Energy Creation and Social Infrastructure Solutions: Current Status and Future Outlook

FUJIWARA, Masahiro*

1. Introduction

The global demand for electric power is predicted to increase continuously at an annual rate of 1.9% in non-member countries of the Organization for Economic Cooperation and Development (OECD) and at 0.6% even in OECD member countries where demand has already become saturated. From a global perspective, it is necessary to address the unstable trend of oil prices and the mitigation of emission of CO_2 and other global greenhouse gases based on the "Paris Agreement" effectuated in fall 2016. In Japan, there are issues that must be addressed, such as reliable implementation of electricity reform, working on the measures for "Long-term Energy Supply and Demand Outlook" formulated in 2015, the revision of the "Feed-in Tariff (FIT) Scheme for renewable energy," and the full liberalization of retail trade in gas from April 2017. In order to address these issues, Fuji Electric is committed to improving the comprehensive economy of its customers by providing higher operation efficiency and maintainability. In the area of energy creation, we have been working on technology development and commercialization in the fields of thermal power generation, geothermal power generation, nuclear power generation, photovoltaic power generation, wind power generation and fuel cells.

Social infrastructure solutions are connected to supporting people's life and economic activities. The conventional solutions have been developed with the aim of creating a comfortable and effective system. On the other hand, the experience of accidents that resulted from aging facilities and several earthquake disasters have caused urgent demand for addressing new evaluation measures such as intrinsic safety, environmental performance and resilience.

Fuji Electric has set "through our innovation in energy and environment technology, we contribute to the creation of responsible and sustainable societies" in its management policies and has been carrying out constant innovation in a wide variety of energy and environmental technologies. For energy creation and social infrastructure solutions, in particular, we continue daily activities with the slogan of "maximized environmental performance, efficiency, economic benefits, value, and innovation" as we carry out our business operations. This paper introduces Fuji Electric's current efforts toward energy creation and social infrastructure solutions in its representative fields and describes the current status and future outlook.

2. Thermal Power Generation Field

Outside Japan, there are strong needs for thermal power generation in Taiwan, South Korea, Southeast Asia and some parts of Africa, which have strong electricity demand. In Japan, there is some need for thermal power generation against the background of a problem with restarting nuclear power plants, biomass power generation*1 in response to FIT, and securing power source by power producers and suppliers.

While improving the economy of thermal power generation, Fuji Electric has reduced environmental load and significantly improved efficiency to help its customers create values. Specifically, we have offered stable and reliable technologies, for example, high temperature and high pressure steam operation, small- to medium-capacity turbines applicable to reheating process, compact steam turbines, and reduction of the number of casings. By using these technologies and know-how effectively, Fuji Electric is currently involved in many projects such as in-

* Power & Social Infrastructure Business Group, Fuji Electric Co., Ltd.

***1: Biomass power generation**

Biomass means organic resources derived from plants or animals. Biomass power generation uses these resources as fuel for thermal power generation to generate power. Biomass can be made from wastes or cultivated plants. When used as fuel, it is dried or processed into the form of chips or pellets.

land-type large gas turbine combined-cycle power generation, ultra supercritical pressure thermal power generation*2 and biomass power generation. We are proceeding with design, manufacturing and construction as we aim for on-schedule completion. We are willing to make efforts in technology innovation and engineering ability improvement now and in the future so that we can meet the requests from our customers inside and outside Japan.

As for after-sales service, Fuji Electric has provided not only simple periodic repairs and rehabilitation but has also been working on improving efficiency and operations by actively applying the latest technologies. Our preventive maintenance has been effective for making a considerable improvement to availability through the application of various diagnosis technologies. We have been contributing to the effort of minimizing the downtime of power plants by strengthening our overseas service bases (the Americas, Taiwan, South Korea, Southeast Asia and the Middle and Near East) as well as by developing on-site maintenance and repair techniques. Furthermore, the Plant Operation Support Center established in the Kawasaki area remotely monitors the operation of plants located inside and outside Japan to provide effective advice from the aspect of operation and maintenance. Fuji Electric will make active suggestions for services while meeting various needs of its customers also in the future.

3. Geothermal Power Generation Field

Geothermal power generation including hot spring power generation has been appreciated anew inside and outside Japan as a renewable energy source that ensures a stable power supply that is independent of the weather and other natural conditions. Geothermal sources applicable for flash cycle power generation*3 have been already used for power plant operation or under planning or development. On the other hand, binary cycle power generation*4 that can utilize low-grade heat sources has great potential in the future. It seems only a matter of time until binary cycle generation surpasses flash cycle generation in terms of the scale of new plants built in a year.

