers on power conversion circuits using SiC-MOSFETs are steadily starting to appear in academic societies.

Eguchi: Fuji Electric's development of SiC is based on its joint work with the National Institute of Advanced Industrial Science and Technology (AIST). Joint research with university labs or commissioned research to those was formerly the mainstream as a way of implementing external research and development, but the results never seemed sufficient enough. I thought research didn't go smoothly unless we worked closely with our counterpart. We are currently sending lots of talented human resources to the AIST. This is open innovation in the true sense of the word. We have been able to achieve our goals and have obtained results that exceed our expectations.

Akagi: I also have been interested in SiC power devices for about 10 years and have been watching closely the papers related to SiC devices and their applications that are published at major technical journals and conferences throughout the world. Honestly, in the beginning, I thought that Japan's SiC power devices lagged behind those of Europe and the United States. However, it appeared to me that whenever a European or American company produced sample SiC power devices, they easily sold them to users. Japanese companies, on the other hand, were extremely careful in providing users with samples, and therefore I think that this aspect simply cannot be compared to European and American companies.

Eguchi: Do you think that Japanese power electronics is leading the way in this field?

Akagi: With regards to large and medium capacity power converters, which are my field of specialty, I believe that Japan has taken the lead. Recently, the focus has been on modular multilevel converters that were originally developed in Europe. The Europeans are extremely specialized in certain areas. Japan focuses on a broader range of research, and from the viewpoint of penetration, I think Japan is not losing.

Eguchi: The development of SiC power devices has expanded the possibilities of power electronics for the future, ranging from a high-frequency field to a high-voltage field. It seems that it will also make a full-scale entry into power systems as well. I believe that the trend is moving closer and closer to your own world of research. Examples of such cases include flexible AC transmission systems (FACTS).

Akagi: Yes, you are right. FACTS were proposed by Dr. Hingorani, the Electric Power Research Institute (EPRI) in the United States in the 1990s. However, at that time, only gate-turn-off (GTO) thyristors were available, so there was a lot of switching loss. Particularly in the case of power system equipment that is always running, it is really important to reduce the loss of power converters. It is equivalent to increasing the fuel efficiency in cars. So, this power-loss problem produced bottlenecks and as a result, FACTS devices and power system equipment that used GTO thyristors didn't become widespread to a great extent.

When using SiC-MOSFETs in power electronics equipment for power systems, the efficiency is considered to be above 99% in the case of a STATCOM (static synchronous compensator) installed with 6.6kV power distribution lines in Japan. This efficiency is about the same as that of line-frequency (50/60Hz) transformers with the same capacity. Therefore, I think that power loss in converters will no longer be a problem in the future.

AKAGI, Hirofumi

Born in 1951. Assistant and then Associate Professor at Nagaoka University of Technology in 1979 and 1984. Professor at Okayama University in 1991. Professor in the department of electrical and electronic engineering at Tokyo Institute of Technology in 2000 (present post). IEEE Fellow in 1996. IEEE Power Electronics Society President from 2007 to 2008. Scheduled to assume the position of IEEE Division II Director from January 2015 to December 2016. Also active as the IEEE Division II Director-Elect throughout 2014.

Power Electronics is a National Project for Japan and the United States

Eguchi: It seems that we are about to enter a new age where power systems can be controlled by semiconductors. Power devices will also probably evolve more.

At our company, we are currently undertaking research and development of gallium nitride (GaN) as part of wide energy-band-gap devices development, and possibly diamond in the future.

What are your dreams for the future?

Akagi: As I said before, my dream is to reduce the power loss of SiC converters to a level below that of line-frequency transformers of the same capacity. For example, I would like to reduce the power loss of a power converter rated at 6.6kV and 1,000kW, to approximately the same as that of transformers, and in some cases even less. This is a very challenging dream, but I believe it can be achieved through the use of SiC power devices. This is because the performance of SiC power devices will continue to improve in the future.

My other dream is downsizing. Downsized products reduce costs and widen their market. A good example of this is a mobile phone. When mobile phones first appeared on the market, they had to be carried on your shoulders and they were very expensive. However, they became more affordable as their size reduced, and now everyone from a junior high school student to a senior citizen has a mobile phone.

Eguchi: Our dream is to engage ourselves in a rich variety of business projects using power electronics as core technology.

Since wireless communications can now be achieved, the demand for sensors has increased. At the same time, digital signal processors (DSPs) which control devices have achieved higher performance. I believe that intelligent products are feasible through the combination of sensors, control devices and power electronics.

Akagi: That is true. I can give an example of the power conversion based on power electronics. It used to be quite common that a large capacity converter rated at 1,000kW or 10MW consisted of a single conversion circuit utilizing high-voltage large-current power devices. However, now with the ability to exchange information wirelessly with sensors at an acceptable level of reliability allows building up a large capacity converter consisting of serial-parallel connections of multiple standardized medium or small capacity converters with the same voltage and current ratings. Although its control is complicated, we will certainly realize such a converter if the performance further improves in a DSP, which can process digital signals quickly, and in a field-programmable gate array (FPGA), which is an advanced programmable logic device.

Eguchi: With regards to that, I would like to discuss these matters more with professors so that we can further contribute to the future of power electronics.

During a speech on January 15, 2014, President Obama mentioned that Next-Generation Power Electronics Manufacturing Innovation Institute would be established in North Carolina State University, and Prime Minister Abe also spoke about the importance of next-generation power electronics during the 2013 Council for Science and Technology Policy. In both Japan and the United States, power electronics is a keyword of the next generation.

It seems that your role in the future will be increasing more and more. You have also been appointed to an important position within the Institute of Electrical and Electronics Engineers (IEEE).

Akagi: The IEEE is the world's largest technical society with about 400,000 members worldwide. From January 2015, I will assume the position of the Division II Director for a period of two years. This year I was appointed Director-Elect before the official assumption of the position. I will have more opportunities to visit the headquarters of the IEEE in New Brunswick (New Jersey), as well as have more IEEE related work.

Eguchi: Being positioned like that on the international stage will surely help promote the presence of Japan's power electronics.

Akagi: Of course, I intend to do everything I can. Actually, I also have a request. I would like companies to also actively contribute papers to the IEEE.

There are approximately 40 technical societies under IEEE Divisions. Only about 10% of the technical societies are increasing their membership, and the IEEE Power Electronics Society is one of the few societies showing growth in membership. The number of engineers engaged in power electronics in the United States is also increasing.

Pursuing Synergies between Power Electronics and Devices

Eguchi: Power electronics require a wide range of knowledge in many fields, and Fuji Electric has positioned itself in an environment that can pursue synergy effect since it possesses both device technology and application technology. I would like to hear your opinion on this.

Akagi: I think that it is a big advantage to a company when it can do business utilizing both power devices and their applications. Since it is very hard for a single person to fully understand both technologies, I hope that everyone can help each other by asking about certain aspects of the technologies with which he/she is not familiar. I tell the graduate students in the research lab that by self-education, it would take a full two years to completely understand the so-called "vector control," that is a control technology that uses high-performance motor drive systems. However, when I teach them little by little, they continue to steadily make progress in their understanding. I think that if you and other officers take the initiative to break down the barriers between sections in your company, you will create an atmosphere where it is easy to listen to each other freely. This is important because outside of the company, it is very difficult to acquire information.

Eguchi: The power devices section and the power electronics section of our company used to be divided by the force of sectionalism, but there are no longer any more barriers between these two sections. I inherited the duties of the Technological Development Department at Fuji Electric from Dr. Shigekane, who specialized in devices. Since I was specializing in circuit applications, we both led engineers

so that barriers would not be built. Also, when we were developing a new power device for three-level inverters, we decided the specifications based on the requirements of the circuit, and in the development of a SiC power device, device and circuit engineers discussed how to make full use of the technology.

Efforts to Develop a Smart Grid

Eguchi: Recently smart communities and smart grids are attracting a lot of attention, and I think this is probably a market in which power electronics can be used effectively. Please tell me what your outlook is on this market.

Akagi: Smart grids, defined in a broad sense, are to solve an issue of voltage and frequency stabilization if a large amount of fluctuating or intermitted electric power such as solar and wind power flows into utility transmission and distribution systems. Therefore, the amount of electric energy to be used needs to be adjusted to a certain extent on the utility customer side. Dynamic pricing intended for changing the charge of electricity, depending on the time period, has also been undergoing demonstrating projects in Japan. On the other hand, the development of grid-level battery energy storage systems that store and release electric energy is also urgently being pursued. Since roof-top photovoltaic power generation (PV) systems for individual houses, office buildings, and factories have come down in price, I expect that they will be widely used.

Eguchi: If that is the case, a micro grid will be an important factor, and also it will be extremely important to determine how to efficiently use the direct current (DC). I think that the unidirectional or bidirectional isolated DC-DC converter technology that you are working on will become increasingly necessary.

Akagi: Yes, I agree. There are two reasons why Edison's DC distribution lost out to the AC distribution developed by Tesla. One reason is that the electrical engineering technology at the time had hardly to freely change DC voltage. The other reason is related to a DC circuit breaker for protecting the DC system against a large amount of DC fault current. The leading-edge power electronic technology can solve the two problems inherent in the DC distribution. Of course, to change DC voltage, DC power is being converted to high-frequency AC power, but bidirectional isolated DC-DC converters have also become a sufficient target for utilization. I believe that DC power transmission and distribution systems will become widespread in a wide range of applications, which include its usage in the home.

Even though GTO thyristors weren't able to achieve practical usage due to cost and performance issues, the development of SiC-MOSFETs has opened the door to a whole new direction.

Power Electronics Requires Extensive Knowledge

Eguchi: Our biggest concern now is that there are not enough power electronics engineers. Do you have any good advice with regards to this problem?

Akagi: Since power electronics requires a vast range of knowledge, it obviously takes a very long time to train people in this field. As a result, universities are often not able to provide companies with the human resources they demand.

Power electronics requires a basic knowledge of circuits as well as an understanding of control technology. On top of this, engineers are also required to know analog and digital signal processing based on the latest A/D converters, DSPs, FPGAs and so on. When doing research and development on adjustable-speed motor drives, it is obvious that knowledge of motors is essential. In the case of the power electronics equipment being installed on power systems, knowledge is required of the power systems. And then, an understanding of semiconductors is needed to master the usage of power devices. This results in being related to almost all the courses in electrical and electronic engineering departments. Engineers who graduated with degrees in fields other than electrical and electronic engineering will need to first study circuit theory and electromagnetics, and after this they will have to proceed into the study of power electronics circuits.

Another problem is that there are not enough instructors who can guide students along the path of researching power electronics. Even at a hub university, there is only one power electronics laboratory. The reason why there are so few qualified instructors is because of the high amount of emphasis placed on research results and papers when hiring university faculty members. Power electronics research papers require a lot of time to write since they include nearly all of the content required in engineering papers such as research theme setting, analysis, simulation, laboratory experimental design and set-up, experimental data evaluation, and so on. The result is that the number of research papers written by instructors in this field is far less than that in other fields. In the field of electrical and electronic engineering, the goal is not to hire a wide diversity of instructors, but there needs to be means for evaluating instructors limited to those who specialize in power electronics, or by emphasizing the qual-

ity and content of research papers rather than the quantity of them.

Eguchi: Since students who are trained well by the qualified university instructors will immediately contribute to the workplace, it is my hope that we will be able to employ some talented young people.

Fuji Electric is currently doing power electronics R&D overseas in countries including Germany and the United States, but it is very hard employing overseas personnel. From your perspective, what do you think are the differences between researchers in Japan and overseas researchers?

Akagi: Internationalism is the big difference when compared to the United States. Many of the students studying power electronics in the U.S. were not born and raised there. Many come from India and China. Most of the directors of the IEEE Power Electronics Society were also not born and raised in the U.S. Out of approximately thirty members, only about three of them were raised in the United States. American society readily accepts people who have specialized abilities. From a different perspective, people who speak English as their native language also have a big advantage.

However, when thinking about this issue from different angles, I don't think it is appropriate to compare Japan and the U.S. I have always thought that it is better to compare Japan and Germany since Germany is characteristically similar to Japan in many aspects. The U.S. is totally different when it comes to geographical size, natural resources and the cost of energy such as electricity. It is also different with respect to its perspective on research.

How to Increase the Number of Power Electronics Engineers

Eguchi: Fuji Electric is now trying different strategies to train and cultivate their young employees to prepare them for work in next-generation power electronics. Tsukuba University has established an endowed course on power electronics, and I will work as an instructor for the power electronics summer school held every August at Tsukuba Innovation Arena (TIA).

Akagi: I have also been giving lectures since 2012. There have also been some famous lectures by Dr. Shigekane of Fuji Electric. The vice president himself gave a 90-minutes lecture that really inspired young students and engineers. So, from this year, the baton has been handed over to you.

Although students receive four days of lectures during summer school, what they learn is usually not immediately apparent to them, but it gives them some valuable hints and tips that they will find very useful later on in their lives.

The graduate students attending these lectures are the people who will be engaged in the future work of power electronics at universities and companies. Of course, some engineers who are actively working at companies also attend the lectures, and it is a lot of fun giving the lectures. You'll see the sparkle in the eyes of the students. I have also been teaching power electronics to students in the second half of their third year as part of the electrical and electronic engineering curriculum at my university. Although about 60 undergraduate students attend my lectures, I would say that only about 10% of them will work in the field of power electronics in the future.

Eguchi: I think that the challenges provided by the summer school will be a good chance to cultivate Japan's engineers so that they can contribute to the development of power electronics.

Akagi: What is difficult about power electronics is that even though they are used in our most familiar equipment and appliances such as Shinkansen bullet trains, refrigerators and air-conditioners, they exist in their sub-systems, so power electronics remains hidden to most people. Most people seem really interested in technologies such as the motor drive system (sub-system), which is one of the core technologies of the Shinkansen system. Therefore, I would like to see the mass media write more articles that focus on the sub-systems of these systems.

Eguchi: By appealing the technology to the general public, don't you think that the number of students studying power electronics will increase in the future? I would also love to see women become interested in this field.

Akagi: It is sad to say, but the number of women interested in power electronics in Japan is very small. I have given a lecture of power electronics for nearly 13 years at the Tokyo Institute of Technology, and there have never been more than 3 female students in class, and in some years there were none. In the U.S., there are always a certain number of female students in class whether it is at Massachusetts Institute of Technology (MIT) or at the University of Wisconsin-Madison.

Eguchi: There are four women engineers working in the power electronics

development center at Fuji Electric. I think that if we can find a way to get women more involved, we will also be able to increase the number of power electronics engineers.

Akagi: In Japan, there are about 15 universities that provide a complete education in power electronics from theory to lab work. When it is assumed that about 6 students finish their master's degree programs at each school every year, these 15 universities produce about 90 engineers in total, and many companies in need of engineers scramble for these 90 very valuable students.

On the other hand, from the perspective of the students, they never need to worry about finding jobs. The master's degree students in my laboratory are very popular with recruiters. Doctoral students are also actively employed at many companies. Although the mass media runs with stories that say things like "Even People with PhDs Cannot Find Work," this certainly is not the case for students studying power electronics.

Encouraging Japanese Engineers to Become More Active Internationally!

Eguchi: Fuji Electric intends to expand its business more internationally, but it is still not completely possible to hire power electronics students from overseas institutions. Since language problems would be a big obstacle, we have been hesitant to hire people from abroad.

Akagi: Setting aside conversation in Japanese, reading and writing Japanese are difficult to engineers from abroad. Furthermore, it is not always possible or practical to translate information into English. For Japanese engineers, it's better to master English. Their first goal is to learn their specialized technology well, and English is usually a secondary goal to them.

According to one Japanese engineer that I know, when he was younger, he was able to speak broken English and somehow managed to use this skill to do his job. Thinking about this, I would say that since he knew the technology, his colleagues would carefully listen to him, regardless of how bad his English was. On the other hand, if he didn't know the technology, they probably wouldn't have listened to him no matter how good his English was.

Eguchi: That seems to be the nature of things. There are currently six engineers of Fuji Electric studying abroad. They are taking courses at RWTH Aachen University in Germany and the University of Wisconsin-Madison in the United States. They all specialize in devices, but they are studying circuits to expand their potential. We also have a software specialist who is attending Swiss Federal Institute of Technology (ETH). He is studying power electronics device design. We are sending our employees to various countries so that we can also gain a more global perspective and advantage.

Akagi: If they can spend a year or two in the laboratory, they will make a great network of human connections, and Fuji Electric can definitely make use of this in the form of exchange and discussion opportunities. Studying abroad is extremely important in this sense.

Personally, I have visited many countries around the world on business. If I count them all, I would say that I stayed at least one night in 36 different countries. When you go abroad, you get the chance to meet various engineers of different religions and races, but when you talk one-on-one about technology, it is basically the same as talking to a Japanese person. It is within the range of different personalities.

I would really like to see Japanese researchers and engineers become more active overseas by pursing activities such as publishing papers at the top class international conferences in Europe and the United States.

Eguchi: We here at Fuji Electric have high aspirations as we develop power electronics as our core technology to contribute to people all over the world from the perspective of energy and the environment in areas such as energy savings, the promotion of renewable energy and the reduction of CO_2. We have an urgent need to train engineers who can be active on the international scene as we grow our business globally. Professor Akagi's support is greatly needed and appreciated by us here at Fuji Electric, as well as by the young engineers of the world who carry the future of power electronics on their shoulders. I thank you very much for visiting with us today.

Achievements and Future Outlook

Providing Energy Solutions

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

1. Introduction

Fuji Electric formulated the brand statement "Innovating Energy Technology" in July 2012 based on our concept to develop products that maximize energy efficiency through our pursuit of innovation in electrical and thermal energy technology and to contribute to realization of a safe, secure and sustainable society. In order to realize this basal concept, Fuji Electric has been concentrating research resources on developing technologies for supplying and utilizing electrical energy safely, securely and efficiently as well as technologies for utilizing thermal energies with no loss and techniques that optimally control these technologies. In our mid-term management plan for 2013, we described our research policy for providing energy solutions as shown in Fig. 1. This policy positions our power semiconductor and power electronics technologies as its core, while enhancing our differentiated measuring equipment and thermal components in order to provide energy solutions by packaging them together as a control technology platform. This paper presents an outline of our solutions.

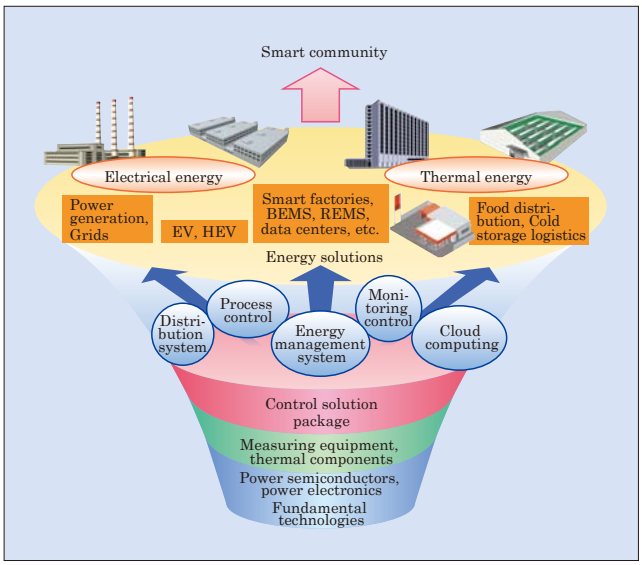

Fig.1 Fuji Electric's core technology and areas of focus

2. Power Semiconductors and Power Electronics

Power semiconductors and power electronics technologies 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.

We are aiming at low loss, low noise, downsizing and high reliability with regards to our power semiconductors, and developing technologies that include insulated gate bipolar transistor (IGBT) modules, intelligent power module (IPM), metal-oxide-semiconductor field-effect transistor (MOSFET), discrete devices and power IC.

We have established a package technology to raise the continuous operating temperature from the current 150 °C to 175 °C in order to achieve further downsizing and higher power density of the IGBT module. As a means to prevent the power cycle life shortening due to high-temperature continuous operation, we have developed a highly heat-resistant aluminum wire, as well as a new solder alloy that has high strength at high temperatures as a way to bond solder to mount the chip onto the insulating board. In addition, we have also developed an electrode structure in order to reduce the occurrence of thermal stress. The IGBT module that ensures continuous operation at 175 °C applying these new technologies has been confirmed to have a longer lifespan compared to the current module that ensures continuous operation at 150 °C[(1)].

As downsizing and light-weight features are being required in the IPM for controlling the power of hybrid cars, we have developed a large capacity IPM that combines two inverters and a step-up/down converter. Using our heat removal design technology and new solder technology that has high strength at high temperatures, we have achieved direct cooling structure that integrates the module and aluminum heat sink, achieving a 30% reduction in volume and 60% reduction in mass compared to conventional devices.

As an application of our advanced power semiconductor technology, we have applied our new three-level power conversion circuit that utilizes reverse-blocking IGBT (RB-IGBT), which is Fuji Electric's original

power semiconductor, to develop highly-efficient and compact power electronics equipment. Furthermore, we have developed the three-phase four-wire high-capacity UPS “7000HX-T4” for overseas markets including countries in Asia. The unit has total efficiency of 96.5% and makes it possible to reduce the installation area by 30% or more compared to conventional products.

In addition, we have also developed a general-purpose inverter “FRENIC-Ace” that utilizes a 6th generation “V Series” IGBT. This inverter comes standard with a customization function that allows users to add their own functions, as well as provides optimized customization package software for applications such as wire drawing machines, hoists and spinning machines.

With regards to our next-generation device development, we are working on the development of a silicon carbide (SiC) semiconductor that dramatically reduces power loss surpassing the physical limits of Si devices.

Matsumoto Factory, our production base for power semiconductors, is the first in this industry to construct and implement a process production line of front-end process 6-inch SiC wafers (see Fig. 2) and has started mass production of 600 to 1,700 V withstand voltage Schottky barrier diode (SBD) and 1,200 V withstand voltage MOSFET.

Furthermore, we are currently evaluating our prototypes as we continue new SBD and MOSFET device development. These devices have high withstand voltages such as 3,300 V, which are capable of demonstrating the benefits of SiC.

At the same time, we are also developing micro-sized, highly reliable All-SiC modules that have high operation temperature, high heat removal and low inductance features in order to maximize the performance possessed by SiC devices. Currently, we are developing power conditioners (PCS) based on this module, which is used for photovoltaic power generation and features extremely low power loss and space-saving (see Fig. 3), as well as high-performance stack type inverters of the 690 V series that utilize SiC hybrid modules and can be used for large-sized cranes and plants (see Fig. 4). Sales are scheduled to start during FY2014.

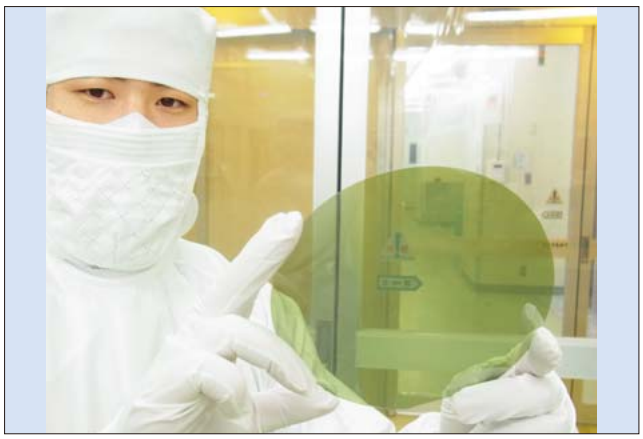

Fig.2 6-inch SiC wafer

Fig.3 PCS for photovoltaic power generation utilizing All-SiC modules

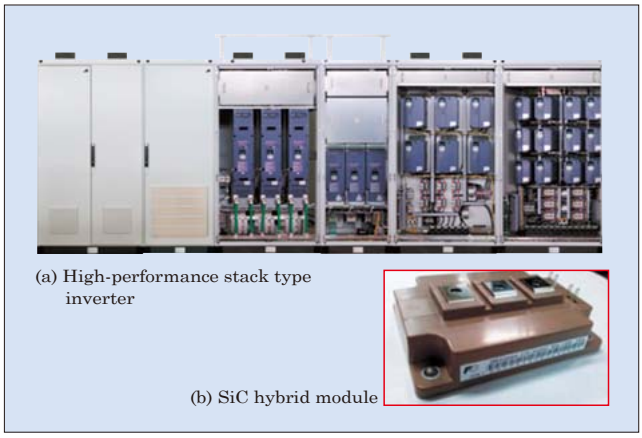

Fig.4 High-performance stack type inverter utilizing SiC hybrid modules

With regards to power receiving and distributing equipment and control device components, we have developed power receiving and distributing equipment that can meet the needs of facilities and control systems that require space-savings and high reliability. We have developed a high voltage AC load break switch (LBS) equipped with a striker tripping current limiting fuse that has improved operability and is compliant with the RoHS Directive*1. As shown in Fig. 5, a fixed contact and arc guide have been installed on the inside of the arc-extinguishing chamber to optimize the distance and rotation speed of the moving contact required for extinguishing the arc. The result of these enhancements is that volume of the arc-extinguishing chamber has been miniaturized to nearly half of that of previous products.

For the photovoltaic power generation system, we have developed a string monitoring unit that measures the current and voltage for each photovoltaic panel string (a group of power generation composed of 10 to 20 photovoltaic panels), which works with the host system to help early detection of an abnormality in any

*1 RoHS Directive: EU (European Union) Directive regarding restrictions of the use of certain hazardous substances contained in electrical and electronic equipment

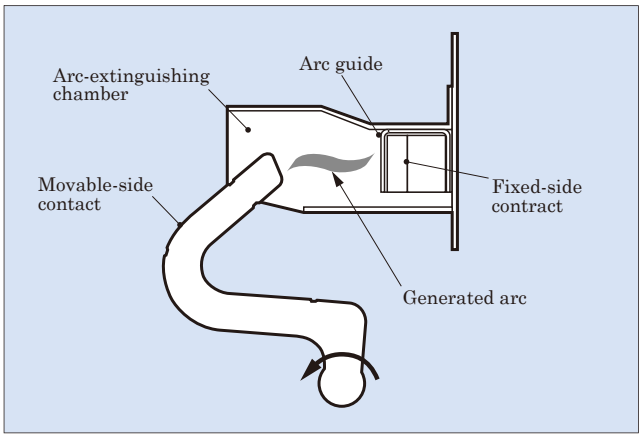

Fig.5 Structure of LBS arc-extinguishing part

photovoltaic panel and identification of a faulty section[2].

We have also developed an emergency stop push-button switch that is equipped with a synchro-safe contact for use with control equipment and machines. We have enhanced the safety by providing a mechanism that opens the main circuit at the time of contact disconnection.

3. Measuring Equipment and Thermal Components

We have developed a line of measuring equipment that is characterized by its contributions to energy saving in the process. For the first time in the world, we developed a direct-insertion type laser gas analyzer "ZSS," capable of high-speed response and has the ability to measure two elements ($CO+O_2$) in real time. As shown in Fig. 6, we have achieved two-element analysis by applying optical technology and combining two laser light emitting and receiving devices for use with each element on the same axis. Furthermore, the purge gas for dealing with dust is not based on nitrogen, which is conventionally used, but is characterized by its ability to use instrument air. By applying ZSS high-speed response to the combustion process control, we have enabled to achieve the precise implementation of combustion air volume control, which has contributed greatly to energy savings[3].

For the thermal component, we have developed an exhaust heat recovery type steam generation heat pump system, and we are currently implementing verification test for it at our Mie Factory. It recovers exhaust heat from the warm effluent (below 100 °C) that was conventionally not used in factories, and reuses this heat as steam. We have used our refrigeration cycle technology that we cultivated in our vending machine business to generate 120 °C saturated stream from 60 °C to 80 °C warm effluent. On this occasion, the coefficient of performance (COP) is 4.0, making it an industry top class unit. This heat pump system can be installed dispersively near the steam facilities in order to decrease the loss from the heating pipes. This is a key component for creating total energy-saving solutions for factories, including the utilization of heat.

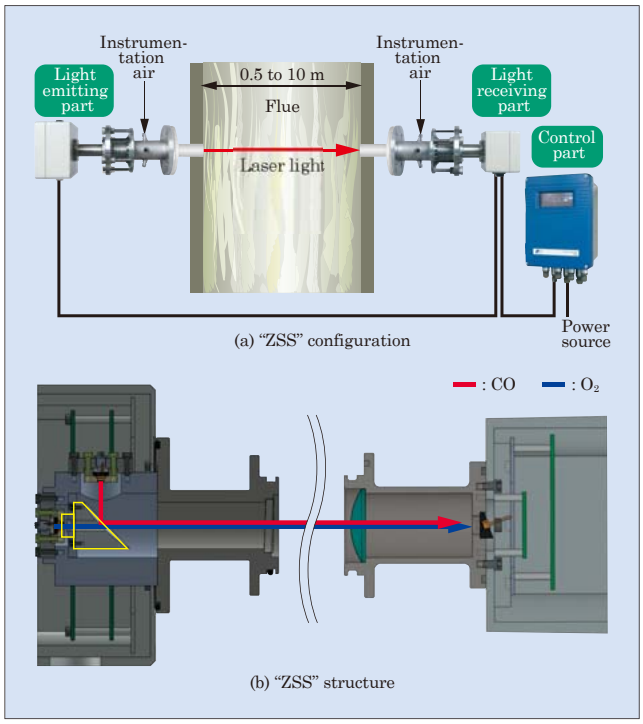

Fig.6 "ZSS" direct-insertion type laser two-element gas analyzer

Furthermore, we have also achieved higher efficiency cooling systems for vending machines that use CO_2 which is environmentally-friendly natural refrigerant. This has been done by reducing compression power via an ejector which makes use of the characteristics of the CO_2 refrigerant that has high operating pressure, by attaining a higher efficiency via a high performance aluminum heat exchanger and through the optimized operating control of compressor by employing inverter.

