

Development of Smart Grid Demonstration Systems

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Sumitomo Electric Industries, Ltd. has developed two smart grid demonstration systems. One is the micro smart grid demonstration system operating at the Osaka Works from June 2011. This system interconnects four types of renewable power generators and a storage battery with a DC cable to balance fluctuations in natural power generation and power consumption, thereby ensuring stable and efficient power supply to the facilities and equipment of the Works without any commercial power network. The other is the megawatt-class power generation/storage system established at the Yokohama Works in July 2012. This system consists of the world's largest redox flow battery (capacity: 1 MW x 5 hours) and Japan's largest concentrated photovoltaic (CPV) units (maximum total power generation: 100 kW). Connected to a commercial power supply network, the system can store electricity during the night. Both systems employ an energy management system (EMS) that monitors generated electric power, battery storage and power consumption, and stores measured data on a central server.

Keywords: smart grid, micro grid, energy management system, redox flow battery, concentrated photovoltaic

1. Introduction

In association with the transition of electric power supply systems from traditional independent, large-scale and concentrated schemes to diversified, flexible distributed schemes, many organizations have in recent years been actively promoting technological development in the field of so-called "smart grids." The objectives of such a transition of power supply systems are to promote the use of renewable energy, to ensure stable supply of electric power even in emergency situations, to consume electric power more wisely, and to more efficiently manage electric power supply and demand.

Sumitomo Electric Industries, Ltd. has energetically promoted the development of various smart grid-related products and systems to expand its business by entering the smart grid market. In line with this strategy, Sumitomo Electric has developed two smart grid demonstration systems. One is a micro smart grid demonstration system that was installed on the premises of the Osaka Works and commenced operation in June 2011, and the other is a megawatt-class power generation/storage system that was installed on the premises of the Yokohama Works and commenced operation in July 2012. Since then, these systems have been operating 24 hours a day. This paper describes the configuration, performance, and other features of these two demonstration systems.

2. Micro Smart Grid Demonstration System

The micro smart grid demonstration system, which was completed in June 2011, interconnects photovoltaic systems, a wind power generator, and a storage battery with a DC cable to sophisticatedly manage highly fluctuating natural energy and power demand, thereby ensuring stable

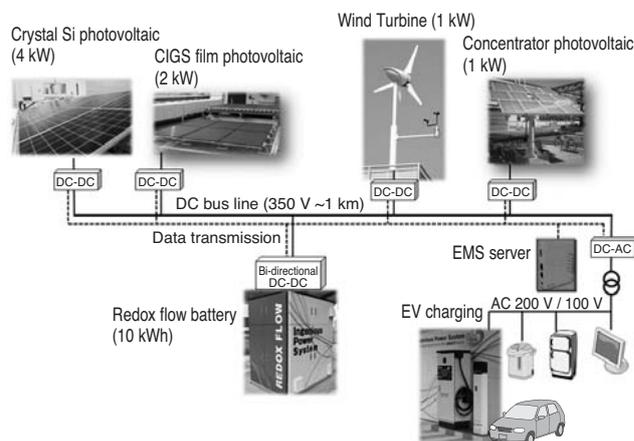


Fig. 1. Overview of Micro Smart Grid System in Osaka Works

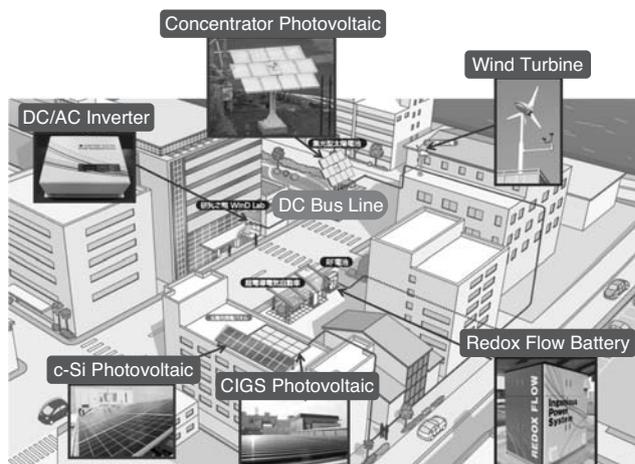


Fig. 2. Bird's Eye View of Micro Smart Grid System in Osaka Works

and efficient power supply to various electrical load devices independently of commercial power supply networks⁽¹⁾. The configuration and schematic bird's eye view of the system are shown in **Fig. 1 and 2**, respectively.

