Establishment of Optimal Equipment Design and Nationwide Monitoring for Environmentally Friendly, Disaster Resilient Green Base Stations

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1. Introduction

While establishing environmentally friendly and self-sufficient renewable energy sources (mainly Photovoltaic (PV)), NTT DOCOMO continues to research green base stations to achieve long-lasting backup power supplies and visualized PV power generation data*1 enabled by large-capacity cycle-type*2 batteries and Green Power Controllers (GPC). Since determining commercial green base station viability through verification of their operation in the R&D Center [1] and at ten field trial stations in the Kanto Koshinetsu region [2], NTT DOCOMO set up commercial green base stations in 11 locations from Hokkaido to Kyushu in FY 2014, to bring the total to 21 stations, which began operations in April of 2015.

This article describes the basic structure of green base stations set up for the field trials and optimal design patterns for commercial green base station installation (power-receiving stations, and solar-powered stations). Also, the article describes the monitoring methods using an integrated monitoring system that enables visualization of PV power generation data, and example data acquisition.

2. Green Base Station Power Supply Structures

2.1 Field Trial Stations

Figure 1 shows the basic structures of the green base stations set up for field trials. While using commercially available power from a utility, these green base stations have been configured by adding (1) PV, (2) large-capacity cycle-type batteries, and (3) GPC.

The following describes these added components and facilities:

(1) PV: Equipment consisting of solar panels and PV converters. The number of solar panels installed must meet a rated power generation capacity larger than the power consumed the communications load. When there is sufficient sunlight striking the surface of the solar panels, the base station can run on PV alone, while the surplus power generated, i.e. power not consumed by radio equipment (the load), is used to charge in large-capacity cycle-type batteries. PV converters in these stations have functions to measure the

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*1 **PV power generation data:** In this article, PV power generation data refers to both the power being generated by PV (kW), and overall amount of PV generation (kWh).

*2 **Cycle-type:** A battery system involving cyclic charging and discharging.

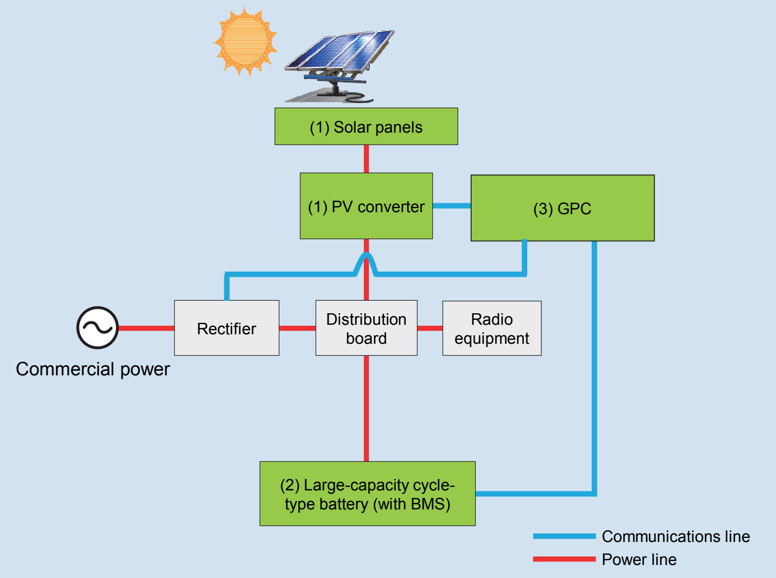

Figure 1　Green base station basic structure

amount of power generated by the solar panels and communicate it to GPC, as well as DC*3-DC voltage conversion functions to convert the direct current from the solar panels to the 48 V direct current required by the communications systems. By connecting solar panels to the direct current communications power supply in this way, base stations can operate on PV alone, which means mobile communications during the day can be secured even if the commercial power supply (alternating current) is cut off during a disaster.

(2) Large-capacity cycle-type battery: Compared to conventional float type*4 lead-acid batteries*5, these large-capacity cycle-type batteries (nickel-hydride*6 or lithium-ion*7 types) have approximately twice the battery capacity*8, and can provide 14 to 16 hours of backup power to base stations while only taking up a small amount of space. Also, the use of large-capacity cycle-type batteries with Battery Management Systems (BMS)*9 that can communicate with GPC enables flexible charge and discharge control.

