Optimum Operation Control of Distributed Energy Resources Using ENERGYMATE-Factory

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Amid the changes in electrical power supply in Japan, Nissin Electric Co, Ltd. has been developing the Smart Power Supply Systems (SPSS) as a solution that integrates various distributed energy resources for power saving and stable power supply. The core system of SPSS, ENERGYMATE-Factory, enables the optimized control of energy provided by the combination of an electrical substation, one of the company's major products, and various distributed energy resources such as solar power generators, cogeneration systems, and grid energy storages. This paper describes the ENERGYMATE-Factory and its features, and introduces a practical-scale demonstration conducted at the Maebashi plant.

Keywords: energy management system (EMS), storage battery, generator, optimum utilization, and energy cost reduction

1. Introduction

The electric power energy industry in Japan is in the midst of a significant transformation. The industry is facing various energy-related challenges posed by renewable energy dissemination, increasing environmental and business continuity planning (BCP) awareness, and the necessity for addressing electricity system reform including electric utility deregulation. Nissin Electric Co., Ltd. (hereinafter, Nissin Electric) has so far delivered substation equipment and central monitoring and control equipment to many consumers including extra high-voltage or high-voltage consumers, water treatment facilities, and public utilities for highways. In view of this, Nissin Electric is promoting a smart power supply system (SPSS), which integrates a variety of distributed energy sources by making full use of our long-cultivated system interconnection technology and substation equipment technology, as a solution to realize energy conservation and stable supply of energy. The aim is to contribute to the creation of a smart community that will lead to an affluent society (Fig. 1).

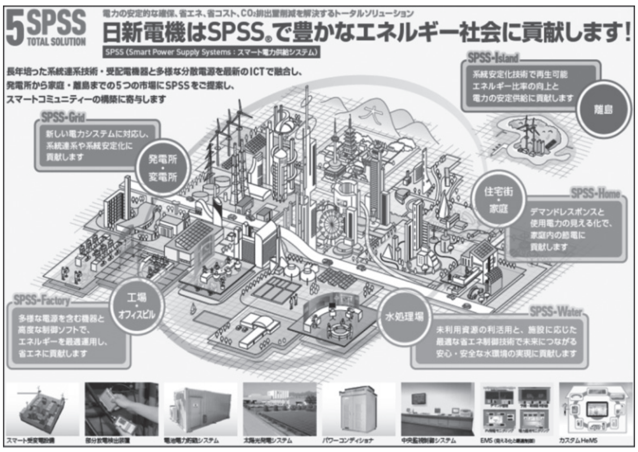

Fig. 1. Image of the SPSS

The ENERGYMATE-Factory (F) introduced in this paper is an energy management system (EMS) that provides the core function of the SPSS. It combines substation equipment, one of our major products, with a variety of distributed energy sources such as a photovoltaic power generation system, a cogeneration system (CGS), and a storage battery, to enable optimal power supply control. "ENERGYMATE-F" integrates hardware with software to achieve a solution for energy cost reduction.

2. System Outline

With the energy environment experiencing great change, we are proceeding toward an era in which we can choose energy as we like and use it smartly. For using energy more smartly, for example, through environmentally friendly and effective use of energy, diversification of energy supply risks, and local production and consumption of energy, it will be important to utilize a variety of distributed energy sources such as photovoltaic (PV) power generation, CGS, and storage batteries. This system predicts PV power generation and load demand. Based on this prediction, and taking account of the complicated operational conditions, such as equipment capacity utilization rate, target electric power, and the equipment characteristics of the distributed energy sources, the system plans and controls the operation of the distributed energy sources so as to minimize the energy cost.

When installing multiple distributed energy sources such as a CGS and a storage battery, the facility administrator needs to set operational patterns for each piece of equipment while taking into account the complex operational conditions to maintain the optimum operation of each distributed energy source. By integrating the operations of all distributed energy sources, this system reduces the operational burdens on the facility administrator and enables "operation at minimum energy cost," "peak consumption reduction," and "surplus power exploitation."

Figure 2 shows the system image, and Fig. 3 shows an outline of the functions.

