Energy Management System (*s*EMSA) Achieving Energy Cost Minimization

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We have developed an energy management system “*s*EMSA,” which optimally controls multiple power sources based on mathematical programming in customer premises. *s*EMSA realizes energy cost minimization by newly developed “optimal planning of power sources” and “real time control.” In addition, this system automatically regulates grid incoming power corresponding to the power company's demand requests. We have completed field tests of *s*EMSA at Sumitomo Electric Yokohama Works and another company's factory. *s*EMSA for factory use will be released in 2015.

Keywords: mathematical programming, demand response, battery, generator, photovoltaic generation (PV)

1. Introduction

With the widespread use of regenerative energy and other distributed power sources, the establishment of energy policies, and advances in power supply and demand adjustment across an entire region based on demand response, the need to enhance the operational efficiency of distributed power sources has been increasing recently.

Sumitomo Electric Industries, Ltd. has developed an energy management system (*s*EMSA) that can optimally control two or more different types of distributed power sources and can also automatically respond to demand response requests. **Figure 1** is the schema of *s*EMSA.

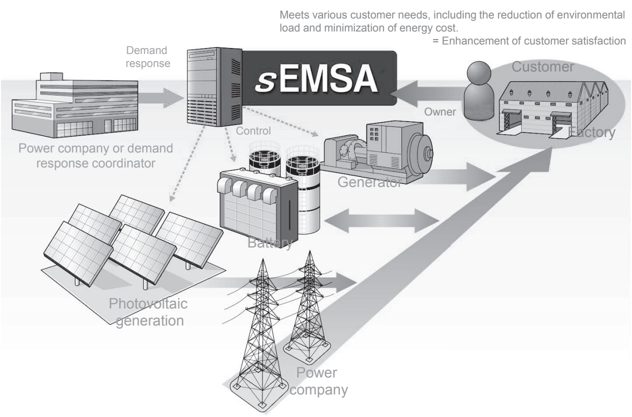

Fig. 1. Schematic illustration of *s*EMSA’s functions

*s*EMSA predicts power demand and photovoltaic generation and, based on the prediction results, draws up an optimal distributed power source operation plan for up to 48 hours ahead by using mathematical programming. Since the time granularity of the operation plan is set at 10 minutes, much shorter than the conventional demand time limit of 30 minutes, *s*EMSA can draw up a high accuracy operation plan. *s*EMSA is also robust against the effects of prediction error since it repeats its calculations at a high frequency to review and revise the operation plan every 10 minutes. In addition, *s*EMSA is provided with a unique dynamic reallocation control (DRC) system that monitors the power receiving points at intervals of several seconds and performs feedback control after taking the plan into account. This control system prevents the excess of 30-minute demand and reduces the receiving power by accurately responding to demand response requests. As described above, the two outstanding features of *s*EMSA are an optimal operation planning function and dynamic reallocation control.

*s*EMSA was introduced in 2014 in Sumitomo Electric Yokohama Works and a factory of a different company (hereinafter referred to as N-company) and its demonstration tests were carried out at these two places. The distributed power sources installed in the factory and its power contract with the power company differed from the Yokohama Works. These demonstration tests have proved that *s*EMSA can continue automatic operation and is effective. This report outlines *s*EMSA and describes the results of the demonstration tests carried out at the Yokohama Works and the factory of N-company.

2. Guideline for the Development of *s*EMSA

The development of *s*EMSA was performed in accordance with the Sumitomo Electric energy management system (EMS) architecture shown in **Figure 2**.

The Sumitomo Electric EMS architecture stratified the elements required for EMS into five layers. These layers are separated from each other by the interface defined between them.

