Weathercast Linking | Sunlight Control Mode | Autonomous/Regeneration Mode

Technology Reports

Weathercast-linked Control in Environmentally Friendly, Disaster-resistant Green Base Stations and Field Trials

Recent years have seen a full-scale rollout of green base stations applying environmentally friendly equipment such as solar panels and lithium-ion batteries to provide an environmental contribution and a countermeasure to disasters. This article describes "weathercast-linked control" as a technology for improving the functional performance of green base stations while achieving the contradictory objectives of an environmental contribution and disaster countermeasure. The technology can be used to control lithium-ion batteries based on information in weather reports, reduce the use of commercial power, and extend service time during a power outage.

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1. Introduction

In the wake of recent power outages brought on by natural disasters and other events, enhancing power-backup measures for mobile communications is becoming increasingly important. Although radio base stations are already equipped with storage batteries for backup purposes during power outages in the utility grid, it is thought that this scheme can be further enhanced by changing from lead-acid batteries to Lithium-ion Batteries (LiB) to increase full-charge battery capacity [1] [2].

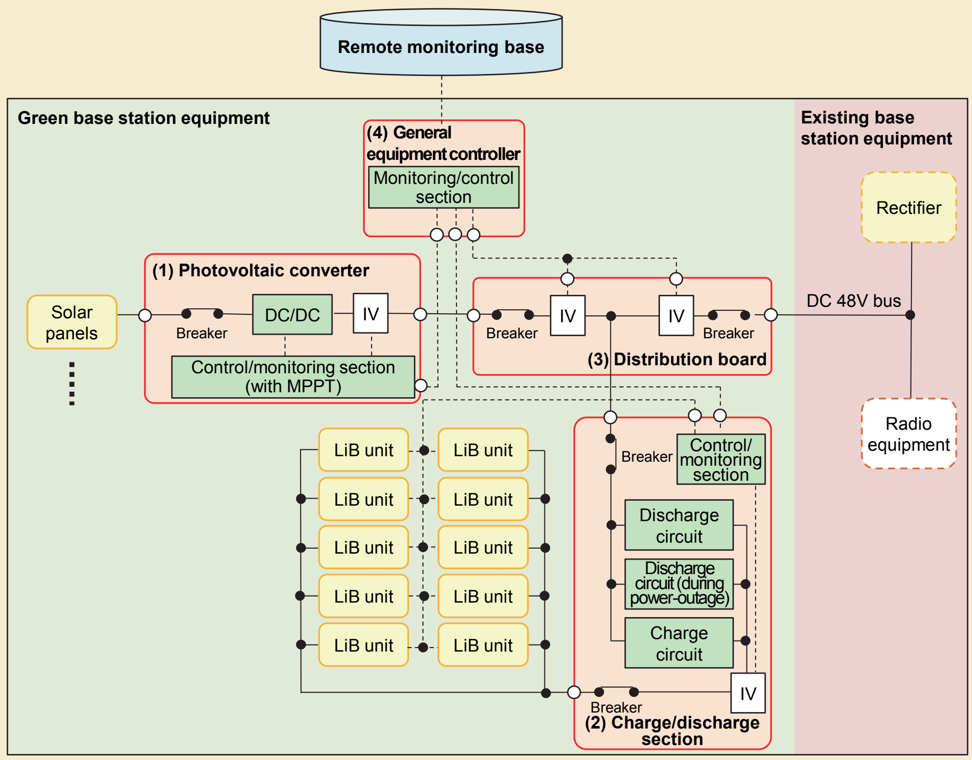
At the same time, studies are being performed on migrating to natural energy as an environmental contribution. In this regard, particular attention is being given to photovoltaic generation, which can generate power during daylight hours when demand is high and therefore reduce demand for commercial power during peak hours. Looking forward, the introduction of natural energy such as photovoltaic power in radio base stations can also be envisioned, and it is said that "green base stations" that can effectively combine storage batteries with natural energy and reduce environmental load can be an effective means of doing so [3].

To demonstrate the effectiveness and reliability of green base stations, NTT DOCOMO has so far installed ten stations for field-testing in the Kanto-Koshinetsu region (Tokyo and Kanagawa, Gunma, Ibaraki, Yamanashi, Nagano, and Niigata prefectures). Furthermore, based on the results obtained from these stations, 44 commercial green base stations have been installed throughout the country, which means that green base stations including the test stations are now operating in every prefecture in Japan.

