Achievements and Future Outlook

IoT-Connected Powerful Components and Solutions Creating Customer Value

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1. Introduction

Fuji Electric has been creating distinctive component and system products designed for the efficient use of energy through innovation in electric and thermal energy technology. For that purpose, we set power semiconductors and power electronics as our core technologies and make full use of instrumentation and control technology. By connecting such products through the Internet of Things (IoT) and utilizing analysis, prediction and optimization engines (analytics software), we have been continuing our thorough pursuit of customer value.

In FY2016, Fuji Electric has completed upgrading its research and development bases in an effort that was launched the previous year (see Fig. 1) and promoted the reorganization of its research and development system. In addition, the IoT Strategy Office was established that will play the role of formulating company-wide IoT strategies and promoting their implementation.

We have set a research and development policy of developing overwhelmingly powerful components and solutions in the areas we focus on and core technologies (see Fig. 2) by positioning the creation of customer value at the center of our activities. Specifically, we made efforts to reap the benefits from our work on silicon carbide (SiC) devices, enhancing and accelerating power electronics development, creating customer value by utilizing the IoT, accelerating the development for overseas business reinforcement, and continuously enhancing the development of common fundamental and advanced technologies. This paper introduces our latest development status.

Fig.1 Completed research and development bases

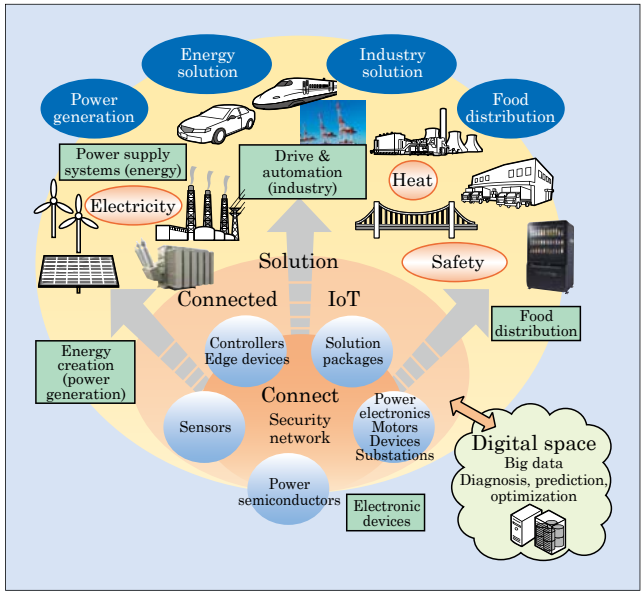

Fig.2 Fuji Electric's focused areas and core technologies

2. Solutions Creating Customer Value through IoT Utilization

The utilization of the IoT has been spreading on a global scale, signifying the beginning of the age of reform through digitalization. When seen from a higher perspective, these efforts have an essential point in common, although their scopes or other conditions are different. The point is to create customer value through the use of information and communication technology (ICT) which is now available at low cost.

Fuji Electric has defined the IoT as "a generic term for systems that digitalize every piece of information in a customer's field (machine, equipment, infrastructure, etc.) and create new customer value in cyberspace"

