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.

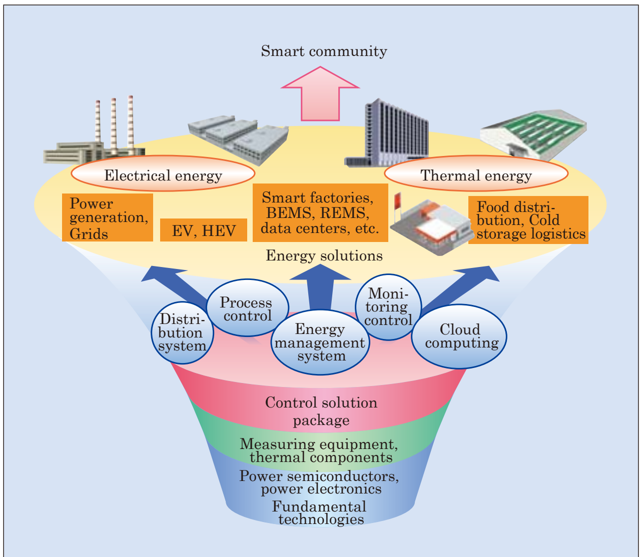


Fig.1 Fuji Electric's core technology and areas of focus

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.

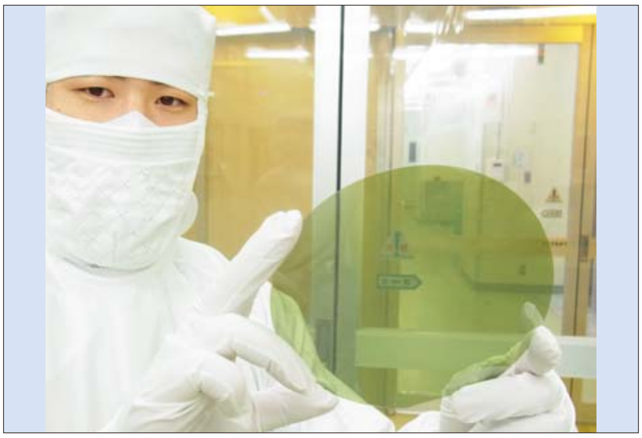
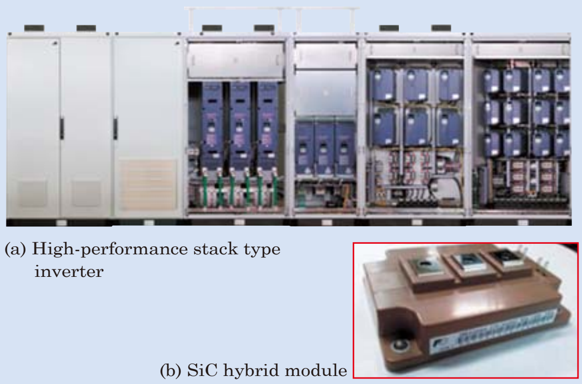