Construction of geothermal power plants is still planned in countries that are aggressively working on geothermal power generation, such as Indonesia, the Philippines, Mexico, Italy, Iceland and Kenya. In Japan, the Long-term Energy Supply and Demand Outlook includes a plan for tripling the percentage of geothermal power generation by 2030. Moreover, as support from the government, financial assistance is available from the Japan Oil, Gas and Metals National Corporation (JOGMEC) for risky attempts to explore geothermal sources or drill wells, which has led to many plans currently being implemented.

As a global top manufacturer in the geothermal power generation field, Fuji Electric has been continuing technology development to improve the economy and operation efficiency and the corrosion resistance, reliability and maintainability of equipment. For after-sales service, as is the case in the thermal power generation field, we have been expanding our service bases and menus and actively making suggestions about services to ensure safe, stable and economical operation of the plants of our customers.

As for flash cycle power generation, Fuji Electric has completed 4 plants in Indonesia and is building plants or manufacturing equipment intended for Iceland, Mexico and the Philippines (refer to "Units 5 and 6 at Lahendong Geothermal Power Plant and Units 3 and 4 at Ulubelu Geothermal Power Plant in Indonesia" on page 12). As for binary cycle power generation, we completed constructing the largest-scale plant in Japan with 5 MW capacity using a substitute for chlorofluorocarbons as the working fluid in March 2017. In addition, we are manufacturing equipment for another plant of the same capacity using normal pentane as the working fluid. We are also entering the hot spring power generation field.

4. Nuclear Power Field

In the Long-term Energy Supply and Demand

***2: Ultra supercritical pressure thermal power generation**

Supercritical pressure power generation is a method for highly efficient power generation conducted under high temperature and high pressure conditions exceeding the critical pressure of water in order to reduce the thermal energy required for water vaporization. The temperature and pressure are increased stepwise to improve power generation efficiency. The condition where the pressure reaches 24.1 MPa or more and the temperature exceeds 566°C is called ultra supercritical pressure power generation.

***3: Flash cycle power generation**

This is a power generation method used when the steam coming from the production well contains much hot water. Only steam is extracted with a steam-water separator and then used to turn the steam turbine directly.

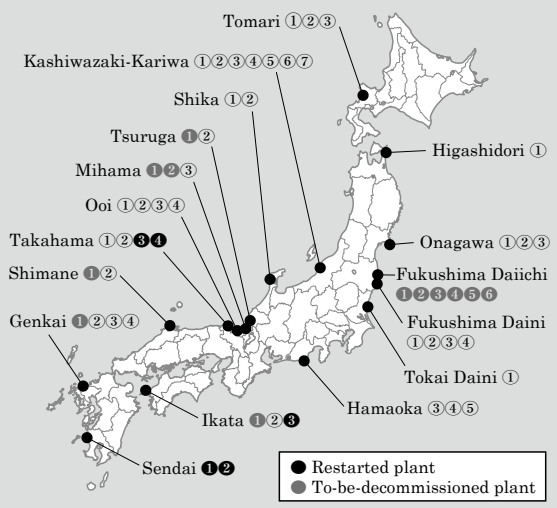
***4: Binary cycle power generation**

This is a power generation method used when steam or hot water at relatively low temperature is used as a heat source. Pentane or another low-boiling-point working fluid is heated to create high-pressure steam which is used to turn the turbine. This method is suitable for low-grade (low-temperature) heat sources that cannot be applied to flash cycle power generation.

Outlook, nuclear power generation is positioned as a power supply covering 20% to 22% of Japan's demand in 2030. However the basic premise is to ensure safety, and the mandatory requirement for restarting plants or continuing construction is to satisfy the new regulatory standards laid down based on the lessons learned from the accident at Fukushima Daiichi Nuclear Power Station. As a result, the decommissioning of 12 reactors has already been decided. Thirty-seven reactors are waiting to be restarted and 5 reactors have been restarted as of the end of 2016 (see Fig. 1).

