Optimal Operation Planning Based on Large-scale Simulation for Renewable Energy Management

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Utilizing renewable energy including photovoltaic (PV) power generation is raising expectations as a key to realizing a sustainable and affluent low-carbon society. However, there is an issue with effectively using such energy in accordance with demand because the amount of energy generated may vary greatly with unpredictable changes in the weather. While PV power generation has a characteristic suited for peak power reduction—more energy is output in the daytime and during the summer when energy demand increases—it is necessary to appropriately deal with the hard-to-predict output variations in order to enhance the peak power reduction effect. This paper presents a technology for optimal operation planning for storage batteries that has been developed for resolving this issue and verification results based on the results of operating a demonstration system built in Fujitsu's Kawasaki Research & Manufacturing Facilities.

1. Introduction

The introduction of renewable energy is moving forward in countries around the world as part of an effort to solve global environmental problems. Japan, as well, is moving in this direction, and it expects solar photovoltaic (PV) power generation to be one of its main forms of renewable energy. In the government's "long-term energy supply-demand outlook (recalculated)" issued in August 2009, the target given for the deployment of PV power generation by fiscal year 2020 was 28 million kW, or about 20 times that of 2005. This target, combined with the government's implementation of a feed-in tariff scheme for renewable energy in July 2012, reflects Japan's earnest efforts to expand the introduction of PV power generation.

PV power generation is environmentally friendly by virtue of emitting no greenhouse gases in the power-generation process, and it is relatively easy to introduce as well. These features make it an attractive form of renewable energy. On the other hand, output from a PV power generation system can fluctuate greatly due to unpredictable changes in the weather, and this makes it difficult to use PV power effectively in accordance with demand. Although PV power generation is well suited to reducing peak power in that it can output more energy in the daytime and during the summer, when energy demand increases, only a small peak reduction is expected without load shifting since the temporal change in power output does not match the temporal change in demand.[1] Accordingly, it is necessary to appropriately deal with the hard-to-predict output variations of PV systems in order to enhance the peak power reduction effect in a stable manner.

Storage batteries are expected to play a major role in achieving such a supply-and-demand balance, but considering that their introduction involves facility costs as well as power losses due to charging and discharging, a technology is needed that can make the operation of storage batteries more effective by maximizing their performance without increasing their storage capacity.

As part of Fujitsu's environmental reference model project,[2] we have been researching and developing technology for making effective use of storage batteries while taking into account the unpredictability of PV power output. The aim is to make effective use of large-scale PV power generation to reduce the overall amount of power used by offices and achieve a reduction in peak power. In this paper, we present the evaluation results of this technology using a demonstration system constructed on the premises of Fujitsu's Kawasaki Research & Manufacturing Facilities.

2. Peak power reduction through PV power generation

Peak power reduction through the use of storage batteries can be achieved by discharging stored electricity in such a way that the amount of purchased utility power does not exceed the peak-cut target value set beforehand. However, when combining PV power generation and storage batteries to reduce peak power, setting an appropriate target value is not a trivial task.[3)]

If the supply-and-demand curves could be reliably predicted, it would be easy to calculate the optimal peak-cut target value from which the maximum peak-cut width can be obtained. Furthermore, if the prediction error could be treated as independent noise, a stable peak-cut effect could be achieved with a peak-cut target value determined by taking a margin for the prediction error into account. On the other hand, the change in solar radiation, which directly affects PV power output, is difficult to predict even in a short term of several hours with a state of the art weather forecasting technology.[4)] As a result, the system may fall into an unmanageable state when setting a peak-cut target value based on a prediction because unexpected subsequent weather changes may occur. For example, if the output from PV power generation drops significantly from that predicted, a situation may arise in which the peak-cut operation fails because the power stored in storage batteries is insufficient.

In other words, when aiming for a reduction in peak power through a system that combines PV power generation and storage batteries, setting an appropriate peak-cut target value is problematic given that weather may change unpredictably.