A green base station improves the self-generation rate*1 by providing power shift control that efficiently stores surplus power generated in the daytime [4]. However, given that the power generated by solar panels may be insufficient or excessive depending on weather conditions, either LiB capacity must be increased or the battery's State Of Charge (SOC) must be brought sufficiently low beforehand to ensure charging without losing use of any surplus power generated. Yet, from the viewpoint of a disaster countermeasure, it is desirable to keep SOC as high as possible to ensure the provision of a power supply in the event of an emergency such as a power outage. However, increasing LiB capacity is constrained by costs and installation space, so keeping SOC low is necessary in practice, but this prevents an environmental contribution and a disaster countermeasure from being achieved together. To solve this issue, NTT DOCOMO has developed a technology called "weathercast-linked control." This article describes the configuration of a green base station, gives an overview of this technology, and reports on the results of field trials conducted at a test station.

2. Configuration of Green Base Station

A typical configuration of a green base station is shown in **Figure 1**. In addition to a rectifier*2, which serves as a power-supply facility in conventional radio base stations, a green base station introduces LiB in place of lead-acid batteries and connects the solar panels to a DC 48V bus*3 (hereinafter referred to as "DC bus") in parallel so that generated power can be used at times of a power outage. By incorporating



IV: Current/voltage measurement location. I: Symbol for current, V: Symbol for voltage.

Figure 1 Typical configuration of a green base station

*1 **Self-generation rate:** Percentage of consumed power covered by photovoltaic generation.

*2 **Rectifier:** A device for converting AC commercial power to DC power for radio equipment.

*3 **DC 48V bus:** Power line between the rectifier and radio equipment. Radio base stations use a DC 48V voltage.

a power-supply control section for high-efficiency control of these three types of power supplies, a green base station achieves effective use of natural energy and deals with peak power demand.

The power-supply control section consists of a (1) photovoltaic converter, (2) charge/discharge section, (3) distribution board, and (4) general equipment controller as described below.

(1) The photovoltaic converter incorporates a Maximum Power Point Tracking (MPPT)*4 function to generate power at maximum efficiency [5] [6]. It also sets the output voltage after Direct Current-to-Direct Current (DC/DC) conversion higher than the rectifier and LiB voltage to give priority to photovoltaic power in the supply of power to the radio equipment.

(2) The charge/discharge section incorporates charge and discharge circuits and performs a specific amount of charging and discharging based on instructions received from the control/monitoring section. The discharge circuit (during power-outage) includes a circuit for detecting voltage drops in the DC bus so that power can be supplied from the batteries without interruption at the time of a power outage.

(3) The distribution board provides a connection to the DC bus and detaches individual equipment from the DC bus at the time of an emergency.

(4) The general equipment controller performs unified management of generated power measured at IV current/voltage measurement locations and of various types of measurement data such as battery-unit information. It includes a monitoring function for passing information to a remote base and a function for responding to remotely received control instructions.

3. Overview of Weathercast-linked Control

An overview of weathercast-linked control is shown in **Figure 2**. This technology features two operation modes: sunlight control mode during normal times and autonomous/regeneration mode during power outages.

- In sunlight control mode, the process makes changes as needed to battery SOC based on information in weather reports so as to make maximum use of