*s*EMSA is an EMS software package that has been developed in accordance with the Sumitomo Electric

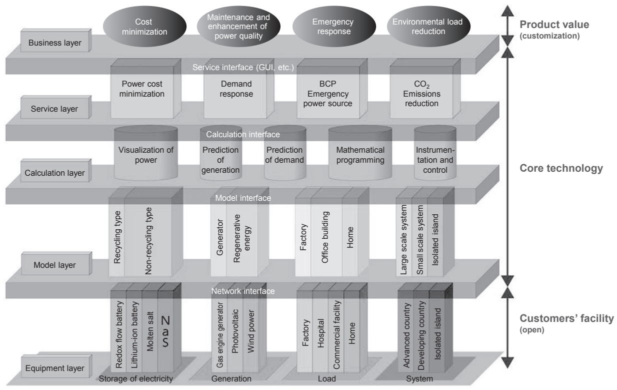

Fig. 2. Sumitomo Electric EMS architecture

EMS architecture. This package can prepare many pieces of software at each layer individually so as to meet a variety of customer needs quickly at low cost.

3. Control Function of sEMSA

3-1 Configuration

*s*EMSA is a system for optimally controlling generators, batteries, and other distributed power sources while meeting the conditions desired by the customer. It is linked to distributed power sources through MELSECNET/H, FL-net, or other industrial network to collect the variety of information necessary to control the power sources. The information collected by *s*EMSA is visualized by a web browser-based graphical user interface (GUI) on a real time basis or as a historical trend (**Figure 3**).

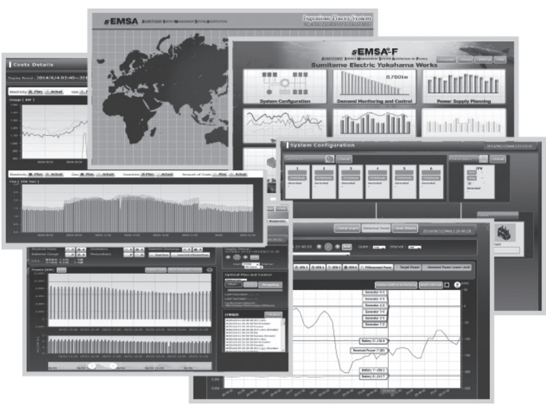

Fig. 3. GUI display image of *s*EMSA

*s*EMSA also predicts power generation and power demand based on past records of power generation by natural energy, weather information, power demand, and other information that have been collected and stored. Using the power generation and power demand prediction results and various other collected information such as the present states of the distributed power sources, *s*EMSA draws up a distributed power source operation plan. Since mathematical programming is used to draw up the operation plan, the plan is assured mathematically to completely meet the conditions desired by the customer. Lastly, *s*EMSA takes into account the established operation plan, the current state of the distributed power sources, the deviation of predicted values from actual results, and other data to determine the command values for controlling the distributed power sources. The control command values determined thus are set for the distributed power sources via an industrial network. **Figure 4** illustrates the system configuration of *s*EMSA.

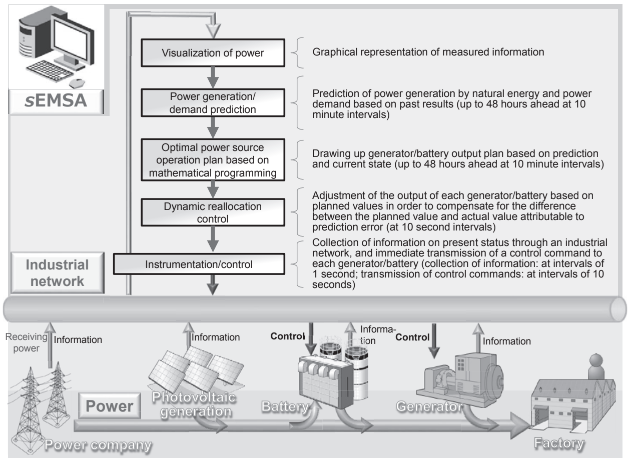

Fig. 4. System configuration of *s*EMSA

3-2 Prediction of photovoltaic generation and power demand

Prediction of photovoltaic generation is a capability of *s*EMSA to predict the power that will be generated by a photovoltaic system in the future based on past power generation results, measured weather data, and weather forecasts. Prediction of power demand is a capability of *s*EMSA to predict future power demand based on the past power demand, measured weather data, and weather forecasts.

