Achievements and Future Outlook

Innovations in Electric and Thermal Energy Technology

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1. Introduction

As part of the reconstruction of areas affected by the Great East Japan Earthquake, the construction of new communities is planned, and in April 2012, eight districts including Aizuwakamatsu-shi were specified by the Japanese Ministry of Economy, Trade and Industry as Smart Community Master Plan Special Districts, and the formulation of specific plans is underway. Additionally, the Feed-in Tariff Scheme for renewable energy began in July 2012, and renewable types of energy such as photovoltaic power generation and wind power generation are rapidly becoming prevalent.

Under these circumstances, in July 2012, Fuji Electric adopted a new brand statement of "Innovating Energy Technology." This statement reflects the company's ongoing pursuit of innovation in electric and thermal energy technology to develop products that maximize the efficient utilization of energy and to contribute to the creation of responsible and sustainable societies. To realize these goals, Fuji Electric is concentrating its research resources on the development of technology for supplying and using electric energy safely, securely and efficiently, technology for utilizing thermal energy without waste, and technology for optimally controlling those types of energy in order to develop systems and solutions that utilize distinctive components and technologies (see Figs.1 and 2). This paper presents an overview of these efforts.

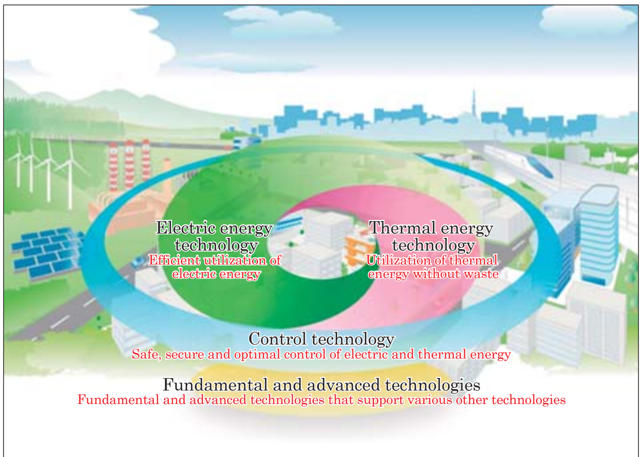


Fig.1 Fuji Electric's Technologies

2. Fuji Electric's Energy Technology

2.1 Electric Energy Technology

In the field of electric energy technology, Fuji Electric utilizes the synergy between power device technology and power electronics technology to develop component products and solutions that lead to energy savings.

With regard to power devices, Fuji Electric is developing insulated gate bipolar transistor (IGBT) modules, metal-oxide-semiconductor field-effect transistors (MOSFET), discrete devices and power ICs with the aim of realizing lower loss, lower noise, smaller size and higher reliability. For IGBT modules, in particular, a new process that forms a V-shaped groove on the backside of a device has been refined to develop an reverse-blocking IGBT (RB-IGBT) having a breakdown voltage of 1,700 V. Targeting the large capacity market, Fuji Electric expanded its series of 3.3 kV IGBT modules that use AlSiC as a base material. As a result of using this new base material, life spans of the heat cycle and the power cycle have been increased by several times. Additionally, for small capacity applications, Fuji Electric has developed a small capacity intelligent power module for use with inverter air conditioners. By combining an IGBT having a field stop type trench gate structure with a high-speed free wheeling diode, loss during light loaded operation, which accounts for approximately 80% of the time of air conditioner operation, was reduced by about 25%. For further optimization of IGBT module design, Fuji Electric performed coupled analysis of semiconductor devices, circuits and thermal structures. With this technique, the error in determining electrical characteristics was reduced to one-fourth compared to the conventional method and the error in determining thermal characteristics error was reduced to one-half.

