Green Base Station Electric Power Interchange Power Production Forecast

Collaboration Projects

Green Base Station Power Control Technologies for Reducing Costs and Disaster Risks

NTT DOCOMO continues to develop green base stations that are environmentally friendly and resilient to disasters to improve the availability of base stations during disasters and reduce base station costs. Therefore, in view of the coming liberalization of the retail electricity market planned for 2016, we devised technologies for predictive and linked control between multiple base stations that have achieved significant efficiencies in green base station power usage, battery cost reductions and that have secured backup time. This research was conducted jointly with the Computer Aided Electromagnetics Laboratory (Professor Shinji Wakao), Graduate School of Advanced Science and Engineering, Waseda University.

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1. Introduction

Energy issues are in focus around the world. In Japan, vulnerabilities in energy supplies were exposed due to large-scale power outages caused by the Great East Japan Earthquake, with approximately 4.66 million households supplied by Tohoku Electric Power Co., Inc. and 4.05 million households supplied by Tokyo Electric Power Company, Incorporated suffering blackouts [1]. When the earthquake occurred, NTT DOCOMO also suffered communications disruptions due to battery depletion in its base stations, which emphasized the importance of securing energy supplies during disasters.

In addition, visible preparations are underway for the 2016 liberalization of the retail electricity market and utilities are beginning to offer a wide range of electricity fee plans designed for a variety of consumer lifestyle patterns. Also, as users find out that their use of expensive daytime electricity is high thanks to the recent installations of smart meters*1, they are more than ever searching for ways to reduce their electricity fees by changing to more optimized fee plans.

Thus, in addition to these changes to the social situation surrounding energy, the managerial issues of energy and environment in terms of reducing costs and carbon dioxide emissions became even more serious when electricity consumption by the NTT DOCOMO Group reached 2.9 billion kWh in FY 2013.

For these reasons, NTT DOCOMO is continuing research into disaster resilient and environmentally friendly renewable energy systems for its radio base stations. This approach involves green base stations equipped with large capacity lithium-ion batteries (hereinafter referred to as "batteries") and photovoltaic panels (hereinafter referred to as "PV"), that

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*1 **Smart meter:** A device that enables real-time measurement and visualization of electricity usage.

are able to operate using only batteries or only PV depending on the situation. **Figure 1** shows the configuration of equipment in such a green base station.

In a green base station, surplus electricity generated by PV during the day or cheap nighttime off-peak electricity is stored in batteries, which can then be discharged to reduce the high costs of daytime commercial power and hence make the use of energy more effective [2] [3]. **Figure 2** describes an example of control using PV and nighttime off-peak electricity and the relationship with the State Of Charge (SOC) of batteries.