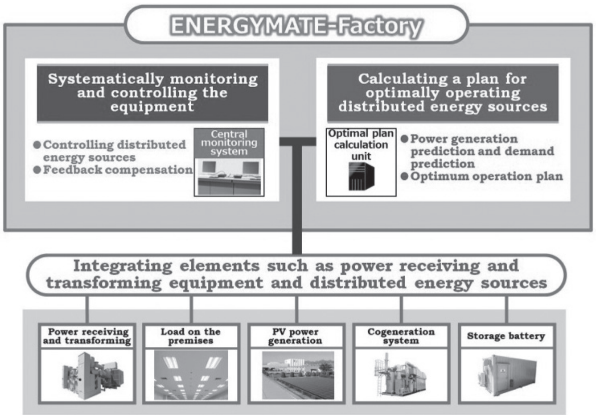

Fig. 2. Image of the ENERGYMATE-F system

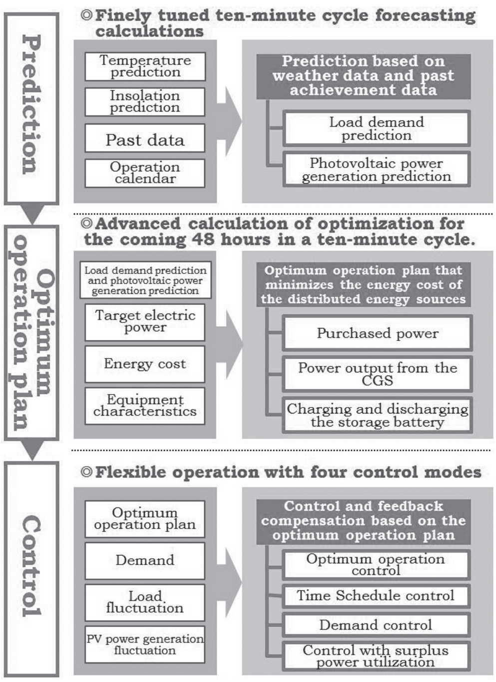

Fig. 3. Function outlines

2-1 Prediction

(1) Load demand prediction

Based on weather forecasts, current weather information, past load demand history, operation plan, and other relevant information, the system predicts load demand for the coming 48 hours in ten-minute cycles.

(2) PV power generation prediction

Based on weather forecasts, current weather information, past power generation history, PV panel installation conditions, and other relevant information, the system predicts PV power generation for the coming 48 hours in ten-minute cycles.

For both the PV power generation prediction and the load demand prediction, the system carries out precise and detailed calculations to minimize errors in the predictions.

2-2 Optimal operation plan

Based on the PV power generation and load demand predictions, the system plans the operation of the distributed energy sources such as the CGS and the storage battery. In this process, by considering operational conditions such as the energy charge unit price, the unit fuel price, the contract type, the target electric power, and the equipment characteristics of the dispersed energy sources, this product draws up a plan for the control command values (start and stop command values and output power values) that minimize the energy cost of the distributed energy sources.

2-3 Control

Based on the optimum operation plan, this product performs control. In addition, it monitors PV power generation and load demand on a real-time basis. If the plan is derailed due to a factor such as a rapid fluctuation in PV power generation or load demand, this product corrects the control command values and outputs the corrected ones.

3. Features of the System

3-1 Advanced calculation for optimum operation

In the above-mentioned optimum operation plan, a long-term plan for the coming 48 hours is carried out in short, ten-minute cycles. In the plan, this product performs an optimization calculation in which the equipment characteristic conditions of the distributed energy sources (which are shown in Table 1) are considered. This optimization calculation enables highly precise control operation.

Mathematical programming is used for the optimum operation plan and is able to provide the most mathematically suitable plan for complicated operational conditions.

Table 1. Examples of equipment characteristic conditions

CGS	Upper and lower limit constraints of output, speed of output response, start time, constraints on the number of starts, output/cost characteristics, etc.
Storage battery	Charging rate, speed of output response, charging and discharging efficiency, charging and discharging output limit values, etc.

3-2 Flexible operation with four control modes

"Optimum operation control," "time schedule control," "demand control," and "control with surplus power utilization." These four control modes (Fig. 4) allow management of the distributed energy sources operation. Optimally combining the control modes enables a flexible operation that is suitable for the situation. In the "optimum operation control" and "time schedule control" modes, the distributed energy sources are controlled according to the plan. However, plan-based control alone cannot always handle rapid fluctuations in photovoltaic power generation or load demand, or a situational change that occurs in the cycle up to the planned one. In "demand control" and "cControl with surplus power utilization" modes, a situational change is followed on a real-time basis, and the control command values are corrected in units of seconds. This constantly allows optimum operation. The outlines are given below.