3. Optimizing operation of storage batteries by exhaustive predictive simulation

This section introduces technology for optimizing the operation of storage batteries with the aim of reducing peak power through the effective use of large-scale PV power generation. This technology controls battery discharge on the basis of the peak-cut target value and adjusts that value in accordance with current circumstances (solar radiation, amount of stored electrical power, etc.) to cope with uncertainty of PV power generation. A key feature of this control is the approach to uncertainty management concerning the peak-cut target value adjustment. At every adjustment time, it calculates an appropriate peak-cut target value for the immediate future (several hours) based on a set of various supply-and-demand scenarios that are likely to occur so that nearly the ideal effect can be obtained if any scenario actually occurs by correcting the peak-cut target value several hours later. The following introduces the configuration and the main functions of a demonstration system incorporating this technology.

3.1 Demonstration system

This demonstration system is broadly divided into two subsystems, namely, an "operation planning system" and a "control system" (**Figure 1**). It manages a microgrid that connects PV-power-generation equipment and storage batteries to an in-house power network that supplies electrical power to lighting and IT equipment on a floor of the main building at Fujitsu Kawasaki Research & Manufacturing Facilities.

1) Operation planning system

The operation planning system constructs an operation-plan database beforehand (every month in the current system) that is used by the control system to select an operation plan suitable for current conditions. Specifically, for each state that the control system could possibly encounter, the operation planning system first creates many projected scenarios (10 000 in the current system) to exhaustively cover any changes in the amount of solar radiation that could subsequently occur. Then, taking all of these scenarios into account, it creates an optimal plan having a high potential of dealing with those uncertain changes. The system registers each plan created for each state in the operation-plan database by associating that plan with conditions that identify the corresponding state.

For example, in the process of creating a database for plan-correction purposes, the operation planning system calculates an optimal peak-cut target value for each of 561 states resulting from a combination of 11 solar-radiation states and 51 stored power states and registers those target values in the database along with the solar-radiation and stored-power conditions

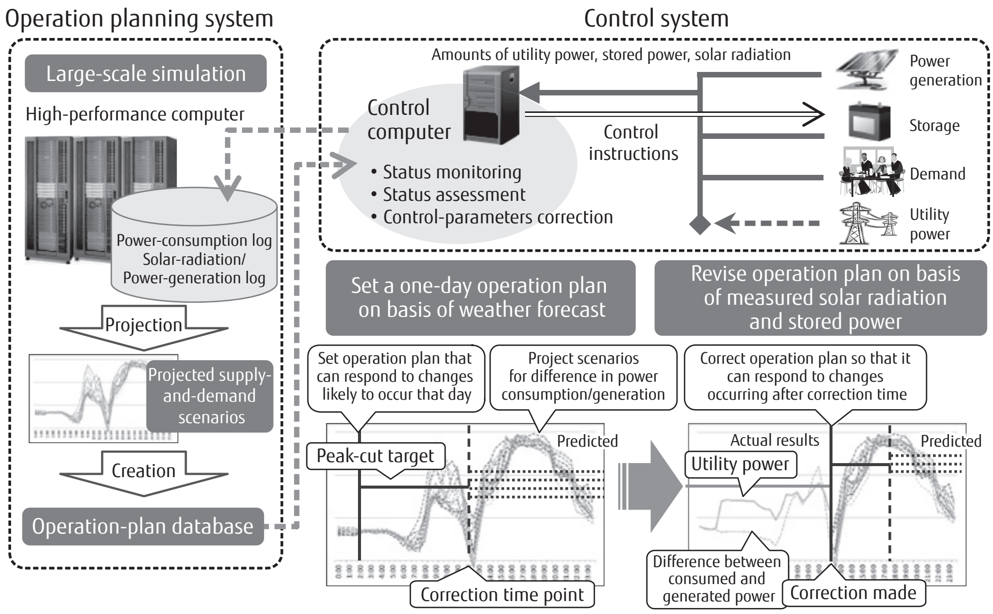

Figure 1
Overview of demonstration system.

corresponding to each.