Compound semiconductors made from SiC (silicon carbide) and GaN (gallium nitride) are being advanced by Fuji Electric as next-generation devices that dra-

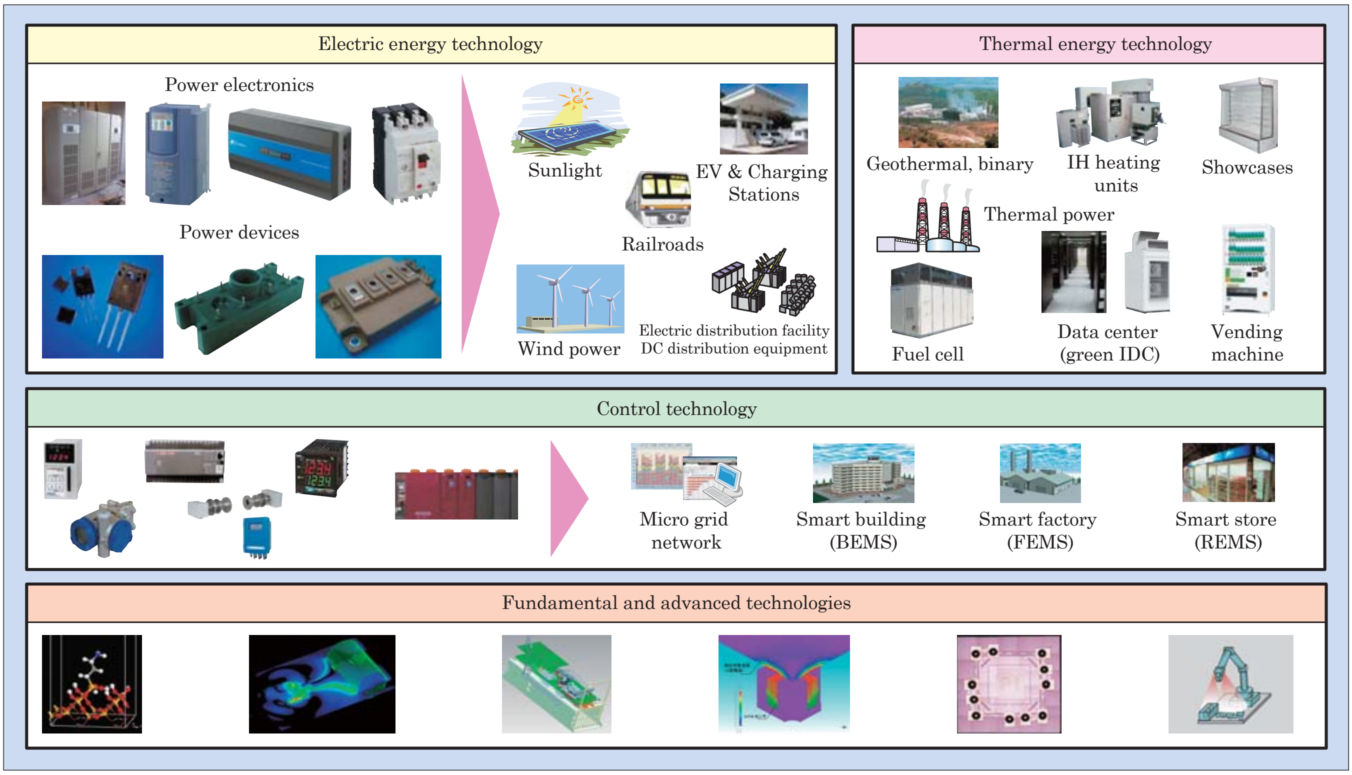


Fig.2 Fuji Electric's Technologies and products

matically reduce loss beyond the physical limits of the existing mainstream Si devices.

For SiC Schottky barrier diodes, Fuji Electric has developed them in cooperation with the National Institute of Advanced Industrial Science and Technology. Fuji Electric is supplying samples, and using these devices, has begun mass production of industrial-use inverters for the first time in Japan. The loss is lower by 20% compared to the previous products. Moreover, with the aim of mass producing SiC-MOSFETs, Fuji Electric is also advancing the development of All-SiC modules, which maximally exhibit the properties of SiC devices.

All-SiC modules use copper pins instead of conventional wire bonding, and also utilize an insulating substrate containing Si_3N_4 (silicon nitride), which has good thermal conductivity, and a newly developed highly heat-resistant epoxy resin to ensure high heat dissipation and high thermal resistance. In addition, a low inductance structure was also used, and one-half footprint of the Si-IGBT module was realized (see Fig. 3).