With the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF) positioned at the center, earnest efforts are currently being made nationwide to fulfill the decommission plan. These include measures against contaminated water, and technology development and equipment design to remove fuel debris. At the same time, the nuclear fuel cycle has also been promoted seriously to reprocess used fuel and use the collected mixture of uranium and plutonium peacefully and effectively. The nuclear power field requires continuous solution technologies at the moment from both aspects of the efforts toward restarting and decommissioning of nuclear power plants.

In order to enable safe treatment, disposal and storage of the radioactive wastes generated in the process of operation and decommission of nuclear power facilities, Fuji Electric has been proceeding with research and development of solidification technology. It has been doing this by utilizing geopolymer materials that have various superior properties in partnership with Amec Foster Wheeler plc in the United Kingdom. Furthermore, we have provided technologies and products that satisfy the new regulatory standards concerning mixed oxide fuel (MOX fuel) manufacturing facilities, remote handling equipment and seismic-resistant switchboards to contribute to the nuclear fuel cycle. (refer to "Seismic-Resistant Switchboards Conforming to New Regulatory Standards Concerning Commercial Nuclear Reactors" on page 18).



(Source: "Current condition of nuclear power generation," The 38th meeting of Japan Atomic Energy Commission, Document 3-1, Federation of Electric Power Companies of Japan, December 1, 2016)

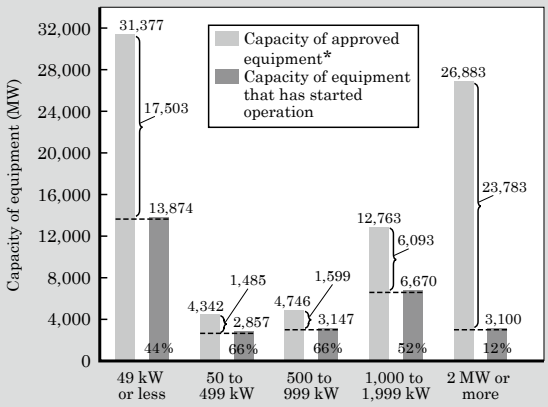
Fig.1 Operating status of nuclear power plants in Japan

5. Photovoltaic Power Generation Field

Since the FIT scheme was introduced in Japan in 2012, the capacity of the equipment that has been approved so far have totaled 80 GW; however, the capacity of the equipment that has started operation remain 30 GW. Among the equipment that has not yet started operation, the total capacity of 49 kW or less low-voltage interconnection power generation equipment is 17.5 GW and that of 2 MW or more extra-high-voltage interconnection power generation equipment is 23.8 GW. This shows the polarized market between small-scale and large-scale equipment (see Fig. 2).

Fuji Electric covers the equipment capacity of 500 kW or more to meet market needs by taking advantage of the know-how in its system components such as power conditioning sub-systems (PCSs) and extra-high-voltage substation equipment as well as in engineering, procurement and construction (EPC, full turn-key solution including site development). The total capacity of the delivered PCSs is 1,800 MW and the total capacity of the deliveries based on EPC is 400 MW including plants under construction.

The most recent issues in this field are as follows: cost savings for ensuring profits despite the reduction in the FIT purchase price, and power system stabilization that becomes necessary with the



(Source: Equipment introduction situation document from METI website "Learn About Reusable Energies")
* Equipment approved by July 2016

Fig.2 Capacity of photovoltaic power generation equipment approved by July 2016 and capacity of equipment that has started operation among them (by capacity)

increased introduction of renewable energies. In order to surely resolve these issues, Fuji Electric has developed and provided PCSs and power system stabilization systems that have achieved high performance and low price (refer to "Kamikita Rokkasho Photovoltaic Power Plant with Capacity of 71 MW DC / 51 MW AC" on page 23).

As for a high-performance, low-cost PCS, our flagship product, a 1-MW outdoor type, is scheduled to be released in October 2017.

We have also developed a new, low-cost power stabilization system by adding large-capacity storage batteries to the conventional one, and it is slated for delivery to several plants. The introduction of this system made it possible to reduce the capacity of the storage battery. This led to a synergy with a reduction in the price of storage batteries to ensure the business feasibility of several projects which had been facing tough conditions.

6. Wind Power Generation Field

Wind power generation has also gained benefit from FIT, and it is expected to be introduced further. Facilities of 7.5 MW or more, however, are mandatory to undergo an environmental assessment that takes about 3 years, so that full-scale construction of large-scale wind farms started in FY2016. Although the purchase price for photovoltaic power generation has decreased greatly, the price for wind power generation has been kept at 22 yen/kWh. Some photovoltaic power generation operators have been making a move to shift to wind power generation as a new investment destination. For the time being, there are expected to be more players planning to introduce wind power.