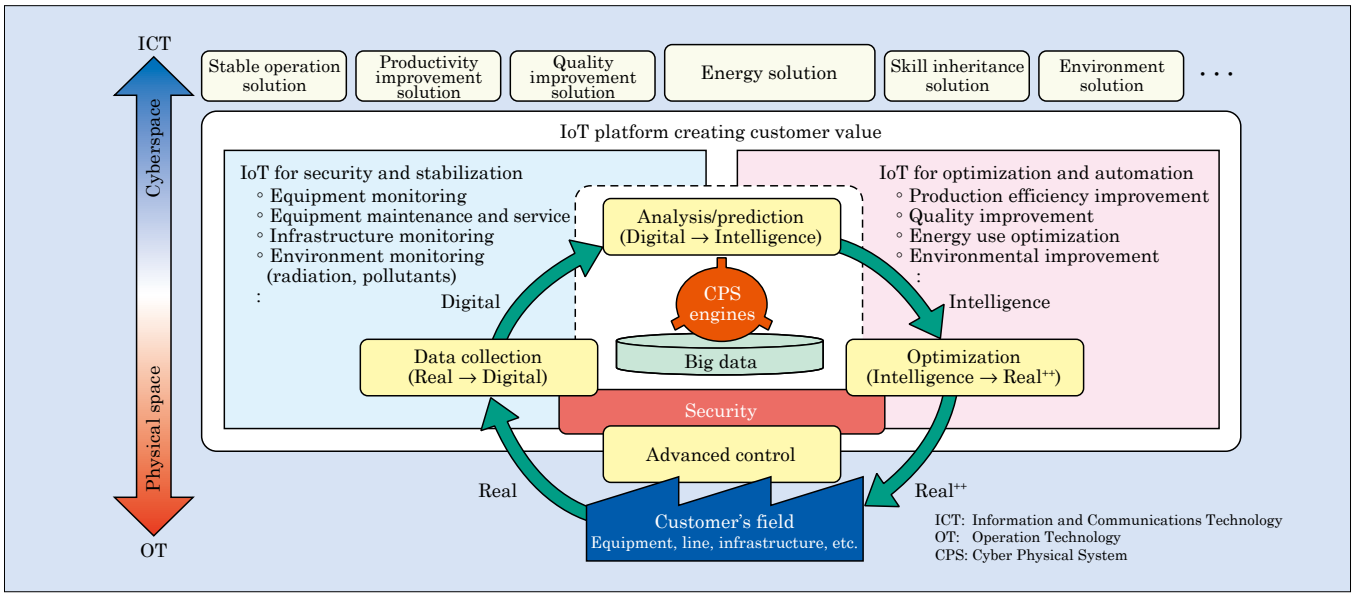

Fig.3 Fuji Electric's IoT concept

(see Fig. 3)[1]. We developed a platform of such value-creation mechanisms and provided solution menus such as energy optimization, stable operation, productivity improvement, quality improvement, skill inheritance and environmental improvement to continue commercialization and functionality enhancement.

With the further penetration of the IoT, an increasing number of things are expected to connect to networks autonomously. Fuji Electric has been developing original products that allow existing devices and equipment manufactured both internally and by other companies to connect to cyberspace (see Fig. 4)[1].

In order to create various customer value such as optimum energy use, stable equipment operation and improved productivity and quality, Fuji Electric possesses many kinds of technologies including analysis, diagnosis, prediction, optimization, advanced control and recognition. We call these technologies cyber-physical system (CPS) engines and position them as core technologies of the IoT platform (see Fig. 5).

Fuji Electric's IoT utilization concept is "Small & Quick Start." We think it important to identify a section that promises good effects and complete the process from implementation to effect evaluation within a short period, instead of trying to apply the IoT for over the entire range to address customer issues at a time. Among CPS engines, multivariate statistical process control (MSPC) is expected to produce good effects in particular on diagnosis and prediction on manufacturing sites. Fuji Electric has commercialized a software package of MSPC and is accumulating track records through its Small & Quick Start approach. We have been confirming operation effects, such as improving productivity, manufacturing quality, operation and maintenance efficiency and plant efficiency as well as ensuring process quality traceability in several projects, including those in our own factories, while increasing application examples. Our IoT utilization is not limited to the energy and industry fields. For