(1) Optimum operation control

Complying with the control command values determined in the optimum operation plan, the product automatically controls the distributed energy sources.

(2) Time schedule control

The product automatically controls the distributed energy sources according to the preset time schedule. The schedule can be finely set in a cycle of one minute. In addition, this mode can control not only the time schedules of the distributed energy sources, but also those of air conditioning and lighting. Therefore, this mode enables integrated operation including operation of the load system.

(3) Demand control

If the target demand is likely to be exceeded, discharge from the storage battery or output from the CGS is performed to meet the demand. Furthermore, this mode has the function of rejecting excess demand load. The combination of dispersed energy source utilization and demand load rejection achieves more reliable control.

(4) Control with surplus power utilization

If the generated output is likely to exceed the load demand, the storage battery is charged, or the output from the CGS is reduced.

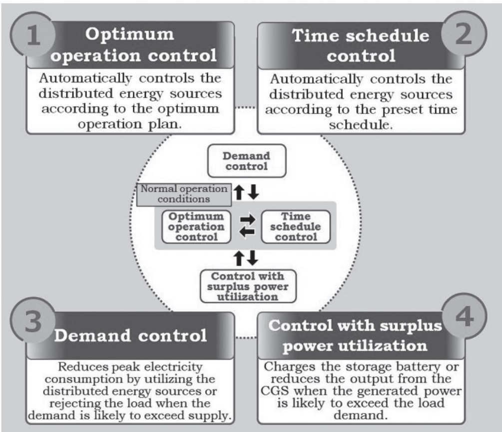

Fig. 4. Four control modes

3-3 User-friendly user interface

This product is equipped with not only an “operation control main window” (Fig. 5) for operating the distributed energy sources, but also other functions such as a “PV power generation prediction/achievement graphic chart,” “load demand prediction/achievement graphic chart,” and “optimum operation plan/achievement graphic chart.” Thus, this product is designed to comfortably handle both normal and maintenance operation. Since the load demand prediction for the coming 48 hours can be checked, future peak time zones and future peak demand can be understood, which enables measures to be taken against peaks ahead of time.

The provided interface allows the user to easily change various operational conditions online. These operational conditions include the energy charge unit price, the unit fuel price, the contract type, the target electric power, and the equipment characteristics of the distributed energy sources. Depending on the use environment, more flexible operations can be provided.

Fig. 5. Operation control main window

In addition, in facilities such as manufacturing plants, large-scale test equipment may be operated on an irregular basis. For the sudden load increases that occur in such cases, an operation calendar set-up function is provided. With this function, the user can set the value of the electric power demand, which will be higher than that during normal hours, in units of ten minutes. Using the value set in the above process as an offset value and reflecting it in the predicted value enables more accurate prediction of load demand.

4. Operation Examples

For development of the energy-related solution business, in 2011 Nissin Electric installed a 110-kW photovoltaic power generation system at the Osaka Works, and began visualization of the power consumed in our plants and office buildings, and the development and verification of a battery energy storage system. We then began to develop the system on a wider scale. At the Maebashi Works, we built a real-scale verification system comprising this product, a PV power generation system, a CGS, and a battery energy storage system, and started operation in March 2014. After that, we continued to develop the verification system towards commercialization.

Since April 2016, Nissin Electric has been continuing practical use of the system. Table 2 shows the system configuration and the effects of its introduction at the Maebashi Works.

Table 2. System configuration and effects of introduction at the Maebashi Works

<System configuration>

Equipment	Volume, etc.
PV power generation system	550 kW
CGS	Gas engine (700 kW)
Battery energy storage system	Lithium-ion battery (96 kW/h)
EMS	ENERGYMATE-F
<Introduction effects>	
Energy cost	Down 26% from FY 2012
CO_2 emissions	Down 8.5% from FY 2012

In addition, Figs. 6 and 7 as well as Photos 1 and 2 show images of the real-scale verification system.