Fuji Electric has also been providing EPC for several megawatt power plants and has been committed to the engineering of grid connection system and power stabilization system as well as on the sales of system components.

Hokkaido and Tohoku are well known to have many sites where wind conditions are suitable for wind power generation. In the area having a power transmission network with relatively small capacity, there is a challenge of power quality affected by output fluctuations due to a change in the wind conditions. For example, Hokkaido Electric Power Co., Inc. released "Technology requirement for the output fluctuation mitigation measures for wind power generation equipment" in FY2016. It requests operators to install storage batteries or take other measures in new wind power plants to be built so as to keep output fluctuations within the level that will not affect the frequency adjustment of electric power systems.

Fuji Electric put a power stabilization system into practical applications by combining a storage battery and PCS for optimum control and started delivery. This system suppresses the output fluctuation in wind power plants and stabilizes the voltage and frequency within a required value range by charging and discharging the storage battery properly (see Fig. 3).

Fig.3 Power conditioning sub-system for power stabilization system

This system has already been delivered to many customers not only within the territory of Tohoku Electric Power Co., Inc. but also to remote Japanese islands and the Galapagos Islands (refer to "Power Stabilization System with Lead-Acid Batteries and Lithium-Ion Batteries for Galapagos Islands" on page 48).

We will work on the EPC for wind power generation equipment in earnest by setting the power stabilization system at the core and adding our know-how acquired in the EPC for photovoltaic power generation equipment.

7. Fuel Cell Field

Fuel cells can use various types of fuels as long as it contains some material that can generate hydrogen through a chemical reaction. Many practical applications use city gas, LPG, biogas such as sewage digestion gas, and even hydrogen.

Fuel cells are characterized by their high power generation efficiency in spite of their small capacity, emissions containing almost no NO_X, SO_X or other air pollutants, and being low-noise, low-vibration power generating equipment with good environmental properties. They are thus suitable for distributed power sources. When their exhaust heat is recovered and used for a cogeneration system, they can be an excellent power supply with a total efficiency reaching 90%.

Fuel cells can be divided into several types depending on the electrolyte used, including a phosphoric acid fuel cell (PAFC), polymer electrolyte fuel cell (PEFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC). Since the operating

temperature and power generation efficiency vary depending on the type, suitable applications are also different (see Table 1).

Fuji Electric started the development of PAFCs in 1973 and has conducted field tests on over 90 units with up to 5-MW capacity for various outputs and applications with support from the government and in partnership with electric power companies and gas companies. By taking advantage of the knowledge acquired from there, we started the delivery of a 100-kW on-site type commercial unit in 1998 and have delivered 75 units around the world by 2016 (see Table 2). The longest cumulative operation time per unit exceeded 124,000 hours (about 15 years). This proves high equipment reliability and an excellent after-sales service system.

Fuji Electric is currently working on enhancing functionality, expanding applications and reducing price in order to promote the prevalence of PAFCs. We plan to expand the sales of PAFCs centered on the following points: in Japan, grid independent power supply for emergency and the application to biogas power generation*5 that is applicable to FIT; and outside Japan, a fire prevention system that creates a low-oxygen atmosphere in the entire target space by using exhaust gas. Moreover, we are striving to develop an SOFC for next-generation high-efficiency cogeneration systems (refer to "Status of Development and Sales Strategy of Fuel Cell Systems" on page 30).

Table 1 Types and applications of fuel cells

Type	Phosphoric acid (PAFC)	Polymer electrolyte (PEFC)	Molten carbonate (MCFC)	Solid oxide (SOFC)
Operating temperature	190 °C to 200 °C	70 °C to 90 °C	600 °C to 700 °C	700 °C to 1,000 °C
Power generation efficiency	40% to 45%	35% to 40%	45% to 50%	45% to 60%
Major application	Commercial use	Home use, automotive use	Commercial use	Commercial use, home use

Table 2 Delivery destinations of commercial PAFC units (as of December 2016)

Destination		Number of units
In Japan	Office building	6
	Training center, exhibition facility	5
	University, government building	8
	Hospital, hotel	8
	Factory	8
	Sewage treatment facility	28
	Verification test	1
Outside Japan (Germany, South Korea, the United States. and South Africa)		11
Total		75

8. Power Distribution Field

At the Great East Japan Earthquake, long blackouts and planned outages revealed the vulnerability of the power distribution. Consequently, the government and municipalities have been promoting various measures to improve energy security. The introduction of FIT, in particular, has led to a significant increase in the construction of power plants using renewable energies, primarily photovoltaic power. As a result, the issue of power system stabilization has come to the surface. Specifically, there are issues of power system frequency affected by the unstable output of photovoltaic power generation or wind power generation, and of voltage in distribution lines affected by the reverse power flow from distributed power sources.