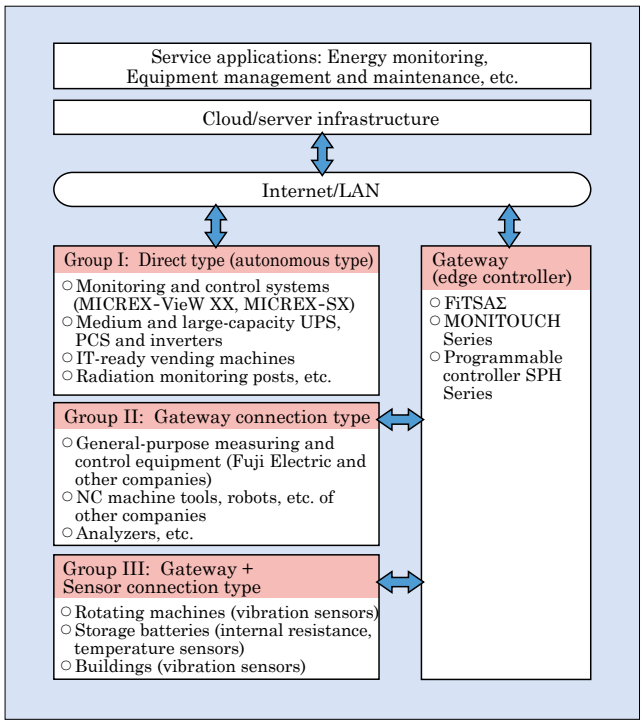

Fig.4 Product development based on type of connection to cyberspace

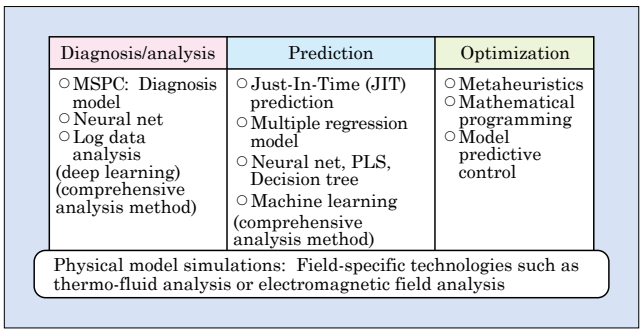

Fig.5 Examples of CPS engines

Fig.6 Digital signage vending machine

example, we are now developing interactive communication technologies for the next-generation vending machines, such as digital signage, linkage with smartphones, voice and face recognition and gestures (see Fig. 6).

We are determined to provide future systems and services that can offer value from the standpoint of customers.

3. Synergy of Power Semiconductors and Power Electronics Technology

Fuji Electric has been pursuing the development of new products and improving the performance of Si power semiconductors. We have already released the 7th-generation insulated gate bipolar transistors (IGBTs). In FY2016, we offered further line-ups of 7th-generation IGBTs. At the same time, we have directed our company-wide research and development efforts toward power semiconductors made of SiC from which a revolution in power semiconductors is expected due to its low switching loss. We have also moved forward with research and development of power electronics products incorporating these power semiconductors to pursue a synergy between power semiconductors and power electronics products.

In order to meet the expanding demand for high-voltage and high-capacity inverters and wind power generation systems, Fuji Electric has developed a high-power IGBT module with a rated voltage of 1,700 V for the line-up of the 7th-generation “X Series” IGBT modules. We reduced power loss by improving the characteristics of semiconductor chips and reduced thermal resistance considerably by using a high thermal conductive insulating substrate. Consequently, we have achieved products with the maximum rating of 1,700 V/1,800 A, which had been difficult with conventional technologies. Moreover, we raised the guaranteed continuous operating temperature to 175 °C from the conventional 150 °C to meet the requests for miniaturization, low loss and high reliability. We have also developed a reverse-conducting IGBT (RC-IGBT), which is an innovative technology, replacing IGBTs and free wheeling diodes (FWDs). RC-IGBTs adopt a technology for integrating an IGBT chip and an FWD chip and can improve the maximum rated current of module packages. We therefore are working on expanding the product line-up intended for the industrial field.

As for power semiconductors for automotive applications, Fuji Electric has been pursuing comprehensive development including discrete devices, modules, inverters and motors according to the increasing trend of electric vehicles. Automotive components are required to be compact. Combining RC-IGBTs with thermal-cooling and packaging technologies enables a considerable size reduction and high power density of modules. RC-IGBTs are thus increasingly adopted in IGBT modules for automotive applications. Sample shipment of direct liquid cooling power modules for automotive applications (see Fig. 7) started in FY2016.

As for SiC devices, Fuji Electric has developed trench gate SiC metal-oxide-semiconductor field-effect transistors (SiC-MOSFETs) using 6-inch substrates, which are the next generation devices of planar gate SiC-MOSFETs, which have already been placed on the market. Compared with Fuji Electric’s planar gate SiC-MOSFETs, this 1.2-kV trench gate SiC-MOSFET is based on the smaller design rules to reduce the cell pitch size to almost half, resulting in a reduction of the on-state resistance per unit area by about 50%. This has achieved high reliability and the greatest low-loss performance in the world ($R_{on}{\cdot}A$ = 3.5 mΩ·cm^2).

