Energy Management System for Local Production of Renewable Energy for Local Consumption

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There has been a rapid deployment of renewable energy systems such as photovoltaic generation systems and wind farms in order to reduce greenhouse gas emissions. However, there is a high risk that many deployments of renewable energy systems may have a negative impact on the existing commercial power grid system due to large fluctuations caused by weather and time of day. The Soma IHI Green Energy Center (SIGC), launched in April 2018, is equipped with the Energy Management System for Local Production for Local Consumption, in which the power generated by photovoltaic generation systems are consumed as much as possible in the center due to restrictions that prohibit backfeeding to the commercial grid. This paper outlines and describes the features of the control implemented by the Energy Management System for Local Production for Local Consumption.

1. Introduction

In order to reduce CO_2 and other greenhouse gas emissions, which are believed to be a cause of global warming, the introduction of renewable energy sources such as photovoltaics (PV) and wind power generation is accelerating both in Japan and overseas. However, PV and wind power generation are also known as variable renewable energy sources, and have the disadvantage that their output fluctuates greatly depending on weather and time. There is concern that introducing large amounts of variable renewable energy may adversely affect the power quality (e.g., voltage and frequency) of existing power grid systems(1). Approximately 40%(2) of the renewable energy that has been introduced in Japan is variable renewable energy, and most of this is PV. During daytime, fluctuations in PV are dealt with by adjusting the balance between power supply and demand using power generation methods whose output can be adjusted such as thermal power generation, but if the fluctuations in PV exceeds the adjustment capacity, it is eventually necessary to reduce PV power generation. **Figure 1**(1) is a graph representing the supply and demand of electricity. When expanding the use of renewable energy, one challenge is dealing with excess power that can not be used; it is desirable to make full and effective use of such excess power generated from renewable energy without adversely affecting existing power grid systems.

As one solution to this challenge, IHI Corporation has developed the Energy Management System for Local Production for Local Consumption (hereinafter referred to as EMS for Local Production for Local Consumption), by which all electricity generated from renewable energy in a community is consumed locally by that community. Currently, the EMS for Local Production for Local Consumption is in operation at the Soma IHI Green Energy Center (SIGC)(3), established in Soma City, Fukushima Prefecture. In the areas surrounding the SIGC, the existing high-voltage distribution grid has no capacity for introducing new renewable energy, and so there is a restriction that PV power generated at the Center cannot be fed back into the existing system. Because of this severe restriction, the EMS for Local Production for Local Consumption converts and stores excess PV power in other energy media, such as storage batteries, hydrogen, or steam, thereby achieving local production of renewable

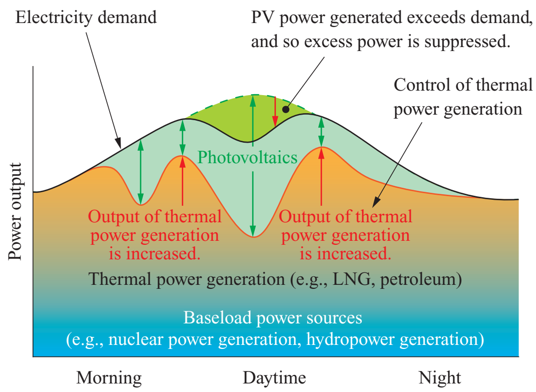


Fig. 1 Schematic view of demand and supply of electricity

energy for local consumption.

This paper describes the efforts being pursued at the SIGC, explains the concept, functions, and control system of the EMS for Local Production for Local Consumption, and states the results of actual operation.

2. Efforts pursued at SIGC

2.1 Concept of the SIGC[4]

IHI established the SIGC, located in Soma Core Industrial Park, jointly with Soma City, Fukushima Prefecture in April 2018 as a core facility for promoting smart community-related projects and demonstrations. **Figure 2** shows an overview of the SIGC.