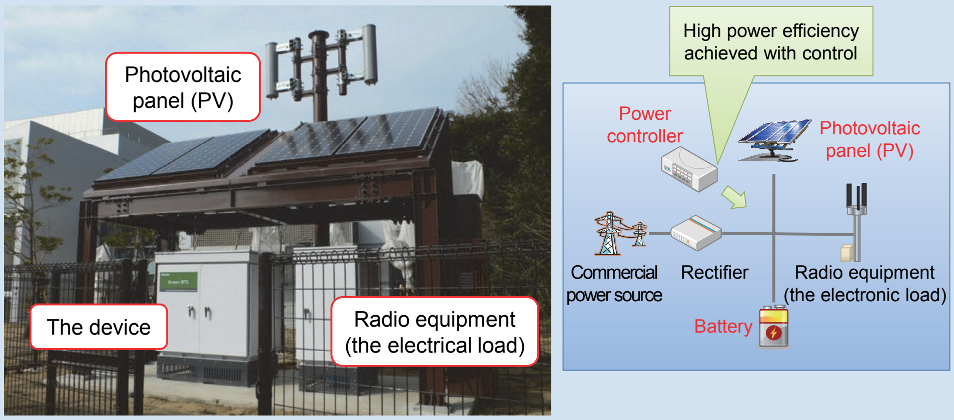

Figure 1 Green base station equipment configuration

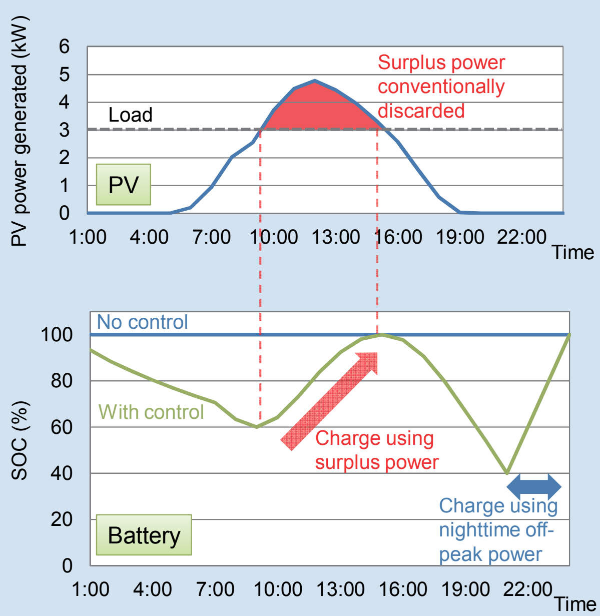

Figure 2 Example of control with PV and nighttime off-peak power, and SOC

To confirm the effectiveness and reliability of green base stations, ten test stations have been set up in the field in the Kanto Koshinetu region, and based on the performance of these test stations, commercial green base station deployment has begun with 11 stations already set up around Japan.

There are two main issues with implementing this type of green base station. The first issue is base station costs. Converting an existing base station to a green base station entails additional initial costs of installing batteries to provide backup power for six or more hours during the heavy traffic that directly follows a disaster, PV to generate sufficient electricity, and efficient power controllers. Therefore, in green base stations, power control must be even more efficient and outrank that of existing base stations in terms of running cost savings.

The second issue is base station disaster resilience. As discussed, the combination of PV and batteries in green base stations raises effectiveness in terms of environmental considerations as well as costs by enabling reduction of daytime use of commercial power by using surplus PV power that was previously discarded and nighttime off-peak power to charge batteries. However, because discharge reduces the backup time available for disasters, battery capacity and discharge must be calculated to keep discharge to a required minimum.

Accordingly, further improvements must be made to both cost reduction and disaster resilience for the ongoing deployment of green base stations. This article describes the power control technologies we have used to solve the above two issues.

This research was conducted jointly with the Computer Aided Electromagnetics Laboratory (Professor Shinji Wakao), Graduate School of Advanced Science and Engineering, Waseda University. As discussed later, our objective in this research was to establish predictive control technologies to estimate the amount of sunlight, because predictive control technologies have been shown to be effective for solving the issues discussed in this article [4]. In this research, we used Japan Meteorological Agency Grid Point Value (GPV) data*2 and Just-In-Time (JIT) modeling*3 for sunlight amount estimation.

2. Calculation for Optimizing Power Control

2.1 Multi-objective Optimization

To optimize power control, it's necessary to simultaneously solve both of the aforementioned issues of cost and disaster resilience as these two issues are in a tradeoff relationship. In this research, we studied solving these issues by multi-objective optimization calculations.

Generally in most cases, optimization implies optimizing for one objective. However, in reality, many of the varied issues in society entail simultaneous consideration of multiple evaluation criteria. As a method of handling these kinds of issues, multi-objective optimization involves calculating multiple solutions called a "Pareto optimality" which enables selection of controls to suit objectives.

As an example with a green base station, **Figure 3** shows a Pareto optimality using the two evaluation functions of battery capacity and electricity cost. As shown in fig. 3, increasing battery capacity reduces the cost of electricity, a running cost, but increases initial installation costs. In contrast, lowering battery capacity increases electricity costs but lowers installation costs. Hence, there is more than one solution (Pareto optimal solution) to this Pareto optimality – solutions for electricity cost reduction or battery cost reduction. Thus, the optimality enables selection of a solution to suit the situation. The following describes specific calculation criteria.

2.2 Evaluation Functions and Design Variables

To solve the two issues, we set the two evaluation functions of "electricity costs" and "disaster resilience index." Electricity costs are the product of the electricity unit price times the amount of power purchased, while the disaster resilience index was obtained by indexing battery operational capability during a power outage. Because it's necessary to consider green base station battery capacity and radio equipment power consumption when making an evaluation, we made our evaluations using a value

*2 **Japan Meteorological Agency GPV data:** Grid point value data for meteorological numerical simulation provided by the Japan Meteorological Agency.