4. Control Solution Package

In a control solution package, we have developed a control system solution package that contributes to the stable supply of energy, energy savings, safety and security and stable equipment operation. As its platform, we have developed a control system platform shown in Fig. 7. We have packaged together Fuji Electric's control technology and equipment in an organic manner so that it can apply to a diverse range of control scenes. Furthermore, as a control system layer for realizing this, we have developed the small and medium scale monitoring control system "MICREX-VieW XX" (see Fig. 8). This system is highly reliable, compact and highly sophisticated and it enables the inheritance of screen displays and program assets of existing system when upgrading customer facility. In addition, the vertical/horizontal integration engineering environment makes it possible to efficiently generate screen displays and programs. In order to achieve high reliability, controllers, networks, I/O, human machine interface (HMI) and databases can be duplicated for each unit. Since this duplication system has no common parts, it

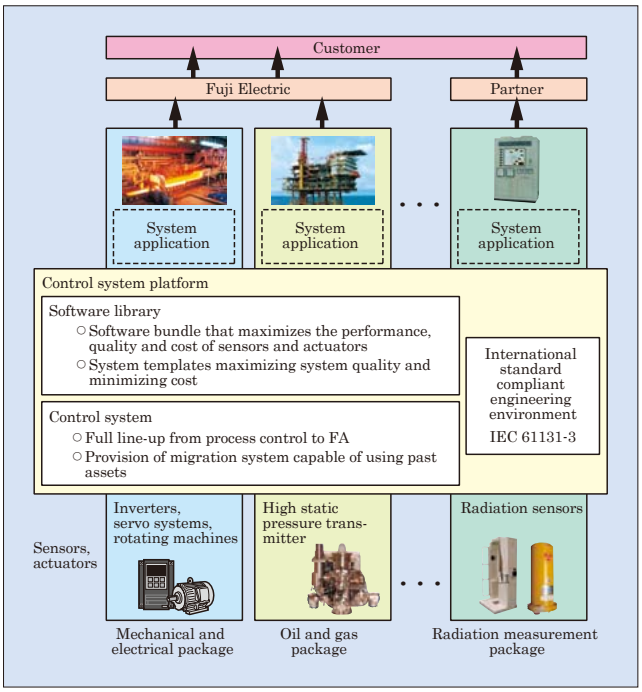

Fig.7 Control system platform

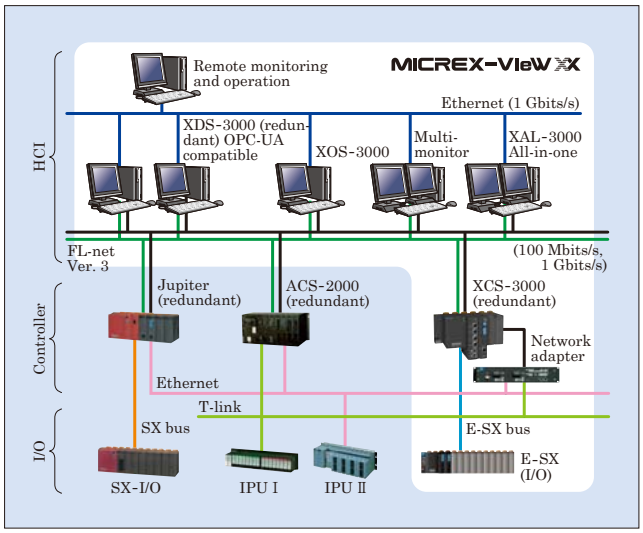

Fig.8 "MICREX-VieW XX" small and medium scale monitoring control system

makes continuous system operation possible even for multiple failure mode[4].

Furthermore, we have developed the "ECOMAX Controller" that achieves overall energy savings by implementing collective management of store cooling equipment, air conditioning apparatus, lighting equipment and utilities (see Fig. 9). Moreover, support of various interfaces for multiple kinds of equipment in stores is available and the following functions have made it possible to implement overall general management of in-store equipment[5]. The unit has the following functions: an air conditioning optimal running function that minimizes the total power consumption of air conditioning and refrigeration units; a feed/exhaust control function that achieves optimum ventilation air flow rate control; and a demand control function or

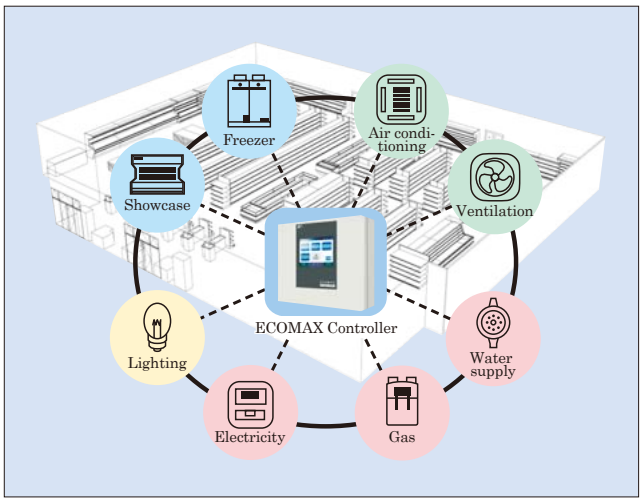

Fig.9 Store management system configuration using the "ECOMAX Controller"

scheduled operation function that provides control to ensure so that power consumption of all the stores does not exceed the target value.

5. Energy Solutions

Our energy solutions provide ongoing high-efficiency of thermal power generation and geothermal power generation in the field of energy creation. In addition, we are also developing various energy management systems (EMS) that realize energy savings through optimizing the control of electrical and thermal energy, aiming to construct a smart community. Figure 10 shows Fuji Electric's concept of EMS.

The "Next-Generation Energy and Social Systems Demonstration Project" launched by the Japanese Ministry of Economy, Trade and Industry since

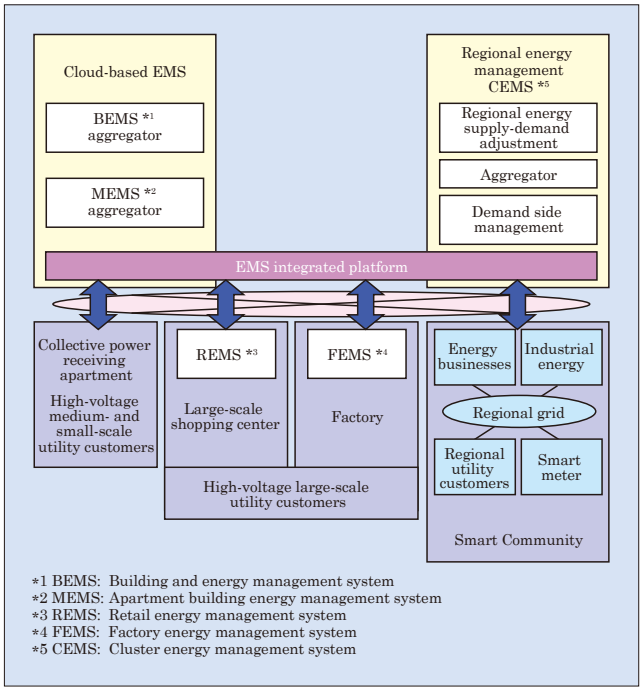

Fig.10 Fuji Electric's concept of EMS

FY2010 in four regions (City of Yokohama, Toyota City, the Kansai Science City, and City of Kitakyushu) eyes on achieving next-generation energy and social systems. These regions implement to utilize renewable energy stably with high efficiency, and develop and verify the EMS.

Fuji Electric has been actively participating in the operational experiment system in the City of Kitakyushu and the Kansai Science City. In the City of Kitakyushu, we developed a cluster energy management system (CEMS) centering on the "regional power-saving station," while implementing demand response operational experiment. For days in the summer and winter when demand for power is expected to be particularly high, we have confirmed a demand reduction of 9 to 13% in the summer and 9 to 12% in the winter through the use of dynamic pricing that raises the price during peak hours, and have verified the effect of the system[6].

On the other hand, for large commercial facilities such as department stores and shopping malls that consume a large amount of energy, it is being required that energy be used efficiently to achieve energy savings thoroughly.

To this end, Fuji Electric has developed a specialized EMS for large-scale commercial facilities (see Fig. 11). We applied our previously developed "Integrated EMS Platform[7]" technology that excels in its flexibility and scalability, and as a result, we have achieved application to a wide range of areas including installation at individual large-scale commercial facilities and linkage with other systems in the smart community. As a function for forecasting demand, by using the load results summed up from each area that has different consumption characteristics, we have calculated the micro demand forecast values for each area and the macro demand forecast for the entire facility aggregated the micro values with high precision.. In order to optimize operation for each facility, we have created models such as those for power generation facilities, power storage equipment and heat sources, and we have implemented energy demand and supply simulations based on the demand forecast to create an operation plan for these facilities. Furthermore, we are able to create a recommended operation guidance specification for the operations manager, and it allows the operations manager to recognize the recommended action and resulting effects[8].

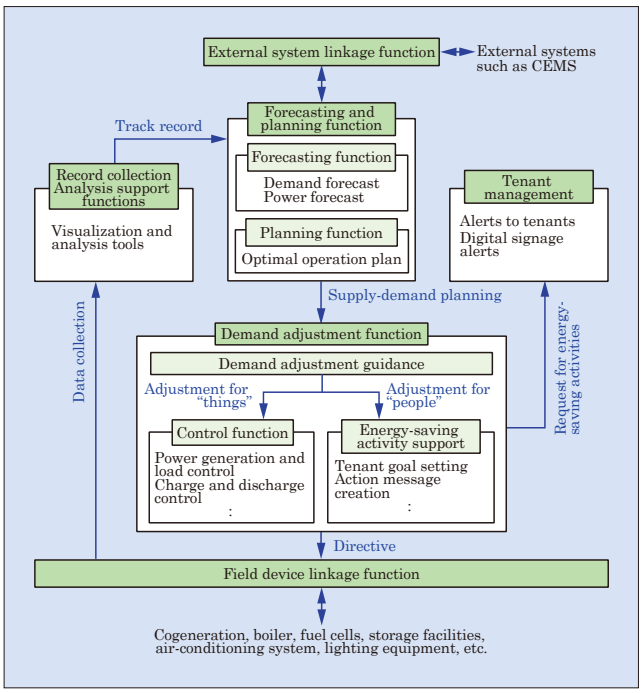

Fig.11 EMS functional configuration for large-scale commercial facilities

6. Fundamental and Advanced Technologies

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

In order to reduce the number of prototypes required when developing power electronics equipment, we have developed a device/circuit cooperation simulation that links the simulations of the L and C components based on the wiring structure and simulation of the device characteristics (see Fig. 12). This makes it possible to estimate the power loss and voltage bounce during switching before designing prototype, and to reflect these findings into the printed circuit board when producing the prototype. Furthermore, by linking the simulation results with the cooling structure design tools, it is also possible to work out the cooling structure design. Through the application of this simulation, it has become possible to reduce development time to approximately one-third of that of conventional methods.

With regards to electromagnetic compatibility (EMC: not producing electrical or magnetic interference or not being influenced by the same), we have developed a simulation that enables to evaluate it with high precision at the equipment design stage. Furthermore, we have developed a method for analyzing the noise coupling between the wiring when the power electronics devices and control devices are equipped in the same board. This makes it possible to prepare better wiring design for the inside of the board from the standpoint of noise.

In addition, the utilization technology of lithium-ion batteries becomes very important with respect to the power leveling equipment that is essential to the promotion of renewable energy. We have also developed a method for quantitatively estimating how much the lifespan of the lithium-ion batteries is likely to be affected from discharge/charge conditions and other factors, and this method can be applied when selecting lithium-ion batteries or designing the optimal capacity.

With regards to our developments of material technologies, we have developed a resin that can withstand 250 °C for use with high-temperature operation device

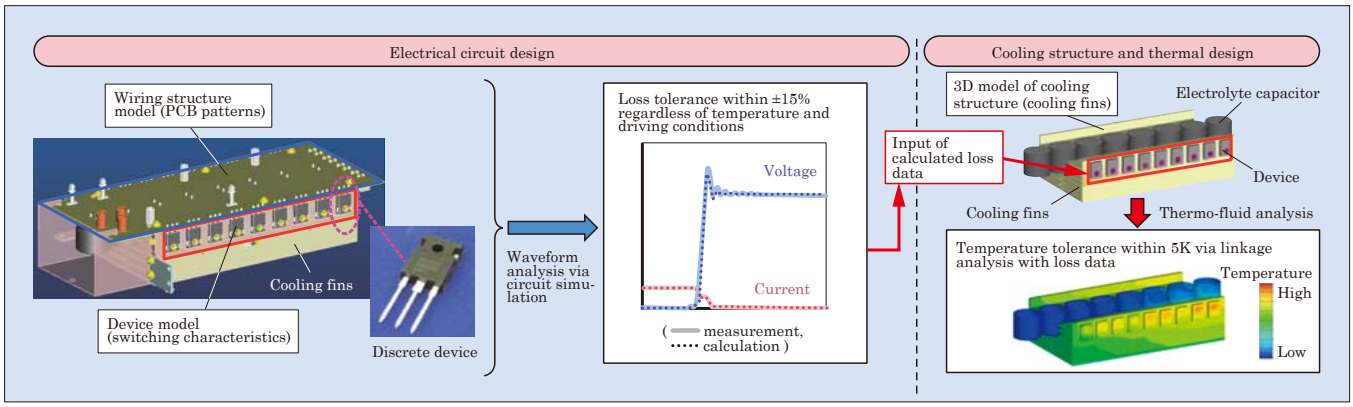

Fig.12 Device and circuit linkage simulation

packages that utilize SiC, as well as dissimilar metal junction technology that uses metallographic structure simulations.

In the realm of advanced technology, we have developed and started demonstrating the world's first aerosol compound analyzer that can in real time measure the mass concentration and ingredient composition of PM2.5, which has gotten a great deal of attention as a new environmental problem, and also can contribute to estimation of the generation source. As shown in Fig. 13, after measuring organic substances using lasers, we apply micro electro mechanical systems (MEMS) technology to concentrate thin PM2.5, enabling to implement compound analysis by using mass spectrometry. This analyzer was developed under the joint efforts with University of Tokyo and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and we won the special award for advanced technology for exhibiting creativity at the 27th (FY2013) ‘Fuji Sankei Business i’ award event.

When developing products for the global market, it is increasingly important to comply with international standards. Fuji Electric has been enhancing its commitment to international standards, and we are making efforts actively to get involved in international committee activities related especially to power electronics and smart communities. We are being successful in our contributions to standard creation activities related to inverter efficiency measurements and EMC of PCS.

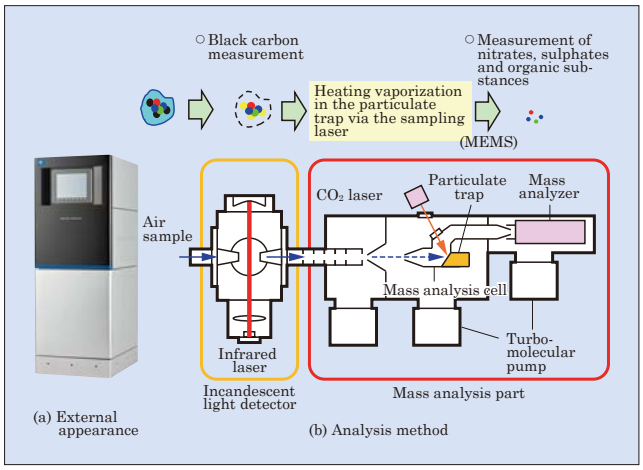

Fig.13 Aerosol compound analyzers

7. 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 minimum loss as well as techniques that optimally control these technologies. We believe that there is no doubt that creating a safe, secure and sustainable society that harmonizes with the environment will become more important. As we continue to proceed with our research and development, Fuji Electric stands committed to its brand statement of developing products that maximize energy efficiency through our pursuit of innovation in electrical and thermal energy technology and contributing to realization of a safe, secure and sustainable society. We are moving forward in our contributions and become a greater corporate citizen in our global society.

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Indoor Stand-Alone Power Conditioner for Photovoltaic Power Generation "PVI1000-3/660"

Fuji Electric is developing power conditioners (PCSs) for large-scale photovoltaic power plants (mega solar plants) whose Japanese market is expanding, and expanding its sales in the market.

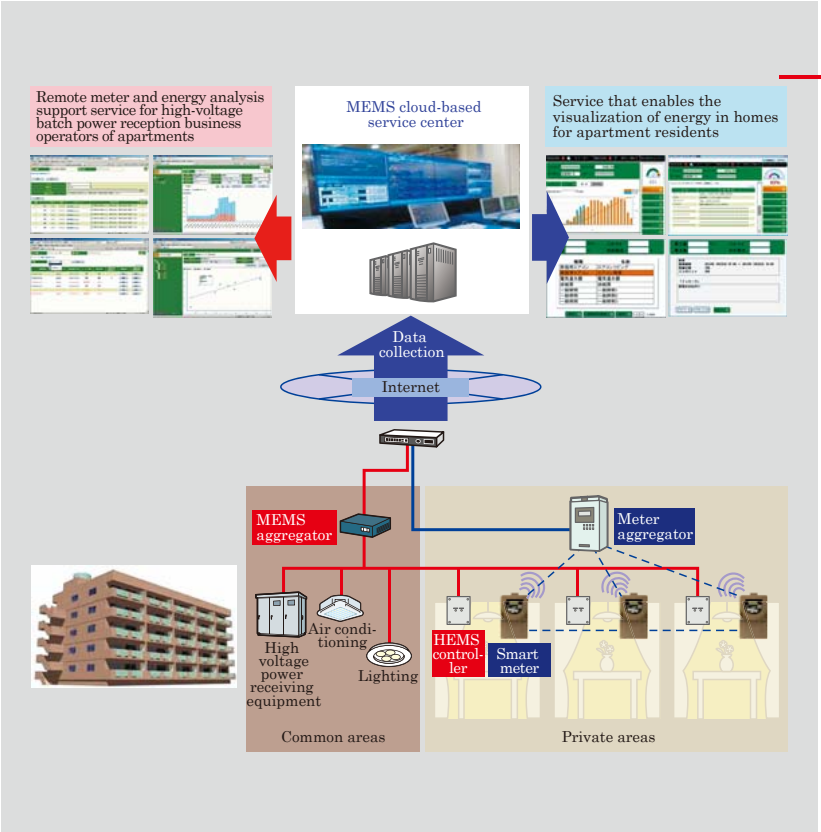
The maximum direct current inlet voltage of this indoor stand-alone PCS for photovoltaic power generation "PVI1000-3/660" is 1,000 V, and the capacity of a single unit is 660 kW. With a three-level insulated gate bipolar transistor (IGBT) module, it has achieved a maximum efficiency of 98.4%.

The main features are as follows:

(1) With the enhanced efficiency of PCSs, the unit size is the same as conventional systems with a capacity of 500 kW.

(2) Three units of this PCS can comprise a power plant with a capacity of less than 2 MW, which is exempt from rating as an extra-high voltage interconnection facility, and can reduce the cost for power distribution wiring work, etc.

(3) Even when the output load power factor is set at 0.8, this system can ensure an output of 500 kW or more.

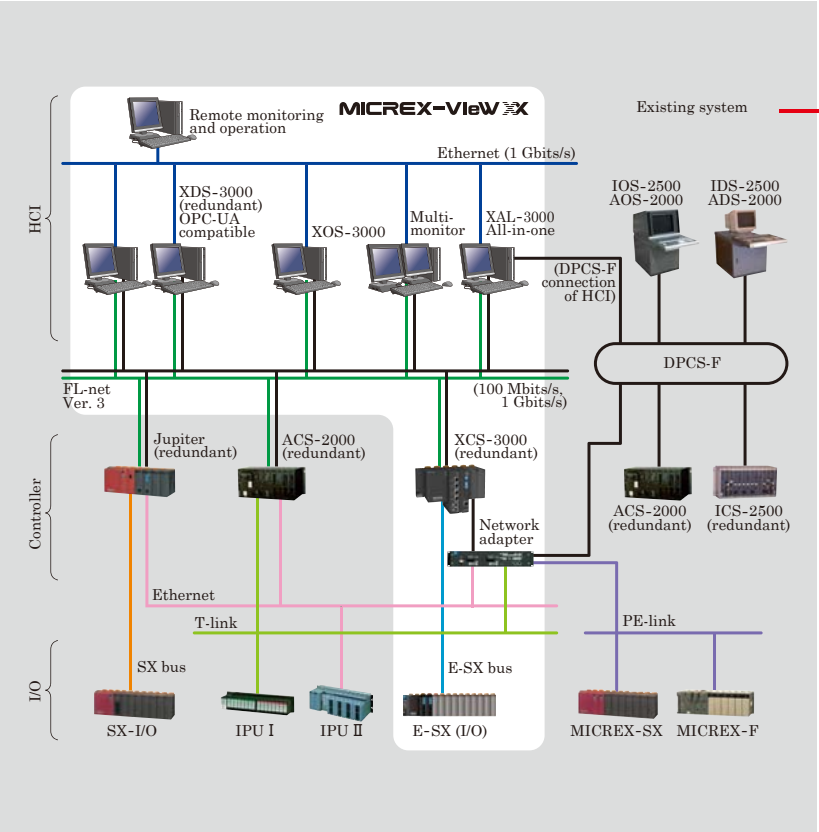


Cloud Type MEMS for Smart Apartments

We have completed the development of a cloud-based apartment building energy management system (MEMS) that meets the requirement functions of the Ministry of Economy, Trade and Industry's "Promotion Project for the Accelerated Introduction of Smart Apartments."

This system proposes a service that enables the visualization of energy in homes for apartment residents, as well as provides remote meter and energy analysis support service for high-voltage batch power reception business operators of apartments. The apartment residents can use Web services to view the energy use situations in their homes respectively using a variety of devices such as smartphones, tablets, and personal computers based on the collected electricity, gas and water usage data in private and common areas of the apartment through a smart meter and home energy management system (HEMS) controller.

Furthermore, in the future we plan to offer a remote control function for home appliances in conformity with the ECHONET Lite standards for apartment residents.



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

Fuji Electric has developed the new smal- and medium-scale monitoring and control system "MICREX-VieW XX," which integrates instrumentation and control with electrical control. This system combines the highly reliable technology based on our extensive track record of delivery of monitoring control systems with the high-speed and high-precision control technology cultivated in the factory automation field. The system maintains compatibility with existing systems and provides advanced operation functions and engineering functions.

The main features are as follows:

(1) High operability via an innovative human communication interface (HCI) architecture

(2) High scalability and highly-efficient engineering via a TAG/variable database that integrates the whole system

(3) Highly reliable system capable of duplicating individual component such as the controller, network, I/O and HCI

(4) It supports inheritance with the equipment assets and software assets of customers through high compatibility with existing systems

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

In recent years, the heat generated by data centers has dramatically increased due to the high performance and high density of servers. Therefore, in an effort to save energy, outside air cooling systems have been progressing as systems that use the natural energy of cool outside air. Fuji Electric has developed the "F-COOL NEO" indirect outside type air conditioner that only utilizes cool outside air cold energy through a heat exchanger without incorporating any outside air directly.

The main features are as follows:

(1) Energy saving operation is possible at a rated cooling capacity (40 kW) throughout the year by combining the operation of an outside air conditioner and built-in refrigeration unit, and as a result, yearly power consumption has been reduced to one-third of that of general air conditioning systems.

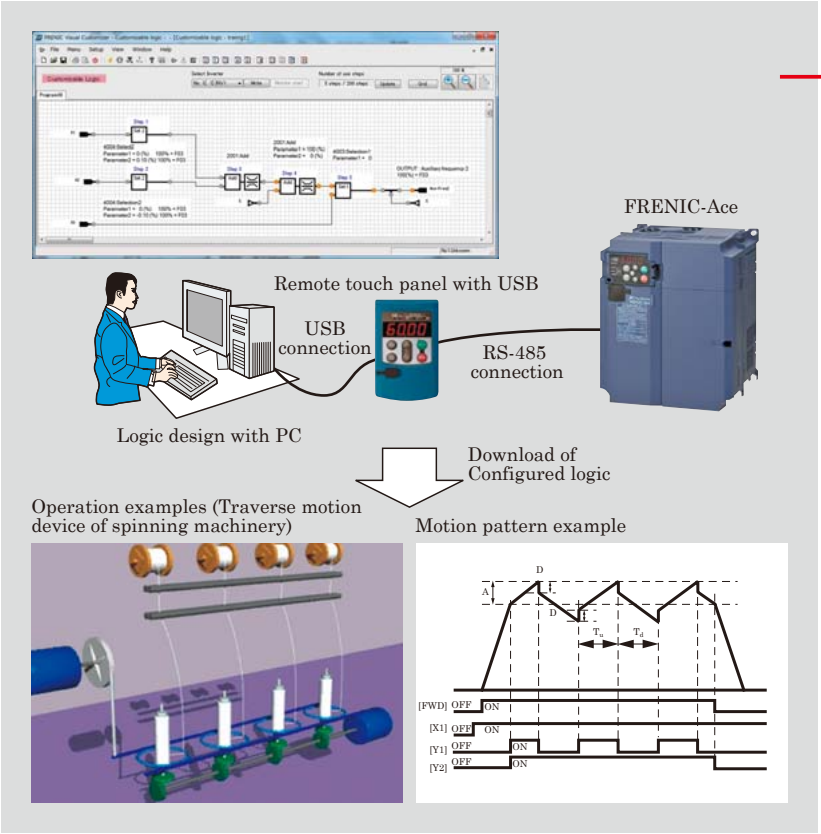
(2) Indirect outside air usage is less susceptible to moisture, dusts such as PM2.5 and corrosive substances contained in outside air.

(3) Power supply is the only required utility. No cooling water or cold water is required.

Japanese Top Runner Standard Compliant MOLTRA "FM-T14"

Against the background of measures to prevent global warming, the second-order Top Runner Standards have been introduced starting from FY2014 for cast resin transformers as specified equipment under the "Act on the Rational Use of Energy" (Energy Conservation Act). Fuji Electric has taken the lead in meeting these requirements by offering a full lineup in its Top Runner MOLTRA 2014 "FM-T14" in June 2013.

The unit was designed to provide reductions in power consumption and energy savings by widely improving the energy consumption efficiency (40% reduction compared with conventional products) through techniques such as optimizing the winding design and adopting magnetic domain control material for the iron core. This has enabled us to suppress CO_2 emissions and electricity costs. The winding structures carries on the tradition of conventional products by employing a vacuum cast molding technology and sheet winding, while also ensuring high insulation reliability. Furthermore, users find this product easy to use and it was designed with consideration given to replacement, by means of greatly improving earthquake resistance, reducing noise (−10 dB compared with conventional products) and having the same floor area dimensions as first-order standard products.



General-Purpose Inverter "FRENIC-Ace Series"

Fuji Electric has developed the general-purpose inverter "FRENIC-Ace Series" which features the customizable logic function for factory equipment and motor drives such as process machinery.

The main features are as follows:

(1) Capacity series
- ○ 3-phase 200 V class: 0.4 to 22 kW
- ○ 3-phase 400 V class: 0.4 to 220 kW

(2) Customizable logic function
- ○ Number of program steps: 200 steps
- ○ Number of program commands: 55 commands
- ○ Programming method: Dedicated visual programming tool
- ○ Application examples: Wire drawing machine, Hoist crane, Traverse motion device of spinning machinery

Stack-Type Inverter "FRENIC-VG Series" (690 V Series)

In recent years, large-scale facilities and equipment such as steel plants and floating cranes have come to require inverters with large capacity, fast response and high accuracy. At the same time, easier maintenance for installation and replacement as well as smaller footprints is required. In FY2012, in order to meet these needs, we launched the stack-type 400 V series as part of the "FRENIC-VG Series" lineup that provides the best performance in the industry.

The 690 V series, which is advantageous to achieve larger capacity, was added to the stack-type lineup this time to expand the Series.

The main features are as follows:

(1) It adopted a hybrid module with SiC-SBD and Si-IGBT by using silicon carbide (SiC) to reduce the size and expand the capacity of a single unit (450 kW max).

(2) The width of the stack is unified to 220 mm to make a thin structure.

(3) It has achieved large capacity by using direct parallel connection.

Large-Capacity UPS "7000HX-T4"

For backup power supplies in data centers, uninterruptible power supplies (UPS) with high reliability and high efficiency are required. This time, we have developed "7000HX-T4" as a large-capacity UPS for overseas. This UPS utilizes the three-level power conversion method with reverse-blocking insulated gate bipolar transistor (RB-IGBT) that is distinctive to Fuji Electric to improve efficiency. It adopts continuous inverter supply that is compatible with the 3-phase, 4-wire type of 400 V power supply that is the mainstream in various places in the world including Asia.

The main features are as follows:

(1) It achieves the world's highest equipment efficiency level of 96.5% and helps reduce the power consumption and the running cost, including air conditioners.

(2) Its footprint is over 30% smaller than conventional products and it helps increase the space available for installing servers.

(3) The output capacity of a single unit is 500 kVA/450 kW and up to 8 units can be connected in parallel for a large capacity (4,000 kVA).

Emergency Stop Pushbutton Switches (ϕ22 and ϕ30)

Fuji Electric has brought emergency stop pushbutton switches to the market that can be installed in either ϕ22 or ϕ30 mounting hole on a panel. To respond to a growing market need for safety in recent years, we have developed a new series having "Synchro Safe Contact" and expanded the lineup.

The main features are as follows:

(1) Structure enabling to attach or detach operator and contact block

When the contact block is detached from the operator, the NC contact opens with a proprietary mechanism and it switches to safe mode. There can be up to six contacts: up to four for NC contacts and up to two for NO contacts.

(2) Obtained overseas safety standard certificates:
- ○ CCC (GB14048-5)
- ○ IEC (EN60947-5-1, EN60947-5-5)
- ○ C-UL (UL508, CSA C22.2)

The 2nd-Generation LLC Current Resonant Control IC "FA6A00N Series"

For switching power supplies used in medium-capacity electronics equipment with a power consumption of around 100 to 500 W, LLC current resonant circuits are attracting attention because they are advantageous in terms of efficiency improvement, noise reduction and profile lowering.

Fuji Electric commercialized a 1st-generation LLC current resonant control IC "FA5760N" that prevents a switching shoot-through phenomenon which is a disadvantage of LLC current resonant circuits and that has achieved lower standby power. Now we have developed the 2nd-generation LLC current resonant control IC "FA6A00N Series" that will further improve the device's properties, offer more sufficient protection functions and provide higher quality.