Fuji Electric has commercialized All-SiC modules with rated capacities up to 1,200 V/100 A by applying copper pin connection and resin molding technology to reduce the wiring inductance inside the modules and enable high-speed, highly-reliable operation of SiC devices at high temperatures. In FY2016, we designed a package with a new structure for capacity enlargement and achieved an All-SiC module with a rated capacity of 1,200 V/400 A that incorporated 1st-generation SiC trench gate MOSFETs (see Fig. 8). In North America, an increasing number of data centers have been built due to the introduction of cloud-based information systems and the IoT. Accordingly, the uninterruptible power system (UPS) market currently with a size of about 100 billion yen is expected to grow at an annual rate of 3% or more. Under such conditions, Fuji

Fig.7 Direct liquid cooling power module for automotive applications

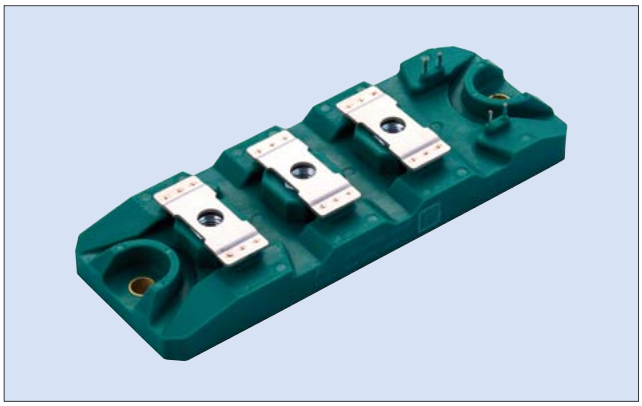

Fig.8 All-SiC module with rated capacity of 1,200 V/400 A

Fig.9 Large-capacity uninterruptible power system with SiC hybrid module incorporated

Electric launched the "7300WX-T3U" large-capacity UPS (300 kVA) (see Fig. 9). This product employs a "3-level power conversion circuit" that uses an internally developed SiC power semiconductor and a reverse-blocking IGBT (RB-IGBT) based on our original technology and have achieved the industry's highest equipment conversion efficiency of 97.5%. Even under a low load (load factor of 25%), this UPS has achieved an equipment conversion efficiency of 96.3%, which reduces power loss and contributes to energy saving.

Following this, we are currently promoting the research and development of power electronics equipment containing All-SiC modules in which both diodes and transistors use SiC. Examples of such products include a high-end inverter characterized by high thermal resistance and low loss, as well as distribution equipment providing high withstand voltage performance.

4. Energy Solutions

The introduction of a great amount of renewable energy sources and the review of the electric power trading market scheme have led to issues in the power system. These include frequency fluctuation in the power system and voltage increases due to the reverse power flow from distributed power sources and are required to be addressed. To meet the requirement, Fuji Electric plans to roll out storage battery control systems and variable inductance-based static var compensators (SVCs) as the core products intended for stabilization. As for the next-generation distribution and control devices, we have also been developing SVCs that take advantage of high withstand voltage, which is one of the features of SiC. Moreover, we initiated a new effort to participate in a demonstration project of a virtual power plant (VPP) that collectively operates utility customers' equipment, such as generators and power storage systems, to use them for electric power adjustment. We are currently studying technical findings and business models.

For the substation system field, Fuji Electric has developed electric distribution facilities and large-capacity power electronics equipment and provided various solution businesses including environmentally friendly systems. In the electric power field, the increase in global energy demand has led to further construction of power plants and substations, resulting in an increase in demand for switchgears. Fuji Electric has been aggressively pursuing global business expansion primarily in Asia, and has recently developed and released the 145-kV gas-insulated switchgear (GIS) "SDH714," which is compliant with the IEC standard (see Fig. 10). Reviewing the breaking mechanism and using aluminum alloy for the sealed container achieve the smallest and lightest class in the industry (30% reduction in footprint and 35% reduction in mass compared with conventional products). The new design has also produced a great improvement in maintainability.