*3 **JIT modeling:** A type of black box modeling for selecting neighborhood data in a database.

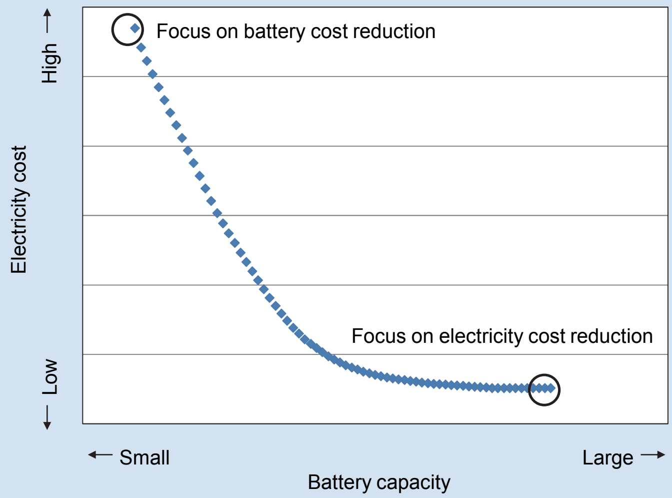

Figure 3 Example of a Pareto optimality

obtained by dividing the depth of discharge*4 with the maximum backup time. In both evaluation functions, the lower the value, the better the control. Also, to calculate the optimum power control techniques for both electricity costs and disaster resilience index, we set design variables*5 for changing the amount of battery charge/discharge and the amount of power for sending to other base stations. Specifically, these are an adjustment coefficient for estimating power generation and an SOC threshold value for power transfer between base stations. These variables are described in detail later.

2.3 Other Prerequisites

The following describes the prerequisites necessary for these calculations. Firstly, we set the range of charge/discharge such that at least six hours of backup power will always be available so that the period of high traffic directly after a disaster will be covered. Also, for green base station equipment requirements, we used the actual data for PV power generation of the three field test stations already set up, and based those requirements on the three test station equipment specifications. **Table 1** describes equipment requirements for each station. We based electricity costs on the unit prices of the low voltage power supplied by the utilities serving the locations of the three stations.

3. Wide Area Linked Control Using Prediction

3.1 Predictive Control

1) Overview

When using optimization calculations to actual power control, it's necessary to estimate power generation using technology to predict the amount of sunlight because the irregularity of PV power generation must be taken into account. Also, studies of discharge control have confirmed the effectiveness of Prior Discharge Equivalent to Surplus PV power (PDESP) as a simple control method for discharging the same amount from a battery right before generating surplus power [5]. However, even though PDESP is an effective solution for both issues of cost reduction and disaster resilience, there can be estimation errors because only the estimated amount of generation is used for control. For this reason, we studied optimization calculations to minimize the effects of errors using simulated estimated values to take prediction errors into account.

2) Handling Prediction Errors

If the amount surplus power is overestimated, backup time for disasters would

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*4 **Depth of discharge:** An index indicating what percentage of a full charge has been discharged.

*5 **Design variables:** Variable parameters used for optimizing evaluation functions.

Table 1 Specifications for the three field test base stations

	Ibaraki station	Nagano station	Niigata station
Load	1.2 kW	2.3 kW	1.0 kW
Battery capacity	40 kWh	27 kWh	9.3 kWh
PV capacity	2.0 kW	3.0 kW	4.5 kW

be reduced because of a low SOC due to discharge greater than the actual available charge capacity. In contrast, if power generation is underestimated, surplus power exceeding spare battery capacity will be generated, which would lead to avoidable extra costs due to surplus power being discarded. For these reasons, we devised ways to compensate for these potential overestimations and underestimations.

To handle overestimations, we implemented a setting for an estimate adjustment coefficient in the design variables. Specifically, this entails applying a reduction rate to the estimated amount of power generation to prevent batteries from falling into a low SOC. This method enables significant improvements to the disaster resilience index while having almost no adverse effect on cost reduction.

To handle underestimation, we implemented settings for standard SOC values. Here, we set an upper charge limit (an SOC standard value) to prevent full charging from commercial power sources, which enables batteries to absorb the difference from underestimated power generation, which thus minimizes the surplus power that ends up being discarded.