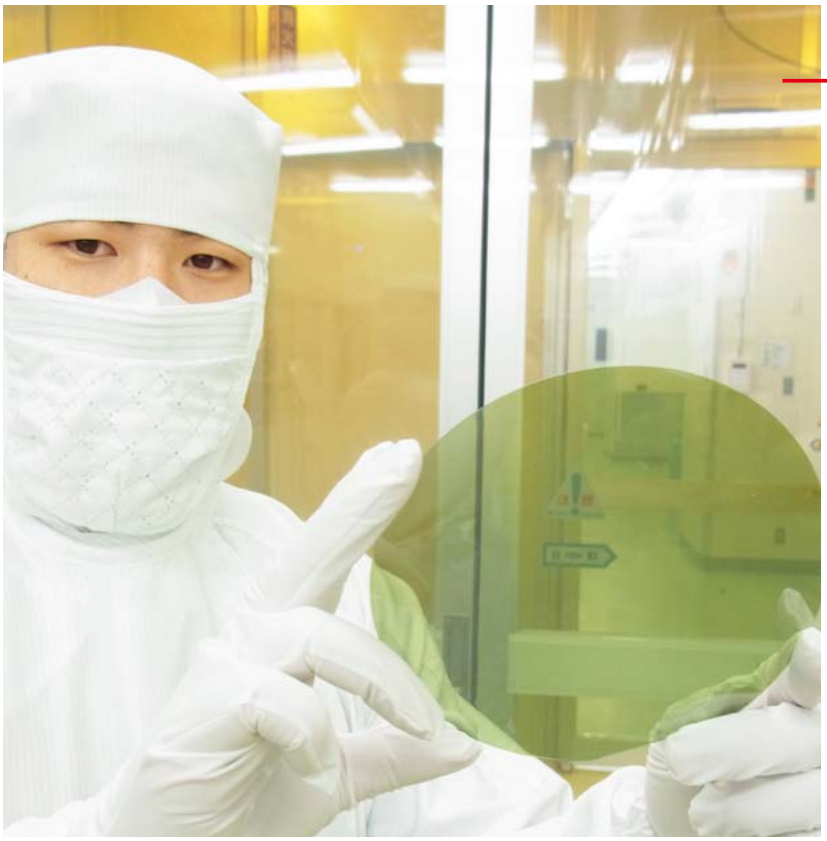
The main features are as follows:

(1) Built-in 600 V withstand voltage start-up device and 630 V withstand voltage driver circuit

(2) Low power dissipation burst control for further reduction of standby power

(3) Primary side over-load protection function using auxiliary winding voltage

(4) Over-current protection with enhanced design flexibility



Starting Mass Production of SiC-SBD Chips in 6-inch Manufacturing Line

In recent years, silicon carbide (SiC) has come to raise expectations as the next-generation semiconductor material. SiC-Schottky barrier diode (SiC-SBD), in particular, has characteristics including an ability to greatly reduce switching loss compared with Si diode, and has already been put to practical use. Fuji Electric has commercialized hybrid modules combining 600 V- or 1,200 V-class SiC-SBD and Si-insulated gate bipolar transistor (Si-IGBT).

To cope with the trend of larger-diameter SiC wafers, Fuji Electric has built a 6-inch manufacturing line and started the mass production and supply of SiC-SBD chips. In this product, we could achieve a Schottky barrier junction of stable quality by optimizing the manufacturing conditions, and succeeded in reducing the reverse-recovery loss by about 70 % while maintaining a forward loss that was almost the same as the conventional Si diode.

Vending Machines with IEC Standard Compliant Glass Front "Twistar"

As the consumer markets continue to grow in Asian countries, the market for vending machines is expected to see a steady expansion in line with rising beverage unit prices and the increase in consumers' disposable income.

Given this, we have developed a vending machine with IEC-standard-compliant glass front "Twistar," ready for overseas production and local specification.

The main features are as follows:

(1) The control unit adopts a specialized currency multi-interface added to the basic features, compatible with the currencies of 10 ASEAN countries.

(2) A single piece of software can handle the communication specifications of VTS and MDB.

(3) Two vending mechanisms have been developed: the twist type which is adaptable to diverse beverage container forms, and the screw type, which is able to handle packed snacks and small food items.
The vending mechanisms can be replaced easily on site, enabling sales of a diverse range of products appropriate to the location.

Next-Generation Cold Storage Container "D-BOX"

It is a significant challenge for the food and beverage distribution business to maintain product quality throughout the supply chain.

Fuji Electric has developed the next-generation cold storage container "D-BOX," which can highly control thermal energy and the internal temperature, throughout the logistical stages to maintain freshness in food and beverage distribution.

The main features are as follows:

(1) The unique cooling unit can conduct rapid refrigeration and enables complete cold storage in a short period (3hours).

(2) The high-efficiency insulation technology used in vending machines enable chilled storage for a long period (5hours) without power supply.

(3) The data on internal temperature and unit door open/close operation during transit can be recorded.

Steam Generating Heat Pump System Utilizing Waste Heat from Factories

Hot water below 100°C sent to drain from factories has been regarded as low-grade thermal energy and has not been reutilized so far. Fuji Electric has developed a steam generating heat pump system that recovers waste heat from hot water and deliver steam as useful heat. Field test of this system is taking place at the Mie factory.

The main features are as follows:

(1) The coefficient of performance (COP) 4.0, which is the industry-leading level of performance, has been achieved through applying the refrigerating cycle technology nurtured in the development of vending machines.

(2) Saturated steam of 120°C is generated from the waste heat source – hot water of 60°C to 80°C.

(3) This is a small-capacity system that can be installed in various locations close to a steam utilization facility. It reduces the heat loss from long distance piping to improve energy-saving properties.

Aerosol Multi-Analysis Technology

Fuji Electric is working on the research and development of an aerosol multi-analysis instrument capable of component analysis of particulate matter (aerosol). This analysis instrument is intended for measuring PM 2.5 (aerosol with a particle diameter of 2.5 μm or less) which is suspected of having an impact on health. By combining optical measurement techniques and mass spectrometric analysis, it can simultaneously measure the mass concentration of PM 2.5 and of some main components such as black carbon or sulfate. The component analysis which took 8 to 12 hours by manual work can now be conducted in real time. We have completed the development of elemental technologies so far and are working toward putting them to practical use in FY2015.

The development of elemental technologies was a joint work with the University of Tokyo and the Japan Agency for Marine-Earth Science and Technology on consignment from the Japan Science and Technology Agency.

Electric Power Generation Systems

Thermal/Geothermal Power Plants
Wind Power Generation Systems
Fuel Cells
Nuclear Power

Outlook

In Japan, Feed-in Tariff (FIT) Scheme for renewable energy was enforced in 2012, and a full-scale process for approving and constructing mainly photovoltaic power generation facilities has been promoted since 2013. On the other hand, as a result of prolonged suspension of nuclear power plants, Japanese power utility companies have started to renew and reinforce their thermal power sources. In addition, to ensure the stable supply of electricity, there are an increasing number of business transactions with independent power producers (IPP) and power producers and suppliers (PPS) in the field of gas turbine combined cycle (GTCC), high-efficiency coal-fired thermal power systems and biomass power systems, etc.

Overseas, mainly in developing countries, it is expected that the need for power generation will grow over the long term. Moreover, despite some delays, the plans to develop geothermal power plants are being materialized primarily in Southeast Asia and Africa.

In the field of thermal power generation, the commercial operation of Unit 2 in Yoshinoura Thermal Power Station, which adopted GTCC, has started in May 2013; and overseas, the thermal power facilities (total of 783.4 MW) Fuji Electric supplied to seven power plants have started operating. In Thailand, by renewing turbines in existing plants on a massive scale, we have tried to increase their operation life and achieved an increased output.

Despite taking a long time to develop resources for domestic businesses, we are aggressively promoting activities to propose geothermal power systems. Concerning transactions with plants overseas, the power generation facilities in Turkey and Philippines (total of 80 MW) Fuji Electric has supplied started operation in FY2013. Furthermore transactions relating to several units are in progress, and we are currently producing them.

In the field of photovoltaic power generation, Fuji Electric is supplying the market with power conditioners for photovoltaic power generation (power conditioning systems, or PCS), step-up transformers, interconnection systems with grid and their components [ring main unit, protective relay and vacuum circuit breaker (VCB)]. Moreover, there is an increasing need for high-voltage direct current for photovoltaic panels and highly efficient PCSs themselves to improve power generation efficiency in solar power plants. We have developed indoor stand-alone 660 kW PCSs—maximum direct current inlet voltage of 1,000 V, three-level insulated gate bipolar transistor (IGBT) module-type and electric conversion efficiency of 98.4%. Three units of this PCS can comprise a power plant whose capacity is less than 2 MW (high voltage interconnection), which results in a space-saving design and reduces construction cost in comparison with conventional plants with four 500 kVA PCSs. Meanwhile, with the aim of increasing efficiency, Fuji Electric has completed the development of PCSs that employ silicon carbide (SiC).

In the field of wind power generation, demand for wind power systems that have a highly efficient power generation capacity is increasing mainly among power generation businesses including investors. Fuji Electric will actively push ahead with its business while placing priority on the following three pillars: components (generators for wind turbines and converters), systems (electric distribution facilities and stabilization equipment) and prime contractor business.

In the field of fuel cell industries, there are increasing expectations for fuel cells to be used in systems that generate power from the sewage digestion gas, and they have a high power generation efficiency compared with other power generation systems. Fuji Electric will make efforts to receive more orders by making use of its many years of achievements regarding systems that generate power from sewage digestion gas. In addition, by using high-temperature exhaust from fuel cells for air conditioning and the preheating of boiler supply water, we are verifying smart factories which will save on the energy consumed in overall systems. Overseas, Fuji Electric delivers products to Germany, typically fuel cells for fire prevention systems with a low-oxygen air supply function.

In the field of nuclear power, three years have passed since the accident at Fukushima Daiichi

Nuclear Power Station. The Station has changed to the phase of the steady site recovery and the preparation for its decommissioning and the construction plan of the intermediate storage facilities are being progressed positively. Under such situation, while participating the activities toward the recovery and decommissioning of Fukushima Daiichi Nuclear Power Station, Fuji Electric is providing proposals and promoting development concerning the following technologies: the radioactive waste treatment technologies which are needed more and more; and the technologies to remotely control equipment and handling and transportation of materials under the high radiation conditions. Fuji Electric is also continuously developing technologies required for the decommissioning. To follow the new regulatory standards relating to the earthquake and the safety, we are cooperating with our customers in the review of seismic evaluations and safety design and manufacturing and delivery of the enhanced safety equipment primarily in the nuclear fuel cycle field which Fuji Electric has already delivered.

Fuji Electric has selected the following as keywords in FY2014: high-efficiency, space-saving and low-carbon. In line with them, we will contribute to the social community by making efforts for environmentally-friendly and highly-efficient power generation; renewable energy which is represented by geothermal power generation, photovoltatic power generation and fuel cells; technologies necessary for the recovery and decommissioning of Fukushima Daiichi Nuclear Power Station; and the field of the nuclear fuel cycle field.

Thermal/Geothermal Power Plants

1 Indonesia ISM Thermal Power Plant Starts Operation

In January 2014, steam turbines and generators (100 MW×2 units), which were ordered through POSCO Engineering & Construction Co., Ltd. in South Korea, finished commissioning test, and the Indonesia ISM Power Station in Krakatau Steel Company Limited started commercial operation.

This power generation system is a reheating and regenerative cycle thermal power plant which is combined with a combustion boiler using heavy oil and by-product gas generated from the steel plant. It will supply electric power and high-pressure steam extracted from turbines to the adjacent Krakatau Steel Company Limited—the largest steel plant in Southeast Asia.

Fuji Electric has delivered steam turbines, generators and their control facilities, and electric facilities. This plant has employed compact single-cylinder condensate reheat steam turbines and adopted brushless excitation air cooling generators, for which we have an extensive delivery record.

Fig.1 100 MW steam turbine and generator

2 Units 1 and 2 in Yoshinoura Thermal Power Station Starts Commercial Operation

Units 1 and 2 in the Yoshinoura Thermal Power Station of the Okinawa Electric Power Company, Incorporated started commercial operation in November 2012 and May 2013 respectively. This power station is LNG-fired single shaft combined cycle power plant, which was established with the objective of stable electricity supply and reduction of greenhouse gases. The power generation facilities were delivered under a turnkey contract by a joint-venture group including Fuji Electric. The main component is comprised of a SGT6-4000F gas turbine made by Siemens, a single-cylinder axial-flow exhaust type steam turbine, and a hydrogen cooled generator made by Fuji Electric. The total gross power output is 502 MW, which is the largest capacity on the main island of Okinawa.

Being a small electrical grid, due to geographical factors, the plant takes role of faster start-up/shut-down and flexible response to demand. It is continuing to operate while playing an important role in promoting environmental measures such as CO_2 emission reduction and low NO_X emissions, etc.

Fig.2 Panoramic view of Yoshinoura Thermal Power Station

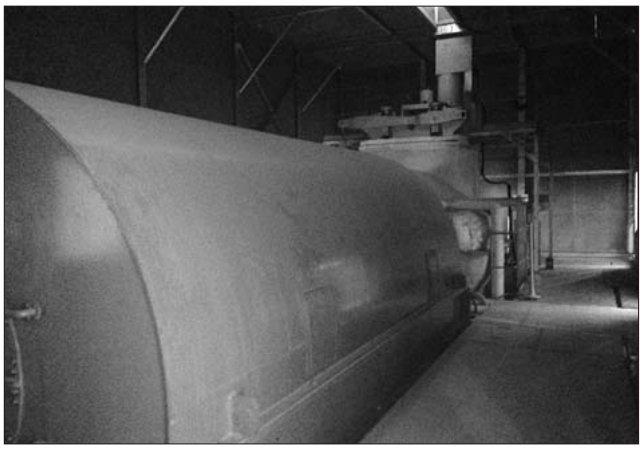
3 PJG#1 Cogeneration Power Plant for China Starts Operation

In February 2014, the steam turbine and generator (71.4 MW×1 unit) for the PJG#1 cogeneration power plant delivered for Chang Chun Chemical Co., Ltd. (China) completed its commissioning work and began full-scale service started commercial operation.

This power plant is a cogeneration plant with coal-fired drum boilers and is used to supply electricity and process steam for chemical factories. Accordingly, it has applied the back pressure turbine which is suitable for supplying steam from turbine to factories.

The back pressure turbine applies a three external extraction control system and can, supply steam to factories without losing their turbine efficiency under a wide range of the load, from high to low by controlling automatically three external extraction control system according to the load.

Fig.3 Steam turbine and generator/power generation facility



Thermal/Geothermal Power Plants

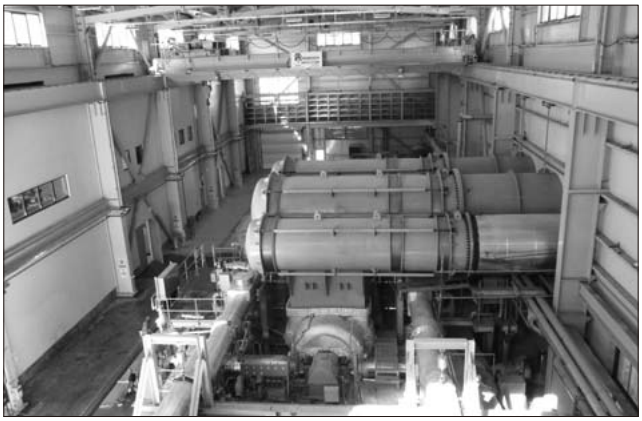
4 Turkey's Kizildere II Geothermal Power Plant Starts Commercial Operation

In October 2013, the Kizildere II Geothermal Power Plant, located in Denizli Province in the west of Turkey, started commercial operation.

Fuji Electric supplied the main equipment (60 MW steam turbines and a generator) and control equipment. Though the development of tandem turbines with back pressure-type high pressure (HP) turbine and condensing-type intermediate and low pressure (ILP) turbine was the first trial for Fuji Electric, we have achieved the smooth start-up/stop and load control by optimally controlling steam flow into each turbine. The HP steam contained an extremely high concentration of non-condensable gas, 16.7 weight percent. we have, however, achieved the performance just as planned by analyzing the effect of gas on the power generation performance.

Turkey has set the goal of increasing the geothermal generation capacity up to 600 MW by 2023, and Fuji Electric will contribute to the goal with this Kizildere II experience.

Fig.4 Tandem steam turbine in Kizildere II Geothermal Power Plant



5 The Philippines' Maibarara Geothermal Power Plant Starts Commercial Operation

Fuji Electric received an order for a 20 MW geothermal power generation system from EEI Corporation, a major general contractor in the Philippines in December 2011. In addition to main equipment such as turbine for geothermal power generation, generator and steam condensers, Fuji Electric provided single units including gas extraction facilities, a cooling tower and hot well pumps. An axial exhaust flow structure is employed for the turbine and direct-contact type barometric-condensers are used, which are the features of the system.

In this project, facilities were shipped in March 2013 just as planned, and the turbine and generator were installed under supervision of instructors of Fuji Electric. Furthermore under the supervision of electric, instrumentation and trial operation instructors, adjustment/trial operation began in January 2014; and performance test and reliability run test were completed in succession. The plant started commercial operation in February 2014.

Fig.5 Panoramic view of Maibarara Geothermal Power Plant

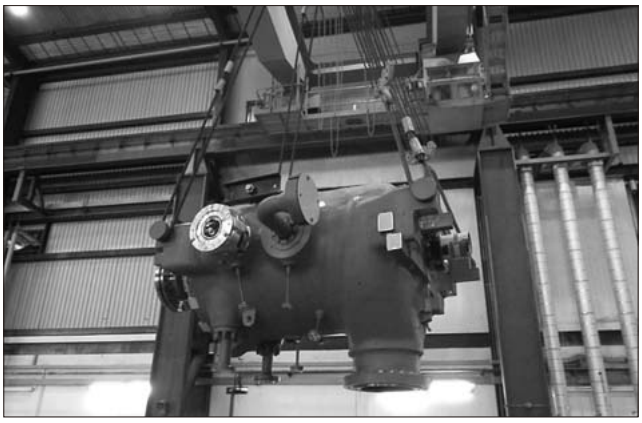
6 Renewal of Turbines in Mae Moh Thermal Power Plant of Electricity Generating Authority in Thailand

The Mae Moh Thermal Power Plant of the Electricity Generating Authority in Thailand is located in the north of Thailand and is the largest class coal-fired thermal power plant in Southeast Asia. Fuji Electric has supplied 10 steam turbines and power generation facilities (Units 4 to 7: 4×150 MW, Units 8 to 13: 6×300 MW).

Fuji Electric manufactured new high-pressure and low-pressure turbines for Unit 12 composed of three cylinders (high-, intermediate- and low-pressure turbines), and replaced the turbines with the new ones to prolong the operation life. In manufacturing the new turbines, Fuji Electric has applied the state-of-the-art technologies to the turbine blades and the gland packing parts to achieve higher efficiency, increasing the output of the steam turbine generator unit.

The construction period in the field was from October to December 2013, and the unit has been in operation successfully.

Fig.6 High-pressure turbine of Unit 12 undergoing renewal in the field



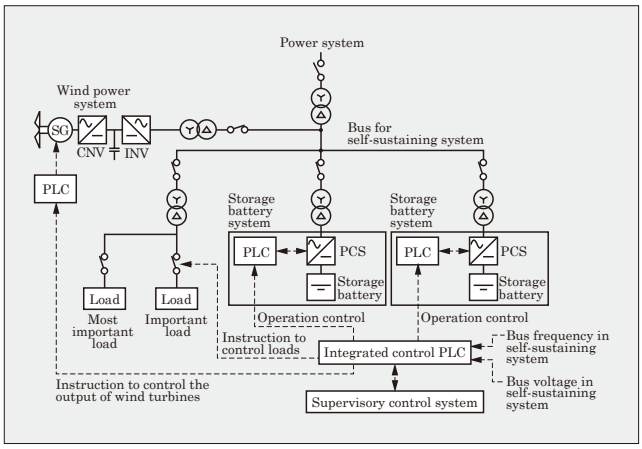
Wind Power Generation Systems

1 Isolated Operation System for Emergencies with Wind Power and Storage Batteries

In association with the further introduction of wind power generation systems and renewable energies, there is increasing demand for emergency power sources using such energies. By installing a storage battery system, Fuji Electric has developed an emergency isolated operation system, which reduces fluctuations in wind power output when it is connected with electrical systems, and supplies electricity to important loads in case of emergencies such as disasters.

For an emergency, wind power generation systems and important loads will be connected with the isolated operation system with a storage battery system to keep them operating independently. During such operation, the system controls the output of wind power, regulates the instruction to adjust and cut off the load and maintains a balance between supply and demand. Moreover, the storage battery system can be used simultaneously with two or more units, and therefore it is possible to apply this system flexibly depending on the scale of the power supply systems. During the simultaneous operation of the system, thanks to the control function to stabilize the state of charge (SOC) of each storage battery, it is possible to supply electricity to important loads for a long time.

Fig.7 Mechanism of emergency self-sustaining system



Fuel Cells

1 Deliveries of Fuel Cells in Japan

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 2, p. 135

Fuji Electric has installed photovoltaic cells and fuel cells in its own factories, and is verifying smart factories which will save the energy consumed in a whole factory.

The fuel cell installed at the Mie factory in December 2013 is used as a city gas-fired cogeneration system in normal operation and has function to switch to LPG-fed operation when city gas supply is stopped. High-temperature exhaust heat of the fuel cell is used for air conditioning.

In addition, in March 2014, Fuji Electric delivered a fuel cell having the same functions to a training center in Japan. There, the exhaust heat is used to preheat water to be supplied to the boiler installed in the accommodation facility in the center.

Fig.8 Fuel cell installed at Mie factory

2 Overseas Deliveries of Fuel Cells

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 2, p. 135

Germany is taking a positive stance in introducing renewable energies as an alternative to nuclear power generation, and has a high expectation for natural gas-fed cogeneration system which will back up fluctuations in power output by the renewable energies.

Fuji Electric has achieved conformity for our fuel cell CE marking, which is required to get into the German market, and delivered the first unit to a commercial building in 2012. Furthermore, we have developed fuel cells for fire prevention systems that can supply low-oxygen air in addition to electricity and heat which are generated in the conventional system, and delivered the the products to a data center or a factory having a warehouse.

For hydrogen infrastructure has been constructed in Germany, Fuji Electric will put highly efficient fuel cells on the market. And we will make efforts to expand the sales by marketing which utilize the advantages of the fuel cell.

Fig.9 CE-marked fuel cell delivered to Germany

Nuclear Power

1 Delivery of Temperature Variable Current Lead

Fuji Electric has produced and delivered, for the National Institute for Fusion Science (in National Institutes of Natural Sciences, Inter-University Research Institute Corporation), current leads which can be cooled with helium gas that is between 4 and 50 K. The National Institute for Fusion Science is pushing ahead with the research and development of fusion power reactors and engaging in research to employ high-temperature superconductors (20 K level) for magnets. The current leads we have delivered this time have a wide temperature setting range and will be used to evaluate both of the high-temperature superconductors and proven conventional low-temperature superconductors.

These current leads have a continuous current rating of 30 kA when the operation temperature is 4 K, and the short-time rating of 75 kA. The short-time rating was determined through a thermal analysis based on the evaluation results we have obtained over the course of our production. A maximum current-carrying capacity of 30 kA is possible when the temperature of helium gas is 50 K, if cooling condition is adjusted.

Fig.10 Temperature variable current lead

Social Infrastructure

Power System and Distribution
Energy Management
Social Environment

Outlook

In the power system and distribution field, stable system operation is more desired than ever for reasons including the impact of the suspension of nuclear power plants. Effective use of hydroelectric power plants is also important for the purpose of ensuring power resources. This has produced demand for highly efficient operation of dams and regulating reservoirs corresponding to the characteristics of water systems and more efficient generator operation achieved by introducing a water outflow forecasting function. What is also desired is international contributions in the form of applying power system control technology used in Japan to developing countries in Asia and other parts of the world that do not have sufficient power supply equipment.

Fuji Electric continuously delivers supervisory control systems in this field and strives to develop dam management systems and power generation centralized supervisory control systems. We have developed and delivered management systems and dam peripheral equipment for the Dashidaira Dam of Kansai Electric Power Co., Inc. and dams under the jurisdiction of the Ministry of Land, Infrastructure, Transport and Tourism and prefectures. In addition, we have delivered a power plant remote control system to the Bureau of Transportation Tokyo Metropolitan Government. For protection control systems, we have developed retrofittable unit relays and proposed a method of renewal that allows existing equipment to be used effectively. In view of complete digitization of electric station local area networks in the future, we are also working on the development of intelligent electronic devices (IEDs). Furthermore, for power distribution automation systems, we have developed software that can be used overseas and started rolling it out to Asian countries, where the average power outage time is longer than in Japan.

In the future, a reform of electricity systems will progress in the power system and distribution field and more efficient energy operation must be pursued. To that end, we have already developed an integrated management system for upstream and downstream dams of pumping-up power plants, which will be rolled out in Japan. In addition, we intend to make use of the gate control technology developed with dam management systems to work on remote supervisory control of floodgates and land sluices as measures against tsunami and contribute to the realization of a safe and secure society.

In the energy management field, effective use of energy is becoming increasingly important in Japan due to the impact of the rising electricity prices caused by the price hike of crude oil, in addition to the impact of the suspension of nuclear power plants. In developing countries in Asia and other parts of the world, growing populations and developing economies have caused energy demand to rapidly increase. In these circumstances, the need for energy management systems (EMSs) that ensure efficient use of electricity and heat is increasing all the more, which lead to cost reductions and environmental awareness.

In Japan, as a principal company participating in the Kitakyushu Smart Community Project, Fuji Electric has used independently developed cluster energy management system (CEMS). This system is the core of the Smart Community Center, to implement continuous field-test for the optimum operation of regional energy by means such as demand response, dynamic pricing and simultaneous balancing control. In addition, we are taking part in the Next-Generation Energy and Social System Demonstration Project run by the Ministry of Economy, Trade and Industry and have delivered a building and energy management system (BEMS) to Keihanna Plaza to work on the optimum operation of energy at facilities. As a new approach, we have developed an intelligent DC multiterminal power supply and verified the technology by using a DC power supply in the Mie University Smart Campus Project run by the Ministry of Economy, Trade and Industry. In the Demonstration Projects for Next-Generation Power Control Systems by Two-Way Communications of the Ministry of Economy, Trade and Industry, we implemented field-test for power output control of new energy power generation using

two-way communications. These two technologies can help to effectively utilize renewable energy. As part of overseas development, we have made use of the technologies and products accumulated and received an order for a micro-grid system from the Kingdom of Tonga and took part in a demonstration of new energy in Zhoushan, China.

In the future, we intend to roll out the CEMS developed in demonstration projects to help create new communities for earthquake disaster recovery and other purposes. In addition, we will make contributions to the provision of advanced energy services that accommodate the standardization trends in view of overseas development and new energy systems.

In the social environment field, the cost reduction effect of applying cloud computing to local government systems is being ascertained by looking at instances of its introduction in forward-thinking local governments. As social infrastructure to support daily life of people, the introduction of the Social Security and Tax Number System is gaining momentum.

In these circumstances, Fuji Electric has been striving to develop the cloud-based Local Government Integrated Address e-System, which accommodates the Social Security and Tax Number System. By enhancing mission-critical and internal information systems, many of which are already in operation as cloud services, with new services, we will accelerate cloud-based shared use that goes beyond the borders of prefectures and municipalities and help further reduce the costs of local governments.

Power System and Distribution

1 Otozawa Power Station Dam Monitoring Console for Kansai Electric Power Co., Inc.

Fuji Electric worked in cooperation with Enegate Co., Ltd. to deliver an Otozawa Power Station dam monitoring console to Dashidaira Dam, which is located on the Kurobe River drainage system, for Kansai Electric Power Co., Inc. in March 2014.

The main features of the dam monitoring console are as follows:

(1) The console is a function distribution system with the outlet facility control function separated from the information function for recording and storing operation results and other data.
(2) The arithmetic processing unit responsible for the control function has a redundant configuration to improve system reliability.
(3) FL-net, an open network standard of the Japan Electrical Manufacturers' Association, is adopted for the inter-device communications of the control function.
(4) Information of dam water level and outflow discharge are linked with the load dispatching control center in real-time to realize smooth water operation of the entire Kurobe River drainage system.

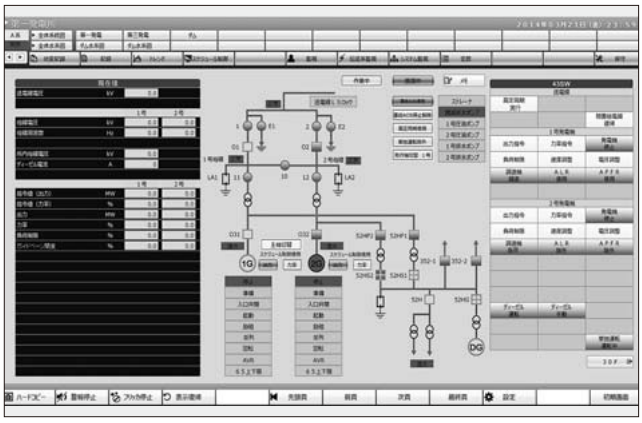
Fig.1 Dam monitoring console

2 Remote Control System for Power Plants of Bureau of Transportation Tokyo Metropolitan Government

For power plants of the Bureau of Transportation Tokyo Metropolitan Government, we delivered a hydroelectric power plant supervisory control system, remote supervisory control system and dam monitoring operation equipment. Remote supervisory control is provided for three hydroelectric power plants and one regulating reservoir dam in Okutama. The main features are as follows:

(1) The hydroelectric power plant supervisory control system is composed of redundant supervisory control servers (UNIX) and three display consoles.
(2) An IP network is used for communications between the hydroelectric power plant supervisory control system and the remote supervisory control system and PMCN, which is an industrial protocol of the Japan Electrical Manufacturers' Association, has been adopted as the transmission scheme.
(3) A universal design has been applied to the screen of the display consoles to improve operability and visibility.
(4) For supervisory control of the regulating reservoir dam, a dedicated dam monitoring operation device has been installed in view of emergency operation and backup operation.