The basic concept of the SIGC is to “build a CO_2-free recycling-oriented society using hydrogen”[5] with the aim of reducing greenhouse gas emissions in the area, strengthening local disaster prevention capabilities and revitalizing the community through the introduction of renewable energy. In addition, it aims to decarbonize energy with a view to achievement of a future hydrogen economy in order to contribute to new community development in line with Soma City’s plan for reconstruction after the Great East Japan Earthquake. Based on this basic concept, the SIGC aims to effectively use excess power by converting it into other energy media and/or storing it in batteries in accordance with fluctuations in renewable energy output in order to achieve “local production of renewable energy for local consumption.” This means that the electricity produced with renewable energy in the community is fully consumed within that community. **Figure 3** illustrates the concept of SIGC smart community.

The following conditions were adopted with respect to construction of equipment and systems:

(1) Because of the location and weather conditions in Soma City, PV is adopted as the renewable energy source.

(2) Since PV power cannot be fed back into the existing power grid system, it is supplied to a sewage disposal plant, and facilities in the SIGC using a dedicated private grid.

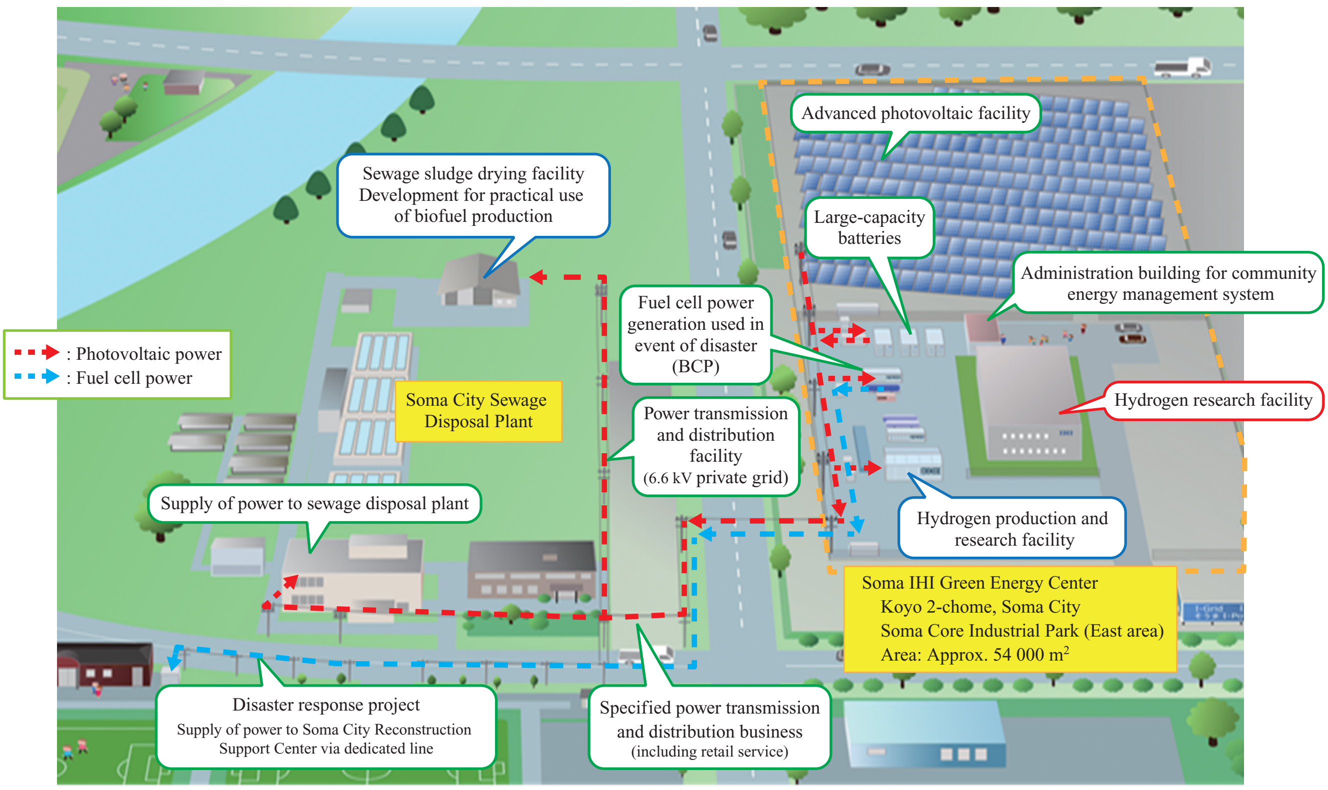
(3) In order to achieve peak shift, excess PV power is charged into batteries, and discharged in the evening and during the night.