The period, time granularity, and duration of photovoltaic generation and power demand prediction are shown in **Table 1**. The period, time granularity, and duration of photovoltaic generation and power demand prediction are equal to those in the optimal power source operation plan.

Table 1. Period, time granularity, and duration of photovoltaic generation and power demand prediction

Item	Specification of sEMSA
Prediction period	10 min
Time granularity of prediction	10 min
Duration of prediction	48 h

*s*EMSA achieves high-accuracy power generation control by predicting photovoltaic generation and power demand at intervals of 10 minutes and thus reducing the prediction error or the difference between prediction and actual result. **Figure 5** compares, with an example, the trend of power demand prediction error between *s*EMSA and a conventional EMS with a prediction/planning period of 12 hours.

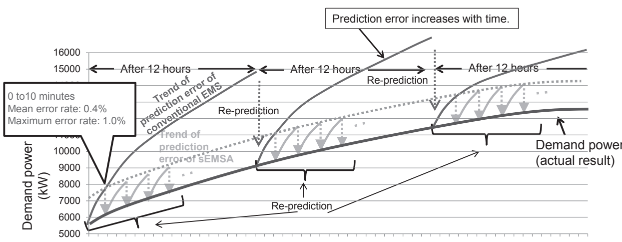

Fig. 5. Trend of power demand prediction error of conventional EMS and that of *s*EMSA

3-3 Optimal operation planning

The optimal operation planning of the *s*EMSA works to draws up a plan for optimally controlling the start/stop status and the output of generators, batteries, and other distributed power sources. This function draws up an operation plan for up to 48 hours ahead with time granularity of 10 minutes, and recalculates the factors of the plan at intervals of 10 minutes. When drawing up the plan, *s*EMSA uses the predicted power demand and predicted photovoltaic generation, and determines the conditions for starting/stopping the distributed power sources and their output value so that the energy cost of the customer is minimized under the restrictions of the balance between power supply and demand, the characteristics of these power sources, and the power/gas contracts of the customer with utility companies. The problems to be solved when an optimal operation plan is drawn up are described below.

[Objective function]

Minimize energy cost.

[Control variable]

- Start/stop status and output value of distributed power sources to be controlled

[Restrictions]

- Balance between power supply and demand
- Upper and lower limits of output of distributed power sources
- Maintenance cost for distributed power sources
- Upper and lower limits of output variation rate and fuel consumption of generators
- SOC (State of Charge) and charge/discharge efficiency
- Upper limit of purchase power

An example of the operation plan drawn up by the function is shown in **Figure 6**. This figure is a stacked bar graph of the purchase power and the output by each distributed power source, in which the upper end of each bar shows the demand power. This operation plan was drawn up so that the purchased power would be maintained below the predetermined contract power by the peak shift operation of the batteries and the peak shaving operation of the generators. The example of operation plan shown in **Fig. 6** was drawn up on the assumption that the unit cost of power generated by the generators is significantly higher than the unit cost of purchased power. Therefore, the generators are scheduled to be used only when the batteries cannot meet the power demand.

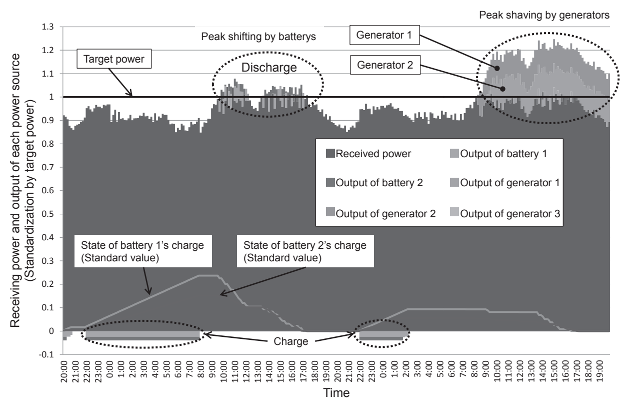

Fig. 6. Example of an operation plan drawn up by the optimal operation planning function