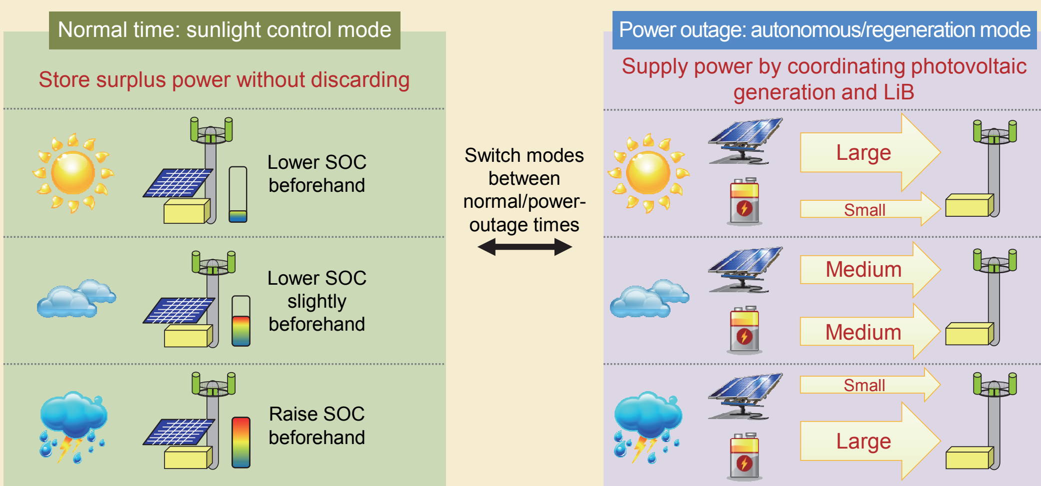


Figure 2 Overview of weathercast-linked control

*4 **MPPT:** A control technique for maximizing power generation by controlling the voltage of solar panels.

generated power. That is to say, it makes use of the fact that power generation by solar panels is highly dependent on the weather. For example, given a forecast of clear weather, SOC could be lowered beforehand at nighttime by discharging the batteries and supplying power to the radio equipment. This would enable charging in the daytime without losing use of any surplus power.

- In autonomous/regeneration mode, LiB supplies power to the radio equipment to make up for the insufficient portion of power from photovoltaic generation. Moreover, whenever surplus power happens to be generated by photovoltaic generation, the process switches to a charging operation without interrupting the above supply of power. This makes for maximum use of generated power the same as during normal times even during power outages.

These two modes make it possible to achieve both an environmental contribution and a disaster countermeasure. Specifically, if a power outage should occur after lowering SOC given a forecast of clear weather, a high backup effect can still be expected and the drop in LiB backup ability can be supplemented by making maximum use of the power generated by the solar panels the same as in normal times. Furthermore, if a power outage should occur after raising SOC given a forecast of rain, photovoltaic generation cannot be expected but the high LiB backup ability at this time can be used to compensate for the drop in solar-panel backup ability.

3.1 Sunlight Control Mode

1) Overview

Weather-dependent operation in sunlight control mode is shown in **Figure 3**. In this mode, the amount of surplus power generated by the solar panels is estimated based on weather forecasts. Then, by discharging that amount by time T when surplus power generation begins, solar-panel generated power that was conventionally discarded can be effectively used even for batteries that cannot hold sufficient capacity other than that needed for backup during a power outage. Moreover, at the time of an emergency such as a power outage, a solar-panel backup effect achieved by switching to autonomous/regeneration

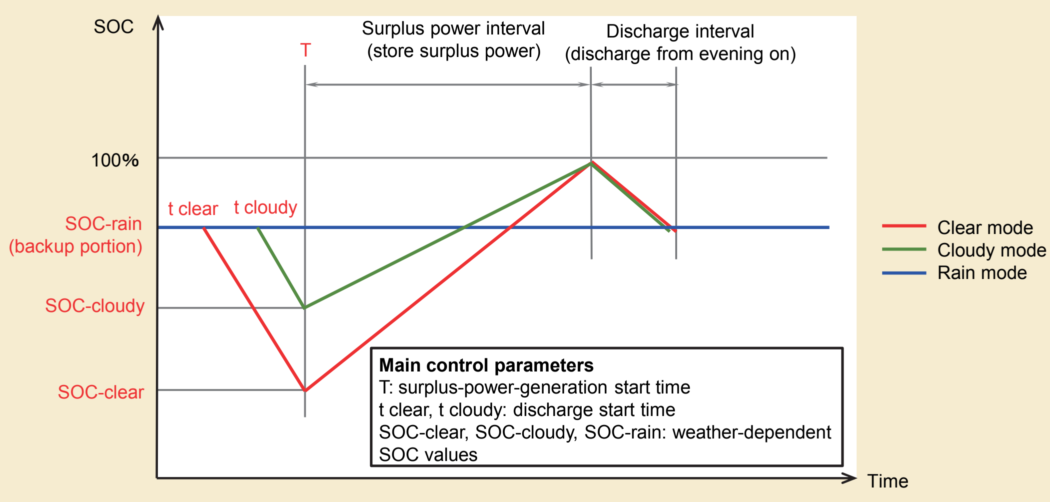


Figure 3 Operation in sunlight control mode

mode enables communication services to be continued for a specific amount of time.