(4) Part of the excess power is converted to the steam and hydrogen for effective use. The steam is produced by electric boilers and the hydrogen by water electrolyzers.

(5) Power generation, the charging and discharging of batteries with excess power, and its conversion to steam and hydrogen are controlled in an integrated manner.

2.2 Overview of the facilities

Table 1 shows an overview of the facilities at SIGC. As output from the PCS (Power Conditioning System), PV can generate 1 250 kW of electricity, which is equivalent to the amount consumed by approximately 500 standard households. The PCS adopts a distributed structure that combines multiple small capacity units and can control PV output according to power generation status, and fluctuations on the demand side.



(Note) BCP : Business Continuity Plan

Fig. 2 Soma IHI Green Energy Center (SIGC)

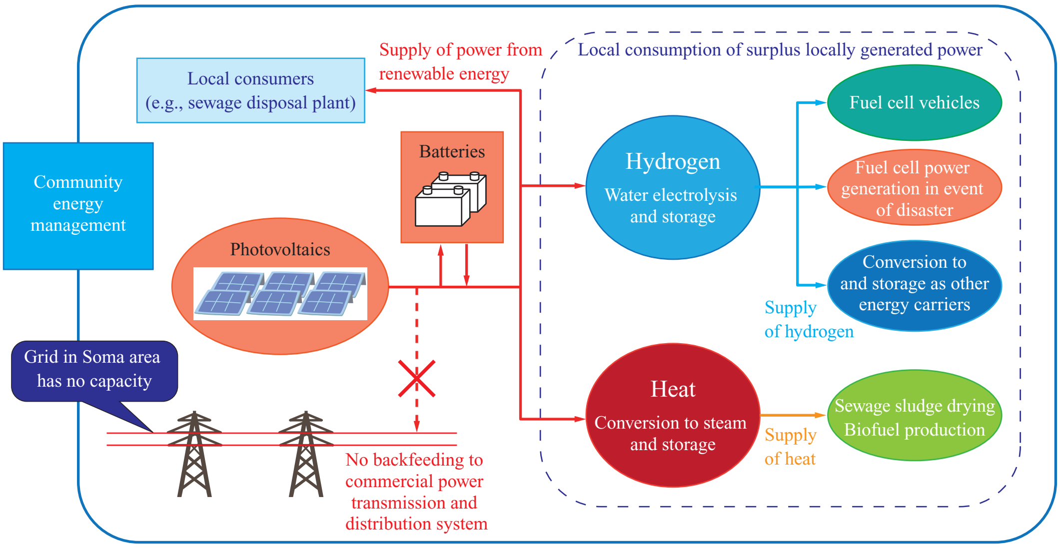


Fig. 3 Concept of SIGC Smart Community

Table 1 Specification of major facilities in SIGC

Type of facility	Facility and equipment name		Specifications
Power generation facility	Photovoltaics (PV)		Power output 1 600 kW, PCS*1 (total 38 units) output 1 250 kW
Power storage facility	Lithium-ion battery		Capacity 2 500 kW·h, PCS*1 500 kW
Thermal conversion facility	Electric boiler		Maximum output 400 kW
Hydrogen conversion facility	Disaster response facility	PEM*2-type water electrolyzer	Hydrogen production capacity 15 Nm^3/h
		Hydrogen storage tank	Hydrogen storage volume 150 Nm^3 (0.85 MPa)
		PEFC*3-type fuel cell	Maximum output 25 kW
	Hydrogen production and research facility	PEM*2-type water electrolyzer	Hydrogen production capacity 30 Nm^3/h
		Alkaline water electrolyzer	Hydrogen production capacity 25 Nm^3/h
Power distribution facility	High-voltage power distribution facility (private grid), grid connection facility		6.6 kV Line length 1 200 m Backfeed prevention function is located at point of connection to existing power grid system.
	Low-voltage power distribution facility for emergencies		200 V/400 V Line length 600 m
Control and monitoring facility (EMS for Local Production for Local Consumption)	CEMS (Community Energy Management System)		Visualization, power generation and demand estimation, condition monitoring, planning
	LLC (Local consumption for Local product Control)		Backfeed prevention control, power generation monitoring, charge/discharge monitoring, excess power distribution control, monitoring of power purchased from existing power grid system