(3) GPC: This enables remote control of the combination of three power supplies used by base stations (commercial power, PV, batteries), and enables "power visualization" of PV power generation data and battery charge levels etc. As an example of controlling power with this equipment, NTT DOCOMO has successfully demonstrated a system called "double power control*10" [3].

2.2 Commercial Green Base Stations

1) Power-receiving Stations

Figure 2 describes the configuration of commercial green base stations. The pattern shown at Fig. 2 (a) describes a power receiving station that operates continually using the existing rectifiers*11 and lead-acid batteries, and is converted to a green base station by adding (1) solar panels, a PV con-

*3 **DC:** The direct current component of electricity (frequency of 0 Hz).
*4 **Float-type:** A type of battery that charges as power is supplied to the load, and discharges during a power outage.
*5 **Lead-acid battery:** A battery that uses lead materials for its electrodes. These are inexpensive compared to other types of battery, but are large and heavy.
*6 **Nickel-hydride battery:** A battery that uses nickel and a hydrogen storing alloy (a metal that can take up hydrogen) for its electrodes. These batteries are very safe because the electrolyte and electrodes are non-flammable.
*7 **Lithium-ion battery:** A type of storage battery in which lithium ions in the electrolyte move during charging and discharging. These batteries are characterized by their high energy density and low self-discharge rate.
*8 **Battery capacity:** The total electrical capacity that can actually be discharged from a battery pack.
*9 **BMS:** A control system that enables monitoring and controlling of battery voltage, input and output current, charge level and temperature, etc.
*10 **Double power control:** Technology to store low environmental load electricity in lithium-ion batteries from daytime surplus PV power generation and from off-peak power at night. Battery power is used from the evening when PV generation stops until 11 at night when off-peak power becomes available.
*11 **Rectifier:** A device for converting AC power to DC power.

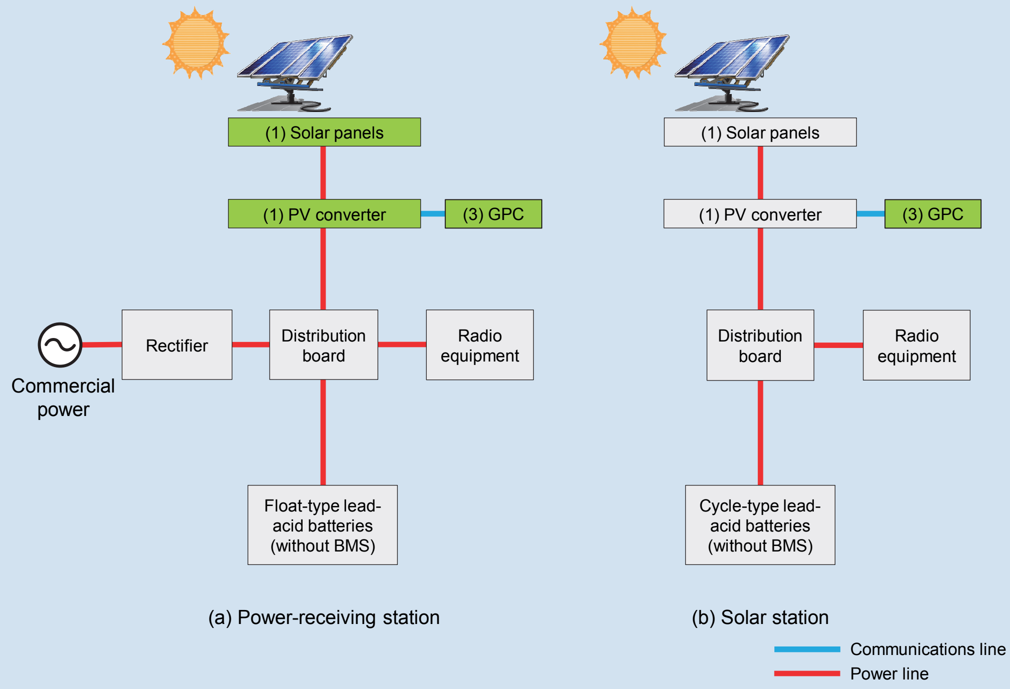

Figure 2 Commercial green base station configuration

verter and (3) GPC. In this case, because the existing lead-acid batteries do not have a BMS, it is not possible to control charging and discharging with GPC, although GPC is installed so that PV power generation data can be collected and sent to the monitoring system (described later) for power visualization.