3-4 Dynamic reallocation control

There will be two problems if distributed power sources are controlled directly in accordance with the operation plan drawn up by the optimal operation planning function. One problem is that the power sources cannot respond to a situation change or requirement unless it continues for 10 minutes or longer, since the time granularity of the operation plan is 10 minutes. Another problem is that, since the operation plan is basically drawn up based on the prediction of power demand and power generation by natural energy, the distributed power sources will be unable to achieve the intended objective if the prediction is incorrect. The dynamic reallocation control is a scheme for solving these problems. With a control period of 10 seconds, which is shorter than the time granularity of the operation plan (10 minutes), the dynamic reallocation control system determines a control command and regulates the output of the distributed power sources so as to compensate for situation change and erroneous prediction. **Figure 7** shows the prediction/optimal operation plan and DRC execution period.

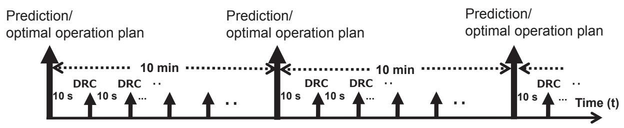

Fig. 7. Prediction/optimal operation plan and DRC execution period

When the output of distributed power sources is regulated, inaccuracy of the plan and prediction, the cost of power generation by each distributed power source, and other characteristics of the equipment are taken into account. In addition, the distributed power sources are operated as required without conforming to the operation plan. Building the dynamic reallocation control system into the optimal operation plan makes it possible to regulate the receiving power as desired.

4. Extended Function of *s*EMSA

4-1 Demand response function

Demand response (DR) is a program in which electricity consumers regulate the balance between their power demand and supply during a shortage of grid power in response to demand response requests from the power company. In practice, the consumers reduce the power they receive from grids by reducing their power consumption, operating their private generators, or taking other measures.

Sumitomo Electric Yokohama Works introduced in 2014 a *s*EMSA to control the distributed power sources including a gas power generator (4 MW), redox flow (RF) batteries (1 MW, 5 MWh), and a concentrating PV (100 kW), and participated as a power consumer in the DR demonstration project led by the Ministry of Economy, Trade and Industry. The configuration of the DR demonstration system is shown in **Figure 8**.

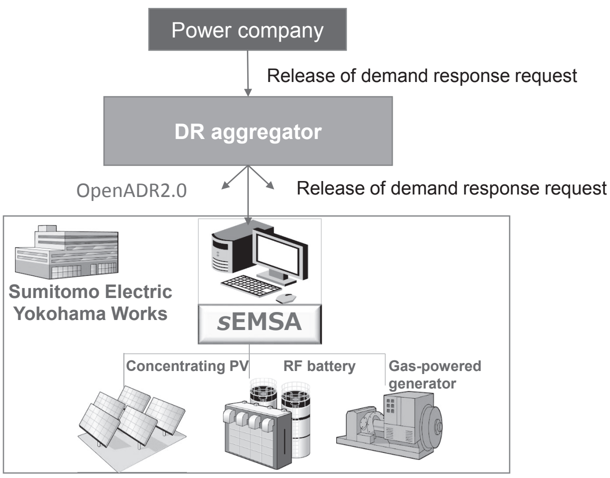

Fig. 8. Configuration of DR demonstration system

The DR demonstration project verified that *s*EMSA can accurately control the following items through the full-automatic operation of distributed power sources.

1) Receiving OpenADR2.0*[1] DR signals from DR aggregator.
2) Drawing up an equipment operation plan immediately after receiving the DR signal, under the restrictions agreed with the aggregator concerning the reduction of receiving power.
3) Receiving the reduced power while minimizing the energy cost.

Figure 9 shows the performance of *s*EMSA to reduce power supplied from the grid in response to DR signals.