2) Control system

Using the operation-plan database, the control system monitors the status of the power network and adjusts the operation plan in accordance with changes in that status. Specifically, at the start (midnight) of each day, the control system selects an operation plan from the operation-plan database on the basis of the amount of solar radiation expected for that morning based on the latest weather forecast and begins to put the storage batteries into operation. Then, at hourly planning correction time points (8:00–18:00), the system selects an optimal operation plan from the operation-plan database on the basis of the measured solar radiation and stored power and revises the peak-cut target value.

3.2 Optimal-plan creation by exhaustive scenario analysis

The operation planning system creates an optimal operation plan in accordance with the following procedure (**Figure 2**).

1) Generate exhaustive set of projected supply-and-demand scenarios

The first step is to create multiple supply-and-demand scenarios that are likely to occur based on targeted conditions (initial state). This is done by constructing a Markov model describing the change in solar radiation per unit time on the basis of past solar-radiation data, using that model to create multiple scenarios indicating possible fluctuations in PV power generation on the basis of Monte Carlo simulation, and generating multiple projected supply-and-demand scenarios by taking the difference between those scenarios and typical demand scenarios determined from demand data.

2) Perform scenario analysis using regret value

The next step is to decide on the operation plan to be used until the next correction time point by using the optimal operation plans for each projected supply-and-demand scenario (scenario-specific optimal operation plans). This is done as follows by simulation (**Figure 3**). For each combination of a candidate plan and a scenario, the effect of peak power reduction by that plan for that scenario is calculated by simulating the case where the storage batteries operate with that plan until a predetermined correction time point and operate with the optimal plan for that scenario after that time point. It is then compared with the ideal effect for that scenario, i.e., the effect corresponding to the case where the storage batteries operate with the scenario-specific optimal plan from the beginning to

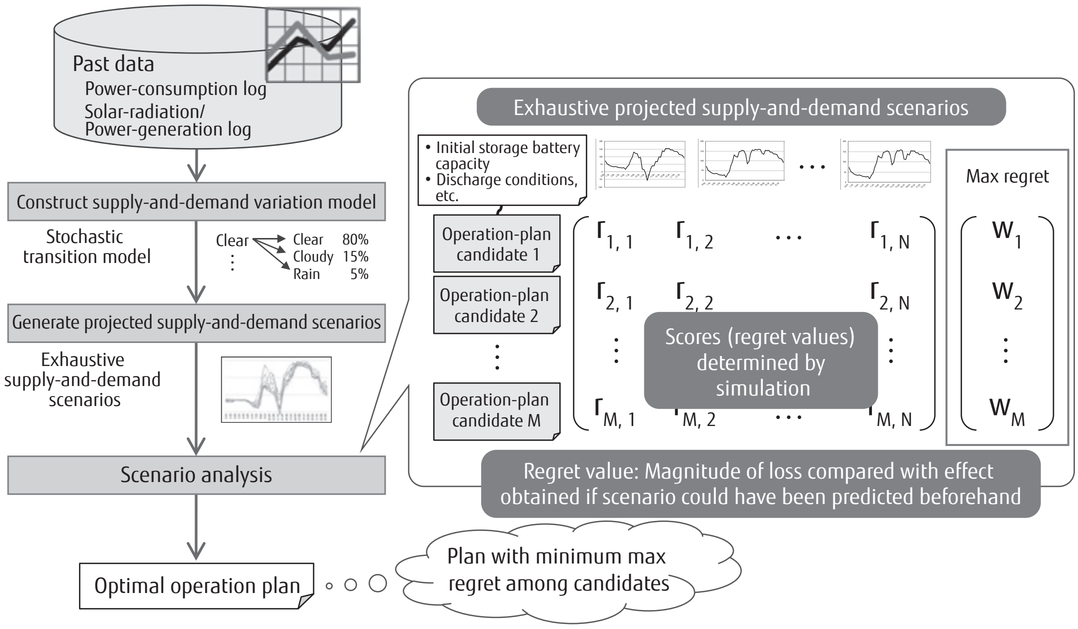

Figure 2
Optimal plan creation by exhaustive scenario analysis.