At the same time, several measures have been promoted such as the freeze on electricity rates, stable supply of power, and increased opportunity for new power providers to enter through the electricity system reform. The Organization for Cross-regional Coordination of Transmission Operators, JAPAN was established in 2015 and the full liberalization of electricity retail trade started from 2016. Further reforms will advance in the future including the abolishment of price control and the separation of power generation and transmission.

The demonstration of a virtual power plant (VPP) is being conducted (see Fig. 4). This is a cluster energy management system (CEMS) developed to be a new stable power supply system.

Timely introduction of various frameworks has been considered as new electric power trading markets, including "an hour-ahead market," "a real-time market," "a capacity market" and "a negawatt market" (see Fig. 5).

At the community level, community energy supply service operations are being planned and established with the aim of local generation for local consumption and for job creation. On the side of utility customers including companies, new energy systems are being developed for minimizing energy costs or in the business continuity plans (BCPs) designed for reducing the loss in business property to a minimum at times of natural disaster.

***5: Biogas power generation**

Biogas refers to gases produced from organic resources such as garbage or sludge through the use of anaerobic microorganisms. Biogas power generation is a method for using such gases to generate power.

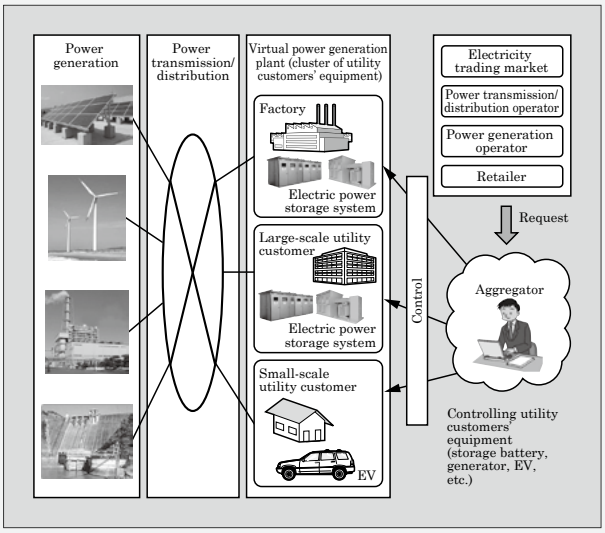


Fig.4 Illustration of virtual power plant demonstration

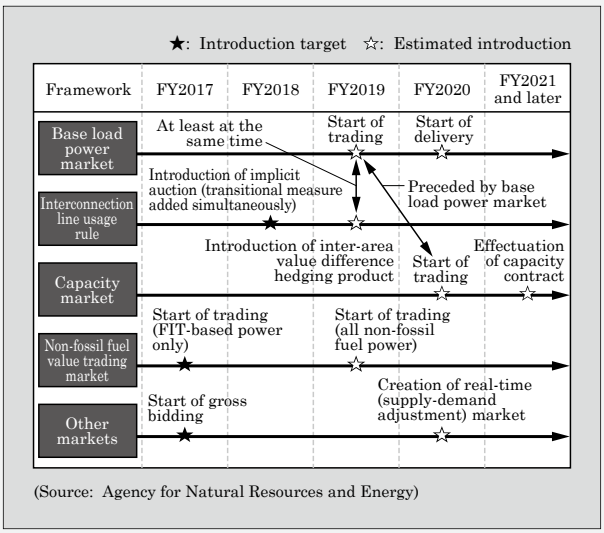


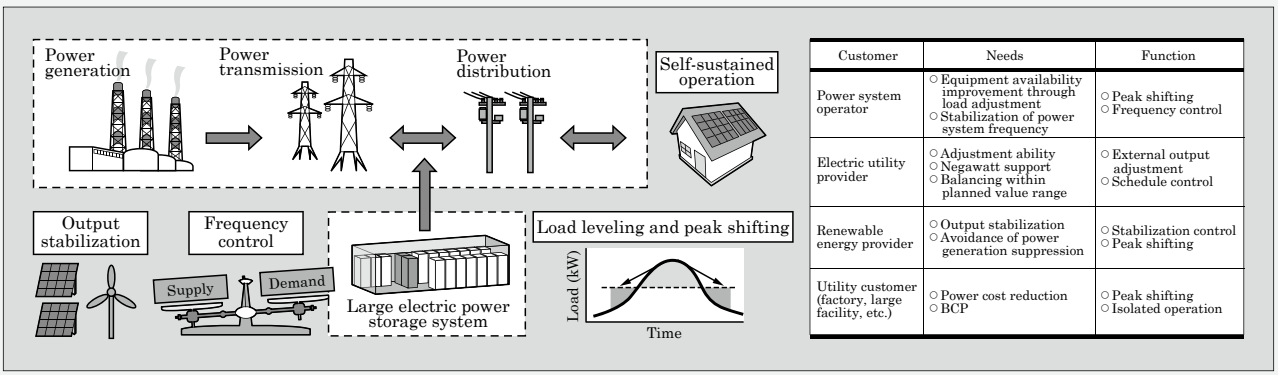
Fig.5 Future outlook in electric power trading market (introduction target and estimated introduction)

Fuji Electric is willing to certainly meet the various needs of its customers by applying the knowledge acquired through various demonstration projects and the results of its independent development as well as by adding information and communication technology (ICT) to the technologies and products related to monitoring, operation and control of power generation equipment and electric distribution facilities. For example, we have developed a computer system for ensuring optimal power system operation, a large electric power storage system designed for power system stabilization and for peak shifting on the demand side, and a static var compensator (SVC) for keeping the power system voltage within the specified value. These systems and equipment have been released onto the market in a timely manner. Introduction examples are shown below.

Figure 6 shows the applications of Fuji Electric's electric power storage system. It achieves all of the storage battery control functions in the figure through a combination of appropriate PCSs and control systems for various needs.