Fig.2 Sample operation screen of the hydroelectric power plant supervisory control system

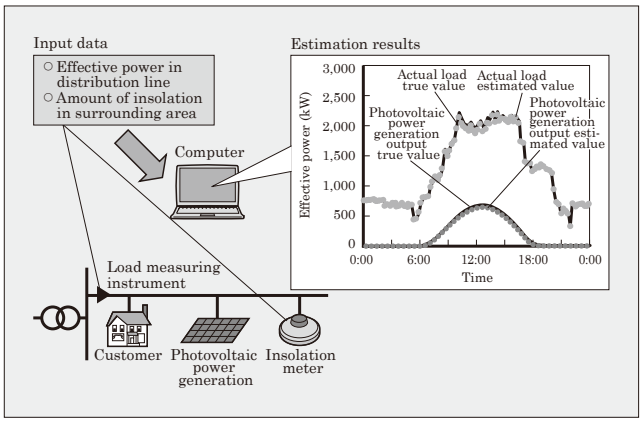


3 Technology to Estimate Photovoltaic Power Generation Output and Load for Power Distribution Automation System

Photovoltaic power generation is becoming rapidly widespread, supported by the Feed-in Tariff Scheme for renewable energy. In a power distribution system with photovoltaic power generation and customers mixed together, the load appears to be light in normal times, which makes it necessary to accurately isolate and grasp the actual load required for recovering from accidents. In reality, however, only the sum of the photovoltaic power generation output and the actual load of customers is measured. Accordingly, as an accident recovery function of the next-generation power distribution automation system, Fuji Electric is working on developing technology to isolate and estimate the respective values from the measured sum.

One main feature is that it estimates the output of photovoltaic power generation and the actual load of customers from the effective power of the distribution line and the amount of insolation in the surrounding area. As a result, it allows the user to grasp the load required for accident recovery without needing to install individual measuring instruments.

Fig.3 Example of photovoltaic power generation output and load estimation results

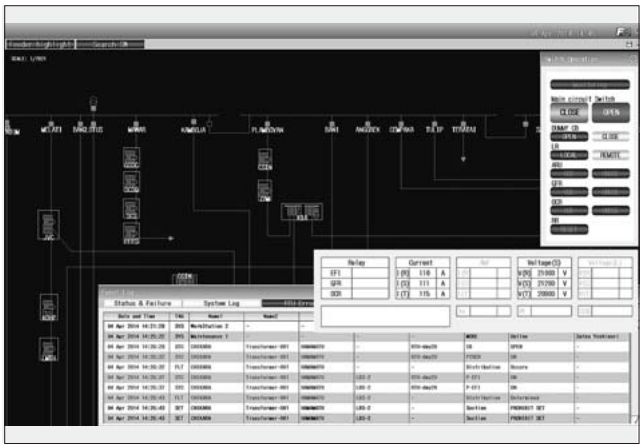


4 Power Distribution Automation System for Overseas Markets

Fuji Electric has made use of our proven track record of installations in Japan to develop a power distribution automation system for overseas markets. The main features are as follows.

(1) The functions have been packaged so that the system can be constructed according to the required function and scale ranging from a small scale to wide-area operation.
(2) The function of recovering from power outage accidents, which has a good track record in Japan, can be applied to power distribution systems in foreign countries to help reduce the power outage time.
(3) A global standard interface (compliant with IEC 60870-5-104) has been implemented to allow the system to be connected with field devices of various device vendors.
(4) A user authority management function provides flexible management of job functions such as the extent of jurisdiction and operations under charge.
(5) The drawing-type user interface can be used for maintaining substation single-line and power distribution system diagrams.

Fig.4 Example of supervisory control window



5 Retrofittable Digital Load Regulator Control Unit

Fuji Electric has developed a retrofittable digital load regulator control unit to be installed on the distribution board for distributing substations of Chubu Electric Power Co., Inc. The main features are as follows.

(1) The structure and interface are fully compatible with the existing model, which allows the unit to be replaced without changing the structure of the distribution board.
(2) Improved measuring accuracy has been realized by the DUJ Series of digital relay units, equipped with a 16-bit A-D converter and 5,760 Hz high-speed sampling function as standard.
(3) The input converter, power supply, arithmetic and other units, which were modularized individually, have been integrated into one module. Simplifying the components has successfully achieved a 10% reduction in the overall weight and 50% reduction in power consumption compared with the existing model.
(4) The noise resistance performance is compliant with JEC-2500 (2010).

Fig.5 Digital load regulator control unit

6 Power Line Communication (PLC) Evaluation Technology

The following technologies have been established, and they will be essential to field application of medium-speed power line communication (medium-speed PLC), a network for EMSs and smart meters.

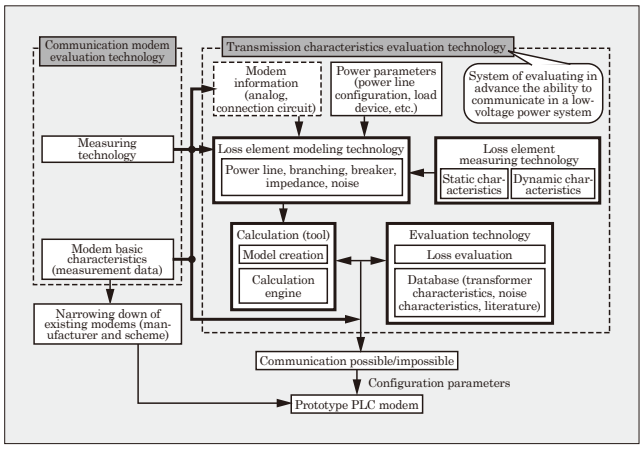
(1) Modeling of transmission line characteristics

Fuji Electric has established a method of measuring and technology for modeling the phase of transmission line characteristics (noise and impedance) and resonance characteristics, which may vary depending on the power line structure (phase wire system and branching) and devices connected. This has made it possible to conduct a preliminary evaluation by simulation and other methods and select configuration parameters.

(2) Verification using prototype

A prototype PLC modem has been used for verification in environments simulating fields such as a factory and a store. It has confirmed the ability to communicate even in the actual noise environment by setting the parameters selected in advance to reduce the communication error rate.

Fig.6 Framework of PLC evaluation technologies



Energy Management

1 Results of Demonstration in Kitakyushu Smart Community Project

As a principal company participating in the Kitakyushu Smart Community Project, Fuji Electric has conducted field tests by introducing community storage batteries, EMS for stores, EMS for hospitals, EMS for factories (FEMS), CEMS for overall control, etc. In this project, we have performed a verification test of demand response using CEMS. Applying dynamic pricing which varies the electric fee to limit the power demand, 10% and 5% peak shaving has been achieved by the EMS for general customers and stores, respectively. Moreover, in consideration of the instability in power distribution system caused by a large-scale introduction of renewable energy in near future, we have implemented a demonstration experiment of load flow control by combining the CEMS and the storage facilities. A simultaneous equal amount control has been performed to aim at limiting the power demand-supply imbalance within 3% at the system interconnection points, and the limitation within 1% has been successfully achieved.

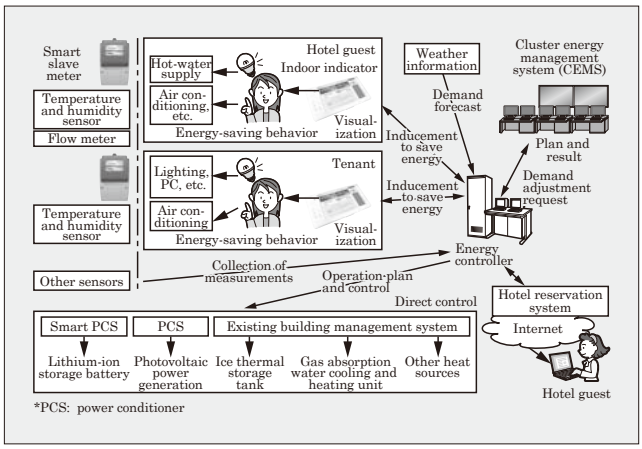
Fig.7 Community energy management system (CEMS)

2 Keihanna BEMS Demonstration Project

In the Next-Generation Energy and Social System Demonstration Project run by the Ministry of Economy, Trade and Industry, Fuji Electric has introduced a building energy management system (BEMS) in Keihanna Plaza to work on a field test. In FY2013, we confirmed the achievement of a peak reduction rate of 5% (75 kW reduction) and CO_2 reduction of 5% and are striving to achieve further effects. The main features are as follows:

(1) Optimum equipment operation based on a demand forecast and photovoltaic power generation forecast in electric and thermal energy supply equipment
(2) Load leveling using next-generation lithium-ion storage batteries using smart PCS for storage batteries
(3) Demand response by incentive programs targeting building tenants (offices, laboratories and stores including restaurants) and hotel guests
(4) Optimum use of regional energy by linking with CEMS

Fig.8 Overall configuration of BEMS

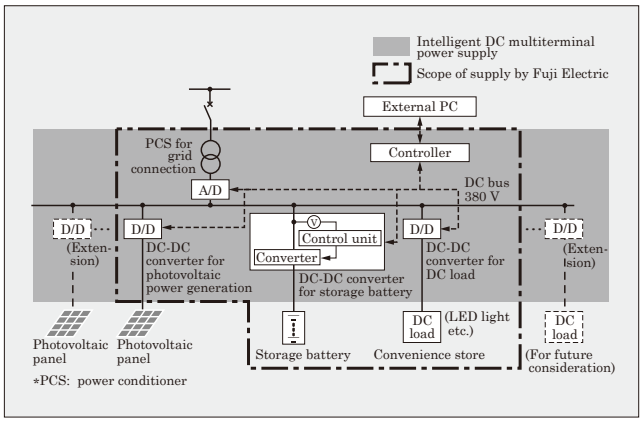


3 Intelligent DC Multiterminal Power Supply

In the Mie University Smart Campus Project run by the Ministry of Economy, Trade and Industry, Fuji Electric has implemented field-test of an intelligent DC multiterminal power supply, which raises expectations for high-efficiency use and power supply stabilization of renewable energy and for power supply at the time of disaster. We connected a power conditioner (PCS) for grid connection, DC-DC converters for photovoltaic power generation and storage battery and DC load (LED light) to a DC bus and obtained the following results. We intend to work on its commercialization in the future.

(1) Photovoltaic-generated power was directly supplied to the LED light as DC power and a power reduction of 18.1% as compared with AC power was confirmed.
(2) A continuous grid-isolation operation function by renewable energy during commercial power outage was demonstrated.
(3) Multiple devices were connected to the DC bus and stable operation against power generation and load fluctuation was confirmed.

Fig.9 System configuration of intelligent DC multiterminal power supply



Energy Management

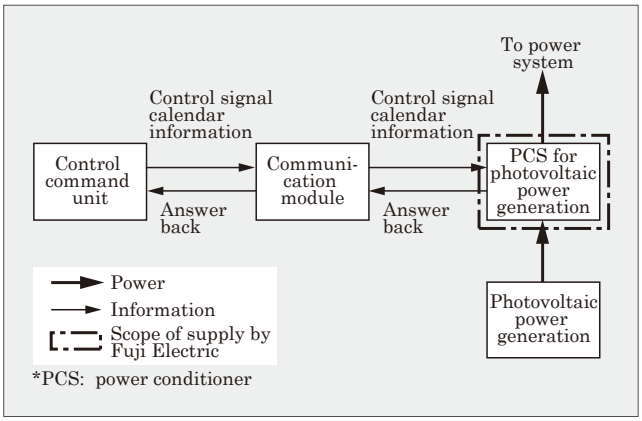
4 Demonstration Projects for Next-Generation Power Control Systems Using Two-Way Communications

In the Demonstration Projects for Next-Generation Power Control Systems by Two-Way Communications of the Ministry of Economy, Trade and Industry, utility companies and manufacturers worked on demonstrations relating to measures for stabilizing the system when photovoltaic-generated power is introduced in large amounts and obtained the following results.

(1) In view of future standardization and certification, a common communication scheme was determined and a power conditioner (PCS) for photovoltaic power generation equipped with the two-way communication function was developed. This PCS is capable of controlling output according to the control signals from the host server.

(2) The voltage-dependent constant power factor control method, in which leading reactive power is output according to the coupling point voltage and photovoltaic power generation output, was implemented in the PCS and the voltage rise control function was confirmed in a verification test. This raises expectations for a voltage rise suppression effect that does not hinder photovoltaic power generation opportunities of the PCS installer as much as possible.

Fig.10 Overall configuration of Demonstration Projects for Next-Generation Power Control Systems Using Two-Way Communications



Social Environment

1 "Local Government Integrated Address e-System" Accommodating Social Security and Tax Number System

In line with the introduction of the Social Security and Tax Number System (My Number system), Fuji Electric has developed the "Local Government Integrated Address e-System" for local governments that meets the need for the My Number system. This system facilitates two tasks essential to handling of the My Number system by local public bodies: management of personal IDs and integrated address IDs; provision and query of specific personal information with the intermediate server. The main features are as follows.

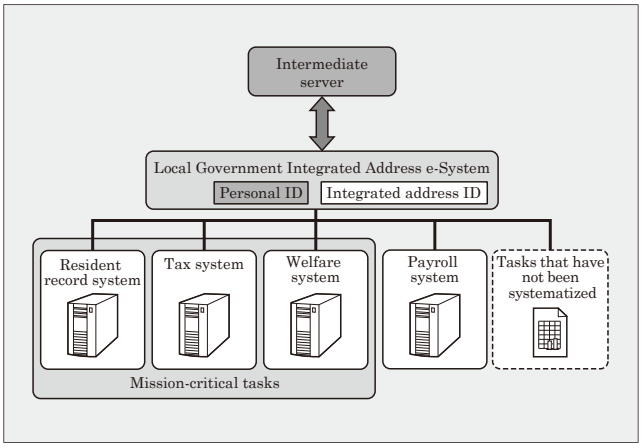
(1) The system can manage personal IDs and integrated address IDs.

(2) The system can interact with intermediate servers having different data formats or communication schemes.

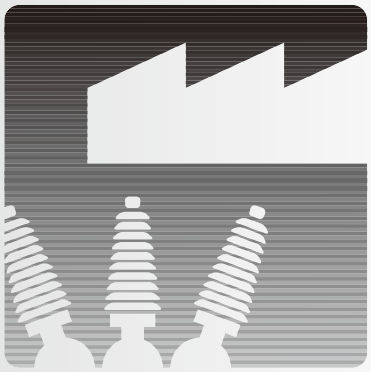
(3) Integrated management is possible including personnel/payroll management and tasks that have not been systematized.

(4) Flexible linking with other business systems has been realized.

Fig.11 Outline of "Local Government Integrated Address e-System"



Industrial Infrastructure



Substation Systems
Machinery and Electric Systems
Instrumentation and Control Systems

Outlook

In Japan, the aging of equipment continues to advance and this has caused a greater need for upgrading equipment and systems in order to achieve safe and stable operations, ensure secure operation and realize energy savings. Furthermore, in overseas markets representative of developing nations such as China and Southeast Asian countries, capital investment remains strong and there has been a strong demand for stable supply of energy, safe and stable operations and secure operation. Fuji Electric has based its industrial infrastructure on the three pillars of a "stable supply of energy," "realization of energy savings" and "provision of safety and security" as it aims to provide solutions for the overall life cycle of the equipment and facilities of its customers at all stages of production activities.

Substation Systems

Our substation system business makes full use of substation and distribution facilities and large capacity power electronics devices for sectors including the electrical power, industrial, facility and transportation sectors, while we also continue to supply business solutions for increasing reliability and efficiency, as well as measures for the environment. In Asia, we have implemented capital participation at Tasco Corporation in Thailand in expectation of infrastructure expansions, and have also established Fuji Tusco Co., Ltd. as the production base of power transformers and switchboards. In addition, we are focusing on strengthening our sales offices and continue to construct systems covering stages from deliver to service supply.

In the substation field, we have completed the delivery of a unit of boosting transformer, and are in the process of manufacturing two units more, with a capacity of over 500 MVA for thermal power plants in Japan in order to support the stable and highly reliable supply of power. Furthermore, we have also delivered and installed a 66 kV substation unit using a turnkey system for Bahrain.

In the industrial and electrical facility field, we have developed a transformer that meets new top runner standards and will commence sales of it starting from April 2014. We are also actively developing proposals to improve reliability through maintenance services such as equipment diagnosis to support the aging of facilities.

In the industrial power field, we have completed and delivered the world's largest rectification facilities for aluminum smelting facility which started manufacturing recently. In similar manner, we have shipped out a total 10 units of "S-FORMER" transformer rectifiers for the world's largest scale petrochemical plant.

In the ground substations field for railways, we have received orders for equipment upgrades of existing substations to ensure reliable transportation. In addition to delivering these services, we have also been actively developing equipment that takes into consideration the environment, energy savings and reduced maintenance such as environmentally friendly dry air cubicle type gas-insulated switchgear (C-GIS).

Machinery and Electric Systems

Our machinery and electric systems business supplies engineering business solutions spanning all stages of the equipment life cycle by optimizing the energy of plants and facilities based on competitive products and models including drive control systems, industrial electric heating systems, air environment systems and factory energy management systems (FEMSs).

In the drive control system field, we have developed packages and upgrade tools for existing facilities that combine data collection with drive and high speed control functions, allowing us to support both new equipment and upgraded equipment for control systems. In addition, our on-shore electrical systems are multi-functional power systems that implement power supply and power generator load tests for ships, and it is anticipated that these systems will also be applied to other fields in the future.

In the industrial electric heat field, Fuji Electric (Zhuhai) Co., Ltd. has started manufacturing and marketing high-capacity induction furnaces, and has delivered insulated gate bipolar transistor (IGBT) power system equipment with a capacity of 8,000 kW.

In the air environment field, we have been developing systems that contribute to environmental improvement and energy savings. In the data center field, we have started selling the "F-eCoMo" container-type data center that contributes to energy savings and shortened installation work periods. In addition to this, we have been promoting the manufacture of a compact and high-performance exhaust gas purification system compatible with SOx and PM regulations in the marine and ship industry. We have delivered information terminals for a rest area that display traffic and weather information for the expressway in multiple languages.

In the FEMS field, we have developed a cloud-based FEMS and self-powered wireless power sensor that does not require wiring in order to reduce the initial investment for plants that are newly introducing FEMS systems. These developments have enabled us to expand our infrastructure export businesses at the new factories of Fuji Electric Manufacturing (Thailand) Co., Ltd., as well as for the New Energy and Industrial Technology Development Organization (NEDO).

Instrumentation and Control Systems

Our instrumentation and control system business has been incorporated in the solutions of a wide range of customer issues by organically integrating the unique equipment and technology of Fuji Electric such as its industrial measurement systems, controllers, measuring equipment and sensors, radiation monitoring equipment and system, power electronics, advanced control technology and service technology.

The industrial measurement system market is flourishing for both upgrading aging systems and for installing new systems required for new customer products. When upgrading systems, we aim at utilizing existing assets and shortening the time required for switchover between old and new equipment. For new systems, we work flexibly to meet specifications and construction schedules. In the future, we will offer a system that further improves both safety and convenience.

In the field of controllers, we have developed the "MICREX-VieW XX" supervisory control system for small and medium scale operations. This product maintains compatibility with existing systems, while also achieving high operability and reliability, allowing us to contribute to our customers' safe, secure and stable operations.

In the measuring equipment and sensor field, we continue to roll out products that focus on the environment and energy. We have also developed and are manufacturing industry-leading gas analyzers that utilize infrared and laser systems as environmental measurement application as well as ultrasonic flowmeters, equipped with calorie counting functions, which are suitable for energy measurements.

In the radiation monitoring equipment and system field, we have developed and started marketing personal dosimeters, high range environmental monitors, radiation monitoring devices for use during emergencies and other devices required for recovery and reconstruction after the accident at the Fukushima Daiichi Nuclear Power Station. In the future, we plan to continue working on radiation measurement devices for decommissioning and intermediate storage facilities.

Substation Systems

1 Delivery of a Main Transformer for the Kawasaki Thermal Power Station of Tokyo Electric Power Company

Since 2007, Fuji Electric has sequentially delivered one 2-1 axis main transformer as well as a series of three main transformers for Unit 1 at the Kawasaki Thermal Power Station of Tokyo Electric Power Company (TEPCO). We are also currently in the process of manufacturing main transformers for the 2-2 axis and 2-3 axis. As shown in the Figure, the 2-1 axis main transformer has a rated voltage of 15.8/283.3 kV and a rated capacity of 545 MVA. The unit started operations in February 2013.

By taking advantage of Fuji Electric's Chiba Plant, which faces the Tokyo Bay, we have been receiving orders continuously for the main transformers of the thermal power stations of Tokyo Electric Power Company in the Tokyo Bay area starting with the Higashiogishima Thermal Power Station in 1990. We have delivered a total of 29 units so far.

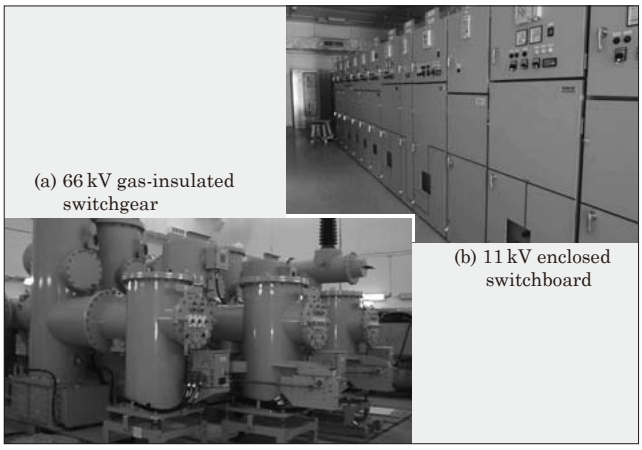
The main transformer for the 2-2 axis is scheduled to start operations in July 2016, while the one for the 2-3 axis in July 2017. With these dates set before us, we are continuing to progress with the manufacturing and on-site construction work for the transformers.

Fig.1 Main transformer for the 2-1 axis at the Kawasaki Thermal Power Station

2 Start of Operations of the JBF 66 kV Substation for the Bahrain Electricity and Water Authority

The JBF 66 kV substation was built for the purpose of supplying power to a polyester plant constructed in Bahrain. It started operations in September 2013. This substation was constructed with 66 kV gas-insulated switchgear, 11 kV metal clad switchgear, control and protection panels, auxiliary power supply equipment, telecommunication equipment, high and low voltage cables and others. This project was contracted as a turnkey project for handling over to the customer in a condition of ready for operation. The project has progressed with local project offices taking a main role where foreign engineers have worked continuously from the time of Japan AE Power Systems Corporation. The project has been highly appreciated by customers on account of the comprehensive activities being carried out locally, such as the basic design of the substation, confirmation of specifications for equipment and material, acquisition of quotation, arrangement of manpower and equipment, schedule control, installation work, testing and a number of meetings with customers.

Fig.2 JBF 66 kV substation



3 Delivery of 200 MVA Transformers at the Kimitsu Works of Nippon Steel & Sumitomo Metal Corporation

Fuji Electric has upgraded the power receiving transformers at the Kimitsu Works of Nippon Steel & Sumitomo Metal Corporation which had worked for approximately 50 years since the founding of the ironworks. In order to enhance facilities, two of the three 100 MVA transformers were upgraded to 200 MVA transformers, and the remaining one was served as a standby.

Though the capacity of the transformers has been doubled compared to the existing one, we streamlined on-site work by reusing the substruction and adopting the primary and secondary terminal connections same as existing ones.

Moreover, the old and new transformers were able to be switched without stopping supply of power to loads. Furthermore, using an on-load tap changing transformer of a vacuum valve type reduces outer dimensions, increases service life, and streamlines maintenance work (purification work is not needed for insulating oils) in order that life cycle costs may decrease. The protection system adopts a digital multifunction relay with a duplicated CPU to ensure reliability.

Fig.3 200 MVA transformer

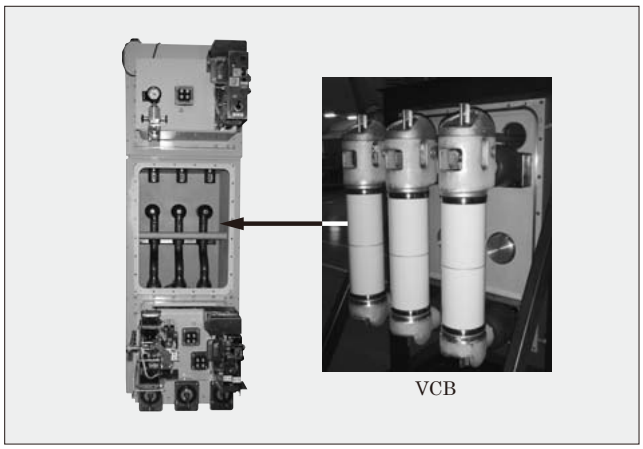
Substation Systems

4 "72 kV Environmentally Friendly C-GIS"

Fuji Electric has developed the environmentally compatible "72 kV environmentally friendly C-GIS," which utilizes dry air that has the lowest Global Warming Potential (GWP=0) as an insulating medium, while the current cubicle type gas-insulated switchgear (C-GIS) utilizes SF_6 gas as an insulating medium. The main features are as follows:

(1) It realizes dry air insulation without SF_6 gas (0.2 MPaG or less).
(2) It employs a composite insulation and ensures insulation performance via techniques such as surface finishing.
(3) Its panel configuration and dimensions are at the same level as the current C-GIS.
(4) The main ratings are as follows:
  (a) Rated voltage and current: 72 kV 800/1,200 A
  (b) Rated frequency: 50/60 Hz
  (c) Rated short-time allowable current 25/31.5 kA
  (d) Withstand voltage: power frequency/lightning impulse: 140/350 kV

Fig4. "72 kV environmentally friendly C-GIS"



5 Upgrade of the Kitatatsumi Substation on Line No. 5 of the Express Electric Tramway of the Osaka Municipal Transportation Bureau

Fuji Electric has completed the work for upgrading existing facilities and installing new facilities: the work for replacing aging power equipment used for electric trains; the work for providing power supply equipment and regenerative power storage equipment for station buildings. The main facilities include 24 kV gas-insulated switchgear, electric railway rectifiers, regenerative energy storage systems and DC 1.5 kV and AC 7.2 kV switchgear. The main features are as follows:

(1) By applying a 24 kV dry air insulated C-GIS and a purified water boiling/cooling type silicon rectifier, we have aimed at increased space savings, reduced maintenance and high reliability.
(2) Harmonic suppression measures have been achieved via 12 pulses technique of the electric railway rectifier.
(3) By applying large-capacity nickel-hydrogen batteries as a regenerative energy storage system and by storing regenerative power generated through the regenerative braking of electric trains, the amount of power used for electric trains has been reduced.

Fig.5 Regenerative energy storage system

6 Shipment of "S-FORMER" Rectifier Units for Sadara Chemical Company in Saudi Arabia

Fuji Electric has shipped out ten "S-FORMER" rectifier units for Sadara Chemical Company, which is currently constructing the world's largest petrochemical plant in Saudi Arabia.

Since the local climate is extremely hot and the environment is very harsh on equipment, It is necessary to assess the local heat area that is induced by large current before rectifier manufacturing. We have conducted 3D electromagnetic field analysis as a countermeasure against local heat to obtain the optimal design of this unit.

Fig.6 "S-FORMER"

Substation Systems

7 Degradation Diagnosis Technology for Electrical Equipment

Electrical equipment plays a role in supporting the supply electrical power to and stable operations of infrastructure, factories and buildings. Fuji Electric has developed its own original degradation diagnosis devices to forecast equipment failure, and this enables us to propose safe and economical maintenance and upgrade plans.

(1) Diagnosis device for rotating machines “ROPAS”

This device measures the frame electric potential and zero-phase current of rotating machines, and diagnoses the insulation degradation from the detected partial discharge (PD) patterns.

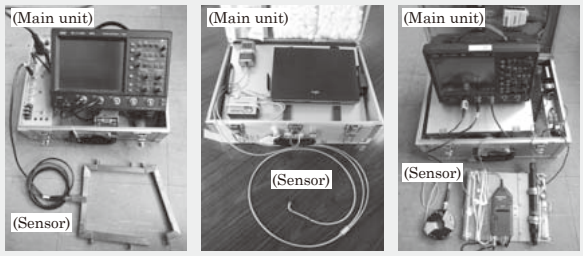
(2) Diagnosis device for molded transformers “Molmos”

This device evaluates molded resin degradation via a unique optical sensor, and diagnoses the remaining life of the equipment by using a resin database.

(3) Diagnosis device for switchboards “Copas”

By making continuous measurements of the acoustic waves in the board and the ground current, this device determines the existence of PD generation in high humidity time zones to diagnose insulation abnormalities.

Fig.7 Representative degradation diagnosis devices



(a) “ROPAS” (b) “Molmos” (c) “Copas”

Machinery and Electric Systems

1 Expansion of Upgrade Tools for Existing Control Systems

Fuji Electric has developed the following lineup as upgrade tools for the existing control systems for steel plants and other factories.

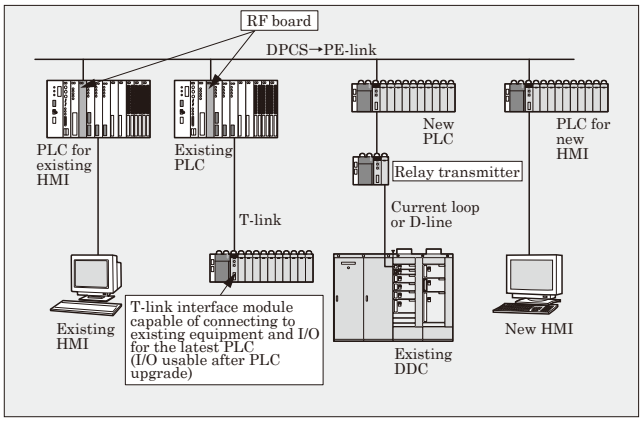
(1) Retro fit board (RF board) connecting new PLCs with existing PLCs and HMIs delivered from 1980 to the early 1990s

(2) T-link interface module capable of connecting the I/O for the latest PLCs to existing PLCs

(3) Relay transmitters capable of connecting new PLCs with existing DDCs (thyristor Leonard systems and inverters)

These devices make partial upgrades possible for large-scale equipment and facilities that are difficult for bulk upgrades, such as the continuous annealing line (CAL) and the continuous galvanizing line (CGL).

Fig.8 Upgrade example of a control system that applies upgrade tools



2 Multi-Functional On-Shore Power System for Ships and Vessels

Fuji Electric has developed a multi-functional on-shore power system for use at shipyards equipped with load testing functions for the on-board power generators and the power supply functions for on-board power systems. Main electrical products such as power converters and control equipment are stored in containers for use outdoors and connect to on-board power systems and commercial (on-shore) power systems using transformers and switchboards. The main features are as follows:

(1) Capacity: 5,000 kVA (one container: 1,667 kVA)

(2) Container dimensions and mass: W7,400×D2,600×H3,200 (mm), and mass is about 21 tons.