Fig.2 6-inch SiC wafer

(a) PCS for photovoltaic power generation

(b) All-SiC module

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



(a) High-performance stack type inverter

(b) SiC hybrid module

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

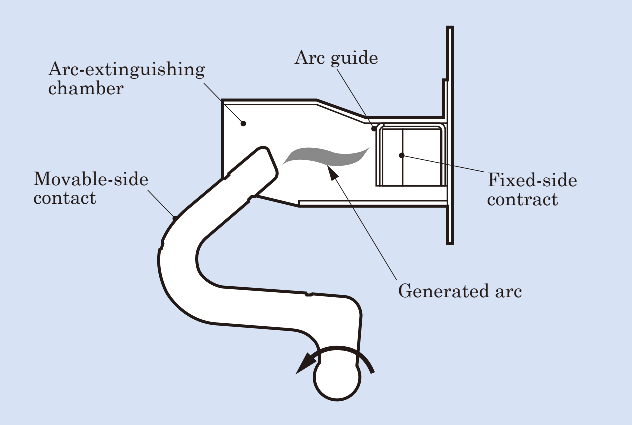


Fig.5 Structure of LBS arc-extinguishing part

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 solu-

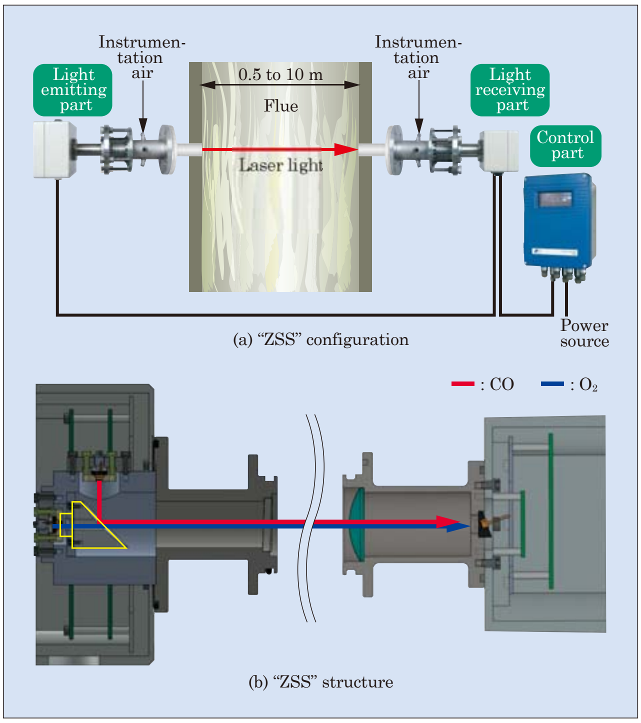


Fig.6 "ZSS" direct-insertion type laser two-element gas analyzer

tions for factories, including the utilization of heat.