Nine of these All-SiC modules were embedded into a three-phase three-level circuit to fabricate a prototype of a 20 kW power conditioner (see Fig. 4) for use in photovoltaic power generation, and a smaller size that is one-fifth that of conventional devices and a main circuit efficiency of 99% were demonstrated[(1)]. In this way, Fuji Electric has also developed circuit technology for applications that leverage the advantages of SiC devices, and has developed innovative products while utilizing the synergies among the three technologies of low on-resistance chip technology, package technology and circuit technology.

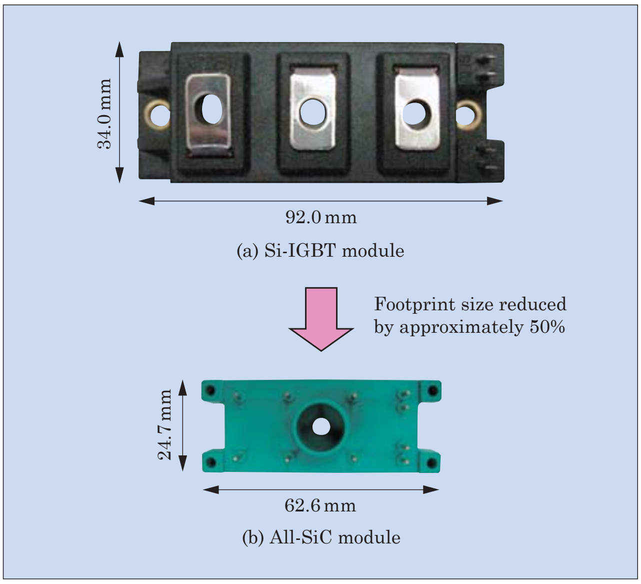
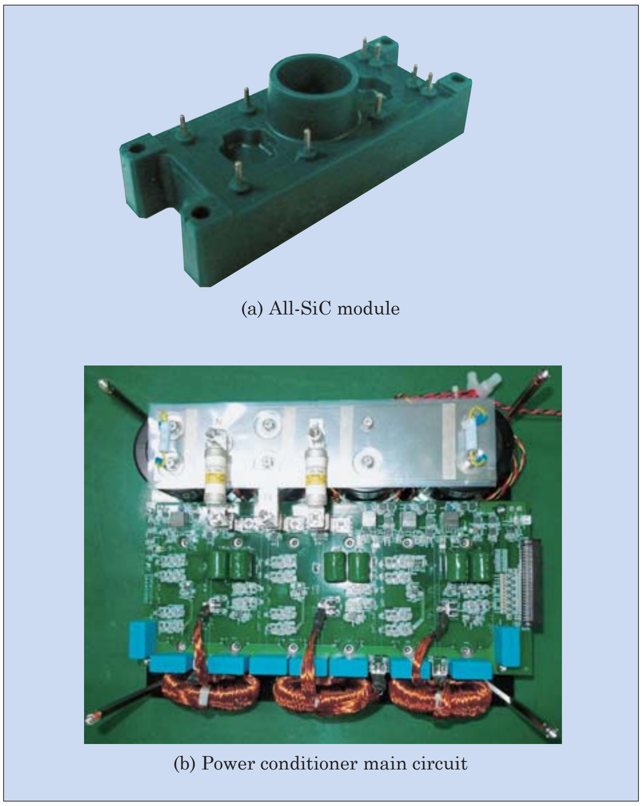


Fig.3 Footprint of All-SiC module

For power electronics equipment, Fuji Electric is advancing the development of low loss devices that maximally leverage the aforementioned power device characteristics.