Figures 8 through 11 show operation examples of the real-scale verification of the performance of the ENERGYMATE-F. Operation example 1 shown in Figs. 8 and 9 is an example based on the presumption that the purchased power is cheaper than the power produced by the CGS. The example shows the operation plan for a day and how the load and achievement of the distributed energy sources has progressed. The operation plan is based on the purchased power, which is cost effective. When the received power exceeds the upper limit of the target electric power, the peak is suppressed by storage battery discharge and CGS output. Conversely, when the received power is below the lower limit of the target electric power, storage battery charge and CGS output are utilized to compensate for the received power.

The “feedback compensation” in Fig. 9, which is an achievement trend chart, shows that the “demand control” and “control with surplus power utilization,” which had been caused by a deviation from the plan, allowed this product to follow and control the fluctuations in PV power generation and load demand in real time. It can be understood from the above that this product always operates

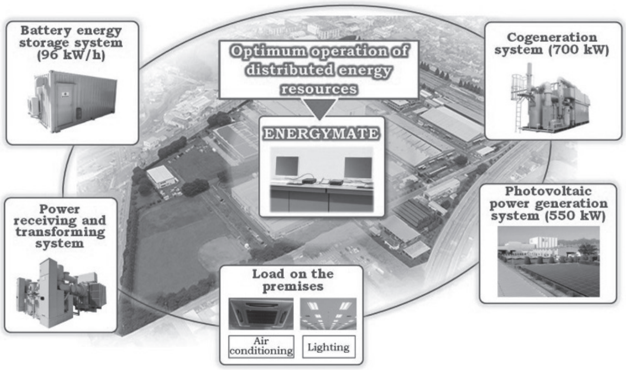

Fig. 6. Our Maebashi Works, a model plant for actual operation

Photo 2. Lithium-ion battery

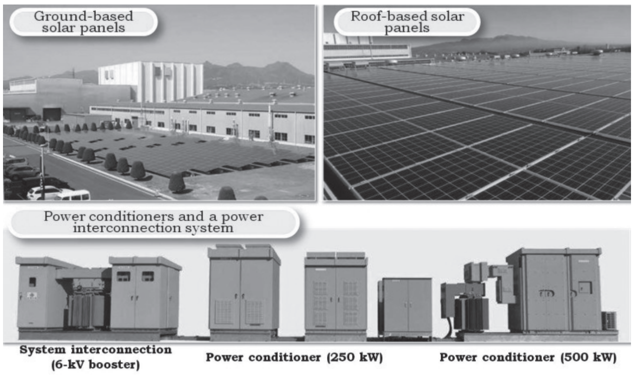

Fig. 7. Photovoltaic power generation system

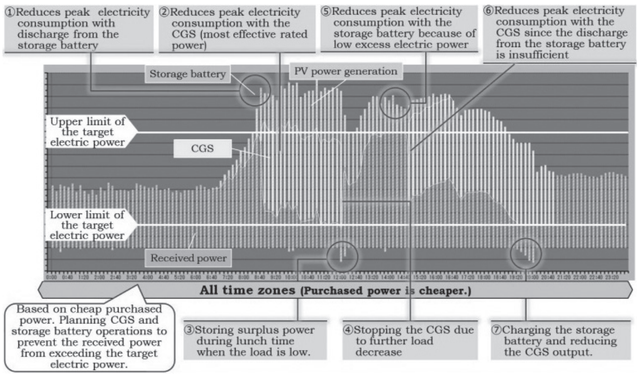

Fig. 8. Operation plan graphic chart of operation example 1
(Purchased power is cheaper.)

Photo 1. Cogeneration system

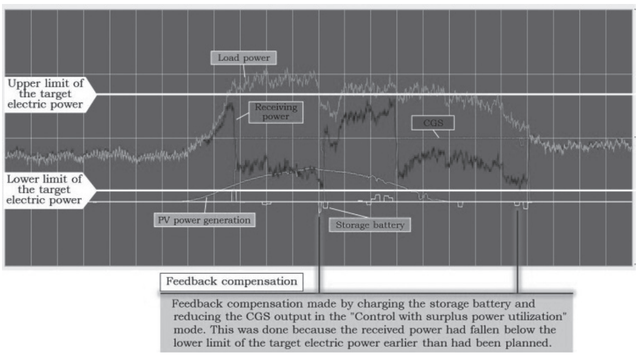

Fig. 9. Achievement trend chart of operation example 1
(Purchased power is cheaper.)

optimally while flexibly responding to an unplanned situational change that may occur in the cycle.