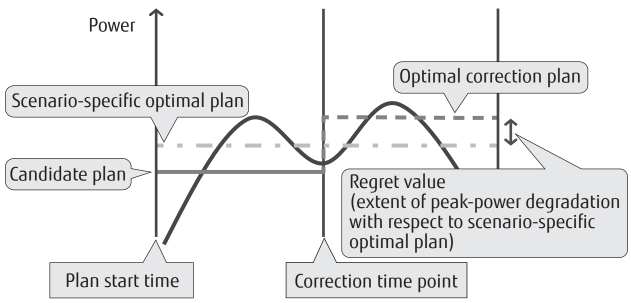

Figure 3
Calculation of regret value.

the end, and the drop in effect (degradation degree of peak power reduction effect) is taken as the score (regret value) for that candidate plan for that scenario. Finally, the candidate plan whose worst score (the regret value of the worst scenario for that plan) is the best among all candidate plans is selected as the operation plan to be adopted.

3.3 Operation plan selection using regret value

Selecting an operation plan on the basis of the regret value means selecting a plan that will minimize the feeling of regret no matter which scenario actually occurs. In other words, given the possibility that a scenario in which a large effect can be obtained by using a certain plan will occur, this approach selects a plan that exploits that chance (scenario), and conversely, avoids selecting an unstable plan that may fail and cause a large loss if a certain possible case (scenario) actually occurs.

Consider, for example, a case in which the weather is initially bad. It is likely that the amount of battery discharge will increase to compensate for the resulting poor PV power generation. It would therefore be reasonable to adopt a high peak-cut target value to prevent depletion of stored power. However, a high target value is not appropriate for when the weather improves because the higher that value, the higher the peak power before the weather recovers, meaning that the one-day peak power cannot be reduced even if the target value is reduced as soon as the recovery is detected. One approach in such a situation is to calculate for each candidate plan the regret value corresponding to the “opportunity loss” that will occur when the weather recovers, i.e., the difference from the ideal effect that would be obtained if the weather recovery could have been accurately predicted. This approach involves simulating the case in which the plan is corrected at a certain time point after detection of the weather recovery and selecting the operation plan that minimizes that loss.

Conversely, we can envision a state in which the weather is initially good so that a low peak-cut target value is set. However, the amount of stored electrical power when the weather turns bad will be insufficient owing to the effects of peak-cut battery discharge in the previous time period. As a result, it may not be possible to achieve a sufficient peak power reduction effect. For such cases, this approach calculates the opportunity loss for each candidate plan and selects the one that minimizes it, i.e., the most robust one.

3.4 Reducing turnaround time by parallel computing

A large amount of computational cost is required to create an operation plan for each possible state that could be encountered at the time of operation because the calculation exhaustively considers possible variations in solar radiation that could likely occur. For instance, it takes about 20 hours to calculate the operation plans for the first correction time point (8:00 AM), which requires the most computing, in a sequential process using one core of a PC server (FUJITSU Server PRIMERGY RX200 S3, 2.66 GHz, 8 cores).

Due to these computational costs and the seasonality of supply and demand, the demonstration system has been operated to prepare the operation-plan database once a month. In addition, the turnaround time (TAT) for creating a monthly database is reduced by applying parallel processing techniques. Specifically, 8–16 cores (1 or 2 nodes) are allocated for each of the parallel processes that individually create an operation-plan database for each correction time point. As a result, TAT is reduced to 2–3 hours. This is short enough to prepare several sets of databases corresponding to different settings, with which we can examine the effects of different operation policies to determine what policy should be used, e.g., to what extent batteries should be charged during lunchtime, when electricity demand in an office drops. From a practical economic point of view, creating the database once a month is reasonable because the cost (e.g., electricity consumption) required for computationally intensive processing to create the database does not significantly increase the total cost.

4. Overview of evaluation results

An example of results obtained from this demonstration system (on July 24, 2012) is shown in **Figure 4**. On this day, while a large drop in power-generation output due to variations in solar radiation occurred twice, the system successfully managed the peak-cut target value using the operation-plan database so that peak power usage was reduced by about 23% and purchased utility power usage by about 8%.