2-1 System configuration

Renewable energy generators include two types of commercially available photovoltaic systems (crystalline silicon and CIGS thin film types), a concentrating photovoltaic (CPV) developed in-house, and a commercially available small-capacity wind generator. A CPV converts solar energy to electricity by densely concentrating sunlight with a lens and irradiating tiny solar cells with the concentrated sunlight. Made from a special compound semiconducting material, the solar cells have the power generation efficiency about twice of currently-marketed silicon panels. Installed high above the ground, the light-concentrating panels provide usable spaces below. The in-house developed CPV is expected as a next-generation photovoltaic system. The light collecting panels of the CPV (output capacity: 1 kW), into which Sumitomo Electric Group's original material technologies have been incorporated, are thinner and lighter than those of conventional CPVs. With the commercialization of the CPV in mind, Sumitomo Electric is currently working to reduce its production cost⁽²⁾.

An in-house developed redox flow battery (capacity: 10 kWh) is used as a storage battery. A storage battery, which stores and discharges electric power in response to fluctuations in generator output, plays a particularly important role in a renewable power generation system that uses sunlight, wind, or other natural energy sources. A redox flow battery can be used for irregular, highly fluctuating charge-discharge operations due to its ability to accurately monitor and control the electric power that it stores. Accordingly, this battery is most suitable for smart grids whose objective is to effectively use electric power generated from such unstable renewable energy sources as sunlight and wind. The electrodes and electrolyte of a redox flow battery rarely deteriorate, even after continuous rapid charge-discharge operations; therefore it has long service life. Since the anode and cathode electrolytes contain the same nonflammable components and can be used at ordinary temperatures, it is easy to maintain and safe. Sumitomo Electric is currently promoting the development of redox flow batteries for use in smart grids on a commercial basis^{(3),(4)}. The principal specifications of the generators and redox flow battery are shown in **Table 1**.

In this micro smart grid demonstration system, the above-described three types of photovoltaic systems, a small-capacity wind power generator, and small-capacity redox flow power storage battery are interconnected by an approximately 1 km-long DC power cable. DC voltage of electric power generated by each generator (the maximum total output: a little less than 10 kW) is raised (to 350 V) by a DC-DC converter, carried on the DC power cable, and either stored in the redox flow battery or fully converted to AC by a DC-AC inverter and supplied to the several electrical loads via a smart distributor and intelligent taps (outlets).

The DC-DC converters are installed at the interconnections between the generators and DC cable and between the storage battery and DC cable. The DC-AC inverter collectively converts DC power into AC immedi-

Table 1. Specifications of Generators and Redox Flow Battery

Photovoltaic	
poly-crystal Si	output: 4 kW
CIGS Film	output: 2 kW
Concentrator PV	output: 1 kW
Wind Turbine	output: 1 kW
Redox Flow Battery	output: 2 kW (Max. 4 kW) charging capacity: 10 kWh

ately before the electrical load devices. Each of the DC-DC converters and DC-AC inverter is provided with power control and communication functions and is connected to a central control server to build an energy management system. More specifically, the central control server acquires data on the generated, stored, and consumed amounts of electric power through a hybrid wired/wireless network and manages the flow of electric power to maintain optimal balance between power supply and demand. Thus the central control server controls the electrical load devices so that they maximize economic advantage without any inconvenience to consumers. The central control server collectively controls measurement data and shows the status of power generation, storage, and consumption on a screen on a real time basis together with the trend of past power generation and consumption. The system control room is shown in **Photo 1**. Sumitomo Electric has developed all of the DC-DC converters, the DC-AC inverter, the control unit mounted on the smart distributor to efficiently supply electric power to the electrical load devices, and the intelligent taps connected to the smart distributor.

Electric power generated by this demonstration system is used for lighting, TV sets, and other electrical appliances in the Osaka Works. The electric power can be also supplied to the superconductor electric vehicle charging station developed jointly with Nissin Electric Co., Ltd., a subsidiary of the Sumitomo Electric Group, which can also charge electric vehicles presently available in the market.