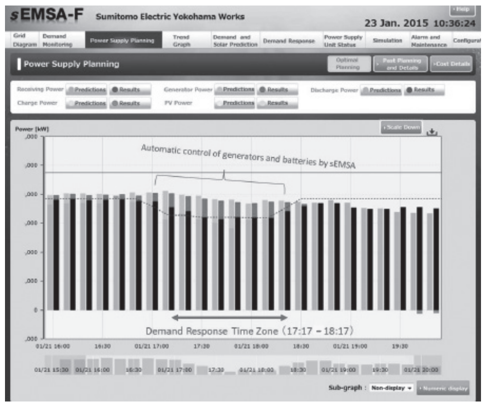

Fig. 9. Performance of *s*EMSA to reduce power supplied from grid in response to DR command

4-2 Contract demand examination support function

The *s*EMSA controls the operation of distributed power sources so that the energy cost is minimized under the condition of a given contract demand. However, to further reduce the energy cost of electricity consumers, it is essential to examine their optimal power demand and review their power demand-supply contracts with power companies. The contract demand examination support function of *s*EMSA makes it possible to simulate the dependence of annual energy cost on contract demand. For the simulation, *s*EMSA uses various bits of information it has collected, including the data on annual power demand, information about electric power rate and fuel price, and information about the distributed power sources.

Figure 10 shows an example of simulation results for the relationship between contract demand and annual energy cost. As discussed above, electricity consumers can use *s*EMSA to determine their contract demand that minimizes their energy cost, as well as the number of generators they should operate routinely and the purpose of use of the generators.

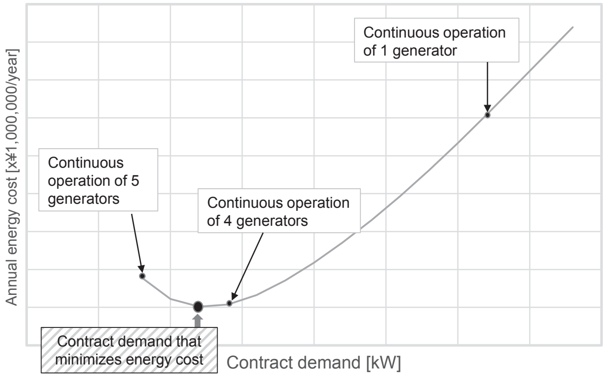

Fig. 10. Relationship between energy cost and contract demand

5. Development Platform

*s*EMSA has not been developed as an EMS for special equipment application. Since electricity consumers use a wide variety of equipment, it is expedient to use a virtual environment instead of actual equipment when customizing *s*EMSA for a specific electricity consumer and verifying the performance of *s*EMSA. In line with the above philosophy, Sumitomo Electric has developed an equipment emulator (**Figure 11**) that can emulate the equipment below the network interface layer shown in **Fig. 2**.

The new emulator is a platform that can simulate a wide variety of conditions. In particular, it supports MELSECNET/H, FL-net, and many other industrial networks in addition to the capability to faithfully reproduce drastic fluctuations of power demand, failures of distributed power sources, and other environmental changes on the electricity consumer side.

We promoted the development of *s*EMSA using this emulator, and verified the practicality of this management system in various usage environments.

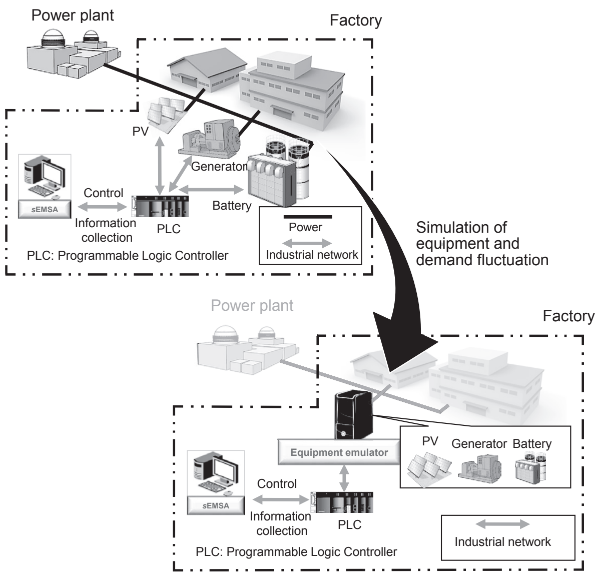

Fig. 11. Equipment emulator for simulating equipment and demand fluctuation

6. Demonstration Result

6-1 Demonstration at Yokohama Works

This section describes the results of the comparative test carried out at the Yokohama Works to compare the control of the distributed power sources by *s*EMSA with constant receiving power control. The configuration of the distributed power sources installed in the Yokohama Works are shown in **Table 2**.