Operation example 2 shown in Figs. 10 and 11 shows the time-of-day rate system. In this system, in the daytime zone, the power produced by the CGS is cheaper than the purchased power, and conversely, in the night time zone, the purchased power is cheaper than the power produced by the CGS. The example is also an irregular case—a Saturday on which the workers came to work. In the daytime zone, the CGS-generating power, which is cheaper, was mainly used. However, the load on the Saturday was lower than the load during weekdays. Therefore, the operation was planned to prevent surplus power from being generated due to the suppression of output from the CGS and to the charge of the storage battery. In the night time zone, the purchased power, which is cheaper, was mainly used instead of the CGS-generating power. Therefore, before the night time zone began, the CGS was stopped. This is the action comprised of the following: (1) the output from the CGS is lowered according to a decrease in the load demand; (2) the lowered output reduces the operating efficiency; and then (3) at a time point in which the purchased power becomes cheaper, this product preferentially uses the purchased power and stops the CGS. In real operation, PV power generation and load demand fluctuate under low-load conditions. Therefore, on the Saturday, the time during which the plan was derailed was longer than that during weekdays. However, as shown in Fig. 11, the feedback compensation caused by the real-time control enabled the continuation of appropriate operation.

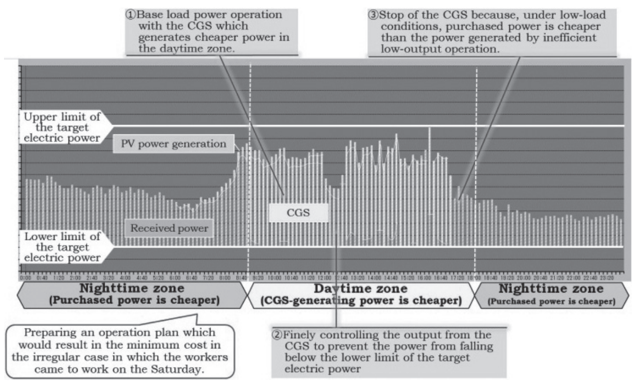

Fig. 10. Operation plan graphic chart of operation example 2 (on an unusual day)

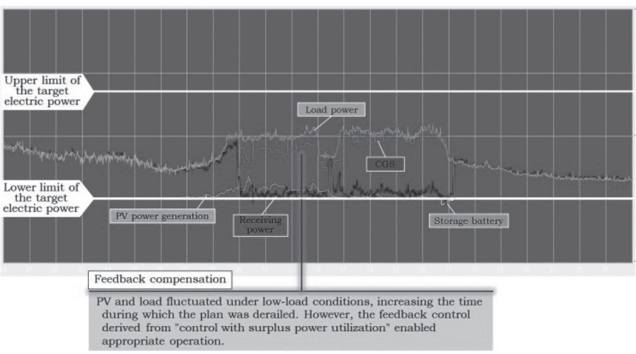

Fig. 11. Achievement trend graphic chart of operation example 2 (on an unusual day)

As described above, while satisfying various conditions such as the efficiency of the CGS, the upper and lower limit constraints of output, the speed of response, and the charging rate of the storage battery, this product can constantly and optimally select and use either the CGS or the storage battery, whichever results in a lower cost.

5. Conclusion

The environment surrounding energy is changing greatly: For example, not only electric power system reform, but also the full-scale liberalization of gas is being promoted. Energy management technology, which controls the balance between the demand and supply of electric power to create the most effective use of energy, will further increase its importance.

The "ENERGYMATE-F" system introduced in this paper is a product aimed at mainly plants and offices (SPSS-F). However, Nissin Electric is going to promote its use in various fields.

For water-treatment facilities, for example, Nissin Electric has a great deal of knowledge on energy-saving technology. We are engaged in research and development in new energy saving control technology which, while maintaining water quality, helps reduce power consumption by optimally controlling load systems such as blowers that consume mass energy and large-capacity pumps. Water-treatment facilities are expanding the introduction of renewable energy use with (1) PV power generation systems, (2) small scale hydropower systems that use effluent drops or small drops in the treatment facility, and (3) biogas power generating systems that utilize digester gas and exploitation of a battery energy storage system for BCP applications.

Under these circumstances, Nissin Electric will work to further optimize energy use by combining optimal control of distributed energy sources with energy saving control technology.

• SPSS and ENERGYMATE are trademarks or registered trademarks of Nissin Electric Co., Ltd.

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