(Notes) *1 : Power Conditioning System
*2 : Polymer Electrolyte Membrane
*3 : Polymer Electrolyte Fuel Cell

PV power is supplied to a sewage disposal plant and each facility in the SIGC via a dedicated 6.6-kV private grid (line length: 1 200 m), which is independent from the existing power grid system. When the PV output or battery level is insufficient, power can be supplied from the existing system.

Excess PV power is stored in batteries, or stored after conversion to steam or hydrogen. Lithium-ion batteries (capacity 2 500 kW·h, PCS output 500 kW) are used to store electricity. The excess power is charged into the batteries during daytime, and is discharged in the evening and during the night in response to demand. In addition, the batteries are charged and discharged in response to rapid fluctuations in PV output so as to enable a stable supply of power. Steam is converted from electricity using electric boilers, and the generated steam is used to dry sludge in the sewage disposal plant, thereby contributing to reduction of sewage sludge and sewage treatment cost. Hydrogen is converted from electricity by multiple water electrolyzers and stored, and in the event of an emergency, such as a power failure, emergency power can be supplied using a fuel cell power generation system and dedicated distribution line which is isolated from power grid, thereby contributing to the enhancement of local disaster prevention capabilities. The stored hydrogen is also used for hydrogen-related research regarding the advent of a hydrogen economy.

These power generation, storage, and consumption facilities are monitored and controlled in an integrated manner by the EMS for Local Production for Local Consumption, and the system operates various controls to ensure a stable supply of PV power and prevent PV power from being fed back into the existing power grid system.

3. Overview of EMS for Local Production for Local Consumption

The existing power grid system in and around the SIGC has no capacity for introducing new renewable energy and so electricity from a new renewable energy source cannot be fed back into the existing system. Therefore the EMS for Local Production for Local Consumption consists of the CEMS (Community Energy Management System) and LLC (Local consumption for Local product Control). The CEMS estimates, monitors, and plans the amount of electricity generated by the PV system and the demand for PV power. The LLC performs integrated control of the facilities and equipment to prevent excess PV power from being fed back to the existing power grid system, to store PV power within the private grid, and to convert PV power to steam or hydrogen so as to enable maximum utilization of renewable energy. Below is a description of the controls of the LLC, which constitute the core of the Energy Management System for Local Production for Local Consumption.

4. Controls of LLC

The LLC performs the following functions when not all excess PV power can be consumed by the sewage disposal plant, etc., or when demand on the private grid is low.

(1) Time shifting of excess power and flattening of fluctuations in PV output through monitoring of charging/discharging of batteries and control based on time of day
(2) Control of the number of PV-PCS units when the load in the private grid is low
(3) Control power to prevent deviation from the upper and lower limits for power which is purchased from the existing power grid system
(4) Control of the amount of steam or hydrogen converted from excess PV power

As stated at the beginning of this paper, PV, which is a form of variable renewable energy, produces varying output depending on the ambient conditions, such as time of day and weather. Through the four above controls, the LLC controls supply and demand within the community in an integrated manner, thereby maintaining the balance between supply power and demand load without backfeeding to the existing power grid system.

Figure 4 shows a block diagram of the LLC feedback loop. The following sections describe the corresponding functions with reference to **Fig. 4**.

4.1 Time shifting of excess power and flattening of fluctuations in PV output through monitoring of charging/discharging of batteries and control based on time of day

The LLC performs time shifting by storing part of the excess PV power during daytime and using it at night. The utilization of this excess power is controlled for each time of day according to a preset battery charging/discharging time schedule, and the charged excess power is used mainly for nighttime load at the sewage disposal plant, thereby contributing to a reduction in the amount of electricity purchased at night.