With the start of the Feed-in Tariff Scheme for renewable energy, domestic Japanese mega solar facilities are rapidly increasing in number. Under these circumstances, Fuji Electric has applied its proprietary advanced T-type neutral-point-clamped 3-level conversion circuit technology to develop and launch a power conditioner that features significantly reduced switching loss, filter loss, and that realizes 98.5% conversion



(a) All-SiC module

(b) Power conditioner main circuit

Fig.4 Application to photovoltaic power conditioner

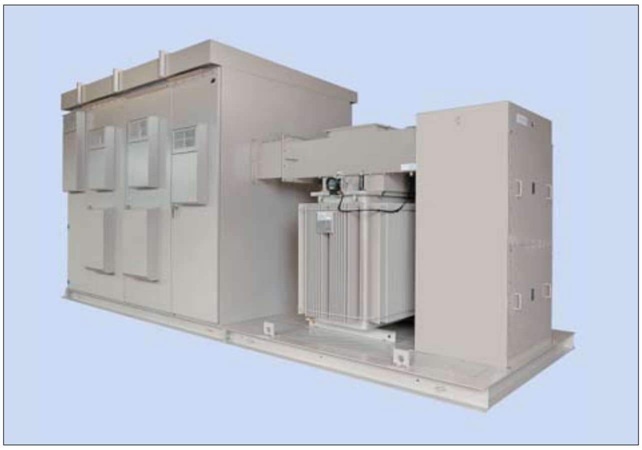


Fig.5 Power conditioner for use with mega solar

efficiency which is the world's highest class for use in 1,000 kW mega solar applications. The integrating of peripheral devices such as switchgears and transformers, and the packaging of basic functions enables onsite installation and assembly work to be performed in a shorter amount of time and construction costs to be reduced (see Fig. 5).

As a drive unit that can contribute to energy savings at large-scale facilities such as iron and steel plants, Fuji Electric has developed a stack-type high performance vector control-type inverter having a maximum output of 3,000 kW. The stack type configuration separates the inverter and converter functions, and direct parallel-connection technology for driving a motor can be applied when using multiple inverters in

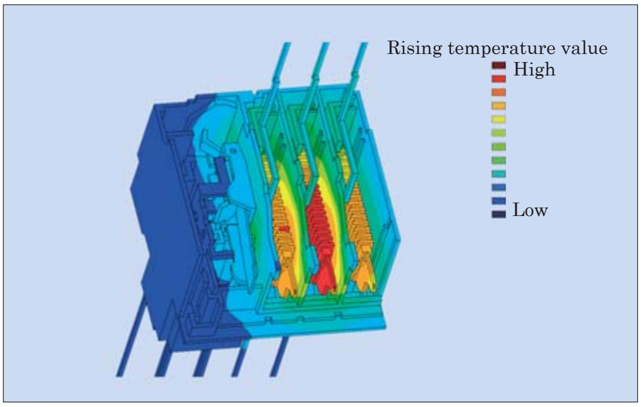


Fig.6 Coupled analysis of the amount of bimetal curvature and the electric current and electric heat.

parallel. In this case, continuous operation will be possible even if an inverter fails, and redundancy and an optimal combination can be realized according to the capacity of the customer's facility.

At factory production facilities, office buildings and commercial facilities, the importance of configuring space-saving, energy-saving and high-reliability distribution equipment and control systems is increasing. As power distribution and switchgear equipment that supports this need, Fuji Electric has developed 32 to 63 AF compact low-voltage circuit breakers and earth leakage circuit breakers for protecting small current circuits such as electric machinery and control panels. Additionally, as shown in Fig. 6, Fuji Electric developed a compact thermal relay by performing coupled analysis of electric current, heat transfer and amount of bimetal deformation to minimize the amount of heat generated by the heater and realize the industry's smallest class size. For higher voltage applications such as photovoltaic power generation systems, Fuji Electric has launched a series of 1,000 V DC nonpolar circuit breakers and switching devices. In addition, using an imbalance compensation algorithm for the earth capacitance, Fuji Electric has developed an Ior insulation monitoring unit for realizing a highly reliable distribution system and a power monitoring unit equipped with SD memory that facilitates the construction of stand-alone power monitoring systems.

2.2 Thermal Energy Technology

In the field of thermal energy, technologies that efficiently utilize high temperature heat, such as for thermal power generation and geothermal power generation, and technologies that efficiently utilize cold heat such as for data centers, vending machines and showcases, are being developed.