2) Control Technique in Sunlight Control Mode

The following describes the control technique in sunlight control mode.

This technique begins by determining the weather-dependent SOC value (SOC-clear, SOC-cloudy, SOC-rain) and the discharge start time (t clear, t cloudy) based on information in the previous day's weather report. If rain is forecast, surplus power from the solar panels cannot be expected, so there is no need to discharge battery power beforehand. In this case, SOC-rain is determined to be the amount of backup needed for ensuring communications during a power outage. SOC-clear, meanwhile, is determined to be a value such that the maximum amount of surplus power generated in the last month is available for battery charging. Finally, SOC-cloudy is determined from the average value of SOC-clear and SOC-rain. Surplus-power-generation start time T is determined as the earliest time from among the actual start times for the last month, and discharge start time t is determined using full-charge battery capacity and the power load such that weather-dependent SOC is reached at surplus-power-generation start time T. Weather information for the base station is obtained before time t, and surplus power generated by the solar panels is used for battery charging after surplus-power-generation start time T. The evening-discharge start time is set from some time in the evening such as sunset when no surplus power is being generated, and on reaching this time, battery discharging begins so that SOC drops to SOC-rain (backup portion), at which time LiB enters a standby state. However, if the weather forecast includes the possibility of a natural disaster, LiB will be put into a fully charged state and operation will continue as usual until the disaster forecast is lifted. Additionally, if a disaster actually occurs and a state of power outage is entered, the radio equipment will be supplied with power from LiB, and when the power-outage state ends, LiB will again be charged up to the SOC-rain level.

3.2 Autonomous/regeneration Mode

1) Overview

Operation in autonomous/regeneration mode is shown in **Figure 4**. In the past, the LiB SOC would decrease monotonously at the time of a power outage due to a natural disaster or other

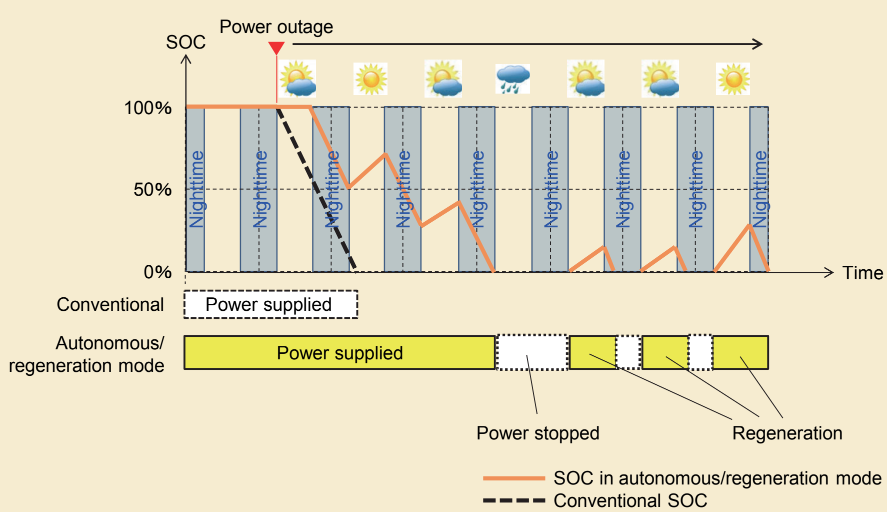


Figure 4　Operation in autonomous/regeneration mode

event, given that radio-equipment load was about constant. As a result, battery power would gradually diminish leading to a cut in service. In autonomous/regeneration mode, however, the power generated by the solar panels can be supplied to the radio equipment during a clear day and surplus power can be used to charge LiB thereby extending service time. Regeneration operation can be performed in the same way even after LiB depletes.

2) Control Technique in Autonomous/regeneration Mode

The following describes the control technique in autonomous/regeneration mode.