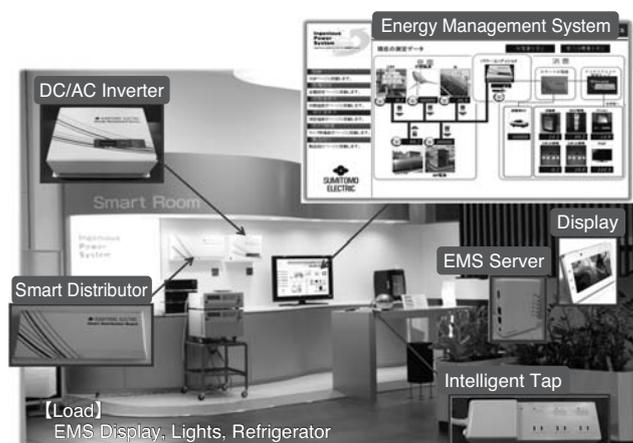


Photo 1. Power Management Room of Micro Smart Grid System

2-2 Features of the whole system

Features of the whole system are summarized below.

- (1) Consisting of only photovoltaic systems and a wind power generator, this smart grid demonstration system is not connected to commercial power supply networks. The energy management system monitors fluctuations of electric power generated by unstable renewable energy sources and the consumption of power by the electrical load devices, and controls the fluctuations using the storage battery. Thus, the whole system makes it possible to use electric power efficiently and stably.
- (2) Compared with traditional AC interconnection systems, the newly-introduced DC interconnection system can reduce the number of necessary DC-AC inversion cycles. DC-AC inversion involves energy loss due to power consumption by the inverter and inversion itself. A reduced number of inversion cycles permits more efficient use of renewable energy. The present power supply to each residence on AC may be switched to DC in future. In such a case, the importance of the DC system interconnection technology will increase. DC power transmission has an advantage over AC power transmission in reducing energy loss on the transmission cables.
- (3) The demonstration system enables flexible interconnection of various types of renewable energy power generators and storage batteries as needed, allowing its use in an electric power system of any scale.

In the meantime, Sumitomo Electric expects that the above items (1) and (2) will improve the energy-saving efficiency of the system by approximately 10%.

Figure 3 shows an example of the demonstration system operation in which electric power generated by the four types of generators and its consumption is balanced stably by the charge/discharge operations of the redox flow battery. The demonstration system has been operating continuously around the clock for more than one year, verifying that a redox flow battery is capable of completely controlling the supply/demand in a DC micro grid. Sumitomo Electric is continuing to acquire various data includ-

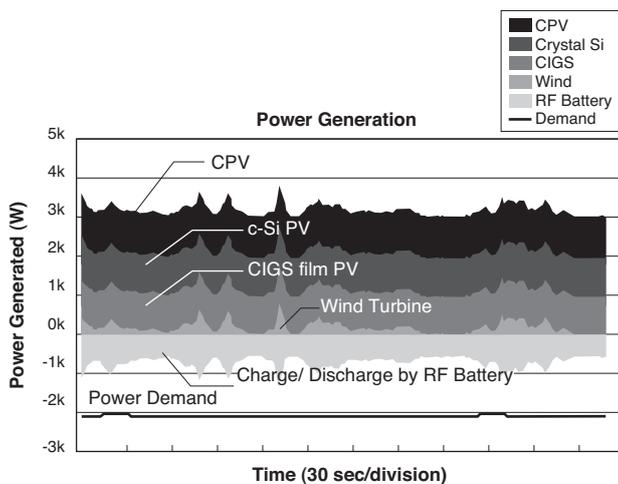


Fig. 3. Example of Micro Grid Operation (Balancing Renewable Power Supply/Demand through RF battery)

ing the relation between the amount of electric power generated and sunshine, wind, and other weather conditions in order to develop a technology that can optimally control the whole smart grid system in response to weather forecasts. Furthermore, Sumitomo Electric will actively expand the practical use of this control technology in association with the diversification of social needs.

3. Megawatt-class Power Generation /Storage System

For expanding the use of renewable energy, it is essential to develop power stabilization technology of unstable generation and systematic power generation technology. To cope with any sudden electric power supply shortage, electric power users are required to cut their peak demand for power supplied from external power grids and also to establish an electric power backup system in preparation for urgent power shortage situations. Furthermore, to meet increasing needs of business facilities and communities for distributed electric power supply systems, the technology for sophisticatedly controlling distributed power is becoming indispensable. Under the above circumstances surrounding electric power supply, Sumitomo Electric has developed a large-scale electric power generation/storage system consisting of the world's largest redox flow battery and Japan's largest concentrator photovoltaic (CPV) installation, and commenced its demonstration operation in July 2012 on the premises of the Yokohama Works as part of the in-plant power supply network.