Fuji Electric delivered, for its first time, uniaxial combined cycle power generation systems to The Okinawa Electric Power Company, Incorporated as No. 1 and No. 2 units of the Yoshinoura Thermal Power Station, and these units were put into commercial operation in November 2012. A gas turbine from Siemens AG and an electric generator and steam turbine from Fuji Electric are arranged uniaxially, with a clutch interposed between the electric generator and the steam turbine. Use of the clutch to optimize the starting of the gas turbine and the steam turbine enables the startup loss to be reduced. Compared to a conventional thermal power generation system that generates power with only a steam turbine, a combined cycle power generation system fueled by natural gas has such advantages as higher power generation efficiency, lower CO_2 emissions, and superior operability with easy startup and shutdown, and the use of combined cycle power generation systems has been expanding in recent years.

Fuji Electric has developed and launched energy-saving showcases for use in supermarkets. Refrigerated and freezer showcases blow out cold air from the front, blocking outside air as if a curtain were in place, and keeping the cold air inside. Thermal fluid simulation technology was used to analyze precisely the air curtain volume and flow, and the cold air blowing unit and the structure of the product display shelves were thoroughly reviewed to realize significant energy savings. Use of these showcases can lower the total power consumption per store for showcases and refrigeration by 30%.

Heat pump technology is a technology that significantly contributes to energy savings. Fuji Electric has developed an indirect outside air cooling system that indirectly introduces outside air and uses a heat pump to perform efficient air conditioning. This system is being used in data centers and the like that consume large amounts of electric power for air conditioning. Additionally, Fuji Electric led the industry in introducing a vending machine that employs heat pump technology to warm beverages using the waste heat generated while cooling products, rather than discarding that heat externally. Moreover, a hybrid heat pump method that takes in, as a heat source, not only the waste heat generated during product cooling but also the heat of the outside air, has also been developed (see Fig. 7). With this method, by controlling a proprietary electronic expansion valve at the same time that the compressor is being driven by the inverter, cooling and heating control is implemented corresponding to the load. As a result, Fuji Electric constructed energy saving technology that eliminates the need for a heater except when there is a high load, such as at the initial installation of the vending machine. In this way, although the installation of the heat pump already reduced the energy consumption by half, the hybrid heat pump method realized an additional energy savings of 30%.

In order to transfer cold and hot heat efficiently, Fuji Electric has developed an all-aluminum heat exchanger that transfers heat from a refrigerant to the air more easily than a conventional fin and tube heat exchanger, and that can significantly improve the heat exchange performance. The thermal transfer performance of this heat exchanger is improved with a perforated tubular structure having multiple refrigerant flow paths and corrugated-shaped fins that are