(3) It can supply power to on-board power systems from commercial power systems.

(4) It is capable of load testing for on-board power generators via power regeneration or load resistor, and load patterns can be set arbitrarily.

(5) It is capable of automatic synchronization and connection to commercial power systems or on-board power systems.

(6) It is capable of suppressing commercial power system disturbances at the time of on-board power system change.

Fig.9 Container for outdoor use

3 Electrical Equipment for Aluminum Material Surface Treatment Process Lines

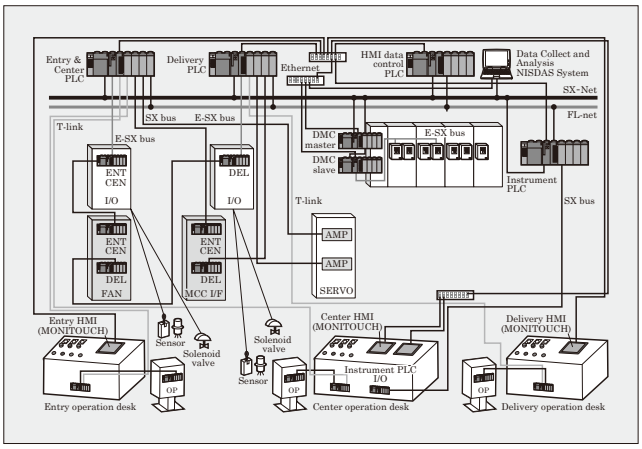
Fuji Electric has delivered electrical equipment for aluminum material surface treatment process lines at a company in Thailand. The equipment utilizes the latest process line control system and it was designed to achieve high-speed and high-precision, while improving maintainability. The main features are as follows:

(1) It was constructed with a network using "SX-Net," while applying "FRENIC-VG" (VGM mode) to the inverter and applying the "SPH3000MG" to inverter control controllers (DMC) and controllers that control each section.

(2) DMC controls up to 64 inverters via a single unit. Remote monitoring and operation of DMC is possible via Ethernet from the loader PC.

(3) The "f(s) NISDAS7" software on the SX-Net makes it possible to have high-speed collection of thousands of plant data (1,024 words/ms).

Fig.10 System configuration



4 Upgrade of Bar and Wire Rod Mill Electrical Equipment for Ege Çelik in Turkey

Fuji Electric delivered the equipment 20 years ago, and performed a complete upgrade of the decrepit bar and wire rod mill electrical equipment by doing 2 times of revamping and commissioning. During Step 1, we upgraded 4 drives and control equipment over 4 days, and during Step 2, we completed the upgrade of 40 drives and control equipment during a 35 day period, and thereafter performed a vertical start-up. We completed all of the equipment upgrades while maintaining continuous operations of either of the bar or wire rod lines. The upgrade work was characterized as following:

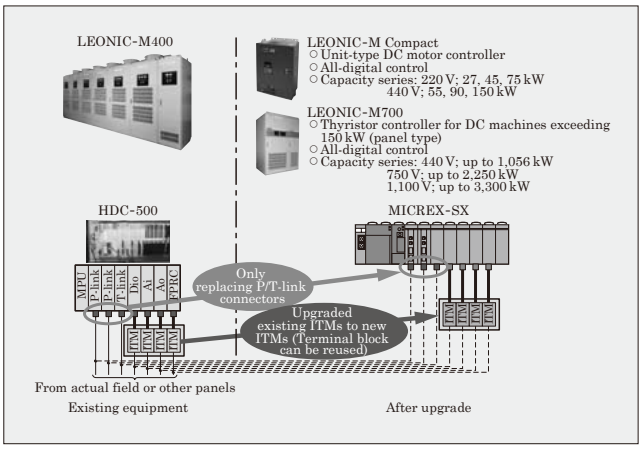
(1) We upgraded the thyristor converter and drive control equipment "LEONIC-M400" with the latest models "LEONIC-M700" and "LEONIC-M Compact"

(2) We upgraded the PLC "HDC-500" and "MICREX-F" with the latest model "MICREX-SX"

(3) We added the latest control functions for the bar and wire rod equipment

(4) We newly installed a "MONITOUCH" as an HMI

Fig.11 Upgrade of bar and wire rod mill electrical equipment



5 Container-Type Data Center "F-eCoMo"

IT innovation and cloud computing have spread rapidly over the past several years, and this has created an increasing demand for small start, stepwise equipment expansion and speedy construction of data centers.

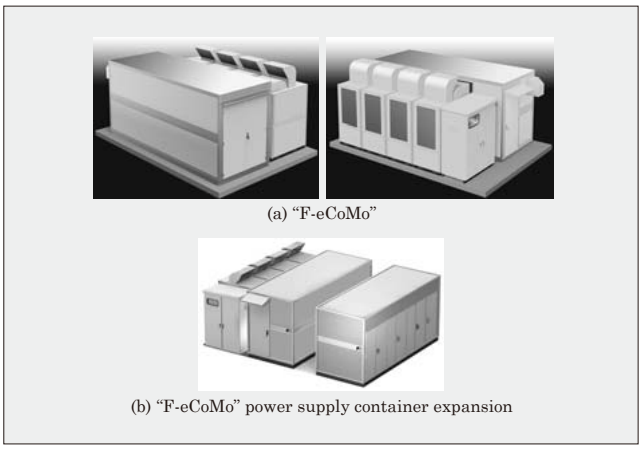
Fuji Electric has responded to these needs through the development of the container-type data center "F-eCoMo" enabling on-demand response. The main features are as follows:

(1) We achieved a more compact data center via standard design based on 20-feet container

(2) Energy saving operation is possible through use of an indirect outside air conditioner that utilizes outside air energy.

(3) Investment optimization is possible through stepwise equipment expansion to meet the increased load demands of server and IT equipment loads.

Fig.12 "F-eCoMo"



Machinery and Electric Systems

6 Delivery of Information Terminals for Rest Areas on the Tomei Expressway

Fuji Electric has delivered information terminals for Central Nippon Expressway Company Limited (NEXCO-Central). The terminals have been installed at rest areas, such as service areas and parking areas and provide expressway users with useful information by displaying traffic and weather information in multiple languages (Japanese, English, Korean and Chinese).

The terminal consists of an apparatus housing rack that houses the control unit, as well as a selection-type monitor that combines both a broadcast monitor for displaying information and touch panel operation function. The selection-type monitor usually displays information only, but since it is also equipped with motion detectors, it automatically switches over to the selection-type screen when a monitor detects that a user is approaching. Furthermore, the terminals provide URL information to Felica equipped mobile phones, and since they are linked to the earthquake early warning system, they are also capable of displaying instant earthquake alert information.

Fig.13 Selection-type monitor

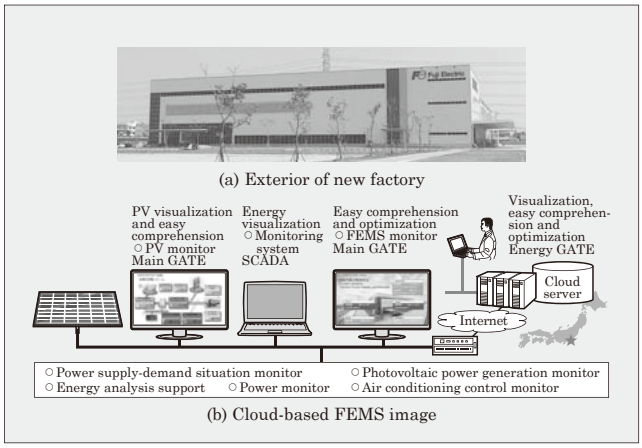
7 Introduction of Global Cloud-Based FEMS System

Fuji Electric has introduced a global cloud-based FEMS system at the new factory of Fuji Electric Manufacturing (Thailand) Co., Ltd. and commenced operations in March 2014.

This system makes use of a cloud-based EMS installed in a data center located in Japan to collect various types of data including energy consumption data, photovoltaic power generation data and air conditioning control data for the factory. The system adopts an Internet-based Web environment that provides analysis support services and monitoring services of energy supply and demand situations. This system is compatible with multiple languages. It displays local information in English, while also allowing users of relevant departments in Japan to view the information in Japanese.

In the future, we plan to utilize to expand our EMS sales activities in Thailand by introducing actual applications of the system to our customers.

Fig.14 Exterior of new factory and cloud-based FEMS image

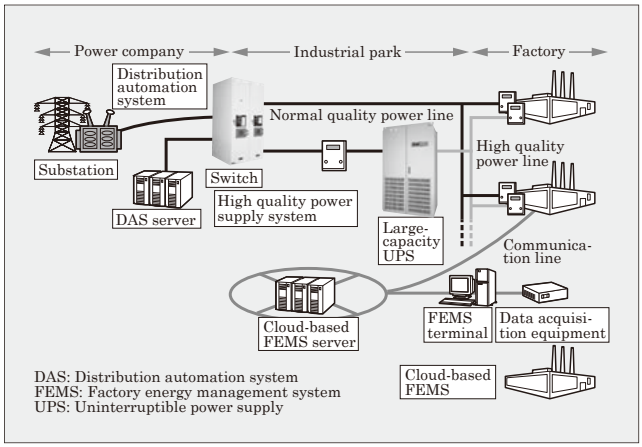


8 NEDO Indonesia Demonstration Project

Fuji Electric has received a commission from the New Energy and Industrial Technology Development Organization (NEDO) to work on a joint project with Sumitomo Corporation, Mitsubishi Electric Corporation and NTT Communications Corporation, and we are currently implementing smart community demonstration projects in Indonesia. We are carrying out demonstration tests for power stabilization, energy savings and construction of an information communication platform in the Suryacipta City of Industry as we aim to adopt a business model that utilizes the advantages of Japanese technology, while also working in combination with it to export infrastructure overseas.

Fuji Electric has introduced a cloud-based FEMS that achieves energy and cost savings, as well as visualizes energy usage situations in the factory, while also incorporating a distribution automation system for early stage automatic recovery during power failures and a high-quality power supply system that protects important facilities from troubles such as power failure and instantaneous voltage drop by using a large-capacity UPS.

Fig.15 Overview of the NEDO Indonesia Demonstration Project



Instrumentation and Control Systems

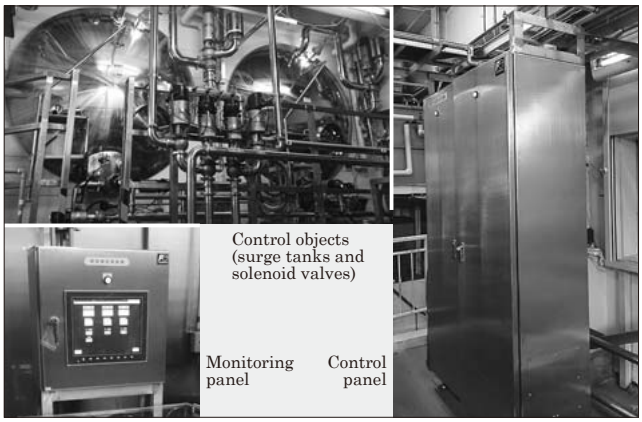
1 Instrumentation and Control System for Food Industry

In the food industry, there has been high demand for a low cost, small and medium scale monitoring control system. When installing control equipment at sites with dense piping, one important issue is the wiring saving of power supply and signal lines.

Fuji Electric has resolved this issue based on its accumulated know-how by using a control system for the food industry, and has developed and delivered an automatic control system for the milk (cow's milk) manufacturing line of the Chino Factory of Yatsugatake Milk Co., Ltd. via Nichiraku Machinery Co., Ltd. The main features are as follows:

(1) It controls about 200 solenoid valves.
(2) In order to achieve a small scale and low cost system, the "MICREX-SX" was adopted for the control system and the "MONITOUCH" for the monitoring equipment, while an AS-Interface device was employed for reducing the wiring in the system.
(3) It is capable of being utilized at small scale plants such as those in the food industry.

Fig.16 Installation and control of the milk (cow's milk) manufacturing line

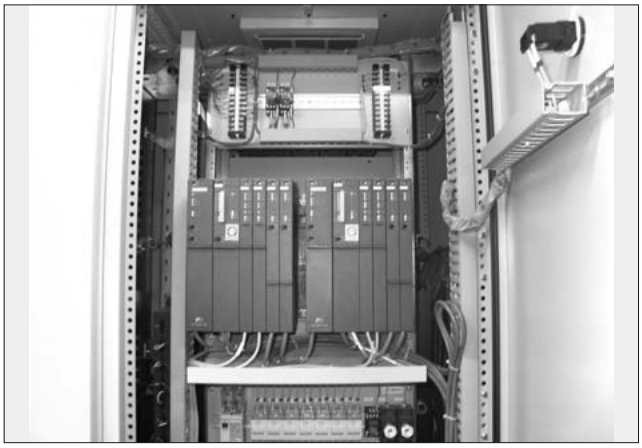


2 Instrumentation and Control System for Iron and Steel Industry

In recent years, efforts for safety have been progressing worldwide, and in Japan, safety regulations (JIS B8415) for industrial furnaces were revised in 2008. Fuji Electric is working to strengthen these efforts and has delivered many safety systems to steel plants. The "MICREX-NX" combustion safety system has the following features:

(1) The controller has received SIL3 certification and is compatible with various safety standards. Furthermore, it makes it possible to install both normal control and safety control functions together in the same controller.
(2) By implementing our application package lineup for building a combustion shutoff circuit and by integrating combustion control and combustion safety via the creation of software for a circuit that had been conventionally built using hardware, we have enabled to construct a compact, highly reliable and safe system.

Fig.17 Combustion safety system controller



3 Instrumentation and Control System for Waste Disposal Plant

Recycling by collecting sorted waste has been advancing in recent years, and as a result, incineration waste emissions are declining and the creation of new facilities is reducing. On the other hand, facilities built in early 2000 for implementing the "Law Concerning Special Measures against Dioxins" have already been operating for 14 years now and are in need of more stability. In order to maintain and stabilize the functional operations for aging incineration facilities in each municipality, upgrading work for core facility distributed control systems (DCS) has been steadily ongoing.

At the Akashi Clean Center, a comprehensive upgrade of the instrumentation and control systems including monitor switching control systems was made during non-operation period of the facility in November 2013. Safety has been prioritized while reducing the time of the replacing by reusing the boards, housing and external cables of existing equipment, and we have achieved a trouble-free upgrade and start-up that contributes greatly to the stable operations of the facility.

Fig.18 Akashi Clean Center central control room

Instrumentation and Control Systems

4 Board-Type “SX Bus I/O”

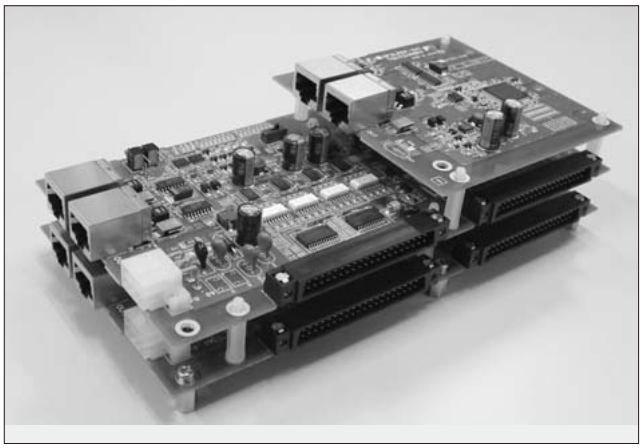
In recent years, controllers (PLC) for small and medium sized machine control devices have become more widespread in popularity as they have become more high-performance, compact and low-cost. Fuji Electric has developed the board-type “SX bus I/O” for meeting the compact, wire-reducing and distributed demands of PLC. The main features are as follows:

(1) A single board has achieved compactness through being equipped with a power supply, base board and digital input/output mixed 64-point module.

(2) Since direct connection to Fuji Electric’s main bus “SX bus” is allowed, it is possible to implement high-speed I/O refresh that synchronizes the control operations of PLC.

(3) SX bus T-branch connection and repeater functions, which are the standard functions of the “MICREX-SX” remote I/O, can also be utilized. By employing these, distributed installation of I/O can be implemented easily.

Fig.19 “SX bus I/O”



5 Information and Process Control System “MICREX-NX”

In recent years, control systems have been required to meet technological innovation, and also to incorporate safety and security measures. Fuji Electric has launched the new version V8.0 of the information and process control system “MICREX-NX” onto the market .This new version contributes to the realization of stable operation and improved equipment safety. The main features are as follows:

(1) Compatible with wide screens and Windows 7 64-bit version

(2) Improving visibility and operability of plant screens

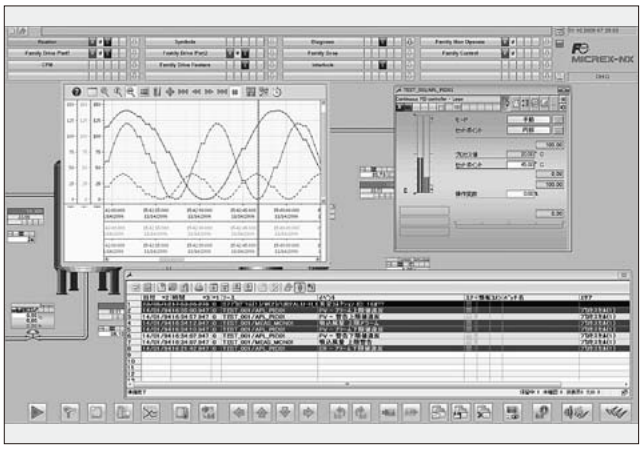
(3) Achieving alarm management compliant with international standards

(4) Achieving a high security system construction via the utilization of components that have acquired Achilles certification*

(5) Anti-virus via whitelisting technology

* Achilles certification: A type of international third-party certification for certifying the robustness of security for control systems

Fig.20 Example of “MICREX-NX” V8.0 plant screen



6 “MICREX-NX” Function Enhancement Related to Solutions for Chemical Field

In order to reduce the risk of major accidents at chemical plants, the reconstruction of safety systems has been proposed and there is increasing demand for improved visibility of monitoring screens and advanced control functions. Fuji Electric has added new control functions to its information and process control system “MICREX-NX” to meet these demands. The main features are as follows:

(1) Advanced process screen module

This module reduces human error during operation and supports safe operations.

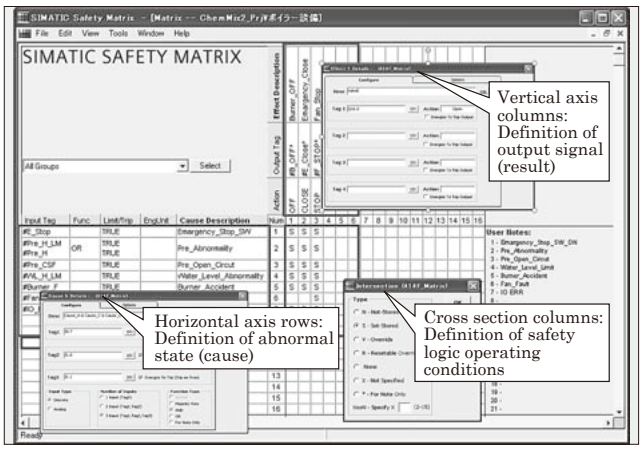
(2) Advanced process control template

This template easily materializes advanced control functions such as advanced model predictions, as well as contributes to improving process value stabilization and product quality.

(3) Safety matrix

Safety instrumentation software can easily be created in a tabular format.

Fig.21 Engineering via safety matrix



7 New Functions of Package Software Supporting Data Collection and Analysis

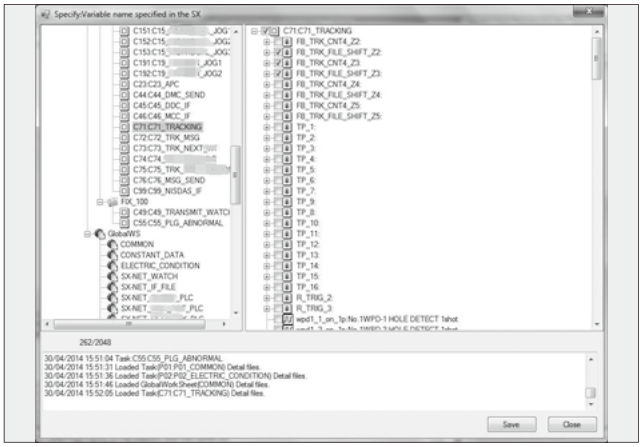
Fuji Electric has started selling the "f(s) NISDAS7" package software supporting data collection and analysis in order to meet the need of stabilization of facility operations, high efficiency operations and preventive maintenance. We have enhanced the functionality as follows in order to improve convenience and expand applicability.

(1) It is now possible to use variable names for both global and local variables in order to collect data. Variable names are defined by "SX-Programmer" programming support tool compliant with the international standard IEC 61131-3.

(2) SX-Programmer Standard tag file reading functionality was added to the conventional SX address assignments collection function.

(3) The integrated controller "SPH3000MM" and "SPH3000MG" were added to the applicable models.

Fig.22 Variable name selection screen



8 New Functions of "HEART" Engineering Tool

Fuji Electric developed and has been operating "HEART" as a unit capable of automatically generating control software from control function specifications. "HEART" is an engineering tool that achieves high quality engineering with high efficiency. We have improved its operability and made it applicable to the new monitoring control system "MICREX-VieW XX." The main features are as follows:

(1) Highly efficient large-scale editing and management functions via label lists

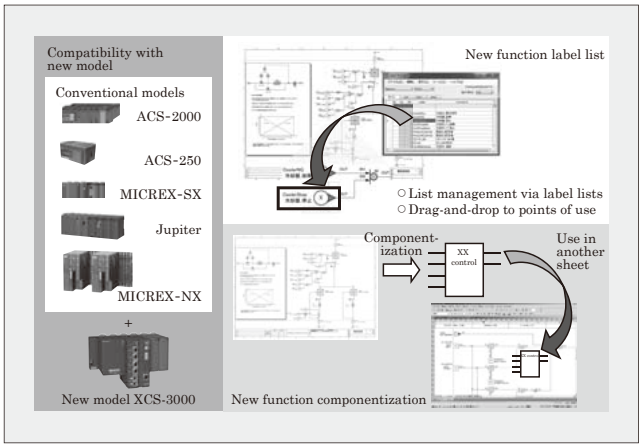
The functions such as engineering without being conscious of addresses and signal definitions with drag-and-drop operation provide easy operation.

(2) Componentization of functions for multiple reuse and component calling functions

The system achieves efficient creation of the same function as the function used before as well as simple and easy-to-read specification documents. Furthermore, the interior of the components can be also monitored on the specification documents in the same manner as conventional models.

Reference: FUJI ELECTRIC REVIEW 2014, vol. 60, no. 1, p. 38

Fig.23 Compatibility with new model and new functions



9 Laser Gas Analyzer for Two-Element ($CO+O_2$) Measurements "ZSS"

Fuji Electric has developed the world's first laser gas analyzer capable of simultaneous measurement of the two elements CO and O_2 by incorporating two laser devices in a single analyzer. By adopting this product, customers will enjoy significant benefits since the unit reduces installation costs and facilitates easy maintenance. The following three main types are applicable to dust of less than or equal to 10 g/m^3 for utilization in combustion control and inflammable gas recovery.

(1) ppmCO+combustion control O_2 (for combustion control)

Application temperature: 400°C to 1,200°C; purge gas: air

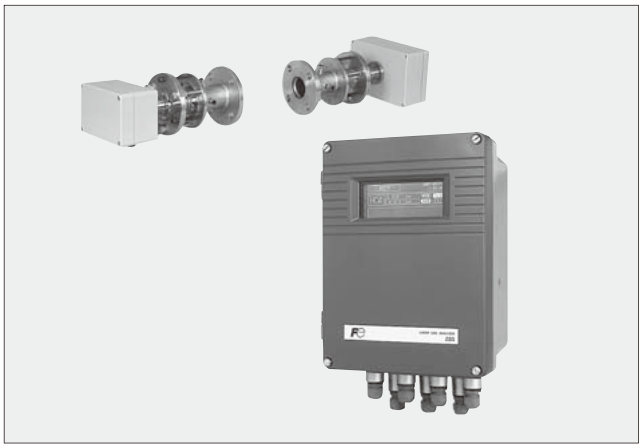
(2) ppmCO+high dust O_2 (for combustion control)

Application temperature: 1,200°C or lower; purge gas: nitrogen

(3) vol%CO+low output O_2 (for inflammable gas recovery)

Application temperature: 300°C or lower; purge gas: nitrogen

Fig.24 "ZSS"



Instrumentation and Control Systems

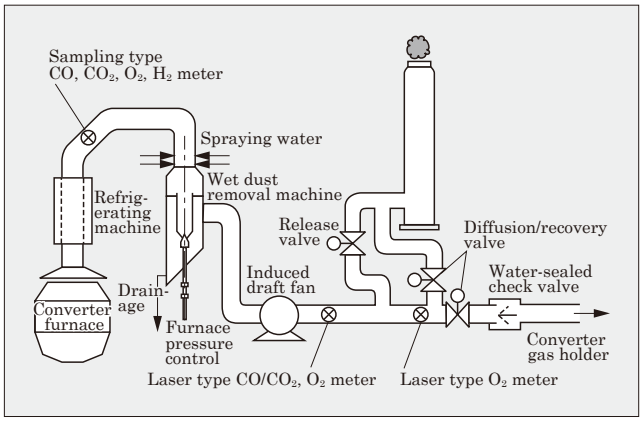
10 Laser Gas Analyzer for Improving Converter Gas Recovery Efficiency

A converter performs decarburization by blowing oxygen into a furnace. The CO gas that is generated at this time is recovered as fuel for steel plant facility. Equipment for recovery is called converter gas recovery equipment (OG equipment) and a CO meter is installed for fuel-use calorie measurements and an O_2 meter for explosion prevention. Gas concentration measurements in OG equipment are conventionally performed by sampling-based analytical devices, but this method has problems in that the response time is slow and daily maintenance needs to be carried out by a technician.

Laser gas analyzer based gas concentration measurement has the following features:

(1) It has a high-speed response time of about 2 seconds, and it is capable of increasing the amount of gas recovered.
(2) Maintenance costs can be reduced since the unit does not require daily maintenance.
(3) It performs continuous measurements not based on sampling and can collect data useful for improving the gas recovery process.

Fig.25 Example of installation in converter gas recovery equipment (OG)



11 Next-Generation Global Standard Temperature Controller "PXF Series"

Fuji Electric's temperature controllers, particularly the "PXR Series" which is characterized by its high-quality and reasonable price, has gained a good reputation with a total of more than 3 million units being sold worldwide. Currently, we are developing the "PXF Series" next-generation global standard temperature controller to be more compact and enhanced with greater functionality and performance. We are planning to commence sales during FY2014. The main features are as follows:

(1) Excellent visibility via a bright and wide-viewing-angle color LCD
(2) High-speed sampling with 50 ms, universal input and high-precision PV input of ±0.3%
(3) Ultra short depth of 58 mm
(4) Equipped with simple power measurement functions (standard) to improve energy efficiency and a 100 A current monitor function (optional)

Fig.26 "PXF Series"

12 Residential Fire (Smoke Type), Gas and CO Alarm "KN-95"

Fuji Electric started marketing in July 2014 a residential fire (smoke type), gas and CO alarm certified by the Minister for Internal Affairs and Communications, based on the revision to the Fire Service Act and compliant to the new inspection regulations of the Japan Fire Equipment Inspection Institute. The main features are as follows:

(1) The product has a slim design of 41 mm thickness.
(2) Low power consumption of 0.5 W while monitoring.
(3) The sweep sound makes an alarm call easy to recognize even by seniors.
(4) The wide display of the fire alarm helps increase the discrimination from the gas alarm and increase the visibility of the fire alarm.
(5) The automatic initialization check function makes it unnecessary to do a gas check when installing the alarm unit.
(6) The unit reduces false alarms via new logic alarm determination and a fine mesh structure.

Fig.27 "KN-95"

Instrumentation and Control Systems

13 Enhancement of Vibration Sensor

Fuji Electric applied its MEMS technology in FY2012 to develop and commence sales of a vibration sensor that can measure acceleration with high sensitivity. The vibration sensor was developed to support the health diagnostics of structures and this has positioned its use in diverse number of fields since its launch on the market.