The amount of electricity generated by the PV system can fluctuate, in one second, by over 50% of the rated value due to the effect of the shadows cast by clouds. By charging/discharging PV power into/from batteries, the LLC flattens the actual PV power generated and reduces fluctuations in PV output, thereby enhancing the stability of the balance between power supply and demand in the private grid. More specifically, the difference between the actual value of PV power generated and a value obtained from the moving

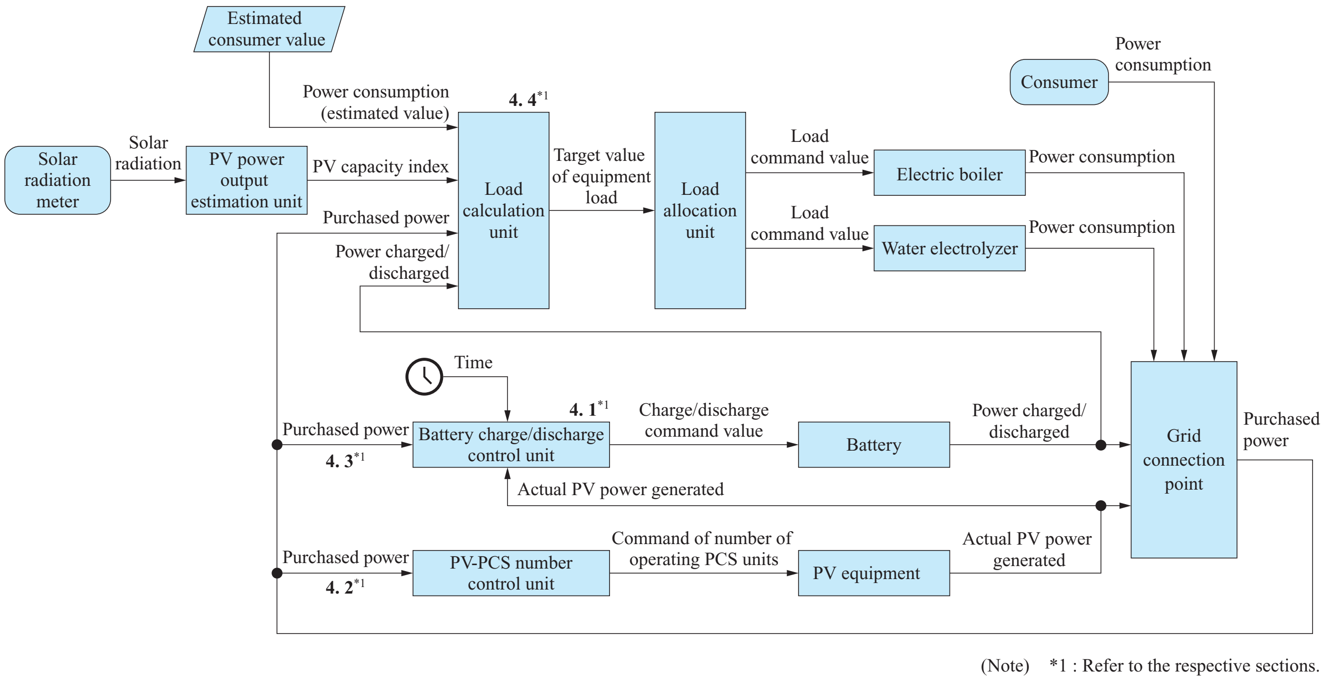


Fig. 4 Block diagram of Energy Management System for Local Production for Local Consumption

average is set as the charge/discharge command value used in flattening fluctuations in the actual PV power.