Table 2. Configuration of distributed power sources in Yokohama Works

Equipment	Type	Output/capacity
Battery	Redox flow battery	500 kW (2,500 kWh), 1 unit 250 kW (1,250 kWh), 2 units
Photovoltaic	Concentration compound	100 kW, 1 unit
Generator	Cogeneration	648 kW, 6 units

Constant receiving power control is a technique that has conventionally been used to control generators. This technique consists of a start/stop control and feedback control. In the start/stop control, the generators are started one after another when the receiving power exceeds a target value for a given period of time, while they are stopped one after another when the receiving power decreases below the target value for another given period of time. In the feedback control, on the other hand, the output of each generator in operation is controlled so that the receiving power is maintained at the target value. In the constant receiving power control, the generators are not linked with each other but are controlled independently.

For a comparative test, the development platform described in the preceding section was used to simulate the environment of the Yokohama Works. Three generators were used as the distributed power sources that should respond to power demand during three weekdays in summer. The unit cost of power generated by the generators was set at a value substantially higher than the unit cost of purchased power. The results of the comparative test are shown in **Figure 12**. This figure shows that, compared with the constant receiving power control, the control by *s*EMSA reduced the number of inessential start/stop operations of the generators and increased the receiving power to a value closer to the contract demand. The reason for the above is that *s*EMSA reduced the output of the generators to a minimum since the unit cost of power generated by the generators was substantially high.

As discussed above, the demonstration test verified that *s*EMSA controlled power efficiently and reduced the meter-based electricity rate by approximately ¥20,000 per day. If the number of working days in summer is assumed to be around 64, *s*EMSA will yield an annual cost benefit of approximately ¥1.28 million. A proper allowance is set for the target receiving power to prevent power consumption from exceeding the contract demand. Controlling power by *s*EMSA makes it possible to reduce the allowance from that set for constant receiving power control. Therefore, *s*EMSA can further reduce the contract demand in addition to fixed expense saving by suppressing inessential start/stop of the generators.

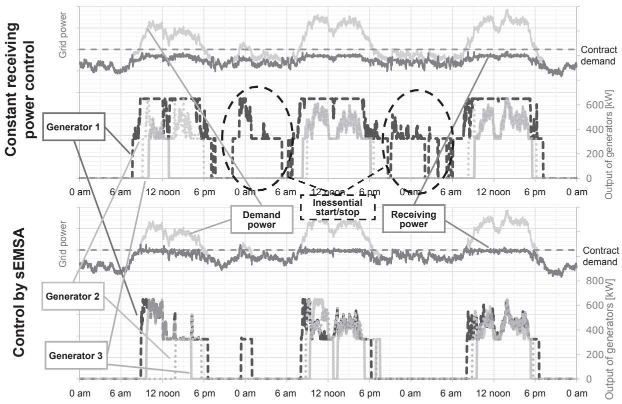

Fig. 12. Comparative test result for different generator control techniques

6-2 Demonstration at a factory of N-company

N-company introduced in January 2015 *s*EMSA into the distributed power sources installed in one of its factories and carried out a demonstration test. This section describes its results. The configuration of the distributed power sources in this factory is shown in **Table 3**.

Table 3. Configuration of distributed power sources in a factory of N-company

Equipment	Type	Output/capacity
Battery	Lithium ion battery	250 kW (96 kWh), 1 unit
Photovoltaic	Polycrystalline silicon	500 kW, 1 unit
Generator	Cogeneration	700 kW, 1 unit

The maximum power demand of this factory at the time of the demonstration test was approximately 1,800 kW. The photovoltaic generator in this factory has an output capacity that can cover most of the above power demand.

The demonstration test verified the following two significant functions of *s*EMSA. One is that control by sEMSA can shave the peak demand (the maximum receiving power: 1,300 kW) while fully using renewable energy generators whose output is difficult to control, and the other is that control by *s*EMSA can minimize energy costs by operating the lithium ion battery and generator while preventing reverse power flow by limiting the minimum receiving power to 100 kW.