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

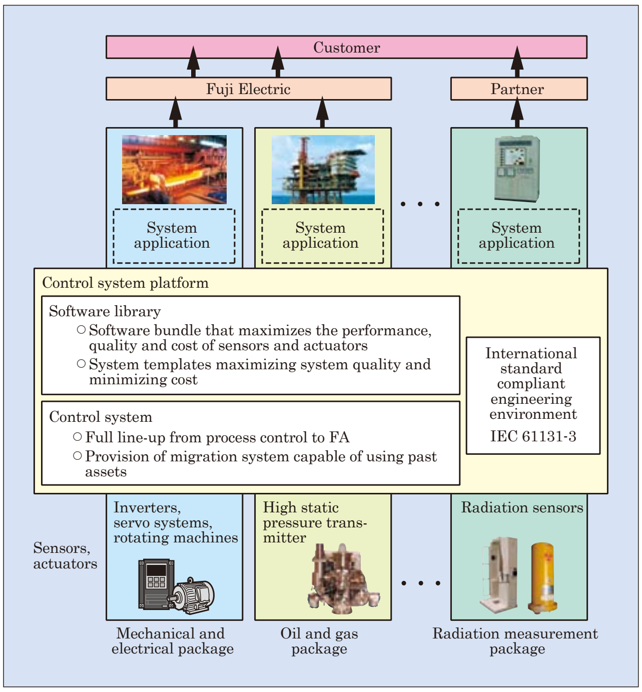


Fig.7 Control system platform

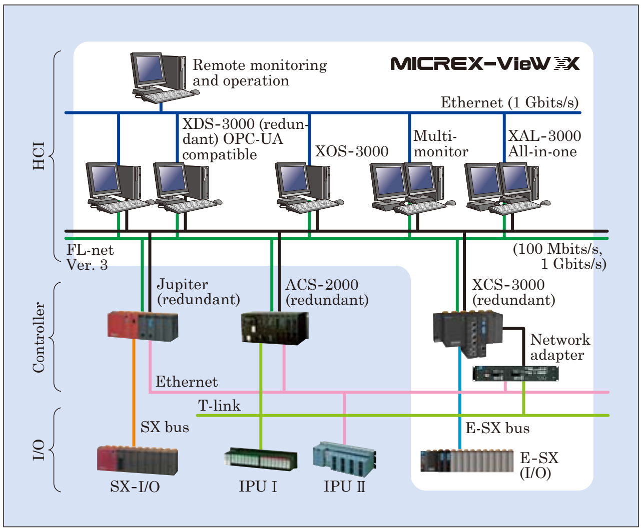


Fig.8 “MICREX-VieW XX” small and medium scale monitoring control system

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

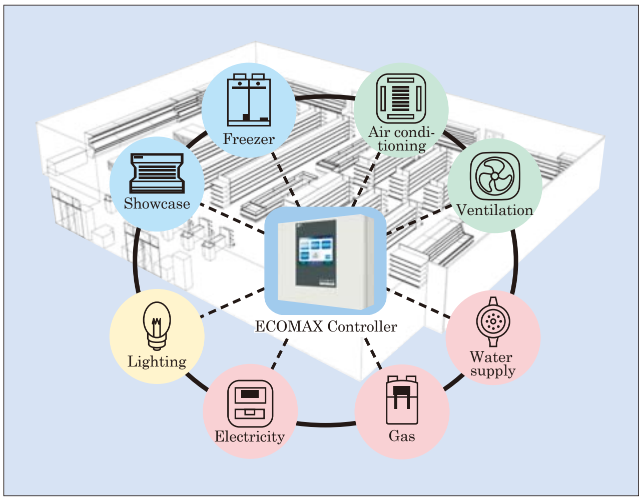


Fig.9 Store management system configuration using the “ECOMAX Controller”

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

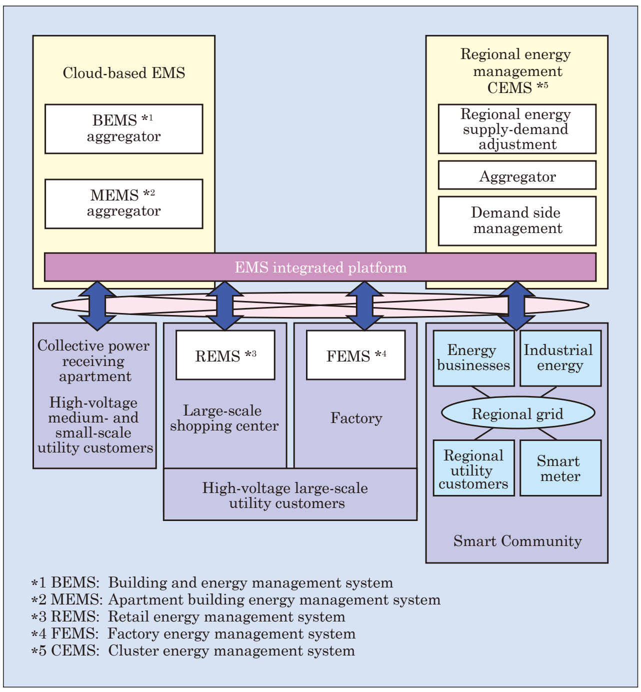


Fig.10 Fuji Electric's concept of EMS

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].