Power storage systems for power system operators such as electric power companies tends to grow in scale and their capacities often increase to several tens of MWh. Fuji Electric delivered a redox flow battery control system to the Minami-Hayakita Substation of Hokkaido Electric Power Co., Inc. in 2015. This system optimally controls the multiple storage banks of the battery system (15 MW, 60 MWh) manufactured by Sumitomo Electric Industries, Ltd. (see Fig. 7). Storage batteries are normally characterized by fast response and easy scalability. They also have advantages of a shorter lead time and less limitation on installation sites compared with pumped storage power generation that has been used conventionally for peak shifting. Consequently, they are expected to be further introduced in the future (refer to "Large-Scale Power Conditioning System for Grid Storage Battery System with Redox Flow Battery Having World's Highest Capacity Class of 60 MWh" on page 41).

As a method for controlling the voltage of the distribution system, Fuji Electric uses an SVC that has no limitation on the number of operations instead of a step voltage regulator (SVR) that is mostly used in present systems although its num-



Customer	Needs	Function
Power system operator	○ Equipment availability improvement through load adjustment ○ Stabilization of power system frequency	○ Peak shifting ○ Frequency control
Electric utility provider	○ Adjustment ability ○ Negawatt support ○ Balancing within planned value range	○ External output adjustment ○ Schedule control
Renewable energy provider	○ Output stabilization ○ Avoidance of power generation suppression	○ Stabilization control ○ Peak shifting
Utility customer (factory, large facility, etc.)	○ Power cost reduction ○ BCP	○ Peak shifting ○ Isolated operation

Fig.6 Applications of electric power storage system in electric power system

Fig.7 Large electric power storage system of Minami-Hayakita Substation

Fig.8 Wastewater treatment facility

ber of operations is limited. SVCs are divided into 2 types, switching converter type or variable impedance type, depending on the method of generating reactive power. The variable impedance type distribution SVC was developed in partnership with Tohoku Electric Power Co., Inc. The step-less, continuous control has been enabled through the use of a variable inductor. The structure without a cooling fan has made it possible to create a smaller and lighter SVC with higher reliability compared with conventional SVCs. As a result, this SVC can be mounted on a utility pole. In the "Demonstration Project on Next-Generation Power Grid Construction for Distributed Energy" of the New Energy and Industrial Technology Development Organization (NEDO), we are currently developing a next-generation SVC that will achieve higher performance, smaller size and lighter weight and can be mounted on a single utility pole using silicon carbide (SiC) modules. Fuji Electric will provide the product together with computing systems for monitoring control to contribute to maintaining the voltage of an entire distribution system (refer to "Distribution Static Var Compensators and Static Synchronous Compensators for Suppressing Voltage Fluctuation" on page 36).