3.2 Cooperative Control

Historically, NTT DOCOMO has controlled power individually in its base stations, but has studied cooperative controls to transfer power between base stations to further raise power control efficiency. Cooperative control entails moving power from base stations with surplus PV power generation to those lacking PV power generation due to weather conditions, and holds promise of reducing battery costs, improving battery lifespan and improving backup time because it enables reductions in installed battery capacity and the frequency of battery charging. In this development, we performed optimization calculations for power transfer control that take into account power sales and wheeling of electric power*6.

Considering that the liberalization of the retail electricity market is a precondition for wheeling of electric power, we set requirements so that more power than reverse power flow*7 is purchased, because excess supply to demand is not possible. Also, with buying and selling power, due to the falling sales price of power in recent years, we assumed the selling and purchase price to be equal to clarify the effectiveness of linked control. We calculated the total unit price using the prices of the utilities servicing each base station location.

We also performed calculations using two patterns for cooperative control—from the perspective of a single base station, and from the wide area perspective. The single base station perspective is a method that involves PDESP for a single base station irrespective of the power generation conditions of other base stations, which entails only transferring surplus power that cannot be absorbed due to estimation errors. On the other hand, the wide area perspective involves power control that takes into account the power generation state of other base stations. To achieve this wide area control, we added SOC threshold levels to the design variables for optimization calculations. To date, in the single base station perspective, the single base station should give priority to fully charging itself, but by setting a threshold for SOC, once a base station has charged up to its SOC threshold, power can then be prioritized for transfer to base stations that have low PV power generation or backup time. This prevents a base station from overcharging and being unable to accept power from other base stations, or overdischarging because it has used up its surplus power.

4. Power Control Calculation Results

Figure 4 shows the results of optimization calculations. The axes show the evaluation functions. The vertical axis

*6 **Wheeling of electric power:** Supplying generated power to other locations via utility power transmission and distribution networks.

*7 **Reverse power flow:** Flowing generated electric power through a commercial power distribution network.

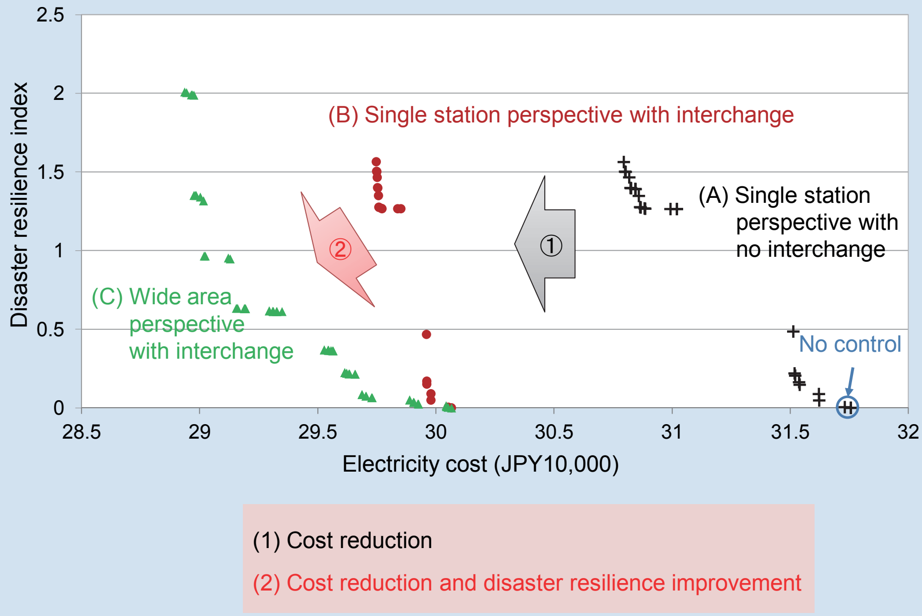

Figure 4 Results of optimization calculations

is the disaster resilience index, while the horizontal axis is the electricity price. This graph shows results calculated for a total of eight months for the three base stations described in Table 1. We performed optimization calculations for the three types of control methods. The first involves power control for a single base station (no power interchange) (fig. 4 (A)). The 0 disaster resilience index for (A) indicates that there was no charging or discharging, and hence no control. The second involves the single base station perspective control with power interchange (fig. 4 (B)), while the third involves wide area perspective control with power interchange (fig. 4 (C)).