3-1 System configuration

The configuration of the system is shown in **Fig. 4** and its overall view is shown in **Photo 2**. Consisting of 15 CPV units (maximum total power output capacity: 100 kW) and a redox flow battery (capacity: 1 MW x 5 h), the system is connected to a commercial power supply network. The CPV units generate electric power from a renewable energy

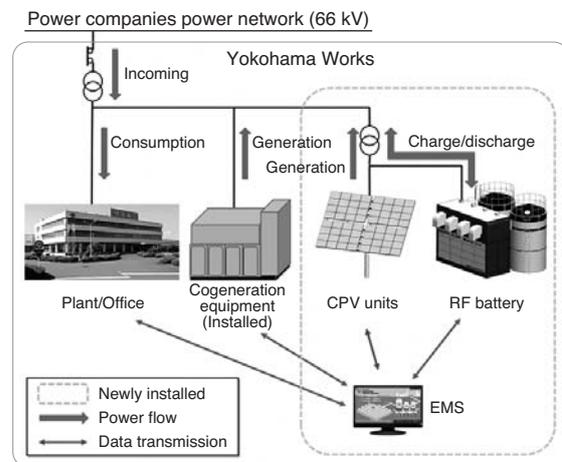


Fig. 4. Overview of Energy Generation/Storage System in Yokohama Works



Photo 2. Overview of Power Generation/Storage System in Yokohama Works

source, while the redox flow battery stores CPV-generated power and nighttime power provided by a commercial power supply network. Power generation by the CPV units and the charge/discharge operations of the redox flow battery are monitored by an energy management system (EMS), while the measurement data are collectively controlled by an EMS server.

Furthermore, an existing gas engine-driven generator is combined with the redox flow battery and CPV units to demonstrate the factory energy management system (FEMS) in order to optimize the overall electrical energy consumption at the Yokohama Works.

Features of the components are summarized below.

(1) Redox flow battery (capacity: 1 MW x 5 h)

The redox flow battery is comprised of charging/discharging cell stack cubicles and tanks filled with vanadium ion electrolyte. Incorporated with Sumitomo Electric's leading edge technologies, this battery exhibits a maximum output capacity of 1 MW using eight 125 kW cell stack cubicles. Each cubicle is provided with a pair of anode and cathode electrolyte tanks (a total of eight pairs (16 tanks)). The external appearance of the battery is shown in **Photo 3**.

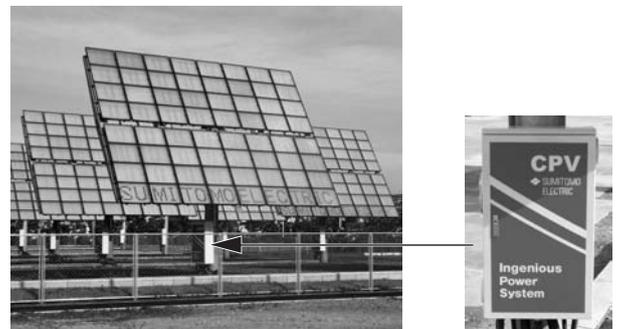
(2) Concentrating photovoltaic (CPV) units (maximum power output capacity: 100 kW)

Each CPV panel comprises high-efficiency photovoltaic cells made from a GaAs-base compound semicon-

ducting material. Each CPV unit consists of 64 CPV panels and its maximum rated power output is 7.5 kW. Accordingly, this system consisting of 15 CPV units has a rated power output of 100 kW. The CPV units are DC-interconnected with each other through a DC-DC converter provided for each unit. Their operation is subjected to a maximum power point tracking (MPPT) control. The amount of power they generate is also monitored through the DC-DC converter. **Photo 4** shows the in-house developed CPV and DC-DC converter. This in-house developed CPV can also display characters and illustrations on its photovoltaic panels without decreasing its power generation. **Photo 4 (a)** shows an example of the characters displayed on the panels.



Photo 3. Redox Flow Battery



(a) (b)

Photo 4. (a) Concentrator Photovoltaic and (b) DC/DC Converter Each CPV unit is DC-linked via a DC/DC converter to perform maximum power point tracking (MPPT).

(3) Power conditioner

The electric power generation/storage system is provided with a 500 kW power conditioner made by Meidensha Corporation and two 250 kW power conditioners made by Nissin Electric Co., Ltd., all of which are installed between the redox flow battery and a commercial power supply network⁽⁵⁾. External appearances of these power conditioners are shown in **Photo 5**.



Photo 5. Power Conditioning Subsystem
 (a) 500 kW PCS by Meidensha Corporation
 (b) 250 kW PCS by Nissin Electric Co., Ltd.