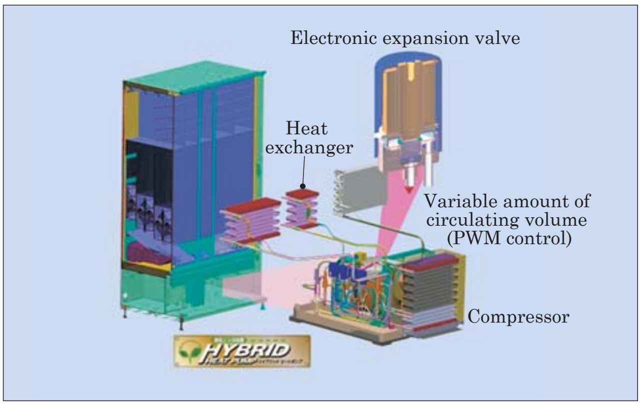


Fig.7 Hybrid heat pump method

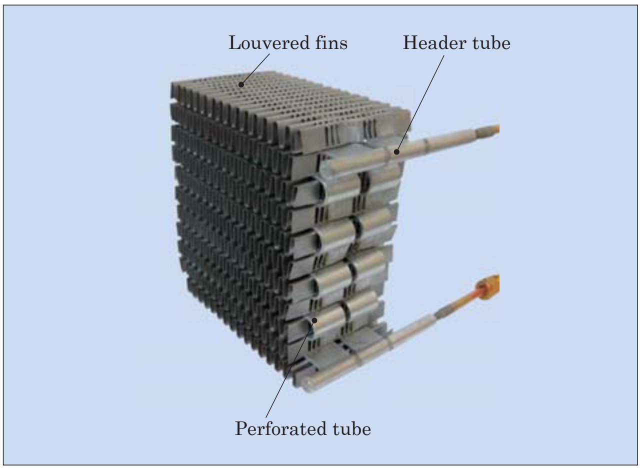


Fig.8 All aluminum heat exchanger

integrally attached by solder (see Fig. 8). This heat exchanger is used in vending machines that employ the above-described hybrid heat pump method. Utilizing thermal technology having such features, Fuji Electric intends to develop a wide range of thermal energy management technology for factories, office buildings, data centers and the like, and to contribute to the energy savings of thermal energy as well as electric energy.

2.3 Control Technology

In order to create responsible and sustainable societies by fully utilizing electric and thermal energy technology, optimal control technology for electric energy and thermal energy storage, including electric power storage and heat storage, is indispensable. As such a control system, development and demonstration work is moving ahead for Fuji Electric's energy management system (EMS) that communicates demand side and supply side energy information bidirectionally to utilize energy efficiently based on that information and realize energy savings.

Fuji Electric is advancing the development of factory energy management systems (FEMSs), building and energy management systems (BEMSs) and retail energy management systems (REMSs) that visualize the energy consumption of energy consumers such as factories, stores and buildings, and introduce and optimally control various energy-saving devices.

Common parts for constructing these EMSs were made into a platform and a mechanism that facilitates efficient system development was established. Each EMS has been developed in a smart community demonstration project, to be described later, and demonstrations of their effectiveness are already underway.

The concept of smart communities, which aim for sustainable development of the entire community, including the efficient usage of energy, cyclic utilization of resources, environmental protection and the like, has been attracting attention. This is a concept that greatly expands the idea of smart grids that aim to provide electric power grids with the ability to perform optimal control of the supply and demand control of electric power, expand the introduction of renewable energy, and reduce the consumption of electric power.

As mentioned below, many technologies and solutions are presented in organic combinations. These technologies and solutions address the challenges of supplying power using renewable energy, improving the efficiency of the supply of energy including thermal energy and adopting green technology. The implementation of energy saving buildings, factories and stores that use each EMS to control energy consumption optimally, ecofriendly transportation systems, safe and secure water supply and sewerage systems, wastewater treatment, and the like.

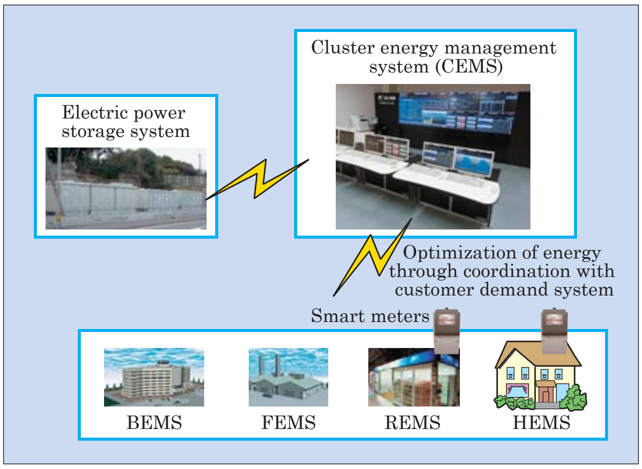


Fig.9 Kitakyushu Smart Community Creation Project

While participating in smart community demonstration projects, Fuji Electric is also developing these technologies. In Japan, Fuji Electric is participating in the development and demonstration of a cluster energy management system (CEMS) in Kita Kyushu City (see Fig. 9). Technical development such as optimal energy control with a CEMS, power stabilization by using storage batteries, supply and demand control through the use of smart meters, and optimal energy control for hospitals, factories and stores was carried out, and demonstration testing of these systems has begun. Through using a CEMS and a smart meter in a public demonstration to verify the effect on power consumption due to dynamic pricing, which causes the unit price of power to fluctuate according to power demand, a maximum peak cut of 13% was confirmed for the summer months.