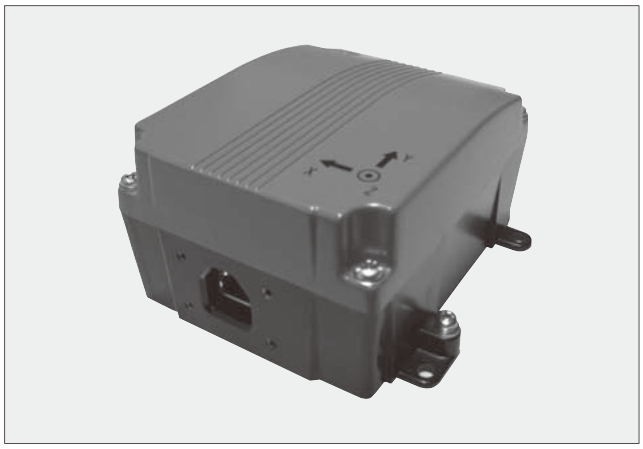
We have currently enhanced the measurement range to expand its applicability. It can be expected that these enhancements will contribute to more safety and security in society. We have aimed to contribute to a broader range of social infrastructure, which includes bridges and roads in addition to the conventional application focused on buildings. The main features are as follows:

(1) Acceleration measurement range: ±2.0 G (Conventional products: ±1.5 G)
(2) Resolution: X-Y axis 0.02 Gal*, Z axis 0.07 Gal
(3) Frequency range: 0.1 to 50 Hz

* Gal: Unit of acceleration where 1 Gal = 0.01 m/s^2

Reference: FUJI ELECTRIC REVIEW 2014, vol. 60, no. 1, p. 54

Fig.28 Vibration sensor



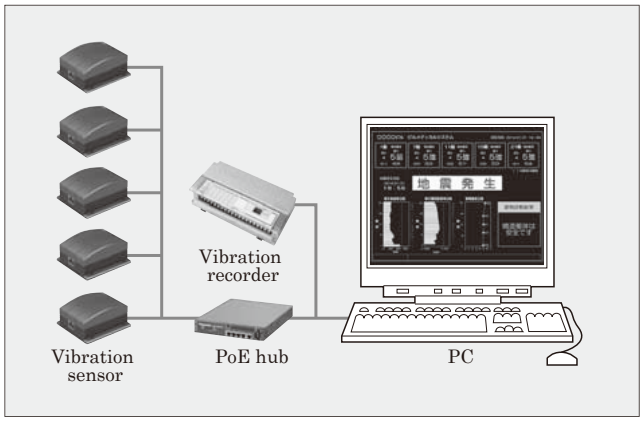
14 Health Monitoring System for Building Structures

By using a vibration sensor that applies MEMS, Fuji Electric has commercialized, through joint development with Toda Corporation, a monitoring system for diagnosing the structural performance of buildings. By using a vibration sensor that applies MEMS instead of a servo accelerometer, it has been possible to construct a low cost system. Based on the acceleration response measured during an earthquake by multiple vibration sensors installed in a building, it makes possible to carry out primary diagnosis shortly after the earthquake to determine if the building is healthy or not. This system enables building users and administrators to make an initial response based on actual measurement data. The main functions are as follows:

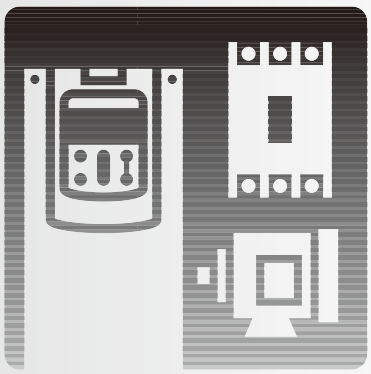
(1) It displays information such as building seismic intensity on sensor installed floors, maximum acceleration distribution of all floors and estimation results of maximum interstories deformation angle distribution, as well as primary diagnostic results.
(2) It supports linkage with a broadcast system to perform broadcasting to entire building.

Reference: FUJI ELECTRIC REVIEW 2014, vol. 60, no. 1, p. 54

Fig.29 Example of the configuration of structural health monitoring system



Power Electronics Equipment



Drives
Power Supply
Transportation Power Electronics
Electric Distribution and Control Devices

Outlook

The Great East Japan Earthquake raised people's awareness about the importance of electricity and focused attention on smart utilization of clean electrical energy. Fuji Electric set "creation," "connection" and "usage" of energy as keywords and has been developing power electronics technologies that become foundations to generate, supply and utilize (apply) electrical energy, and providing various products. We are expanding our range of products corresponding to globalization by developing technologies that are compliant with international standards in areas including functional safety. Moreover, we are focusing on the development of application technologies and products that use silicon carbide (SiC), a material that is expected to be used in next-generation power semiconductor devices.

In the field of power drive system, equipment that can directly drive high-voltage motors without using a transformer even though the voltage is different between input and output, was added to the lineup of the "FRENIC4600FM5" high-voltage inverters and put into production. The stack-type 690 V series was added to the lineup of the "FRENIC-VG Series" fast-response and high-accuracy inverters to provide large capacity up to 800 kW with a direct parallel connection. For plant facility and processing machinery, we have developed and launched "FRENIC-Ace Series" general-purpose inverters, which have the customizable logic function so that users can program the inverter control to suit their intended use. We have also expanded the voltage lineup of the "FRENIC-HVAC Series" inverters for HVAC with a DC reactor and an EMC filter built-in. IP55 protective structure employs the same size as IP21 and it does not require any cubicle board. "ALPHA5" servo amplifiers are compatible with an "E-SX bus," a synchronous bus distinctive to Fuji Electric. These can be combined with "MICREX-SX" to achieve high-speed, high-accuracy motion systems.

In the field of power supply system, we have been manufacturing and providing uninterruptible power supplies (UPS) which are required to be highly reliable and efficient as backup power supplies for data centers. In addition to these, we have developed "7000HX-T4" high-efficiency, high-capacity UPS, which applies on-line double conversion system and is compatible with 3-phase, 4-wire type of 400 V power supply systems that are the mainstream overseas. They adopt the new three-level power conversion system with reverse-blocking insulated gate bipolar transistor (RB-IGBT) that is distinctive to Fuji Electric. As a front-end power supply for servers, we have developed a switching power supply that achieves both platinum-level conversion efficiency and the best-in-industry power density. We have also developed the "UX Series" as small-capacity, standby power system UPS for industrial equipment and PCs by expanding the OS shutdown system for PCs and enhancing the high-speed switching to battery operation.

In the field of power electronics equipment for transportation, we have manufactured and delivered power supply equipment for the coaches of the Cruise Train Seven Stars in Kyushu that has been in the spotlight since Kyushu Railway Company started its operation in October 2013. We have also manufactured and delivered linear motor driven doors series E233 trains, which are operated by East Japan Railway Company on the Saikyo Line and Yokohama Line. Furthermore, we have manufactured a door system that uses a combination of a flat-shape rotating type permanent magnet synchronous motor with a rack and pinion mechanism instead of a linear motor, and delivered it to Yurikamome Inc. for its new model trains. In the automotive field, we have continued to manufacture and delivered off-board battery chargers for electric vehicles and plug-in hybrid electric vehicles. At the same time, we have succeeded in creating the smallest on-board charger in the industry to directly charge batteries using an AC source with a power density of 1 W/cm^3.

In the field of power receiving and distribution equipment and control device components, the expectations for technologies that can more safely and efficiently supply electrical energy and commercial products that are compatible with new energy are becoming higher. Along with this, it is becoming more important to construct power receiving and distribution facilities

and control systems that provide space-savings and high reliability for production equipment, office buildings and commercial facilities. In response, we combined the power receiving and distribution equipment with a current-limiting fuse and changed the high-voltage AC load switch model that is mainly used as a PF-type or an S-type main circuit breaker for 300 kVA or less, resulting in reduction of the volume by 10%. For photovoltaic power generation systems, we have developed the string monitoring unit "F-MPC PV" that measures the current and voltage in each photovoltaic panel string unit (consisting of multiple panels) and works with the higher level system to help early detection of an abnormality in any photovoltaic panel and identification of a faulty section. We have also developed an emergency stop pushbutton switch that is equipped with a synchro-safe contact for use with control devices. We have enhanced the safety by providing the mechanism that opens the main circuit when the contact block is detached from the operation button.

Fuji Electric will continue to reinforce technologies and product lineups to provide various solutions and pursue customer satisfaction in the power electronics equipment business.

Drives

1 Expansion of "FRENIC-HVAC Series" Inverters for Air Conditioning (200 V and 575 V)

"FRENIC-HVAC Series," which is suitable for Air Conditioning, now has the 200 V series [90 kW (125 HP) max] for a better voltage lineup. The main targets are Japan and North America. Moreover, Fuji Electric has a plan to put 575 V series (300 HP max) into production. The main features are as follows:

(1) IP21 and IP55 have become to be provided in the same size. Thanks to the IP55 structure with a built-in EMC filter, it no longer has to be stored in a control panel and can help reduce equipment investment and cut down on the installation space required.
(2) It has BACnet communication protocol installed as standard (BTL certified).
(3) It has multiple functions such as a real-time clock and 4 PID (with an autotuning function).

Fig.1 "FRENIC-HVAC Series" (200 V and 575 V)

2 Capacity Expansion of Compact Inverter "FRENIC-Mini (C2S) Series"

For the "FRENIC-Mini (C2S) Series" of compact inverters, Fuji Electric has developed 5.5 to 15 kW products for 3-phase 200 V and 400 V input series and expanded the lineup. The main features are as follows:

(1) Because these have the same functions as the already launched models rated 3.7 kW or less, the peripheral sequencers can be carried over and will be able to meet the needs for higher capacity of various applications.
(2) These are certified by the UL standards and CE marking and can be distributed all over the world in places such as Asia, China, North America and Europe.

Fig.2 "FRENIC-Mini (C2S) Series"

3 "E-SX Bus" Compatible Servo Amplifier "ALPHA5"

A high-speed serial bus servo amplifier that is compatible with "E-SX bus," a high-speed, high-accuracy synchronous bus distinctive to Fuji Electric, was added to the "ALPHA5 Series" servo systems. It can realize high-speed and high-accuracy control when combined with the "SPH3000MM" controller. The main features are as follows:

(1) The minimum tact cycle is 0.25 ms. If the tact cycle is 1 ms, it can perform synchronous control of up to 32 axes.
(2) ALPHA5 Series has a standard type (VE type) and a built-in positioning function type (LE type) for all capacities of the 200 V product lineup (0.05 to 5 kW).
(3) Application software can be diverted by sharing the IQ area (memory map of the transmission data) with the existing "SX bus."

Fig.3 "ALPHA5"

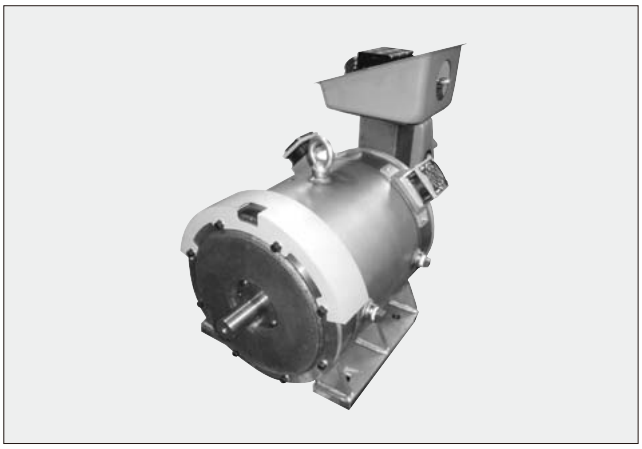
Drives

4 High-Speed Motor for Automotive Testers "GNQ1165A"

Fuji Electric has developed the "GNQ1165A" high-speed motor for automotive testers to test motors that are going to be mounted on hybrid electric vehicles or electric vehicles. The main features are as follows:

(1) The maximum rotational speed is 20,000 r/min, the rated torque is 100 N•m and the rated output is 42 kW.
(2) To reduce the moment of inertia, it uses a permanent magnet synchronous motor (PM motor) to realize a low cogging torque with its unique rotor shape. The tester can measure torque with high accuracy.
(3) It applies a grease-sealed bearing for better maintenance. We will expand the capacities up to 400 N•m and 170 kW in the future.

Fig.4 "GNQ1165A"



5 Medium-Voltage Inverter that is Compatible with Different Input/Output Voltages

The medium-voltage inverter can directly drive medium-voltage motors at variable speeds and is increasingly used in more applications to fans and pumps for attaining energy saving operation. Fuji Electric has put into production a new medium-voltage inverter that is compatible with different input/output voltages where the output voltage differs from the input voltage. The main features are as follows:

(1) Voltage series, capacity series
  (a) Input 11 kV, output 3.3 kV, 390 to 3,500 kVA
  (b) Input 11 kV, output 6.6 kV, 780 to 5,200 kVA
(2) It can directly drive medium-voltage motors at variable speeds.
(3) Input transformer is installed in the panel.
  It is unnecessary to implement wiring for the transformer and converter in the field.
(4) Equipment efficiency: Approx. 97%
(5) Power factor: 0.95 or higher

Fig.5 Medium-voltage inverter that is compatible with different input/output voltages

Power Supply

1 Small-Capacity Offline UPS "UX Series"

Highly efficient and inexpensive offline UPS is used as a backup power supply for industrial equipment and PCs.

Fuji Electric has developed the "UX Series" as a small-capacity UPS for continuous commercial power feeding UPS. Functions were added to maintain stable power feeding and reduce the output voltage fluctuations for connected equipment. It has an improved OS shutdown system for PCs and enables to select mode for high-speed switching to battery operation in case there is a problem with a commercial power source. The main features are as follows:

(1) The OS shutdown system is established by using a USB (HID) to reduce customers' verification load.
(2) The commercial power failure detection sensitivity is enhanced for faster switching and it can continue to feed the power stably by reducing the output voltage fluctuations.
(3) It sends out sine waves during backup operation.

Fig.6 "UX Series"

Power Supply

2 High-Efficiency Front-End Power Supply "FH02650UAD" for Servers

The data center market continues to grow and there is an urgent need to reduce the energy consumption of information and communication equipment. Thus, Fuji Electric has introduced "FH02650UAD" high-efficiency front-end power supply for servers to the market. It achieved high efficiency ranked as "Platinum" (e.g., at least 94% with a 50% load factor) according to the conversion efficiency standards, 80PLUS, and a top-class high-power density (1.7 W/cm^3) in the industry. It contributes to downsizing and power consumption reduction of information and communication equipment. The main specifications are as follows:

(1) Input voltage: 200 to 240 V, Output voltage: 12 V
(2) Output power: 2,640 W
(3) Dimensions: W100×D400×H41 (mm)

Fig.7 "FH02650UAD"

3 Low-Voltage, Large-Capacity Momentary Voltage-Drop Protector "UPS8000D-3/500S"

Momentary voltage drops can cause enormous damage to the production lines of high-value-added products at plants. The occurrences of momentary voltage drops are expected to increase in the future because distributed power sources are becoming popular.

Up to now, high-voltage products (6,600 V series) have been used for large-capacity, momentary voltage-drop protectors. This time, Fuji Electric has developed "UPS8000D-3/500S" as a 200 V series of low-voltage, large-capacity momentary line-drop protectors (output power 500 kVA/450 kW). The main features are as follows:

(1) An electric double-layer capacitor (EDLC) is adopted to help reduce the running cost and environmental impact.
(2) Larger-capacity systems can be established through a parallel run.
(3) It helps to reduce size and weight (35% less than conventional ones).

Fig.8 "UPS8000D-3/500S"

Transportation Power Electronics

1 Rack and Pinion Door System for 7300 Series Trains Owned by Yurikamome Inc.

Fuji Electric has delivered a rack and pinion door system for the Yurikamome 7300 series trains, which were introduced as the new model starting the operation on January 18, 2014. The new trains form 18 train sets consisting of 108 cars with 432 door system equipment. The main features of the rack and pinion door system are as follows:

(1) The mechanism of the linear door system is adopted to succeed in its high reliability and safety design.
(2) The power consumption is reduced by 52% with the modification of the motor characteristics.
(3) The weight of the equipment is reduced by 23% majorly by applying the rotary motor, of which the usage volume of the permanent magnet is decreased.
(4) The door control for safety performance is enhanced to achieve higher accuracy in obstacle detection.

Fig.9 Yurikamome 7300 series vehicle and door system

Transportation Power Electronics

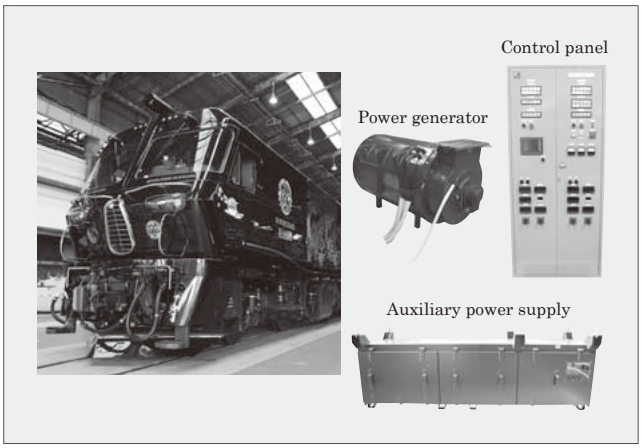
2 Power Supply Equipment for Cruise Train of Kyushu Railway Company

Kyushu Railway Company manufactured a cruise train with sleepers called “Seven Stars in Kyushu” that travels around famous sightseeing destinations in Kyushu, and started commercial operation in October 2013.

By utilizing the experience gained from delivering electric power supply for diesel-powered railcars, Fuji Electric manufactured a power supply unit consisting of power generator and auxiliary power supply. This is a key device that provides power to the coaches that are extremely luxurious and newsworthy. The main features are as follows:

(1) It has two power generators and even if one of them fails, the other will back it up instantly. This power supply equipment has redundancy and is highly reliable.
(2) The control panel installed on the floor can monitor and control the power supply system including the engine.

Fig.10 Cruise train and power supply unit



3 Linear Door System for E233 Series Vehicles for Saikyo Line and Yokohama Line of East Japan Railway Company

Fuji Electric delivered linear door systems to East Japan Railway Company for E233 series vehicles that run on the Saikyo Line (2,000 units, all the train sets started operation in October 2013) and Yokohama Line (1,792 units, operation started in February 2014). The main features are as follows:

(1) It adopted a stand-by redundancy system by employing a complete duplication including the control power supply. More than 20,000 units have been delivered and the failure occurrence rate has become less than one-tenth of the customer requirement specifications.
(2) With the direct drive method using linear motors and the latest power electronics control technologies, it attained high levels of control safety and intrinsic safety.
(3) Based on data obtained from long-term operation, it was redesigned to reinforce the sliding area for improving reliability further.

Fig.11 E233 series vehicles for Saikyo Line and Yokohama Line and linear door system

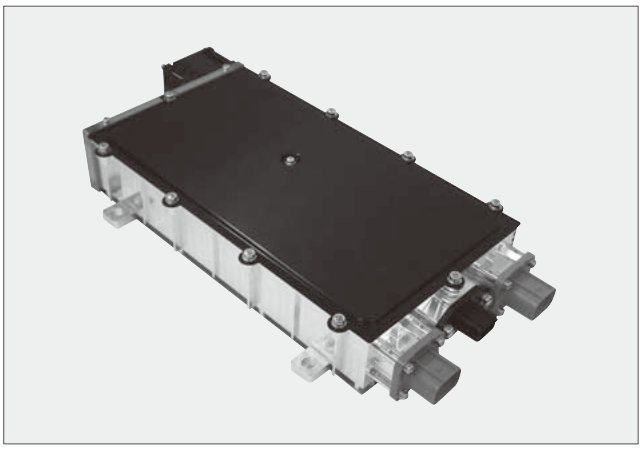
4 On-Board Charger (OBC) for Environmentally-Friendly Vehicles

Approach to environmentally-friendly vehicles has been accelerated around the world. In recent years, new plug-in hybrid electric vehicles that can be easily charged by using a household AC outlet have appeared.

These plug-in hybrid electric vehicles and electric vehicles need an AC to DC power converter on board. To satisfy this need, Fuji Electric has developed an OBC by applying our compact high-efficiency power supply technology and automotive semiconductor technology. The main features are as follows:

(1) Isolated 3.3 kW-output with air-forced cooling
(2) High power density of 1 W/cm^3
(3) Compatible with various domestic and international power sources situation (100 to 240 V AC)

Fig.12 On-board charger (developed product)



Electric Distribution and Control Devices

1 Expansion of Magnetic Contactor "FJ Series" (40 to 95 A)

Magnetic contactors used in developing countries such as China and other Asian countries have different requirements with regards to safety, quality, switching durability and compliance with international standards, depending on the users.

In addition to the standard type, Fuji Electric is providing the "FJ Series" in the lineup. They are small, economical and exclusive products for overseas applications. We have acquired a good reputation so far because we have added product choices to suit the market needs depending on the intended purposes. We developed a product rated 40 to 95 A this time to expand the lineup of economical specifications. The main features are as follows:

(1) The main unit is equipped with a 1NO1NC (1a1b) auxiliary contact required for a simple control circuit as standard.
(2) It is compliant with China Energy Efficiency Standard Class 2.

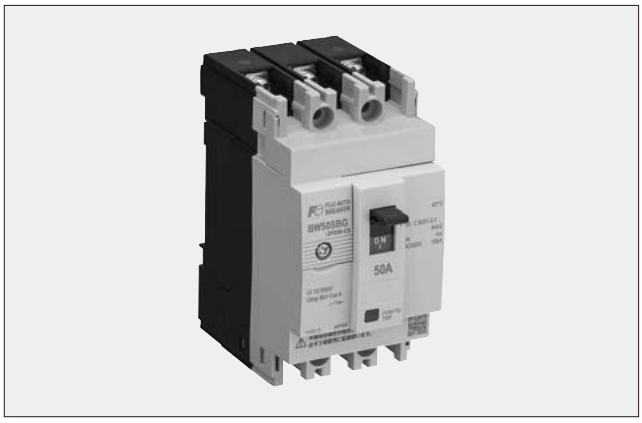
Fig.13 "FJ-B95" rated for 95 A

2 Expansion of Small Low-Voltage Circuit Breakers in "G-TWIN Λ Series"

As direct current equipment becomes popular, there is a greater need for small high-voltage circuit breakers. To meet such market needs, Fuji Electric has developed a neutral circuit breaker for high-voltage direct current (500 V DC, 3 poles) to expand the lineup of the "GTWIN Λ Series." The main features are as follows:

(1) It adopted arc commutation breaking method and acquired a high breaking performance (500 V DC, 10 kA).
(2) The neutral specification allows it to be applied to circuits that change in polarity such as EV charging circuits or battery systems.
(3) The outline dimensions were reduced (54 mm in width) and the mounting space became 30 % less than conventional ones.
(4) Rated current: 10 to 63 A

Fig.14 Circuit breaker for high-voltage direct current (500 V DC, 3 poles)

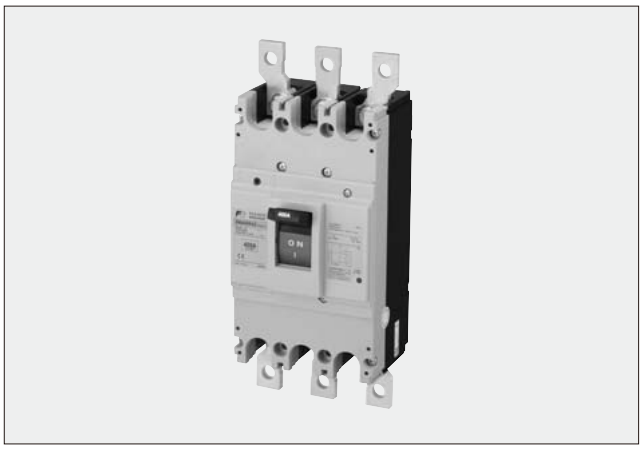


3 Molded Case Neutral Circuit Breaker for High-Voltage Direct Current (400 to 800 AF)

Demand for direct current equipment used in the new energy market, such as photovoltaic power generation, is expected to expand both in Japan and overseas, and there is a need for safety improvement. Fuji Electric has developed this molded case neutral circuit breaker for a high-voltage direct current for industrial photovoltaic power generation equipment. This product will help improve the safety of photovoltaic power generation systems. The main features are as follows:

(1) It maintains compatibility with the conventional products because the rated operational voltage, breaking capacity and outline dimensions are kept in the same, and it actualizes neutral performance. It can be connected in reverse and thus can break a reverse flow current.
(2) Compared with conventional products, the rated insulation voltage was increased from 750 V DC to 800 V DC for the 3-pole product, and from 1,000 V DC to 1,150 V DC for the 4-pole product and also provided better safety.

Fig.15 "BW400RAG-3P400 CP"



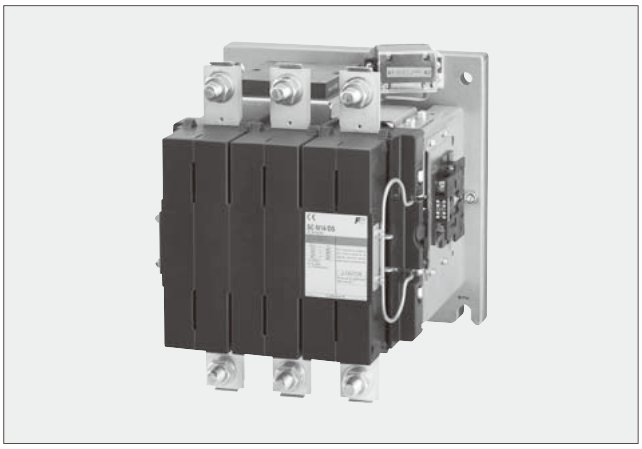
Electric Distribution and Control Devices

4 Magnetic Contactors for Photovoltaic Power Generation Equipment “SC-N14/DS” and “SC-N16/DS”

A magnetic contactor is placed on the alternate current side of the power conditioner (PCS) for photovoltaic power generation equipment and is used to isolate the equipment from the power system during maintenance or in case of equipment failure. Therefore, it needs to be compatible with various installation environments of photovoltaic power generation equipment. Fuji Electric has developed “SC-N14/DS” and “SC-N16/DS” magnetic contactors rated at 660 A and 800 A for photovoltaic power generation equipment to meet the particular growing demand for PCS in mega solar stations. The main features are as follows:

(1) The contact structure with improved performance during current carrying time reduced the calorific loss by approximately 7%.
(2) To be compatible with various use environments, the operational ambient temperature range was expanded. (Conventional product: −5°C to +55°C, developed product: −10°C to +60°C)
(3) By improving the control circuit, the standing loss was decreased by approximately 10%.

Fig.16 “SC-N14/DS” rated for 660 A



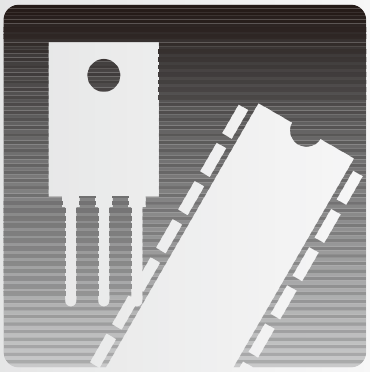
5 Lineup Expansion of Small Contactor “SK Series” (Types SK18 and SK22)

Since the launch of the “SK Series” types SK06 to SK12, the world's smallest contactors (magnetic contactors), they have been well-received because they are best suited for downsizing and globalizing of mechanical equipment and control panels. This time, Fuji Electric has developed types SK18 and SK22 of small contactors as upper frames to expand the lineup of the series. In recent years, servo systems have become more widely utilized for motor control and the magnetic contactors are often placed on the primary side of the servo amplifiers. Thus, types SK18 and SK22 models were particularly developed for these applications. The main features are as follows:

(1) The width was unified to 45 mm (15% less than conventional products).
(2) It achieved 2.4 W as a DC-operated type (66% less than conventional products).
(3) It can accept the inrush current caused by the servo amplifier.

Fig.17 “SK22A”

Electronic Devices



Power Semiconductors
Photoconductors
Disk Media

Outlook

Power Semiconductors

In order to achieve a safe, secure and sustainable society, there are extremely high public expectations and needs for the widespread use of renewable energy and for power electronics technologies to use such energy efficiently. As these needs increase, Fuji Electric is working on the development of power semiconductor products that provide high energy conversion efficiency, reduce noises and are friendly to the global environment. These products have been applied in various fields to contribute to the world, including the environment/energy, industrial machinery, automobiles and home appliances fields.

For the environment/energy field, we expanded a line-up of reverse-blocking insulated gate bipolar transistors (RB-IGBTs) that can be used in 3-level power conversion circuits. In addition to the conventional series of 600 V and 1,200 V types, we have developed a chip that can withstand a voltage of 900 V. This will expand the range of applications for module and discrete products, and enable us to offer best-suited products that satisfy the conditions of customer applications. We also have developed 2-in-1 products of 1,200 V/1,400 A and 1,700 V/1,400 A by forming a layer of phase-change type thermal interface material (TIM) on the back of IGBT module products. A material offering high thermal conductivity and reliability was selected for the TIM and the printing pattern of the formed TIM was designed to allow TIM to extend and spread uniformly and thinly in an optimum pattern when the module is mounted on customer's equipment. This ensures the IGBT module has the maximum heat dissipation performance.

For the industrial machinery field, we have developed a 1,700 V withstand voltage SiC hybrid product for high voltage inverters (1,700 V/400 A 2-in-1). It improves inverter outputs by 30% compared with the conventional products and thus contributes to a reduction of system costs. We have also developed a small-capacity intelligent power module (IPM) for industrial use to be used for small-capacity servo systems and inverters. We applied the latest 6th-generation "V-Series" IGBT and adopted a low-power-loss small package. Furthermore, product series of 600 V/100, 150, 200 A and 1,200 V/50, 75, 100 A have been developed through the application of high-heat dissipating packaging technologies to the IPM, to which the latest 6th-generation IGBT technology has also been applied. The adoption of high-heat dissipation direct copper bonding (DCB) to the conventional package has improved the power density by 30%.

For the automobile field, we have developed a 4th-generation intelligent power switch (IPS) that can help improve the fuel consumption and comfort of vehicles by enabling accurate detection of electric current.

For the power supply field, a 2nd-generation LLC current resonant control IC has been developed. This product contributes to efficiency improvement, noise reduction and profile lowering of power supplies for equipment such as LCDs, reduces standby power and improves protective functions compared with the 1st-generation products. In addition, we have developed the "Super J-MOS FRED Series" that has greatly improved the reverse-recovery parasitic diodes loss, which contributes to improve efficiency of server power supplies for which demand has been growing in recent years.

Photoconductors

The total demand for photoconductors is predicted to have tendency to decrease slightly and some manufacturers of photoconductors and photoconductor materials have decided to withdraw from the business. The business environment is growing increasingly difficult. On the other hand, photoconductors are expected to offer higher performance that enables response to the trend for providing higher speed and longer life on the equipment side.

Fuji Electric developed photoconductors that had improved the sensitivity and durability by 30% compared with the conventional products and started mass producing them to meet the demands of equipment manufacturers, in FY2013. We will further improve performance by developing new materials through uti-

lizing simulations.

Disk Media

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

In FY2013, Fuji Electric developed more advanced characteristics products of a 3.5-inch aluminum substrate medium and a 2.5-inch glass substrate medium offering a storage capacity of 1 TB and 500 GB per disk respectively, and started mass producing them. They will contribute to the improvement of customers' manufacturing yield by enhancing the media performance due to the optimization of material compositions and the manufacturing process. We will push forward with the development of large-capacity media to contribute to the advancement of the IT society.