In the power supply system field, the power consumption in data centers has been increasing sharply because servers are now designed for higher performance and density, and there are increasing needs for energy saving. Fuji Electric can halve the construction period (to about half a year) compared with conventional building-type data centers and undertakes engineering, procurement and construction (EPC) contracts that include an electric distribution facility with energy-saving equipment, UPSs and indirect outside air conditioners. One of the examples is the module-

Fig.10 "SDH714" 145-kV gas-insulated switchgear

Fig.11 External appearance of module-type data center delivered to IDC Frontier Inc.

Fig.12 Application example of “MICREX-VieW XX”

type data center delivered to IDC Frontier Inc. (see Fig. 11).

As for air conditioners intended for data centers, we have offered the “F-COOL NEO” indirect outside type air conditioner, which takes in only cold energy from outside air through a heat exchanger (cooling capacity: 40 kW). To address the exponential increase in heat generation that has resulted from servers being designed for higher performance and density in recent years, we have developed a new type for which the cooling capacity was improved to 56 kW. Some of its features include the combination of outside air-based cooling and a built-in refrigerator that can reduce the annual power consumption to almost one-third of that of typical air conditioning units. Additionally, the indirect use of outside air allows inside air to be less affected by moisture, dust particles such as PM2.5 and corrosive substances contained in outside air. Only a power supply is needed and no cooling water is required. We will continue rolling out EPC solutions for entire systems both within and outside Japan to provide systems and products intended for solving customer issues.

5. Industry Solutions

For the process automation field, Fuji Electric has greatly enhanced the functionality of the “MICREX-VieW XX” plant monitoring and control system for the purpose of addressing customers’ challenges of high-quality product manufacturing and stable and efficient operation. We have developed a remote monitoring station, high-speed data collection and display processing, long-term storage of plant data, and improved security. We will provide the product to monitoring and control systems in various plants, including chemical, oil, gas, and electric power plants. Figure 12 shows an example of application to the monitoring and control system for the Nishi Clean Center of the Environment Bureau of Kobe City.

Fuji Electric has many delivery records of electrical equipment for container cranes operating in ports and harbors around the world. We recently delivered electrical equipment and a control system for a container crane intended for a Japanese port (see Fig. 13). The drive system uses a stack-type PWM converter and a high-performance vector inverter to save space and achieve high performance and high reliability. The monitoring system incorporates the functions of state monitoring, cargo management, failure monitoring and failure trace back of the crane to enable immediate analysis and recovery in case of failure. The adoption of a high-accuracy anti-sway control system allows even inexperienced operators to perform stable operation equivalent to experienced operators.

For the factory automation field, Fuji Electric has been working on the development of components and systems that can satisfy different requests, such as performance-oriented and cost-oriented ones or openness. Through the development of such products, we will provide systems, solutions and services that will create different types of customer value depending on the region or industry. For example, we have developed and released the “ALPHA7” (see Fig. 14) and “SPH3000D.” The former is a new servo system that achieves the highest level of fast and accurate control in the industry and the latter is a motion controller for the “MICREX-SX Series.”

Motion control systems have been used in wide range of fields such as semiconductor manufacturing equipment, machine tools, printing machinery and

Fig.13 Container crane designed for ports and harbors

Fig.14 "ALPHA7" (Motor and servo amplifier)

packaging machinery for the purpose of positioning, speed control and torque control in industrial machines including production equipment and automation machinery in factories. Using the ALPHA7 and SPH3000D in such a system will enable motion control with a single CPU module. Since this eliminates the need for a costly dedicated module for motion control, a highly functional and high-performance motion system can be achieved in a cost-effective configuration.

We will promote its application to the fields of packaging machinery, robots and semiconductor manufacturing equipment.