4.2 Control of the number of PV-PCS units when the load in the private grid is low

In order to prevent backfeeding, purchased power of 0 kW or more must be kept flowing in the private grid. Therefore, the LLC also performs control to prevent backfeeding. **Figure 5** shows the control levels for backfeeding prevention. Five operation modes are provided in response to a decrease in purchased power (when the actual PV power generated is larger than the load in the private grid). At level 0, which occurs when purchased power has fallen below 110 kW, a charge bias control is applied using the batteries. For details, refer to **Section 4.3**. At level 1, which occurs when the purchased power has fallen below 65 kW, one PCS unit is stopped each time the purchased power falls below a preset threshold value. At level 2, which occurs when the purchased power has fallen below 51 kW, four PCS units are stopped per operation period for as long as this level continues. At level 3, all the PCS units are stopped, and at level 4, the reverse power relay trips in order to prevent backfeeding. The level 3 and 4 controls are basically used in the event of an emergency, while the level 0, 1 and 2 controls are used to prevent backfeeding during normal operation.

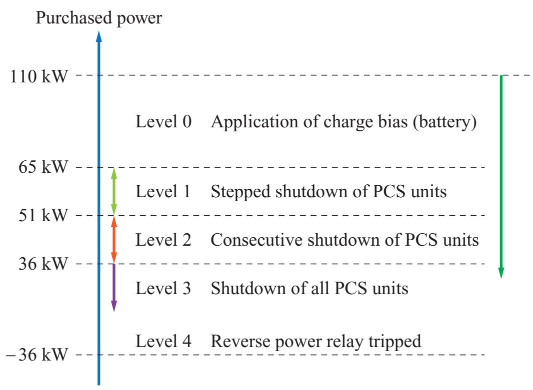


Fig. 5 Settings to prevent backfeeding

4.3 Control power to prevent deviation from the upper and lower limits for power which is purchased from the existing power grid system

In order to prevent backfeeding to the existing power grid system, and avoid an excess of purchased power, the SIGC controls the number of PCS units, as described in **Section 4.2**, and performs charge/discharge bias control in accordance with purchased power. **Figure 6** shows the basic waveform for charge/discharge bias control. More specifically, when the purchased power falls below the lower limit (level 0 in **Fig. 5**) due to an increase in excess PV power, etc., a battery charge bias is applied for a certain period of time to temporarily increase purchased power (**Fig. 6-(a)**). If the purchased power falls below the lower limit again while the bias is being applied, an additional bias waveform is added to the previously applied bias waveform.

Conversely, when the purchased power exceeds the upper limit, a battery discharge bias is applied to temporarily decrease purchased power, thereby preventing it from deviating above the upper limit (**Fig. 6-(b)**). If the purchased power exceeds the upper limit again while the bias is being applied, then in the same manner as for charging, an additional bias waveform is added to the previously applied bias waveform.

4.4 Control of the amount of steam or hydrogen converted from excess PV power

Section 4.2 described restriction of PV output through stepped control of PV-PCS. However, stopping PV-PCS for a continuous, prolonged period of time is undesirable from the viewpoint of energy management, since the power that should have been obtained from the PV system is discarded. When PV power is in excess, the LLC automatically increases the equipment load (power consumption of water electrolyzers and electric boilers) in the grid in order to actively convert the PV power to other energy media (hydrogen and heat) and store it.

The loads of the equipment (water electrolyzers and electric boilers) in the SIGC are calculated by the load calculation unit shown in **Fig. 4**. Consideration of the power balance within the grid shows that Equation (1) holds:

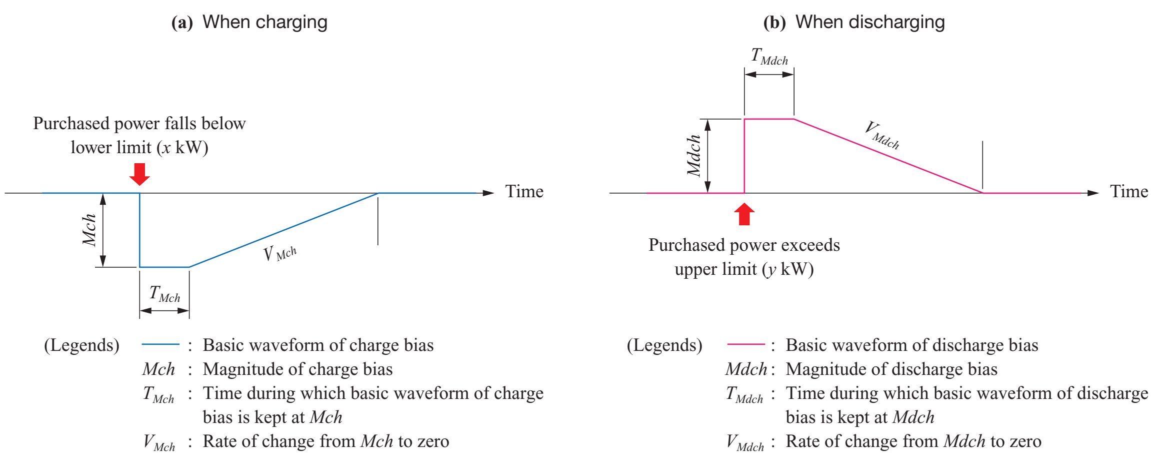


Fig. 6 Basic waveform for charging/discharging bias — under charging

$$P_{buy} + P_{pv} = P_{load} + P_d + P_{bat} \quad \cdots\cdots\cdots(1)$$

P_{buy} : Purchased power
P_{pv} : Actual PV power generated
P_{load} : Equipment load
P_d : Consumer power consumption
P_{bat} : Power charged/discharged into/from batteries (charge: positive, discharge: negative)

Based on Equation (1), the target value of equipment load P_{load}^{ref} is determined by the load calculation unit as follows:

$$P_{load}^{ref} = P_{buy} + P_{pv\text{-}index} - P_d - P_{bat} \quad \cdots\cdots\cdots(2)$$

Here, it should be noted that $P_{pv\text{-}index}$ is the maximum power that can be output by the PV system as calculated from the amount of solar radiation (PV capacity index), and is not the actual PV power. Since P_{pv} is affected by PV-PCS control of the number of units, the excess power suppressed in the PV system cannot be estimated from P_{pv} itself. For this reason, the LLC determines the equipment load based on $P_{pv\text{-}index}$, not P_{pv}. In the SIGC, the main consumer is the sewage disposal plant, and since P_d is more stable than P_{pv}, P_d is set to a fixed value in the load calculation unit.

The target value of equipment load, which is the output of the load calculation unit, is allocated based on the ratio of the rated power consumption of the electric boilers and water electrolyzers, hydrogen demand, heat demand, etc., and each command value is transmitted to the controller of the corresponding piece of equipment. In this way, based on the amount of purchased power, the LLC can convert and store excess PV power not only in batteries but also in energy media such as steam and hydrogen.

5. Actual operation of power supply/demand

This chapter describes actual LLC control in the SIGC. **Figure 7** shows the hourly power supply/demand balance recorded over one day at the SIGC on February 7, 2019. The lower part shows the power demand side, and the upper part shows the power supply side. The total equipment power consumption shown in the figure indicates the sum of the power consumption of the electric boilers and water electrolyzers.

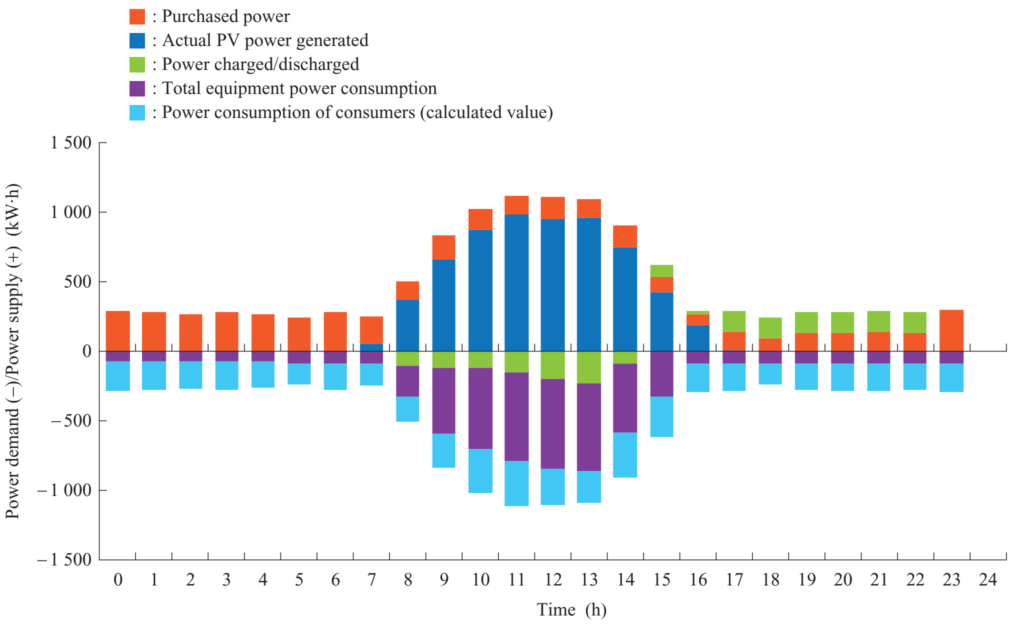
Looking at the power charged/discharged in **Fig. 7**, it can be seen that a time shift is achieved by storing excess PV power during daytime, and discharged it after sunset. It can also be seen that as the actual PV power increases, the total equipment power consumption is also increased, thereby maintaining the balance of power supply and demand in the grid. In addition, the purchased power is stably maintained at approximately 100 kW or more, with no power being fed back into the existing power grid system.