The results of these demonstrations are consolidated as “a compact social infrastructure package,” as depicted in Fig. 10, and their application to smart communities, industrial parks, islands, and other regions without electricity is being promoted. This package also includes power control solutions for maintaining power quality even when large quantities of renewable energy are introduced, energy-saving solutions based on an EMS, safe and secure solutions that utilize environment measurement technologies and ICTs, and service delivery solutions such as environmental measures.

2.4 Fundamental and Advanced Technologies

Fuji Electric is also advancing the research and development of fundamental technologies that com-

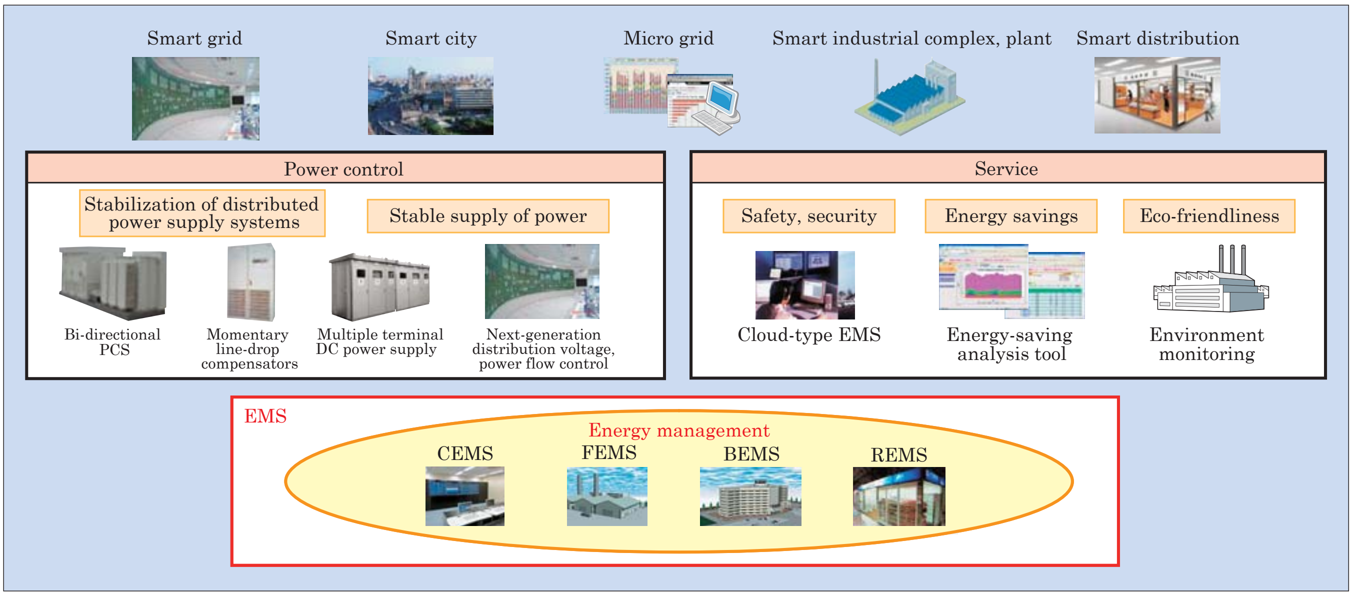


Fig.10 Compact social infrastructure package

monly support the electric and thermal energy technologies and control technologies described above. For materials technologies, to establish guidelines for the required physical properties of resins that are widely used in products, Fuji Electric is studying technologies that utilize molecular simulation techniques. The resins are analyzed in terms of their molecular structure and electron states, and molecular dynamics are used to analyze the effects of fillers that are mixed with the resins to realize higher heat resistance. This technique is applied to the development of materials for various devices, including semiconductor packages.

For insulation technology, Fuji Electric has developed partial discharge visualization technology that combines a high-speed camera and microscope to allow observation of small areas at high speed. This technique allows observation of details of the behavior of the insulation breakdown of foam caused by partial discharge with a gel, and has made it possible to clarify the discharge-generating mechanism, which heretofore had been unknown. Fuji Electric plans to apply this method to the development of high-voltage power semiconductor modules.