Firstly, from the result at (A), it can be seen that electricity cost reduction was achieved with predictive control. Furthermore, in (B) and (C), it can be seen that power interchange enabled lower electricity costs (fig. 4 (1)), while wide area perspective control with power interchange improved both the disaster resilience index and power cost reductions (fig. 4 (2)). These results indicate that linked controls with the wide-area perspective can further reduce costs and improve disaster resilience compared to conventional controls.

Figure 5 describes the no control case compared to the three types of control in terms of the electricity price, the suppressed output amount, and the self-support rate for a disaster resilience index of around 1.5 at which these three types of control (fig. 4 (A, B, C)) have significant effects. The suppressed output amount refers to the amount of surplus power that could not be utilized, while the self-supplied rate refers to the percentage of power consumed covered by the power generated. This combined optimized usage of backup and surplus power is the result of properly distributing power for charging and discharging to and from base stations with low battery capacity and base stations with comparatively high battery capacity respectively. In other words, these results shows that implementing power transfer in operations with the wide area perspective means surplus power that could not be

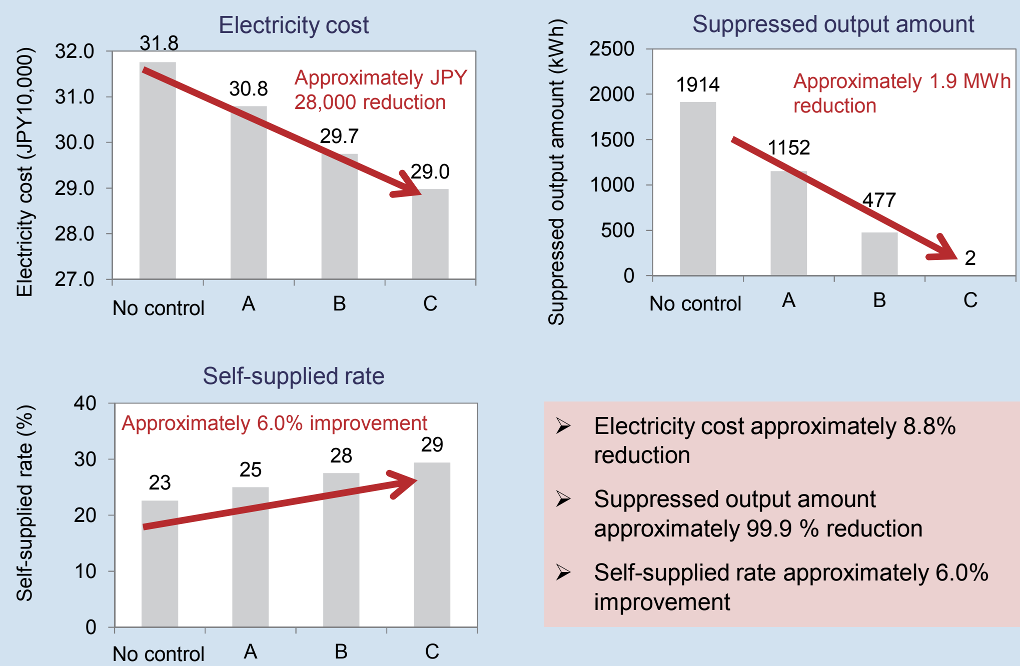

Figure 5 Comparison of results from the three base stations over eight months (with disaster resilience index around 1.5)

completely used by a single base station can be used by other base stations. Compared with no control over eight month at the three stations, wide area linked control enabled an 8.8% electricity cost reduction, a 99.9% reduction in the output suppression rate and a 6.0% percent improvement on the self-supplied rate. Lowering the overall depth of charge with the right controls also promises reduction in frequency of battery replacement and hence costs by slowing down battery deterioration. These systems can also reduce the amount of commercial power consumed which also reduces environmental load.

5. Conclusion

This article has described combined cost reduction and disaster resilience improvements for green base stations enabled by power control through multi-objective optimization calculations. Implementing this control technology promises to not only reduce power costs and raise self-supplied rates, but can also significantly improve the efficiency of battery usage. Going forward, we will continue to research and develop control methods that can respond to the diversification of electricity pricing plans. These control technologies must also be adapted for the small-scale base stations that will be indispensable to the mobile communications systems of the future, as they have the potential to greatly reduce battery capacity requirements compared to those of conventional systems. Thus, into the future, we plan to continue R&D for the implementation of these technologies into a range of different types of base station.

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