2) Solar Stations

In general, commercial base stations are the “power-receiving” type that operate using commercially available power. However, in mountainous or remote locations where commercial power is not available, “solar stations” have existed for some time, and can be converted to green base stations as described by the pattern shown at Fig. 2 (b). Solar stations include enough solar panels to satisfy power generation rated higher than the power consumed by the load. In these stations, the surplus power generated that is not consumed by the load is used to charge lead-acid cycle-type batteries. The power supplies in these stations are designed so that stations can continue to operate even after several continuous days of insufficient sunshine. Since solar stations have PV and cycle-type batteries in common with green base station power supplies, the addition of GPC monitoring equipment enables visualization of PV power generation and enables solar stations to be converted to green base stations. To date, solar stations have featured a battery low voltage alarm to provide an alert if there is insufficient sunlight. However, because conversion to a green base station entails real-time acquisition of PV power generation data, conditions of insufficient sunlight can be detected earlier which means these systems offer better prospects for maintenance and support.

The power supply configurations described above are summarized in **Table 1**. In future, commercial green base stations can be expanded by adding monitoring and control equipment or modifying the equipment as required for the basic green base station structure.

3. Visualization through the Integrated Monitoring System

By installing monitoring equipment in the green base stations in various locations, we have built an integrated system to collect and monitor green base station power data. **Figure 3** describes the structure of this system. This system consists of (1) monitor-

Table 1 Comparison of green base station power supply systems

	Green base station system (field trial stations)	Commercial green base stations	
		Power-receiving stations	Solar stations
Receives commercial power	Y	Y	N
Rectifier	Y *1	Y *1	N
Solar panels	Y	Y	Y
PV converter	Y	Y	Y *1
Battery type	Cycle-type *2	Float-type (lead-acid)	Cycle-type (lead-acid)
Power generation monitoring equipment	GPC, data logger	GPC, data logger	GPC or data logger *1
Equipment monitored	PV converter, rectifier, distribution board, cycle-type batteries	PV converter, rectifier, distribution board	PV converter

*1 If the equipment does not support GPC, power data is acquired through the data logger.
*2 Must have a BMS that can communicate with GPC.

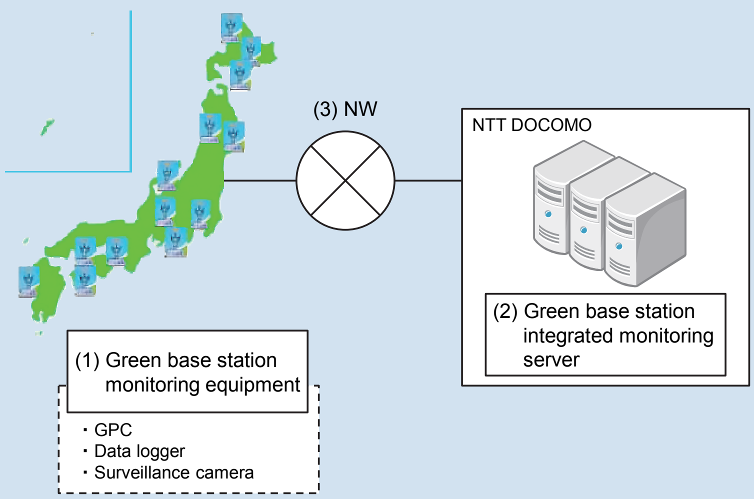

Figure 3 Structure of green base station integrated monitoring system

ing equipment, (2) an integrated monitoring server, and (3) the NetWork (NW).

(1) Monitoring equipment: This consists of GPC, a data logger and a surveillance camera, which provide PV power generation data/battery charge level, power consumption by the load, and an outdoor image of the solar panels respectively. The surveillance camera is included so that the relationship between PV power generation and weather or shade conditions and the conditions of solar panels can be monitored. In selecting equipment, minimizing power consumption increases due to the addition of extra devices and the wide range of operational temperatures around Japan must be carefully considered. For these reasons, we tested and verified equipment operation in the R&D Center before deployment in the base stations.