When using surplus power from photovoltaic generation to charge LiB at the time of a power outage, it is necessary to prevent a loss of power feeding to the radio equipment by using more power than the amount of surplus power for charging. In normal times, when charging batteries with more power than the amount of surplus power, an amount of power equivalent to this excess portion (the shortfall in power fed to the radio equipment) will be provided from the rectifier. However, in autonomous/regeneration mode during a power outage, power feeding from the rectifier cannot be expected. A technique is therefore needed to estimate the amount of surplus power so that charging using more power than that amount will not take place in autonomous/regeneration mode.

Estimating surplus power requires information on generated power and consumed power. While there is a technique for calculating generated power based on measurements of solar irradiance [7], irradiance can, in actuality, vary locally due to partial shading on solar panels and other effects, which makes reliable estimations difficult. In addition, power consumption in radio equipment can fluctuate slightly according to traffic conditions, which adds to the difficulty of making reliable estimates of surplus power.

For the above reasons, we apply a local search algorithm called the hill climbing method*5 as a technique for estimating surplus power in autonomous/regeneration mode. Specifically, when it is seen that rectifier output is zero and surplus power is being generated, this method increases the amount of charging in very small increments. Then, when it is observed that surplus power is not being generated, the method decreases the amount of charging in very small decrements. Repeating this process in such small steps enables surplus power to be estimated and only surplus power to be used for charging. Furthermore, while sudden drops in power generation can occur due to momentary shading by passing clouds on a day that is otherwise clear, the charge/discharge section can deal with this by switching to a discharge state from a charge state so that power feeding to the radio equipment is uninterrupted. The charging amount is then reset to a minimum value in preparation for the next round of charging by surplus power.

4. Field Trials

We installed a green base station providing 1.4 kW-rated photovoltaic generation at a radio base station in Gunma prefecture as a field test station. The power consumption of the radio equipment at this test station was approximately 0.5 kW. During the test, various types of measurement data regarding the power-supply system and any system alarms such as abnormal battery temperature were sent to a remote monitoring base over a communications circuit. The green base station was found to operate well with no system alarms generated during the testing period.

4.1 Test Results for Sunlight Control Mode

Test results for sunlight control mode are shown in **Figure 5**. For this demonstration, we conducted a long-term test from December 4, 2015 to January 3, 2016 using LiB with a capacity of 3.75 kWh. The graphs in the figure overlay the results for this period. Examining the change in SOC in Fig. 5(a), it can be seen from the manner of falling SOC by early-morning discharging that control could be performed according to the three prescribed control patterns (clear, cloudy, rain). Additionally, examining the change in generated power in Fig. 5(b),

*5 **Hill climbing method:** A search algorithm for finding the optimum of a function.

it can be seen that the amount of generated power was generally greater than the power consumption of the radio equipment during the day so that surplus power could be effectively used. These test results show that an improvement in the self-generation rate of approximately 11% can be expected compared with conventional power shift control under the same conditions.

4.2 Test Results for Autonomous/Regeneration Mode

Test results for autonomous/regeneration mode are shown in **Figure 6**. In this test, we used LiB with a capacity