(4) Energy management system (EMS)

The power generation/storage system is provided with an EMS that monitors and manages the amount of power generated by 15 CPV units and the flow of electric power between the commercial power supply network, redox flow battery, CPV, and office/plant. The acquired information is collected and sent through an optical communication network to a central control server and is collectively controlled there. An example of data displayed on the monitor screen is shown in Fig. 5.

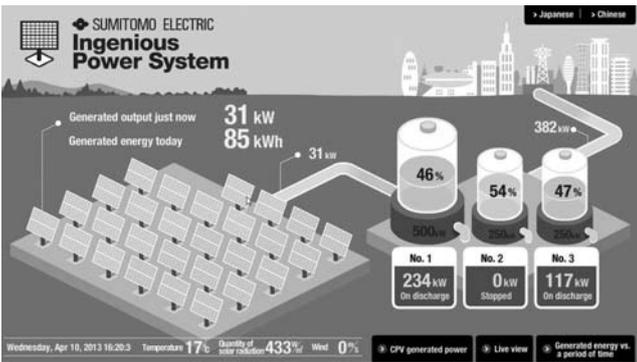


Fig. 5. Example of Monitoring Display of Power Generation/Storage System

3-2 Description of Demonstrative Operation and Its Objectives

The details of the demonstrative operation of the power generation/storage system and the objective of the demonstration are described below:

- (1) Cutting the peak demand (demand control of a maximum of 1 MW), thereby contributing to the mitigation of electric power shortages, which is an urgent issue in Japan.
- (2) Combining a weather-susceptible photovoltaic system with a redox flow battery to generate electric power according to a schedule. The objective is to enhance the practicability of photovoltaic, thereby promoting the wider use of photovoltaic systems.
- (3) Controlling the amount of electric power discharged from a redox flow battery in response to electric load

so that a preset demand schedule is satisfied. The objective is to contribute to reducing the scale of necessary power plants by leveling electric power consumption.

- (4) Leveling the highly fluctuating output of a photovoltaic system by absorbing it utilizing the charge/discharge operations of a redox flow battery. This measure will mitigate the loads to be adjusted at thermal power plants and expand the scale of photovoltaic and wind power generators that can be connected to commercial power supply networks.

As described above, Sumitomo Electric aims to stabilize electric power supply and also contribute to solving electric power shortages by effectively using redox flow batteries for such unstable renewable energy power generation as photovoltaic and wind power generation. Sumitomo Electric has also started demonstrative operation of the FEMS, which is comprised of a redox flow battery, CPV, and an existing gas engine generator. The objective of this operation is to optimize the overall electric energy consumption in the Yokohama Works. The FEMS demonstrative operation is jointly being performed with Meidensha Corporation as the Yokohama Smart City Project, one of the Next Generation Energy and Social System Demonstration Projects 2012 led by the Japanese Ministry of Economy, Trade and Industry (METI).

The FEMS has already been operating in the Yokohama Works to cope with power shortages by cutting peak demand. In response to the needs of factories, commercial facilities, and other large scale energy consumers, Sumitomo Electric will continue to expedite the practical use of these electric power generation/storage systems with the aim to introduce renewable energy sources and their efficient use.

4. Conclusion

This paper has described the two types of smart grid demonstration system developed by Sumitomo Electric.

In parallel with demonstrative operation of these systems, Sumitomo Electric will continue to strive to reduce system component costs. Sumitomo Electric has already formulated a plan to launch a smart grid and related equipment business in a few years, in order to contribute to the modernization of our society's electric power supply system, by responding flexibly to diversified customer needs.

Technical Terms

- *1 Smart grid: A power supply network in which the flow of electricity is controlled from both its supplier and consumer sides to optimally balance the supply and demand. The smart grid helps save energy, reduce cost, and enhance the credibility and transparency of renewable energy power generation.

*2 Energy management system: A tool for optimally managing and controlling electric power generation and storage to ensure efficient energy saving and electric power cost reduction. This system is effective for managing a power consumption pattern in which nighttime electricity is stored for use during the day, thereby leveling the consumption of electric power (peak demand cut) supplied from commercial power supply networks and reducing energy costs. Nighttime electricity, which is produced during the night, when power consumption decreases, is less expensive than daytime electricity that is produced in a stringent demand/supply condition. This system can be also used to improve the lifestyles of electricity consumers by providing them with visualized information about their electricity consumption and other items on a real-time basis.

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