Fuji Electric developed a simulation technique that can be used at the design stage for the accurate evaluation of electromagnetic compatibility (EMC: the generation or reception of electrical or magnetic interference) characteristics (see Fig. 11). The application of this technique to product design has resulted in improved reliability of power electronics equipment and shorter development times.

Compliance with international standards is becoming increasingly important. As in the saying, “that which controls the standards controls the market,” regardless of the excellence of a certain product, that product will not be able to capture its market, unless it meets global standards. Fuji Electric has established an in-house international standardization committee to strengthen its compliance of standards relating to power electronics products and smart communities.

Fuji Electric is participating in such committees as the International Electrotechnical Commission’s TC22 (Technical Committee 22) (power electronics) and TC57 (power system management and the exchange of related information), and is actively involved in EMC functional safety, which will be standardized in the future, and energy efficiency standards and the like.

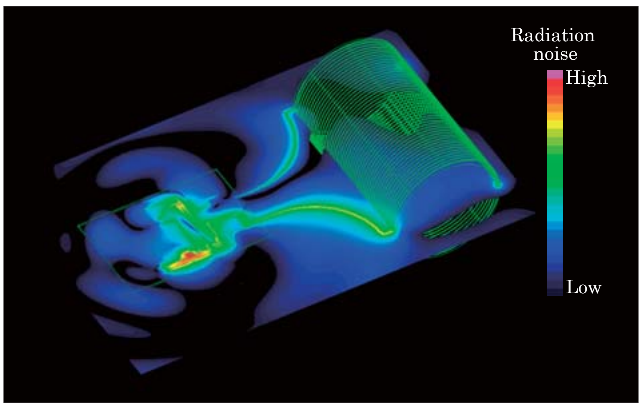


Fig.11 Example of EMC simulation (analysis of radiation noise)

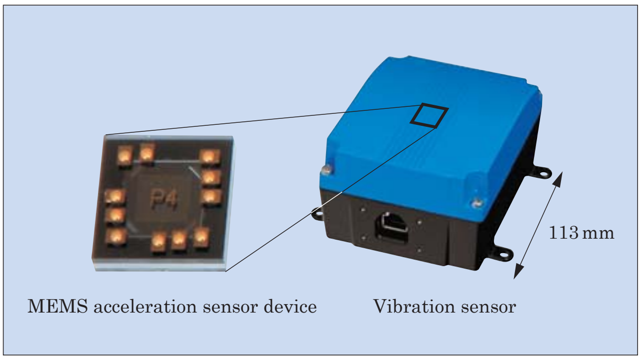


Fig.12 Vibration sensor based on MEMS technology

In terms of advanced technology, Fuji Electric is moving forward with the research and development of distinctive devices that utilize micro electro mechanical systems (MEMS) technology. By applying MEMS technology, Fuji has developed compact, low-cost acceleration sensor devices that can measure acceleration along three axes, the X-axis, Y-axis and Z-axis (see Fig. 12). Utilizing their advantages of compact size and low cost, these acceleration sensor devices are being verified in multi-point vibration measurement applications for large structures such as buildings and bridges, and in high-density applications for seismic measurement and the like, and there is a great deal of interest in these devices.

In addition, Fuji Electric is participating in the project of the Innovation Center for Medical Redox Navigation with Kyushu University, and is carrying out research and development of an optical scanner intended for use in medical devices, where small size is required. To drive the scanner, electrostatic attraction between electrodes fabricated with MEMS technology is used. Techniques to realize even further miniaturization are under development.

3. Postscript

This paper has presented an overview of Fuji Electric’s focused research and development activities in the fields of electric and thermal energy and control technology.

Hereafter, building responsible and sustainable societies that are in harmony with their environments will be accelerated both in Japan and globally. To meet the requirements of such an era, Fuji Electric will continue to advance research and development, and to offer distinctive products and solutions in order to contribute beneficially as a good corporate citizen of the global community.

References

(1) MATSUMOTO, Y. et al. “Characteristics of the power electronics equipments applying the SiC power device.” Proceedings of ICPERE 2012.

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