Figure 4 describes the configuration of monitoring equipment in green base stations. Fig. 4 (a) describes the structure of equipment in power-receiving stations (including field trial stations). As well as GPC, data loggers and surveillance cameras, we also installed Power over Ethernet (PoE)*12 hubs to connect this equipment to the NW, FOMA ubiquitous modules to send data to the integrated monitoring server, and a monitoring equipment power supply to supply power to these devices. In power-receiving stations, mon-

*12 **PoE:** Technology to transmit electrical power to other LAN devices using LAN cables in Category 5 or above (Unshielded Twist Pair (UTP) cables). Standardized in IEEE802.3ef.

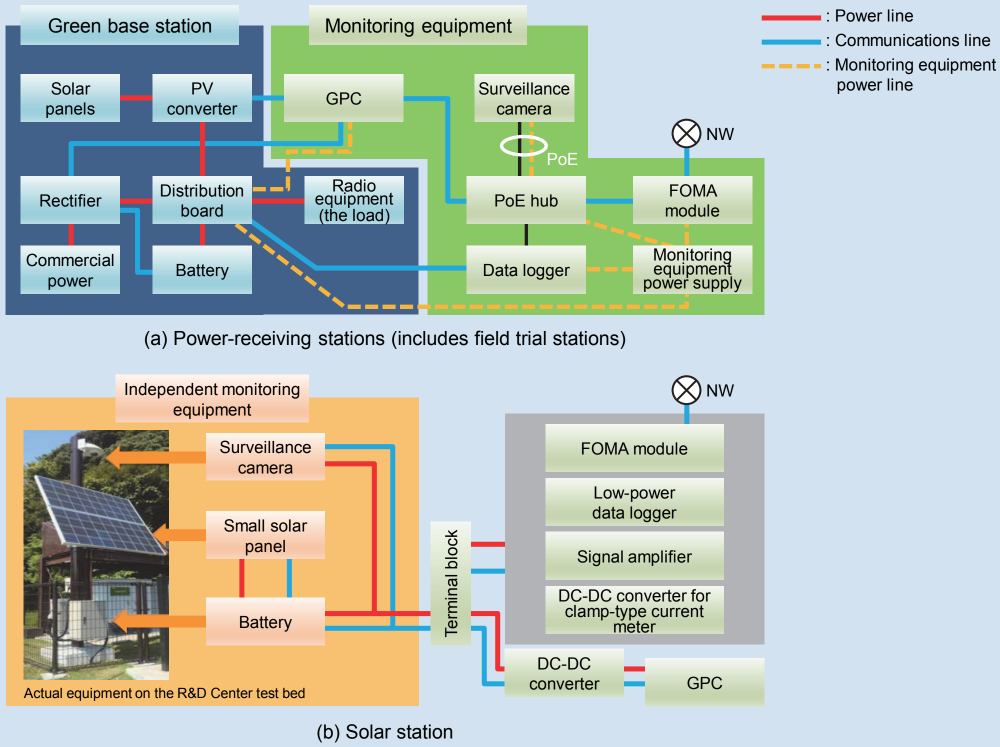

Figure 4 Configuration of monitoring equipment in green base stations

itoring equipment is powered by the commercial supply, whereas in solar stations, small solar panels and batteries are used to supply monitoring equipment with power because changing the design of the communications power supply in a solar station might cause the station to go off the air. Thus, with the addition of the surveillance camera, we have created monitoring equipment that operates independently (Fig. 4 (b)). We selected low-power data loggers and low-power surveillance cameras for use in these configurations.

(2) Integrated monitoring server: This equipment receives data from monitoring equipment via a closed NW, and has functions to record, manage and visualize the data. Data is stored for at least one year so that seasonal comparisons can be made. Also, visualized data can be viewed over the Web by accessing the integrated monitoring server from a terminal connected to the DOCOMO internal network.

(3) NW structure: All monitoring equipment connects to the closed NW via FOMA ubiquitous modules, while the integrated monitoring server connects to it via optical lines. Periodically, monitoring equipment automatically sends data to the integrated monitoring server. The integrated monitoring server identifies each green base station by its unique IP address. Also, for security, monitoring equipment can only communicate with the integrated monitoring server.