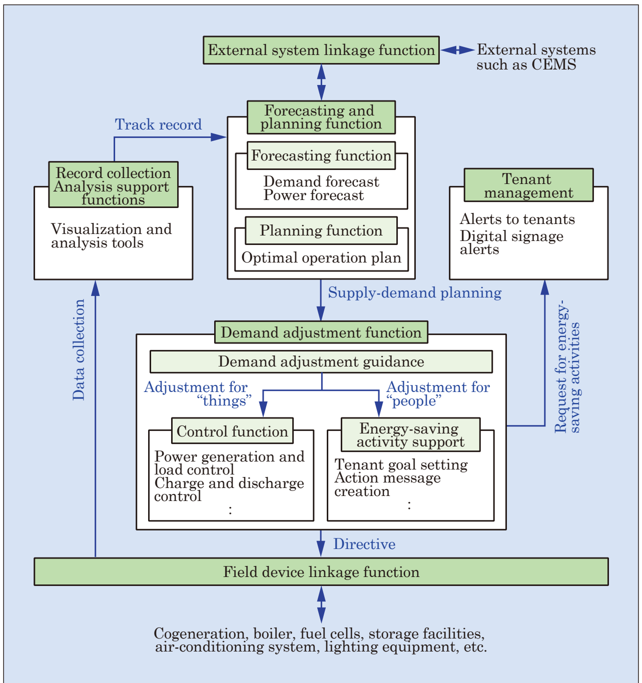


Fig.11 EMS functional configuration for large-scale commercial facilities

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

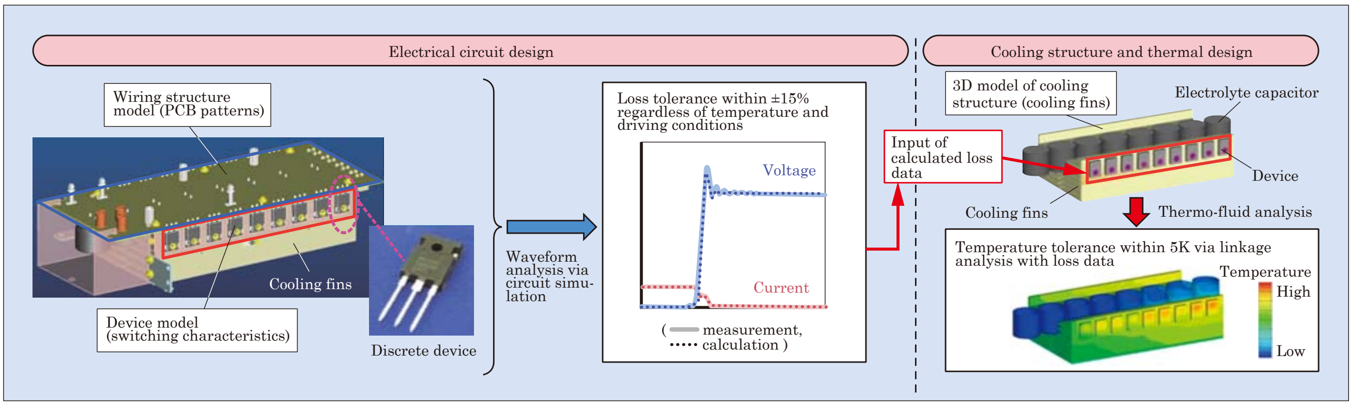


Fig.12 Device and circuit linkage simulation

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.

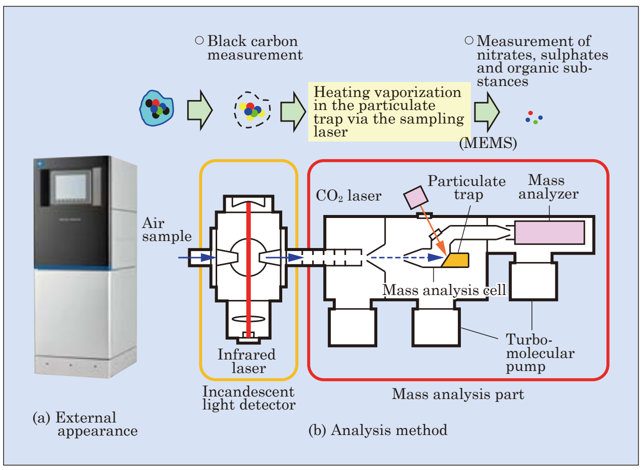


Fig.13 Aerosol compound analyzers

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.

References

(1) Momose, F. et al. New Assembly Technologies for T_{jmax}=175°C Continuous Operation. FUJI ELECTRIC REVEIW. 2013, vol.59, no.4, p.226-229.
(2) Machida, S. “F-MPC PV,” String Monitoring Unit for Photovoltaic Power Generation Systems. FUJI ELECTRIC REVEIW. 2013, vol.59, no.3, p.201-203.
(3) Konishi, H. et al. Cross Stack Laser Gas Analyzer Contributing to Energy Conservation, “ZSS.” FUJI ELECTRIC REVEIW. 2014, vol.60, no.1, p.49-53.
(4) Nishiwaki, T. et al. Small- and Medium-Scale Monitoring and Control System to Realize Inheritance and Evolution of Customer Assets, “MICREX-VieW XX.” FUJI ELECTRIC REVEIW. 2014, vol.60, no.1, p.33-37.
(5) Kido, T. and Kanzaki, K. The “ECOMAX Controller” Realizes an EMS for Use in Stores. FUJI ELECTRIC REVEIW. 2013, vol.59, no.3, p.181-185.
(6) Oga, E. and Kabasawa, A. Social System Demonstration of Dynamic Pricing in the Kitakyushu Smart Community Creation Project. FUJI ELECTRIC REVEIW. 2013, vol.59, no.3, p.152-159.
(7) Horiguchi, H. et al. Integrated Energy Management

System Platform. FUJI ELECTRIC REVEIW. 2011, vol.57, no.4, p.146-151.
(8) Komatsubara, S. et al. EMS for Large-Scale Commercial Facility. FUJI ELECTRIC REVEIW. 2013, vol.59, no.3, p.170-175.

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