9. Water Environment Field

It is mandatory to treat industrial wastewater from factories and offices properly and thoroughly according to stringent water quality regulations based on the Water Pollution Prevention Act and more stringent standards specified in ordinances of local governments. Consequently, new construction or extension of a factory requires its wastewater treatment equipment to be improved (see Fig. 8). Water quality regulations continue to become more stringent year by year. Companies are facing a challenge to strictly observe these wastewater standards while reducing running costs.

For example, in the food and beverage industry, the demand for instant food or retort food is increasing and various types of beverages are released for people in a wide age range. Companies are required to increase production or production items and change manufacturing processes. This leads to a variation in the amount and quality of wastewater, which makes wastewater treatment control difficult. In terms of considering the surrounding environment and improving the work environment, companies and organizations are also required to prevent foul odors such as those emanated from ammonia or hydrogen sulfide. Since most of the wastewater from food and beverage factories is highly concentrated organic wastewater, they are often processed with biological treatment, as typified by a standard activated sludge method. To use this method for a case where the amount of wastewater increases or their quality changes, companies are compelled to take measures involving significant capital investment, such as reinforcing the treatment capacity or adding pre- and post-treatment facilities that may require civil engineering work.

Fuji Electric has developed a new wastewater treatment solution by using *Bacillus**6 that can reduce the treatment cost and prevent odor simultaneously. This solution uses a specific species of *Bacillus* that can degrade organic material efficiently. We combined it with a special activator which we developed through advanced analysis of genes and enzymes to maximize the degradation ability of the *Bacillus* (see Fig. 9).

This new wastewater treatment solution does not require large-scale capital investment and performs excellently to prevent odors while reducing running costs. In more specific terms, this solution is characterized by the ability to not only degrade highly concentrated organic material in a short time but also prevent the generation of excess sludge, which is one type of industrial waste. The cost for sludge disposal can be reduced by 20% to 40% com-

6: *Bacillus
Refer to "Supplemental Explanation" on page 60.

Fig.9 *Bacillus* inoculum and activator

pared with conventional methods while odors can be reduced to the level of the lower detection limit or less. Moreover, the power for operating the aeration blower can also be reduced by 10% to 40% compared with conventional methods because the species is a facultative anaerobe.

In joint research with Utsunomiya University, Fuji Electric has advanced the application of *Bacillus* to develop a sludge-less wastewater treatment system that can dramatically reduce the initial investment and running costs for new construction or extension of wastewater treatment equipment. This system is based on a combination of *Bacillus* and the magnetically activated sludge method of Utsunomiya University, allowing simultaneous reduction of initial investment, running costs and installation space. For example, the system uses a magnetic separator shown in Fig. 10 for solid-liquid separation in biological treatment, so that it can shrink the capacity of a biological treatment tank to a half or a third compared with conventional methods. A settlement tank is also unnecessary, and thus the construction cost (initial investment) can be saved significantly. Moreover, *Bacillus* promote biological autoxidation so that excess sludge is reduced to zero. This eliminates the need for a sludge dehydrator required for sludge disposal as well as for the costs for chemicals, electric power and disposal, resulting in significant reduction also in running costs (refer to "New Wastewater Treatment Solution Using *Bacillus*" on page 54).

Fig.10 Sludge-less wastewater treatment system (magnetic separator)

10. Postscript

This paper introduced Fuji Electric's current efforts toward energy creation and social infrastructure solutions in its representative fields and described the current status and future outlook. In addition to these, various efforts have been also made such as for the hydroelectric power generation field in collaboration with Voith Hydro GmbH & Co. KG in Germany, electricity smart meters that have the top market share in Japan, and sanitization and operation software packages for government offices.

Fuji Electric is determined to work on technological innovation and service improvement also in the future to help its customers create value by focusing on, listening to and working together with customers. We will also provide safe, secure and environment-friendly energy creation and social infrastructure solutions and continue to make large contributions to the creation of sustainable societies.

Fuji Electric

Innovating Energy Technology

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