A time-based pattern operation of the battery and generator was conducted on January 22, 2015 (Thu) and an *s*EMSA-controlled automatic operation of the above power sources was conducted on January 29, 2015 (Fri). The operation results are compared in **Figure 13**. The reason for the comparison is that the power demand and its pattern on the first day were similar to those on the second day, though the power generated by the PV was different.

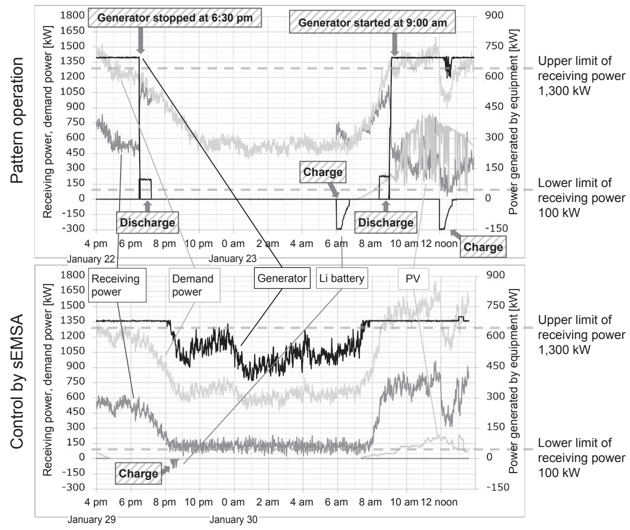

Fig. 13. Result of control by *s*EMSA at a factory of N-company

In the pattern operation, the generator was started at 9:00 a.m. and stopped at 6:30 p.m., while the battery was discharged for 30 minutes after the generator was stopped and before the generator was started. In the operation controlled by *s*EMSA, the generator was operated continuously and its output was controlled automatically so that the receiving power would not drop below a preset lower limit, while the battery was charged when the receiving power was likely to drop below the lower limit.

The following are the reasons for the difference between the results of the *s*EMSA-controlled operation and pattern operation. Since we were given a condition that the unit cost of power generated by the generator was lower by approximately ¥1.25/kWh than the unit cost of power purchased from the grid, we considered that operating the generator at its maximum output would minimize the energy cost and operated the generator continuously as much as possible. To describe the operation in more detail, the generator controlled by *s*EMSA generated a power of 8,055 kWh during the night (from 6:30 p.m. to 9:00 a.m.), a period in which the generator was stopped in the pattern operation. When compared with the cost for purchasing the above amount of power from the grid, the energy cost saved by the *s*EMSA-controlled operation was calculated to be a little more than ¥10,000.

The battery was operated differently between the pattern operation and *s*EMSA-controlled operation. In the former operation, the battery was used as an auxiliary system of the generator to suppress the fluctuation of receiving power when the generator was started/stopped. In contrast, the *s*EMSA-controlled operation selected a measure that can limit the number of battery charge/discharge cycles to save the charge/discharge cost. In addition, the *s*EMSA-controlled operation utilized the feature of the battery that responds to command signals faster than the generator. In practice, the battery was charged to compensate for delays in response of the generator in cases when the receiving power was likely to drop below the lower limit. This means that, in contrast to the pattern operation that the generator and battery used as devices for merely generating power, *s*EMSA coordinated the intrinsic functions of different types of equipment.

7. Conclusions

The authors have described the control technique by *s*EMSA we developed, as well as the results of the demonstration tests carried out at Sumitomo Electric Yokohama Works and a factory of N-company. We will commercialize *s*EMSA in 2015 and will also introduce it into our two manufacturing bases: Osaka Works and Itami Works.

Technical Term

*1 OpenADR2.0 (Automated Demand Response): The second version of the international communication protocol defined for automated demand response.

Reference

(1) T. Ozaki, Y. Ishigaki, Y. Kimura, H. Hori "Development of Energy Management System *s*EMSA for Customers" Annual Conference of Power & Energy Society 309, pp. 07-05-19 (2014)

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