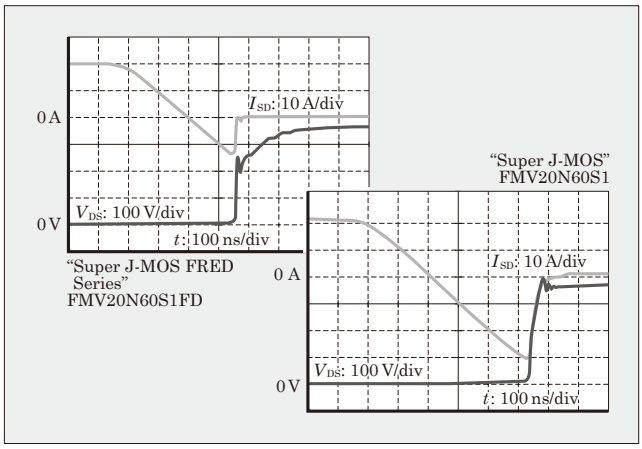
Power Semiconductors

1 "Super J-MOS FRED Series"

The resonant circuit and inverter circuit for uninterruptible power supplies (UPSs), servers, communication power supplies and power conditioners (PCSs) require metal-oxide semiconductor field-effect transistor (MOSFET) that has a built-in diode providing low-reverse recovery loss and high-reverse recovery withstand capability. Fuji Electric has developed the "Super J-MOS FRED Series" to meet such a requirement. While the low on-resistance and low switching loss properties of the conventional Super J-MOS are kept the same, the built-in diode has been improved to provide less reverse-recovery loss and significantly higher reverse-recovery withstand capability. The main features are as follows:

(1) Reverse-recovery time T_{rr}: Reduced by approx. 60% (compared with conventional products)
(2) Reverse-recovery charge quantity Q_{rr}: Reduced by approx. 80% (compared with conventional products.)
(3) Withstand voltage: 600 V
(4) On-resistance (max.): 42, 74, 132, 200 mΩ

Fig.1 Reverse-recovery waveform examples



2 Small IPM for Industrial Use

In recent years, the need for system energy saving has been growing and the demand for general inverters and servo systems is expanding in the industrial field.

For small-capacity industrial applications, Fuji Electric has started mass producing small intelligent power modules (IPMs) of the 600 V/15, 20, 30 A that have a built-in a 3-phase inverter bridge circuit and control ICs.

This product has achieved energy savings with optimized low loss dissipation devices and also has enabled system downsizing and usability improvement by applying ultra-compact package adopting a high thermal conductivity aluminum insulated substrate and by incorporating various protection functions.

Moreover, it satisfies the demand for safety by applying UL-certified (UL1557).

Fig.2 Small IPM for industrial use

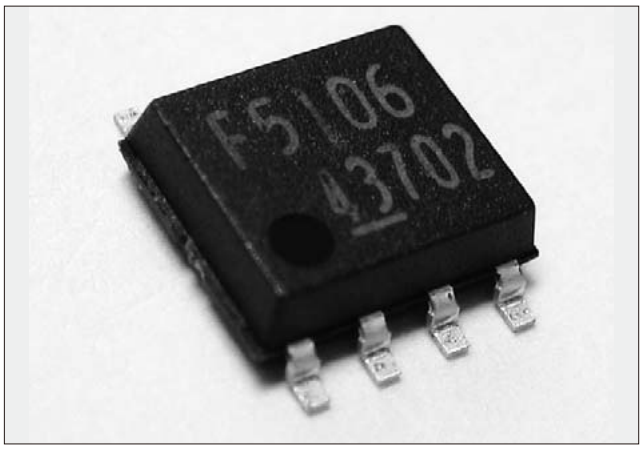
3 One-Chip Linear Control IPS "F5106H"

In the field of vehicle electrical components, the demands for smaller system size, higher reliability and higher functionality are increasing. To meet these demands, Fuji Electric has developed a one-chip linear control intelligent power switch (IPS) "F5106H" that is equipped with a high-precision current detection amplifier in the conventional IPS.

The output stage power metal-oxide semiconductor field-effect transistor (MOSFET) has been changed from the planar gate type to the trench gate type, and the 4th-generation IPS device/process technology using smaller control/protection circuits and multi metal layer technology has been applied. This allows one-chip design and mounting onto the SOP-8 package. In addition, the maximum rating of the junction temperature was set to 175 °C to improve the durability in harsh temperature environments while low power-voltage operation is possible down to 4.5 V.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 251

Fig.3 "F5106H"



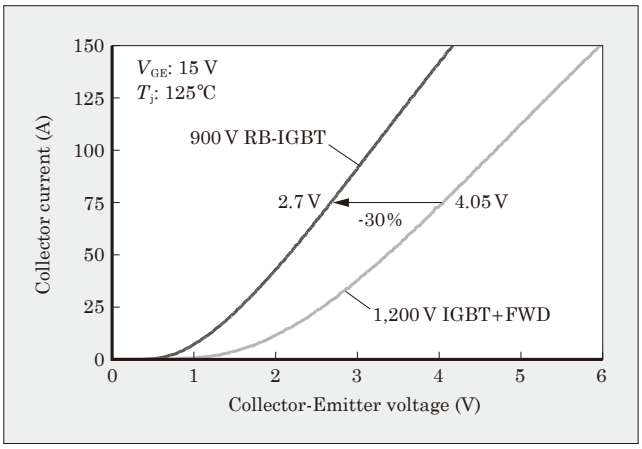
4 900 V Reverse-Blocking IGBT (RB-IGBT)

The demand for reverse-blocking insulated gate bipolar transistors (RB-IGBTs) has been increasing in recent years, including the use as a neutral clamp device of a 3-level power conversion circuit. Fuji Electric has been working on the development of RB-IGBTs that lead to higher efficiency of power converters.

RB-IGBTs of 600 V class are hard to apply to large scale 1,000 V DC (maximum) solar converters, because the larger stray inductance inside/outside IGBT module results critical spike voltage. On the contrary, 1,200 V RB-IGBTs have higher switching loss. To solve these issues, we have developed a 900 V class RB-IGBT.

By reducing the number of devices, we have achieved a 30% reduction of the on-state voltage drop compared with that of 1,200 V IGBT+FWD alternative solution.

Fig.4 Comparison of IV characteristics

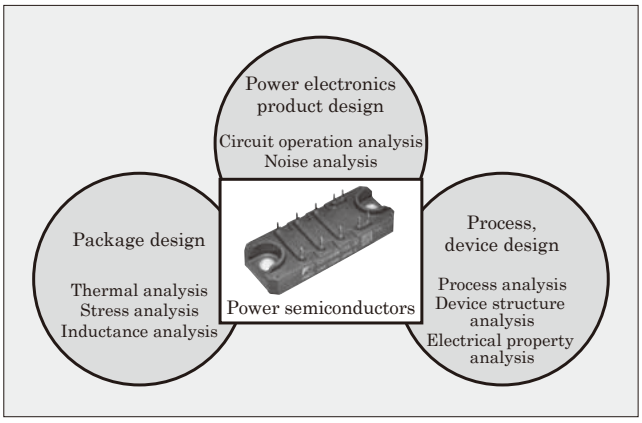


5 Power Semiconductor Simulation Technologies

Fuji Electric is developing simulation technologies for designing devices and packages, and for designing power electronics products equipped with power semiconductors. The combinations of the following simulation technologies are the backbone of the functionality enhancement and quality improvement of Fuji Electric products:

(1) Process, device design: Optimized design of the performance and quality of devices based on analysis of the process and device structure
(2) Package design: Optimization of the structure based on thermal, stress and inductance analyses
(3) Power electronics product design: High-accuracy circuit operation analysis based on precise modeling of the electrical properties of devices or the LCR components of packages; and noise reduction through noise analysis

Fig.5 Simulation technologies used in the development of power semiconductors

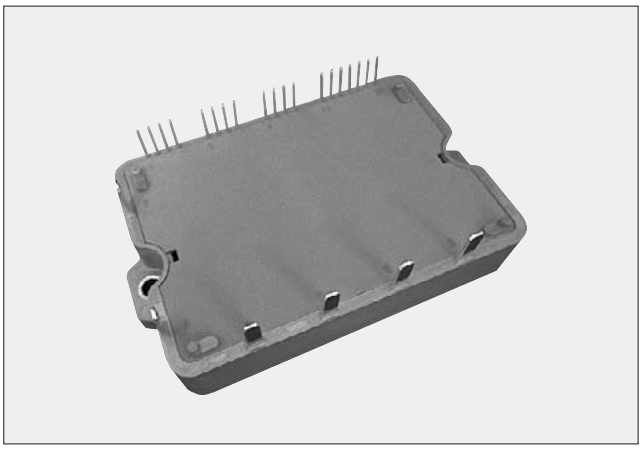


6 Medium-Capacity Small Package of "V-Series" IPM

In recent years, there has been increasing demand for further downsizing and expansion of the rated current value range of the intelligent power modules (IPMs) used in servo control or other equipment. Fuji Electric has now completed the series of "P636 Packages" targeted for servo control equipment; they cover the capacity range of 600 V/100 A and 1,200 V/50 A, incorporate brake circuits and have achieved a footprint size 26% smaller than the conventional products. The main features are as follows:

(1) Outline dimensions: W90×D55×H18.5 (mm)
(2) Rating: 600 V/50, 75, 100 A; 1,200 V/25, 35, 50 A
(3) Circuit configuration: 7-in-1 and 6-in-1 series
(4) Thermal resistance: 20% reduction (compared with conventional products)
(5) Performance/functionality: The 6th generation insulated gate bipolar transistor (IGBT) mounted, built-in IGBT gate drive circuit and protection circuit, alarm identification function, dead time reduction

Fig.6 "P636 Package"



Power Semiconductors

7 1,700 V Withstand Voltage SiC Hybrid Module

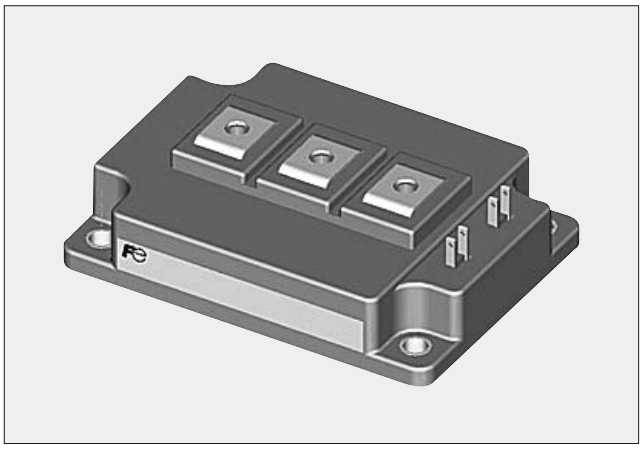
In place of Si devices, SiC devices having heat resistance and high breakdown electric field tolerance are raising expectations to be new devices that achieve efficiency improvement and downsizing of equipment. Fuji Electric is promoting the development of 1,700 V withstand voltage SiC hybrid module intended for high efficiency inverters (690 V series) that contribute to energy conservation.

To Free Wheeling Diode (FWD), we applied the SiC-Schottky barrier diode (SiC-SBD) chip which had been developed jointly with the National Institute of Advanced Industrial Science And Technology and which are set to be mass produced by Fuji Electric. To insulated gate bipolar transistor (IGBT), Fuji Electric's latest product, the 6th-generation "V-Series" IGBT chip has been applied.

By improving leakage current and switching properties, we confirmed that the chip can reduce generated loss in the 300 A product module by approximately 26% compared with the conventional Si modules.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 218

Fig.7 1,700 V withstand voltage SiC hybrid module



8 IGBT Module with Pre-Applied TIM

When an insulated gate bipolar transistor (IGBT) module is mounted, thermal grease is applied between the cooling fin and the IGBT module to encourage quick transfer of the heat generated from the IGBT module. An increasing number of customers request IGBT suppliers to do this thermal grease application.

To meet this requirement, Fuji Electric has developed a family of IGBT modules with pre-applied thermal interface material (TIM) of phase change type. The adopted TIM features heat dissipation performance that is over three times as good as that of the conventional thermal greases. Its transportability is great because it maintains a solid state under a temperature of around 45 °C, though it liquefies above that temperature. This resulted in developing an IGBT module with improved heat dissipation properties and reliability.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 241

Fig.8 IGBT module with pre-applied TIM (rear view)

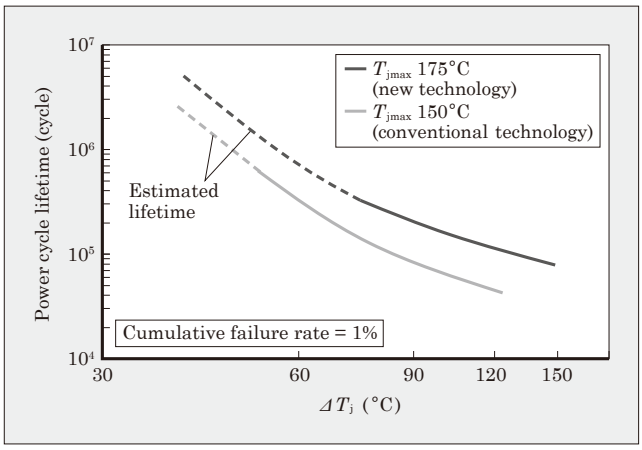
9 New Assembly Technologies for T_{jmax} 175°C Continuous Operation Guaranty of IGBT Module

In order to achieve further downsizing and higher power density of insulated gate bipolar transistor (IGBT) modules, it is required to raise the upper limit of the device temperature T_{jmax} during continuous operation from the current limit of 150 °C to 175 °C.

To guarantee the continuous operation of IGBT modules at 175 °C, Fuji Electric has developed three new bonding technologies: High thermal-resistance aluminum wire; high-strength solder at high temperature; and a structure with Ni layer formed on the chip surface electrode. These packaging technologies have increased power density and achieved doubled power cycle lifetime at all temperature regions compared with the conventional products.

These technologies can be applied to the current manufacturing processes. Hence, conventional facilities can be used to mass producing products that guarantee continuous operation at 175 °C without modification.

Fig. 9 Power cycle test results (T_{jmax} = 175 °C)



Power Semiconductors

10 Packaging Technology of IPMs for Hybrid Electric Vehicles

The popularization of hybrid electric vehicles (HEVs) and electric vehicles (EVs) is accelerating in order to comply with environmental regulations. Fuji Electric started mass producing new intelligent power module (IPM) for HEVs.

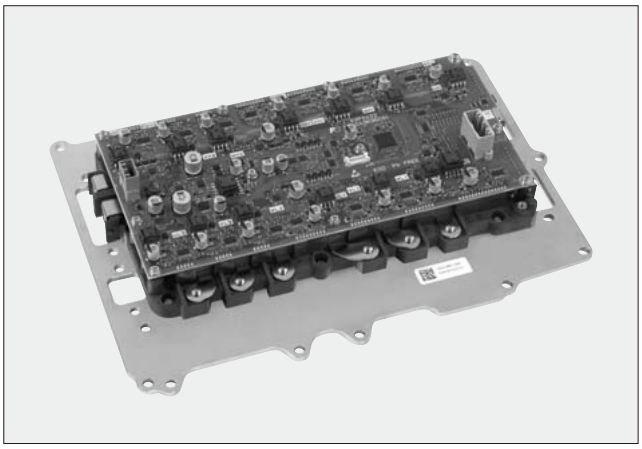
This product integrates two inverter units controlling two motors and a buck-boost converter unit. It adopts an aluminum direct water-cooling structure for a compact design, light weight and high output power density. Two new technologies have been developed:

(1) High cooling design based on this direct water cooling structure

(2) High-strength solder material that makes it possible to joint between aluminum heat sink and a ceramic insulating substrate, having large mismatch in coefficients of thermal expansion.

This product is an all-in-one package integrating the inverter/converter circuits and a controller, resulting in a 30% reduction in volume ratio and 60% reduction in mass ratio compared with the conventional indirect water cooling type.

Fig.10 IPM for hybrid electric vehicles



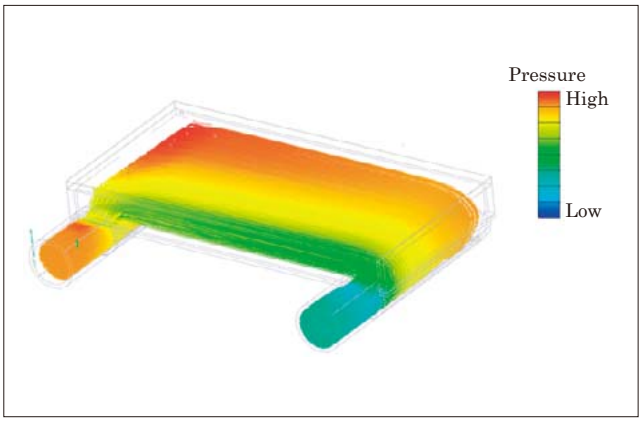
11 Thermal Fluid Simulation Technology

Power semiconductors are used for controlling the motor of hybrid electric vehicles (HEVs) and electric vehicles (EVs). For the purpose of downsizing and lightweight, applications of a liquid-cooling system has been progressing for power semiconductors mounted on HEVs and EVs.

Fuji Electric has established technology for designing the direct-liquid cooling system of power semiconductors. It can determine the coolant flow using thermal fluid analysis and analyze the cooling properties of the coolant in a consistent way.

We have used these technologies for equalizing the coolant flow speed and attempting to design a cooler that has no coolant stagnation points that may cause corrosion by conducting thermal fluid simulation analysis. Furthermore, by offering a total design for cooling systems that are different among individual customers with consideration given to pump performance, we aim to optimize and improve the efficiency of the HEV/EV systems.

Fig.11 Example of coolant flow analysis of the power semiconductor cooling system



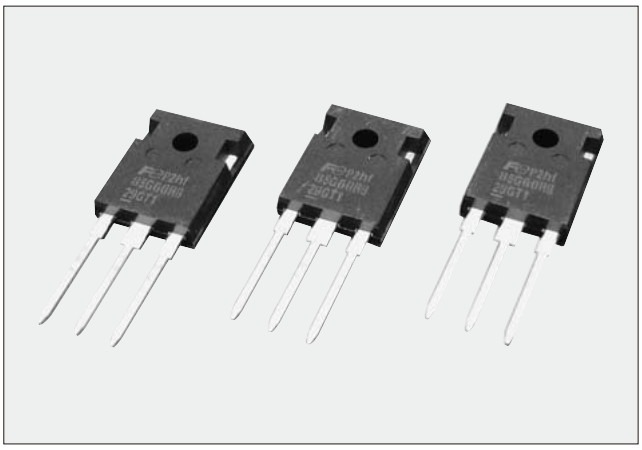
12 600 V Discrete RB-IGBT "FGW85N60RB"

Advanced T-type neutral point clamped (AT-NPC) power conversion circuits including a neutral-point clamp are attracting attention because they improve the efficiency of power conversion equipment. Applying reverse-blocking insulated gate bipolar transistors (RB-IGBTs) that withstand voltage for both forward- and reverse-biases makes it possible to reduce the number of elements used for a neutral-point clamp, allowing for further efficiency improvement.

Fuji Electric has developed proprietary technologies for mass production of RB-IGBT. Following the AT-NPC IGBT module incorporating RB-IGBT, we have commercialized "FGW85N60RB" that incorporates the RB-IGBT developed for discrete products into a TO-247 package. Since the inductances inside the package and of the main circuit are lower than those of module products, a reduction in power dissipation and high-frequency operation can be achieved.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 262

Fig.12 "FGW85N60RB"



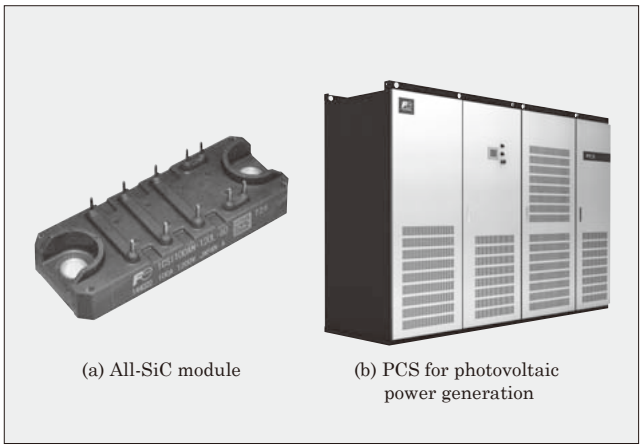
Power Semiconductors

13 All-SiC Module for Power Conditioners

Fuji Electric is moving forward with the product development of All-SiC modules incorporating metal-oxide-semiconductor field-effect transistor (MOSFET) and Schottky barrier diode (SBD) which are SiC devices jointly developed with the National Institute of Advanced Industrial Science And Technology. We are considering their applications to various types of power electronics equipment including power conditioners (PCSs). Figure (a) shows a picture of the All-SiC module that is rated 1,200 V/100 A. We have reduced the module internal inductance to almost one-fourth and the footprint size to almost half compared with Si- insulated gate bipolar transistor (IGBT) modules of the same rating. In addition, the resin sealed structure provides high reliability. Moreover, both the reduction of power dissipation and downsizing of the power module have been achieved simultaneously, which help to improve the power density of PCS for photovoltaic power generation.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 221

Fig.13 All-SiC module and PCS for photovoltaic power generation



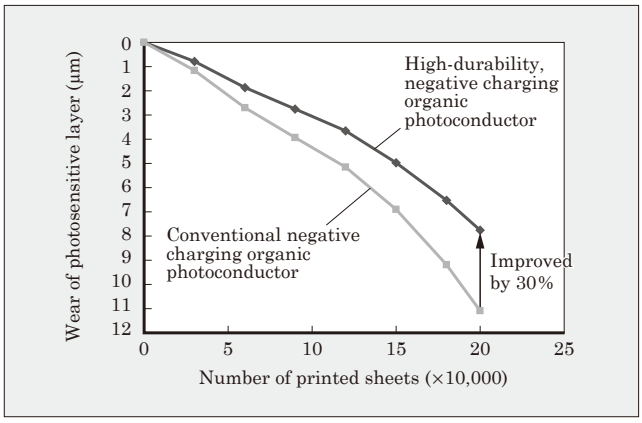
Photoconductors

1 High-Durability, Negative Charging Organic Photoconductors

As the life of printers and copiers extends, there is a growing demand for photoconductors to be highly durable. Inside the equipment, however, the load placed on a photoconductor is increasing and wear is further accelerated due to the increase of various contact processes.

To develop high-durability, negative charging organic photoconductors to meet the needs of such processes, Fuji Electric is developing a binder that is a main component of the charge transport layer on the surface of a photoconductive layer. We succeeded in developing a new binder whose properties far exceed conventional products. This was achieved by working out the molecular design from proprietary simulations focused on hardness and toughness and by conducting tests based on an assumption of various external stresses. The photoconductor to which this binder was applied has improved wear resistance of the photosensitive layer by 30% compared with the conventional products, achieving higher durability.

Fig.14 Printing durability property of high-durability, negative charging organic photoconductor



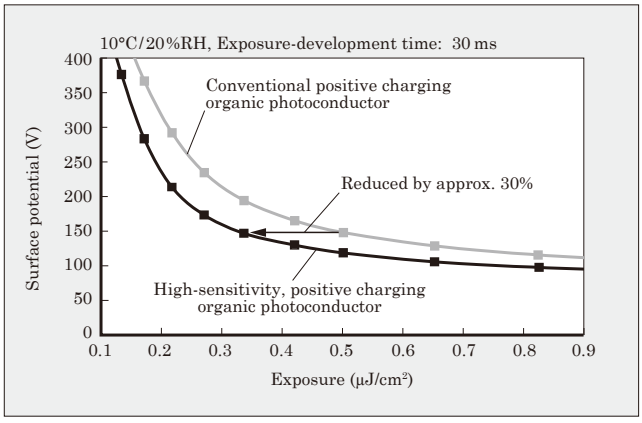
2 High-Sensitivity, Positive Charging Organic Photoconductors

Electrophotography-based laser printers and copiers are designed to be faster, smaller and more power-saving. In tandem with this, there is growing demand for a highly sensitive organic photoconductor that can respond to less exposure in shorter time, so that the design margin of the exposure system can be widened.

Fuji Electric provides positive charging organic photoconductors that have sensitivity properties equivalent to negative charging organic photoconductors by developing a multilayer positive charging organic photoconductor based on proprietary technologies.

This time, by seeking to optimize the combination and compounding ratio of various functional materials including charge transport materials and electron transport materials, we have developed a high-sensitivity, positive charging organic photoconductor. It works with about 30% less exposure even under low-temperature and low-humidity conditions where response speed tends to be slower. We will provide organic photoconductors based on this technology from now on.

Fig.15 Photo-induced discharge characteristics of high-sensitivity, positive charging organic photoconductors

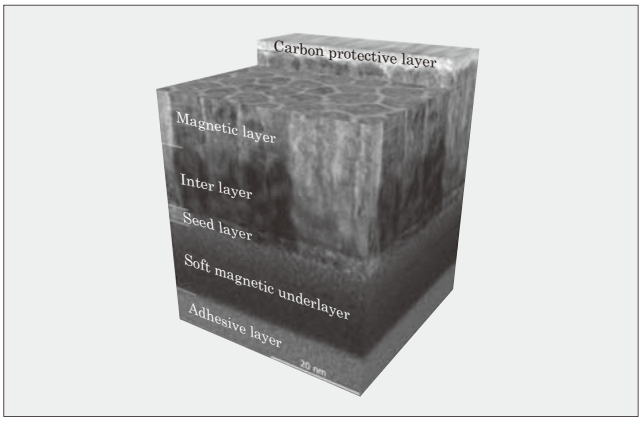


Disk Media

1 Large-Capacity, High-Reliability Perpendicular Magnetic Recording Media

With the expansion of cloud computing, the main driving force in the HDD market is shifting from PCs to the demand of data centers. The market is growing steadily and the demands for magnetic recording media with a larger recording capacity are still high. Fuji Electric has pursued both high reliability and reduction of magnetic spacing through optimization of the lubricant and the carbon protective layer. We have also achieved finer and more uniform crystal grains by optimizing the composition/deposition conditions of a medium layer structure including a multilayer granular layer. Moreover, we have established a system to allow HDD to be evaluated in-house using actual equipment to achieve more accurate and faster evaluations of medium properties. By implementing these measures, we succeeded in achieving a recording density of 1,064 Gbits/in^2 (712 GB per 2.5-inch medium) ahead of other companies. This technology is scheduled to be applied to the media for HDD that will be commercialized in FY2014.

Fig.16 Cross-sectional and top views of TEM image of developed magnetic recording medium



Food and Beverage Distribution

Vending Machines
Cold Thermal Energy Control Technology
Currency Handling Equipment

Outlook

The keywords for R&D in the food and beverage distribution field in FY2013 were "energy conservation," "convenience," "globalization" and "safety and security." Research and development has been focused on improving the technology to control cold thermal energy so as to achieve better energy efficiency of cold thermal equipment, particularly since the Great East Japan Earthquake.

The products in the food and beverage distribution field that apply the technology to control cold thermal energy include vending machines, which heat and cool beverages, and food showcases in shops.

For vending machines, Fuji Electric commenced producing the 2014 model of Fuji Electric's unique hybrid heat pump vending machines that use external air as well as internal exhaust as heat source. The 2014 model is 26% more energy-efficient than the previous model. The newly developed freezer circuit has improved the heating capacity of the heat pump, while the load for heating and cooling has been reduced by improving internal ventilation. As a result, the product has achieved an annual power consumption of 590 kWh.

Also, the coin and bill validator mounted on the vending machines has reduced the power consumption in standby mode by 30%. The validator makes a transition to the energy-saving mode by the control of the vending machine, which enabled such substantial reduction.

There has been great demand from the convenience store industry for a reduction in the power consumption of showcases, and Fuji Electric has developed a wall-type refrigerated and freezer showcase with a built-in inverter freezer, cutting the power consumption by 30% compared with the previous model. Under normal conditions, the showcase keeps the freezer device running at a low operational speed continuously, thereby reducing the power consumption by 24% compared with the previous model. Furthermore, the new jet structure lowers the inflow of external air, making it possible to reduce the required freezing power and stabilize product temperature.

Fuji Electric has developed a glass-front vending machine that can hold a large volume of a wide range of products, and be used in public venues and offices serving as an unmanned satellite shop for convenience stores. With the added sales modules, the machines can sell a variety of abundant foods that were previously impossible to handle in vending machines. Furthermore, the glass area of the main body has been widened to improve the showcase's functionality while its storage capacity has been significantly increased.

Aiming to compete in the global market, we have developed a vending machine with an IEC-standard-compliant glass front, for future export to the East Asia region, where the economy is showing remarkable growth. The vending machine has a built-in currency multi-interface to be compatible with the currencies in 10 ASEAN countries, with two types of vending mechanisms: the twist type which is adaptable to diverse beverage container forms depending on the local products, and the screw type, which can handle packed snacks and small foods.

We have developed a next-generation cold storage container "D-BOX" as part of our efforts to enter new fields and apply the technology to control cold thermal energy. This improves the temperature control throughout the logistical stages to deliver safety and security to the entire supply chain. The D-BOX can complete cold storage in a short period of time (3 hours), and maintain it for a long time (5 hours) "without a power supply" during transportation, using hyper insulation technology. A centralized control system, the "High Quality Cold Chain System," has also been developed, utilizing a cloud environment to manage D-BOX data on temperature, running time and locations.

In the area of currency handling equipment, Fuji Electric has improved the sensor for coin roll stockers, which is an integral part of automated change dispensers used in supermarkets, for more efficient checkout work. The sensor monitors the stored coin rolls and ensures the machine does not run out of change. We have achieved the industry's largest coin roll storage

capacity.

Fuji Electric will continue to develop and further expand environmentally friendly products leveraging the company's unique technology to control thermal energy.

Vending Machines

1 Wall-Type Freezer Showcase with Built-in Inverter Freezer

The demand to reduce power consumption in-store equipment is increasing greater than ever in the convenience store industry. Fuji Electric has developed a wall-type freezer showcase with a built-in inverter freezer, with enhanced energy saving. The main features are as follows:

(1) Optimized pull-down control and constant low-speed operation control of the freezer realized high-efficiency operation, reducing freezer power consumption by 24% compared with previous showcases.

(2) New jet structure allowed optimization of the air flow balance in a case longitudinal direction and at ventilation output opening, resulting to reduce the inflow of external air and also the freezing power required, as well as stabilizing product temperature.

(3) Improved ventilation and anti-condensation heater with enhanced capacity and its optimized layout reduced power consumption by 9%.

Fig.1 Wall-type freezer showcase with built-in inverter freezer

2 Foods Vending Machine for Convenience Stores “FGS260W”

Fuji Electric has developed a foods vending machine “FGS260W” for convenience stores aiming to expand their business. The vending machine can be placed in public venues and offices, serving as an unmanned satellite shop.