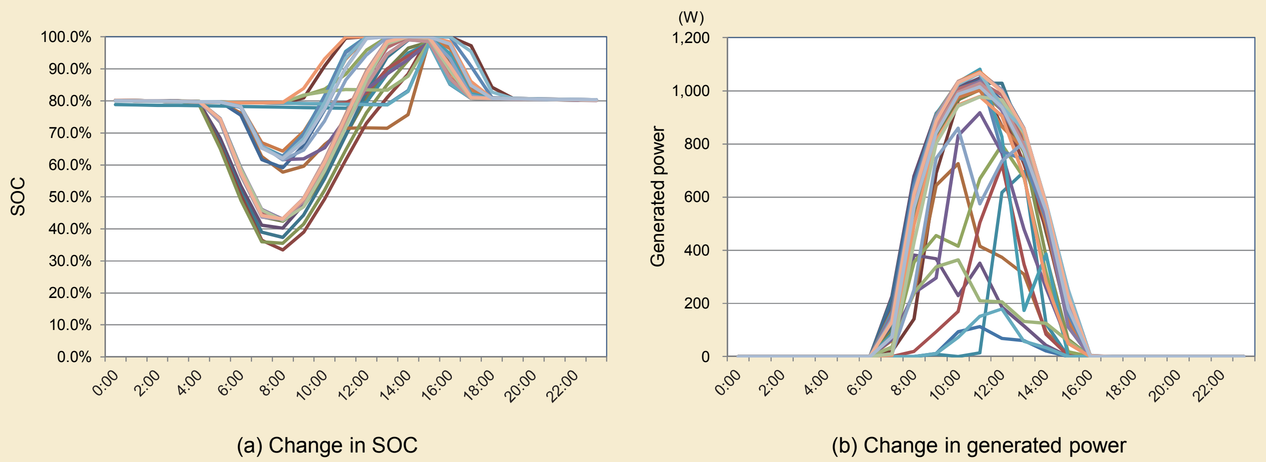


Figure 5 Test results for sunlight control mode

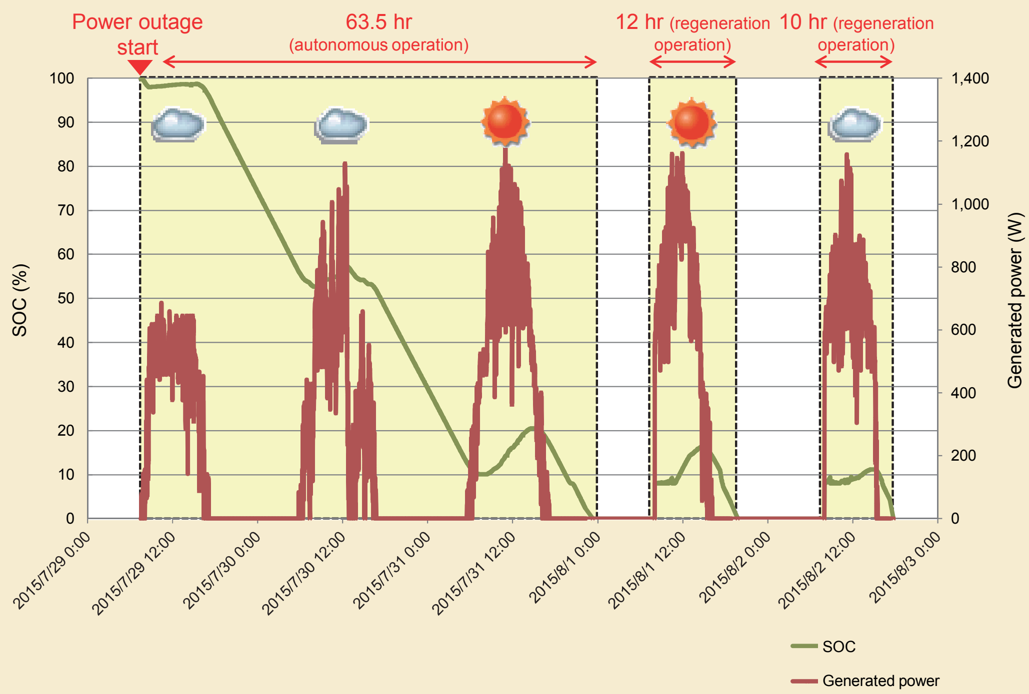


Figure 6 Test results for autonomous/regeneration mode

of 13.5 kWh and reproduced power-outage conditions by turning off the power supply to the rectifier in the field test station. The graphs in the figure show photovoltaic power generation (brown plot) and LiB SOC (green plot) after the beginning of a power outage. It can be seen that LiB charging took place even during a power outage, which means that power generation that included surplus power greater than the amount of power consumed by the radio equipment was performed. These results show that the autonomous operation period was approximately 2.4 times that when using LiB of the same capacity as an emergency power supply. It can also be seen from these results that the radio base station could operate for a certain period of time through power supplied from LiB even after sunset depending on the amount of power stored during the day.

5. Conclusion

This article described weathercast-linked control that achieves both an environmental contribution and a disaster countermeasure in green base stations. The use of this control technology can be expected to improve the self-generation rate, reduce the amount of commercial power used, and extend service time during a power outage. Going forward, we plan to enhance the service-time extension effect during power outages without diminishing the self-generation rate by further dividing control/operation modes to raise the level of LiB backup time. We also plan to promote the introduction of this technology in parallel with the expansion of green base stations.

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