6. Fundamental and Advanced Technologies

Fuji Electric has been continuing with research and development of fundamental technologies that support the technologies described above in a common way, while moving forward with advanced technologies with an eye to the future. Our efforts for common fundamental technologies include experiments, evaluation, analysis and simulations regarding electromagnetics, insulation, electromagnetic compatibility (EMC), thermal fluid dynamics, machinery and resin, metal materials. The efforts in the advanced technologies include research on gallium nitride (GaN) or other semiconductor materials that will take the lead over SiC, and computational science for predicting material physical properties and degradation phenomena.

In thermal power plants, ultra super critical (USC) turbines in which the steam temperature is raised to about 600 °C to improve efficiency are becoming the mainstream. The breakage risk of turbines increases due to the aging degradation of the material. Consequently, it is indispensable to have a remaining life diagnostic technology for predicting aging degradation. Unfortunately, there was no accurate remaining life diagnostic technology for USC turbines because they showed complex degradation phenomena. Fuji Electric has clarified the mechanisms of degradation phenomena including creep and embrittlement by way of long-duration tests and simulations. We established a life expectancy calculation formula that can predict degradation phenomena based on the changes in the grain diameter of the deposits in the material. We

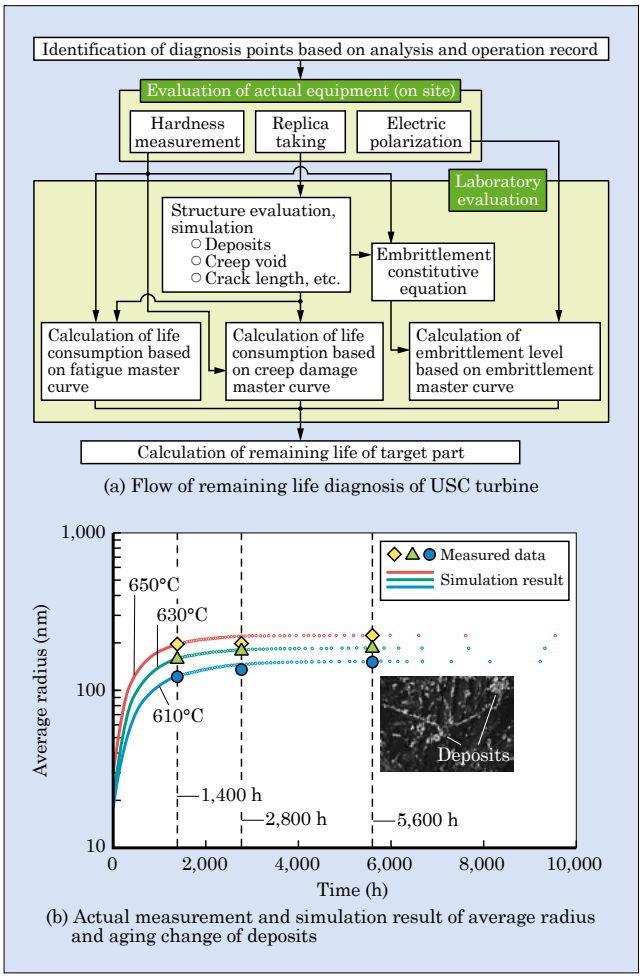

Fig.15 Remaining life diagnostic technology

have also developed a high-accuracy remaining life diagnostic technology by applying non-destructive inspection techniques such as electric polarization (see Fig. 15).

7. Postscript

This paper introduced an overview of the technologies on which Fuji Electric has been working: Technologies of using electric energy sources safely, securely and efficiently; technologies that contribute to energy saving through the effective use of thermal energy sources; and solution technologies that increase added value by optimally controlling these technologies and connecting them through the IoT. The importance of the creation of sustainable societies in harmony with the environment will further increase in the future.

Fuji Electric has embarked on reforming the new product development process from FY2016 to design products contributing to the creation of customer value and pursue research and development to serve that purpose.

We will continue to contribute to the creation of responsible and sustainable societies by providing high-value-added, environmentally friendly products and systems to our customers through our innovation in energy and environment technology.

References

(1) Kondo, S; Fukuzumi, M. Instrumentation and Control Solutions in the New Age of the IoT: Current Status and Future Outlook. FUJI ELECTRIC REVIEW. 2016, vol.62, no.3, p.132-140.

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