As shown by this example, the demonstration system operated well throughout the operation period: an average peak power reduction of about 23% was achieved through the use of a PV power generation system rated at 25 kW, the generation power of which covered about 20% of demand, and storage batteries with an effective capacity of 50 kWh (**Figure 5**). In particular, a peak power reduction rate greater than 20% was obtained for nearly every month. This value

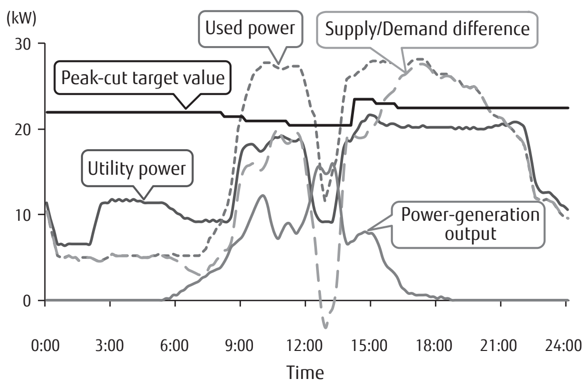

Figure 4
Example of demonstration system operation.

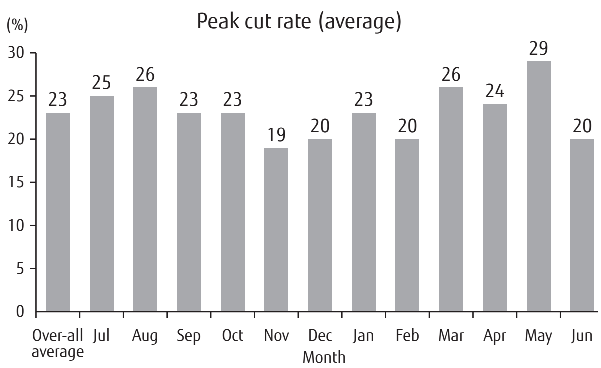

Figure 5
Operation results of demonstration system.

corresponds to the standard rate of discharge at which the storage batteries in this demonstration system can discharge continuously. This means that the operational ability of these storage batteries was sufficiently utilized, at least on average.

In addition, the effectiveness of a control technique that adjusts the peak-cut target value hourly using the operation-plan database was evaluated through simulations based on solar-radiation and power-demand data obtained from the demonstration system. This technique boosted the average peak cut rate by about 20%. Comparison of this control technique with one that adjusts the target value so as to obtain an optimal effect with respect to a single projected scenario showed that the former improves the average effect in a stable manner.[5)]

5. Conclusion

This paper introduced technology developed by Fujitsu for optimizing operation of storage batteries with the aim of making a significant reduction in the environmental load through the use of large-scale PV power generation. It also presented the evaluation results of this technology based on one year's worth of operation data.

A key feature of this technology is the creation of a plan with which we can manage the changes in conditions that are difficult to predict. This is achieved by using the computational power of parallel computers to perform simulations against many projected scenarios that are generated to exhaustively cover the conditions that are likely to occur. In other words, the approach taken is to optimize an operation plan that, for each scenario, minimizes loss with respect to the ideal effect that would be obtained if that scenario could have been accurately predicted beforehand, and does so even if any of those likely scenarios actually occur. This approach is based on the minimax-regret strategy in decision-making theory under uncertainty. In addition to this approach, a configuration that enables plan corrections to be made as needed on the basis of the amount of solar radiation measured in real time makes the developed technology even more effective.

A benefit of this approach is that problems with a plan can be specifically extracted in the form of disadvantageous scenarios by evaluating the plan through simulations based on various projected scenarios. Another benefit is that scenarios that can be dealt with by the same plan can be discovered when determining an optimal plan for each scenario. That is, if problems and relationships associated with certain conditions can be clarified in the form of scenarios and plans, this approach can be used to support human decision-making, to investigate combinations with other measures, etc.

To make effective use of natural energy that is inherently uncertain and to make the dream of a prosperous society in harmony with nature a reality, a more comprehensive approach than simply controlling distributed power supplies will be needed. Specifically, human activities will also have to be taken into account to effectively operate the entire system. Going forward, we are committed to expanding our research in this direction.

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