In order to widen the range of products to be sold, it adopted spiral type and conveyor-belt type modules. Both types are designed to allow for flexible setting alterations and packed foods replacement. These modules make it possible to handle foods that were impossible previously, including 280-mm wide snack packs and packages with a thickness of 7 mm. In terms of holding capacity, the new vending machine can store 540 rice balls, for example. This is a significant increase from its old model that could hold 192 rice balls. Furthermore, the glass area of the main body has been increased by 53% to improve the showcase’s functionality.

More than 500 units have already been distributed in and around the Tokyo Metropolitan area.

Fig.2 “FGS260W”

3 Canned Beverage Vending Machine with Hybrid Heat Pump II “FA25M5RD4WK-FOP”

We have commenced production of “FA25M5RD4WK-FOP,” a canned beverage vending machine with a hybrid heat pump (HP) II. Its energy-saving features have been improved by 26% on an annual power consumption basis compared with the industry's top-class hybrid-HP vending machines. The applied energy-saving technologies are as follows:

(1) The optimized refrigeration cycle, achieved with an enlarged external evaporator, and newly-developed refrigerator circuit have improved the heating efficiency of the heat pump.

(2) The exhaust heat from the compressor is proactively used by feeding it into the vending machine, which has enhanced the heat pump’s heating efficiency.

(3) The load for heating and cooling is reduced by shortening the internal ventilation route and improving the air flow so that the internal temperature distribution is divided into zones.

These technologies enabled FA25M5RD4WK-FOP to achieve an annual power consumption of 590 kWh.

Fig.3 “FA25M5RD4WK-FOP”

Cold Thermal Energy Control Technology

1 "High-Quality Cold Chain System"

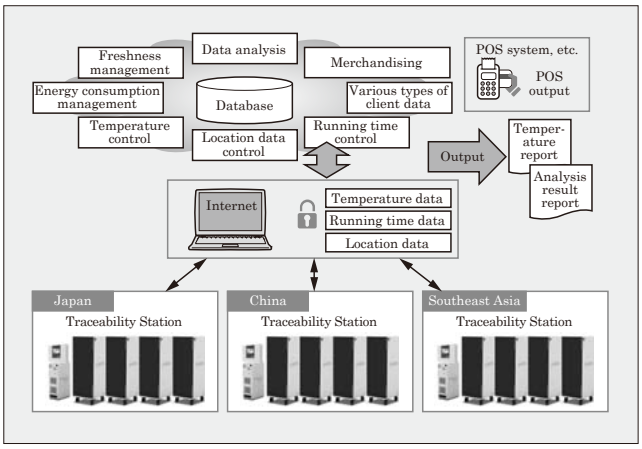
Fuji Electric has developed a centralized control system "High-Quality Cold Chain System" (HQCCS) related to development of "D-BOX." It can manage "D-BOX" data on internal temperature, running time, and locations utilizing cloud computing environment. The system can realize safe and efficient logistic structure, and it enable users to offer high-quality cold chains into the market. The main features are as follows:

(1) The system can control traceability of merchandise by gathering "D-BOX" data.
"D-BOX" data is as follows: internal temperature, running time, door open/close operation, and locations.

(2) The system can manage identification of "D-BOX" and oversee the rate of operation, which contribute to enhancement of the maintenance and quick judgment of a period of the maintenance.

(3) Clients can use the system as a strategic merchandising tool by linking the freshness of products and consumer's purchase activities.

Fig.4 "High-Quality Cold Chain System"



Currency Handling Equipment

1 Coin Mech "FEVT Series"

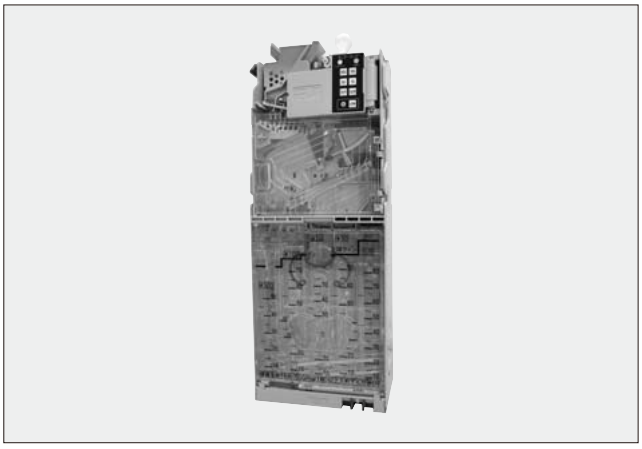
Manufacturers have a social responsibility to improve energy conservation, and the same is required for 24-hour-operational vending machines. We have developed a new type of coin mechanism to meet this social requirement. The main features are as follows:

(1) The coin mechanism achieved a significant reduction (30%) in power consumption by adopting an independent, time-sharing control method as opposed to the previous method which operates multiple coin sensors altogether at all times. Furthermore, the vending machine can prompt the coin mech. to switch to the energy-saving mode, reducing power consumption by up to 80%.

(2) All units come with a change pay-out confirmation sensor as standard, enhancing the reliability of change dispensing.

(3) A new sensor with high sensitivity to identify minute design characteristics of coins, which are produced with high anti-counterfeiting technology, for improved coin verification.

Fig.5 "FEVT Series"



2 Large Storage Capacity Coin Roll Stocker "CST770"

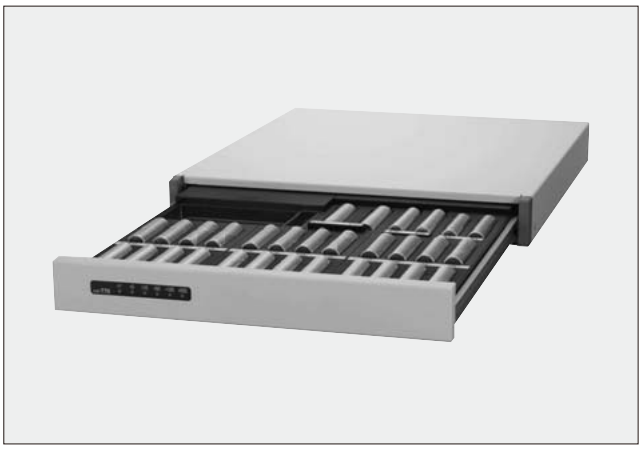
For avoiding running out of change in automated change dispensers, coin roll stockers need to increase their storage capacity in order to improve the efficiency of checkout work. Fuji Electric has responded to this request, and launched on the market a large-storage coin roll stocker "CST770" that interlocks with automated change dispensers. The main features are as follows:

(1) The improved sensor has made it possible to improve the storage capacity up to the industry's top level of 30 rolls, compared to the conventional 18.

(2) In the stocker, there is a tray structure that contain units made from four coin rolls each, for easy and flexible rearrangement. This allows customers to easily customize the unit so as to add or remove coin domination types as required.

(3) A magnet sensor is used to discriminate domination for precise management of coin rolls.

Fig.6 "CST770"



Fundamental and Advanced Technologies

Fundamental Technology
Advanced Technology

Outlook

Global competition is increasingly getting fierce with the expansion of emerging markets centered on Asia. Most Japanese companies are pressing ahead with the selection and concentration of their businesses, promoting structural reform by allocating research and development resources preferentially to product development, and trying to gain competitive advantages. On the other hand, too much focus on product development has raised concerns about sustained growth, such as a shorter research and development scope and insufficient investment in advanced studies. As a countermeasure, an increasing number of companies employ open innovation-style technology strategies to seek out external resources. Such strategies are also important to promptly and properly address customer needs for the technologies that were found to be nonexistent in the company as a result of the selection and concentration effort.

We at Fuji Electric have set power semiconductors and power electronics at the center of our core technologies and systematized these core technologies through instrumentation and control technologies to reinforce our efforts in electrical and thermal energy-related solutions. We are also actively involved in the fundamental and advanced technologies supporting these core technologies to contribute to continuing innovations and improving the quality of research and development. As open innovation efforts, we participated in a large-scale project of industry-government-academia cooperation to reinforce our core technologies such as a wide-band gap power semiconductor technology. We are also conducting joint research with universities and other external research institutions to refine our fundamental technologies and to seek prospective advanced technologies.

As for the advanced technologies for power semiconductors, we have developed a 1,700 V withstand voltage class SiC-Schottky barrier diode (SiC-SBD), a 1,200 V withstand voltage class SiC-metal-oxide-semiconductor field-effect transistor (SiC-MOSFET) and a 13 kV class ultra-high withstand voltage SiC-insulated gate bipolar transistor (SiC-IGBT) by conducting the joint research or by participating in a program of the National Institute of Advanced Industrial Science And Technology. When mounted on inverters or other power electronics equipment, SiC-SBDs and SiC-MOSFETs are expected to significantly reduce the power loss in the equipment. Ultra-high withstand voltage SiC-IGBTs are expected to be used for applications in fields requiring ultra-high withstand voltage such as power transmission/distribution equipment. To develop these devices it is necessary to control the interfacial properties between metal and SiC or an oxide film and SiC in a highly reproducible manner. Consequently, we have developed an analysis technology to compare the density distribution and binding state of atoms at a resolution level of several atomic layers by combining synchrotron radiation photoemission spectroscopy and analysis technique using transmission electron microscope.

In order to accurately predict losses that occur in the semiconductor devices in power electronics products, we have developed a loss prediction technology that uses a device equivalent circuit model. Moreover, we participated in IEC committee activities and promoted development of standard-conforming technologies to advance the global expansion of power electronics products.

As instrumentation and control technologies required for systematization, a high-speed database technology that can manage a large volume of measurement data simply and a virtual hardware application technology that helps reduce development person-hours for built-in software have been developed. A machine learning technology that lets a computing machine learn from a large volume of image data groups and generate algorithms automatically has been developed and applied to robot vision.

Power magnetic materials used in electrical equipment such as rotating machines or transformers have a great influence on the equipment performance because their magnetic properties change depending on their manufacturing and design conditions. By measuring the magnetic properties under environment simulating

such conditions, we have developed a technology that can optimally utilize power magnetic materials.

As a component used for thermal energy solutions, we have developed a steam generating heat pump system utilizing warm water discharge from factories and conducted a field test at the Mie factory.

We worked on magnetic layer technology for heat assisted magnetic recording method that is expected to be the next-generation recording method for hard disk with areal density of 1.4 Tbits/in^2 or higher. We have developed a material that decreases the Curie temperature by 100 °C while keeping magnetic anisotropy energy that is twice as high as the level now in use.

A reactor concept using a modular high temperature gas-cooled reactor has been established. In the concept, the reactor can cool down by natural heat radiation during an emergency shutdown and has complete passive safety characteristics.

We have completed development of elemental technologies for a multi-analysis instrument that is capable of measuring PM 2.5 based on a combination of optical techniques and mass analysis techniques. It enables real-time measurement of component analysis, which took at least 8 hours with a conventional method.

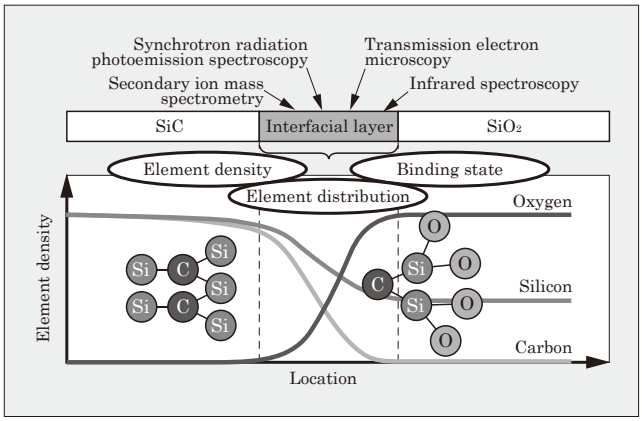
Fuji Electric will take on the challenge of developing advanced technologies that will lead to innovations in electrical and thermal energy technologies and instrumentation and control technologies, while making full use of the fundamental technologies that support such development to improve the quality of research and development in the future.

Fundamental Technology

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

In order to improve the reliability of SiC-MOSFET, it is necessary to ensure good interfacial properties of a gate oxide film. As in the same way for Si, a gate oxide film is formed by thermal oxidation. However, a complicated structure is generated between the SiC substrate and oxide film owing to elements added to improve interfacial properties and carbon emitted during the formation process, which may interrupt the flow of electrons and decrease reliability. Fuji Electric utilized various analysis techniques including synchrotron radiation photoemission spectroscopy and transmission electron microscopy, and has established a method to evaluate the interfacial surface structure of a gate oxide film in terms of element density, distribution and binding state. As a result, we were able to acquire a deeper understanding of the relationship between the oxide film formation process and interfacial structure and improve the properties of the interfacial surface of a gate oxide film to increase the reliability of SiC-MOSFET.

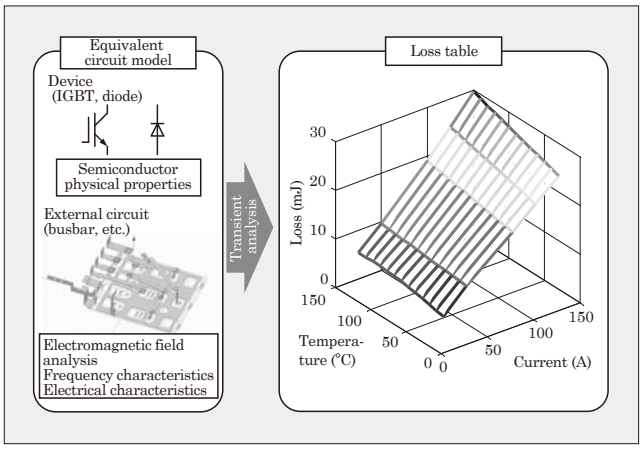
Fig.1 Schematic diagram of density, distribution and binding state of interfacial elements



2 Equipment Loss Prediction Technology Using Device Equivalent Circuit Model

In the power electronics equipment, it is extremely important to accurately determine the losses that occur in semiconductor devices, in the design of equipment structures and heat sinks. These generated losses, however, vary depending on the operating conditions such as temperature or electric current, parasitic inductance resulting from equipment wiring and external circuits such as a gate drive circuit. Therefore, to determine such losses, repeated prototyping and measurement were required. Fuji Electric is developing a simulation technology to predict the generation of losses by combining a device equivalent circuit model and an external circuit model. The simulation technology enables the highly accurate analysis which is independent of the operating conditions because the device equivalent circuit model is based on the physical properties. Moreover, when the relationship between the losses and operating conditions are tabularized and combined with thermal analysis, the losses caused by the change in temperature can be predicted. Thus the simulation technology indicates the potential of a shorter period of equipment design review.

Fig.2 Loss table using an equivalent circuit model



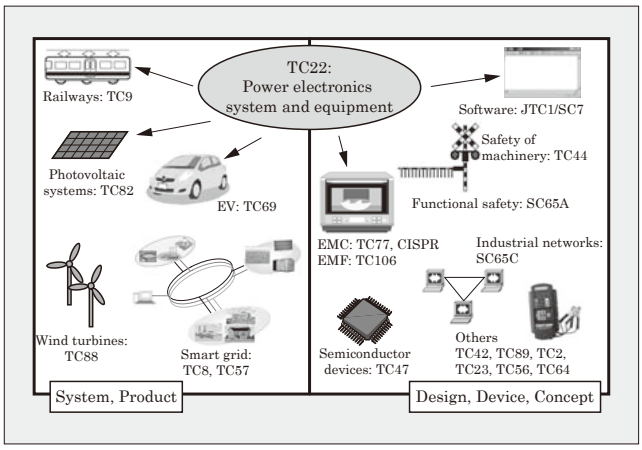
3 Conformance to Power Electronics-Related International Standards

In order to promote the global expansion of its primary product line of power electronics products, Fuji Electric has been involved in several technical committees of the International Electrotechnical Commission (IEC), especially in TC22 (power electronics), SC22G (drive) and CISPR (EMC), while developing technologies to ensure conformance to standards. The main achievements are as follows:

(1) Assumed the post of a project leader for the EMC standards for photovoltaicr power conversion systems and is leading the standard creation processes.
(2) Conducted a verification test for drive efficiency standards in Japan, presented views in standard review meetings and obtained the understanding of each country.
(3) Worked on the first draft of the EMC testing technologies for the functional safety standard that is under revision and made Japan's view reflect in it.

Fuji Electric will advance product development and standard creation simultaneously for the EMC standards about which more active discussion is expected, and for standardization related to system interconnection.

Fig.3 International standards related to power electronics



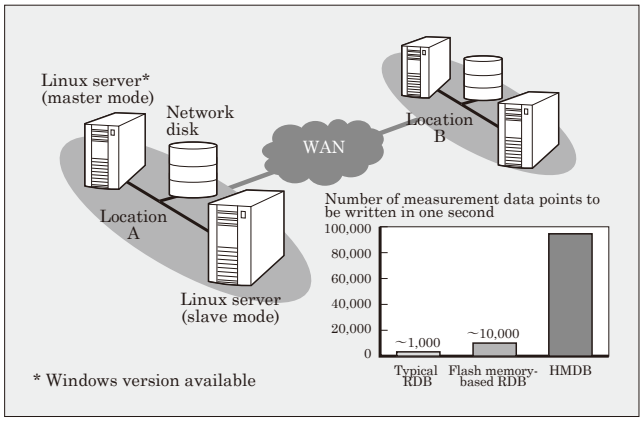
4 High-Speed Database Technology

Fuji Electric has developed a database called high-speed measurement database (HMDB) to enable simple and high-speed management of a large volume of data measured at a constant cycle such as smart meter readings in meter data management system (MDMS) or various energy values collected by the building and energy management system (BEMS) aggregators.

By specializing in measurement data storage, the database allows even a Linux server with a single configuration to store 30 million smart meter readings within six minutes.

It also supports high-reliability options such as a redundant system and dual location system, and can also be implemented as infrastructure middleware of an industrial/social system.

Fig.4 HMDB system configuration and number of measurement data points to be written



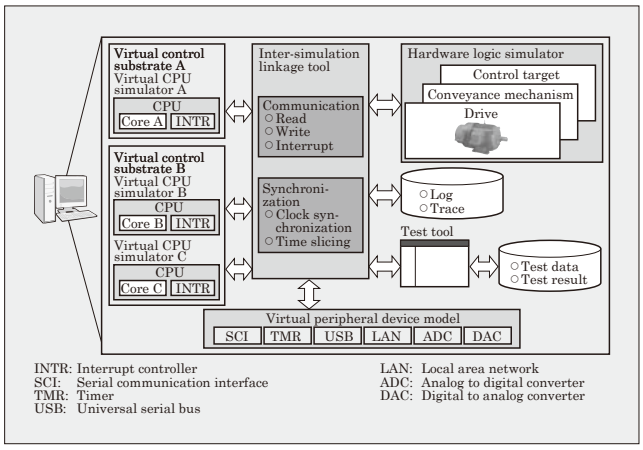
5 Virtual Hardware Application Technology for Development of Built-in Equipment

In order to reduce the development period (by 35%) and development person-hours (by 30%) for built-in software, Fuji Electric developed a virtual hardware development environment for built-in equipment that allows built-in CPU's binary codes to work on a PC without any modification.

This development environment consists of a virtual CPU simulator on which built-in programs are enabled to run, an inter-simulation linkage tool and simulators (virtual peripheral device model, hardware logical simulator and test tool).

The virtual peripheral device model can be used in common when it is connected with respective virtual CPU simulators via the inter-simulation linkage tool. Even a test of hardware abnormalities, which is normally difficult to make happen, can be automated in a virtual environment, resulting in improved reliability as well as reduced development person-hours.

Fig.5 Virtual hardware development environment

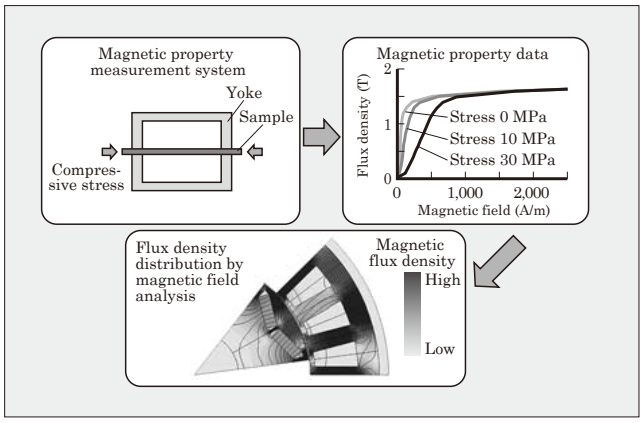


6 Technology of Optimum Utilization of Power Magnetic Materials

It is known that power magnetic materials used in electrical equipment such as rotating machines or transformers have a great influence on the equipment performance because their magnetic properties change depending on the product manufacturing and design conditions. Electrical steel sheets, in particular, have a strong tendency to show such properties. Consequently, there is a need to optimize electrical equipment based on a design method that takes into account the magnetic properties of the magnetic materials under the actual usage environment.

Fuji Electric has established a technology to optimally utilize power magnetic materials by obtaining the magnetic properties under an environment that simulates manufacturing conditions (e.g., fixed stress, press punching, inter-locking and welding) and design conditions (e.g., inverter excitation, flux leakage to surrounding structural materials and DC-biased excitation), and then applying them to magnetic field analysis. This technology is being used to improve product performance and to shorten design period by reducing the number of prototyping attempts.

Fig.6 Example of a design method that takes into account the magnetic properties under the actual usage environment

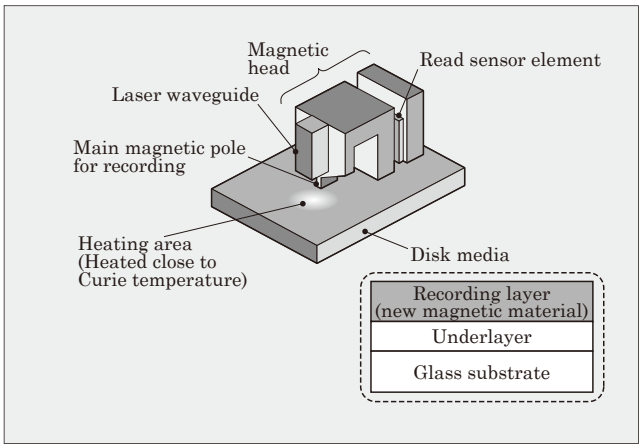


Advanced Technology

1 Magnetic Layer Technology for Heat Assisted Magnetic Recording

It is expected that the recording method will be shifted to heat assisted magnetic recording for hard disk drives (HDDs) with areal density of 1.4 Tbits/in^2 (1 TB per 65-mm disk) or higher. The recording layer must be made of a magnetic material having high magnetic anisotropy energy such as ordered FePt alloy; however, ordered FePt alloy has a high Curie temperature. Reducing the Curie temperature is desirable because limiting the heating temperature during recording and reducing the power of the heat source laser can improve reliability. Fuji Electric found a material that has about twice the magnetic anisotropy energy of the current material (1.6×10^7 erg/cm^3) and a Curie temperature of at least 100°C lower than that of ordered FePt alloy, and can maintain a fine granular structure. The recording layer using this material can be expected to reduce the laser power by 20% and improve reliability.

Fig.7 Structure of thermally assisted magnetic recording

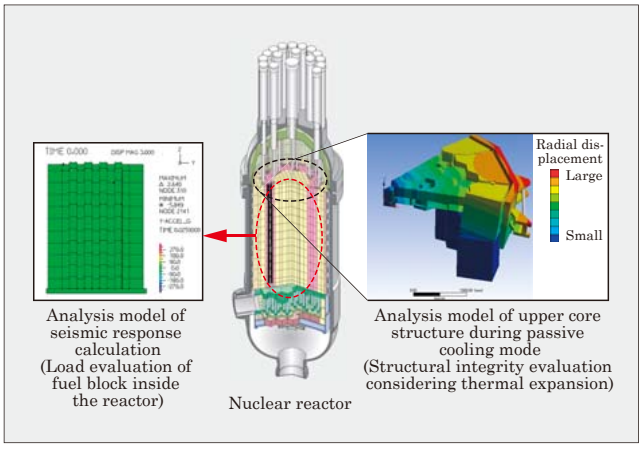


2 Modular High Temperature Gas-Cooled Reactor Featuring Complete Passive Safety Characteristics

High temperature gas-cooled reactor (HTGR) is a next-generation nuclear reactor that has features as follows: (1) it has fully passive safety features, such as that it can be cooled only by natural phenomena after an emergency shutdown; and (2) it can supply high temperature heat to realize various heat applications, such as high-efficiency gas turbine power generation and hydrogen production from water.

Fuji Electric is focusing research and development to establish a reactor concept which realizes complete passive cooling and is used to very high temperature reactor (VHTR) offering much higher temperature. The design technology for structural integrity evaluation of the reactor internals during passive cooling mode, the seismic response analysis technology of reactor core consisting of graphite blocks and the reactor core design technology supporting a higher burn-up operation have been developed. As a result, a basic concept of reactor structure adopting a metallic core restraint mechanism proven in a high-temperature engineering test reactor (HTTR), the first very-high temperature gas reactor in Japan has been established, which achieves complete passive cooling even in a VHTR reactor with an outlet temperature of 900°C.

Fig.8 Example of seismic response and structural analysis



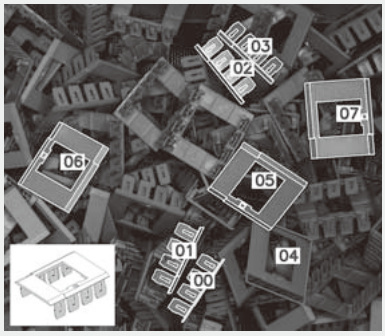
3 Application of Machine Learning Technology to Robot Vision

In the robot vision field, research and development work has been continued to help robots recognize the position and pose of randomly stacked parts and take out a specific component.

In the previous development approach, developers focused on shape patterns that were considered to be characteristic of individual parts and then built algorithms so that robots could recognize the position and pose of the parts. When the parts were changed, the development work had to be started over again.

The application of "machine learning" that takes an approach of letting a computing machine learn the characteristic patterns of the parts from a large volume of image data groups and generate optimum algorithms automatically has made it possible to greatly reduce the development person-hours required for new parts.

Fig.9 Result of part position and pose recognized by machine learning



Recognized parts: 00, 01, 02, 03, 05, 06, 07

Advanced Technology

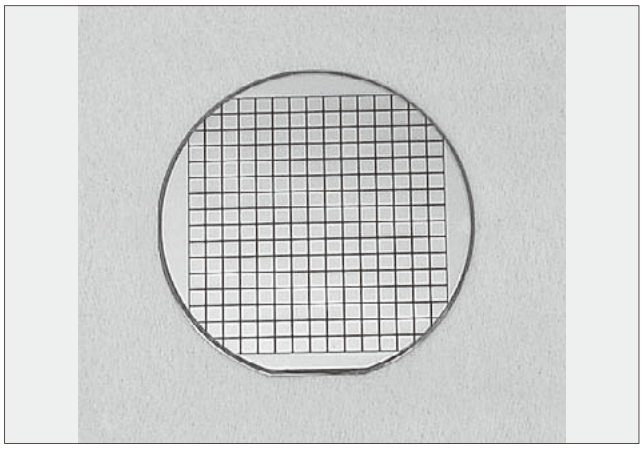
4 1,700 V Withstand Voltage Class SiC-SBD

To meet the further power-saving requirement of power electronics systems, free wheeling diodes using silicon (Si-FWDs) are being replaced with silicon carbide Schottky barrier diodes (SiC-SBDs).

Fuji Electric has developed 1,700 V withstand voltage class SiC-SBDs together with the National Institute of Advanced Industrial Science and Technology. By replacing Si-FWDs with these SiC-SBDs, we succeeded in reducing the power loss generated in the latest Si-IGBT module by 39%. These developed SiC-SBDs are enable to be operated at high temperature exceeding 200°C and have avalanche withstanding capability at least 10 times higher than that of Si-FWDs. Fuji Electric is planning to equip various types of next generation power electronics systems with these 1,700 V withstand voltage class SiC-SBDs.

Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 218

Fig.10 1,700 V withstand voltage class SiC-SBDs within a wafer

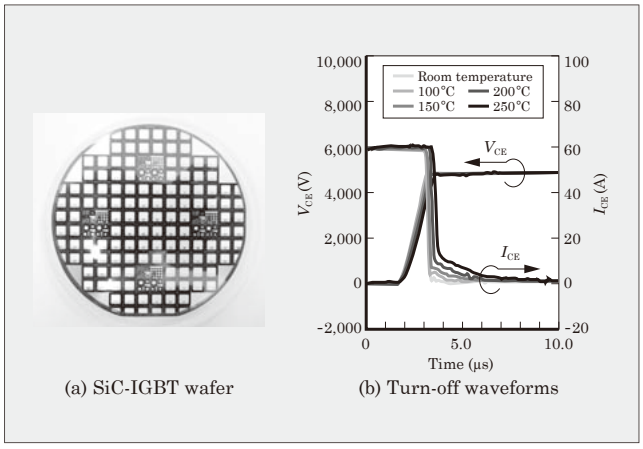


5 13 kV Class Ultra-High Withstand Voltage SiC-IGBT

Fuji Electric participated in the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST) led by the National Institute of Advanced Industrial Science and Technology, and has developed a 13 kV class ultra-high withstand voltage SiC-insulated gate bipolar transistor (SiC-IGBT). This device is expected to be used for applications requiring ultra-high withstand voltage such as power transmission/distribution equipment in a smart grid. Because of its higher withstand voltage and lower power dissipation than those of conventional silicon devices, this device allows energy savings as well as downsizing and weight reduction of equipment.

This device is characterized by the use of a high-quality flip-type wafer with all layers formed by epitaxial growth technique. The combination of the new oxidation technique and Carbon-face IEMOS structure has achieved good electrical properties. These technologies has realized properties of the highest level in the world, such as differential on-resistance of 11 mΩcm² and withstand voltage of 16 kV.

Fig.11 13 kV class ultra-high withstand voltage SiC-IGBT



(a) SiC-IGBT wafer (b) Turn-off waveforms

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* Non-consolidated subsidiaries

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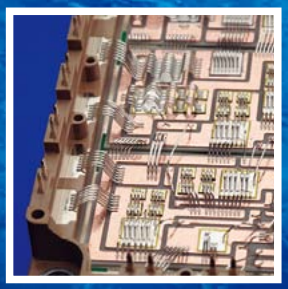

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Power Electronics Technology

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