Figure 8 shows the actual PV power generated on the same day and the number of operating PV-PCS units (up to 38) per minute. Several PV-PCS units stopped during some periods of daytime, but the number of operating units immediately recovered. It indicates that PV suppression was minimal.

The above data clearly shows that, by controlling batteries, electric boilers, and water electrolyzers in an integrated manner, the LLC makes effective use of the excess PV power generated in the micro grid, and thereby achieves local production of renewable energy for local consumption.

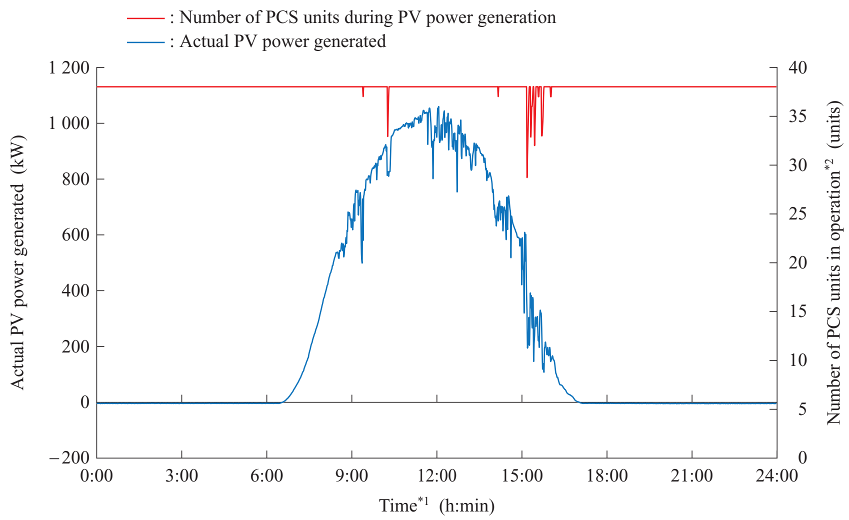
6. Conclusion

By controlling photovoltaics, batteries, excess power, and other loads in an integrated manner, the LLC, which constitutes the core part of the EMS for Local Production for Local Consumption described in this paper, completely achieves local production of renewable energy for local consumption in the SIGC. In the future, as large-quantity renewable energy, especially variable renewable energy, increases, the introduced quantity may be restricted due to power grid



(Note) Power supply/demand balance recorded over one day at SIGC on February 7, 2019

Fig. 7 Power supply/demand balance at SIGC



(Notes) *1 : On February 7, 2019 at SIGC
*2 : Up to 38 units

Fig. 8 Actual PV power generation and number of PCS units in operation

capacity issues, or there may be greater restrictions on output than expected. Even in such situations, this EMS enables expanded use of renewable energy without affecting existing power grid systems. Hence, the authors believe that this EMS constitutes a solution to issues arising from expanded use of renewable energy in the future.

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