Figure 5 shows an example of the integrated monitoring screen for the green base stations. The screen displays PV power generation data by region for each of the ten field trial stations and the 11 commercial green base stations, for a total of 21 stations. In the pie charts for each region, the upper value shows the current power being generated (at the time of access), while the lower value indicates the rated power generation for the solar panels. The graph shows this proportion. If there is more than one green base station in one region, the total for the region is displayed, and the total for the whole country is displayed on the left of the screen.

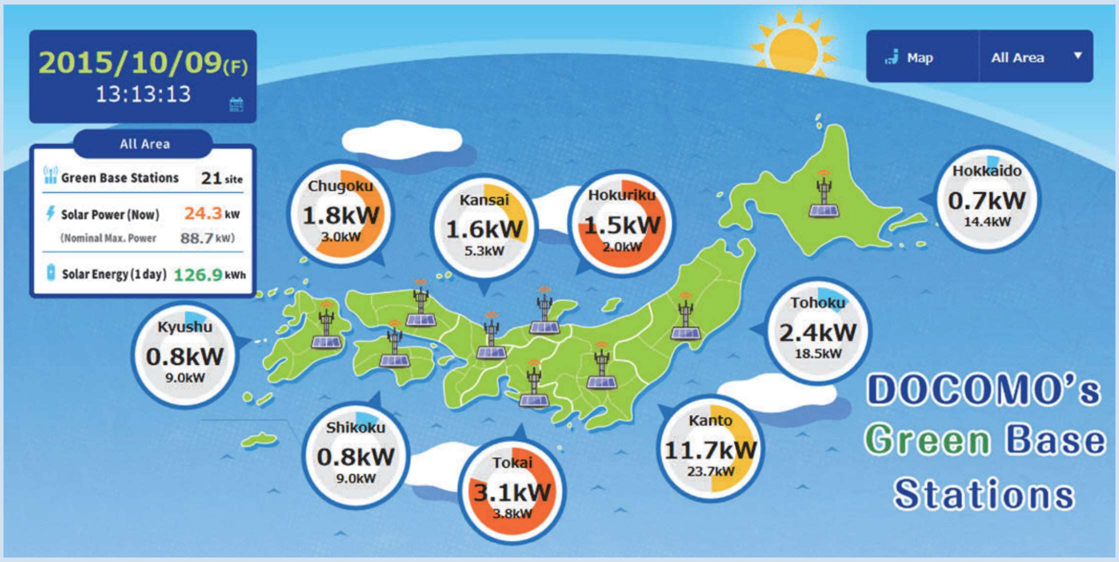

Figure 5 Example of a screen for monitoring green base stations

4. Nationwide Green Base Stations Deployment and Data Collection Examples

Figure 6 shows the locations of green base stations. The red circle shows the ten field trial stations in the Kanto Koshinetsu area, while the green circle shows the 11 commercial green base stations. Station locations are selected and facilities are designed to configure mobile telephone coverage areas, which means that in selecting stations to be converted to green base stations, facilities such as solar panels must be added in consideration of the constraints of those stations. With power-receiving stations, solar panels and PV converters must be installed anew, which means there must be some leeway in the station space to accommodate these additions, and there must be no obstacles casting shadows on the panels. This means there are cases that are less than ideal due to the influence of antenna towers and surrounding structures. For these reasons, solar panels are installed spatially separate, and cabling aligned so that the adverse effects of shadows on power generation are kept to a minimum. In contrast, solar stations, which are usually in mountainous or remote areas, have favorable installation space and surrounding environments, and are designed with solar panels on bigger scale than the power consumed by the load to enable power supply resilient to periods of low sunlight.

As an example of commercial green base station data acquisition, **Table 2** shows the amount of PV power generated and the self-sufficiency rate. The self-sufficiency rate is a value defined as the ratio of the amount of PV power generated to the amount of power consumed by the load, and is an index that describes the level of power secured independently by PV. Here, we defined the average values of self-sufficiency rate, from daily PV power generation measured from the stations from June 1-10, 2015. When measurement began at the solar stations, the battery capacity was not considered, but because the power used for charging during the period of measurement comes from PV (PV surplus power), it is used to calculate the PV power generation for that day. If there is insufficient sunlight on the day, the self-sufficiency rate is low because charging with power from PV does not take place. However, stations are designed to operate using power stored on previous days when necessary. Table 2 shows how we have been able to visualize the self-sufficiency rate using power data collected by the integrated monitoring system.

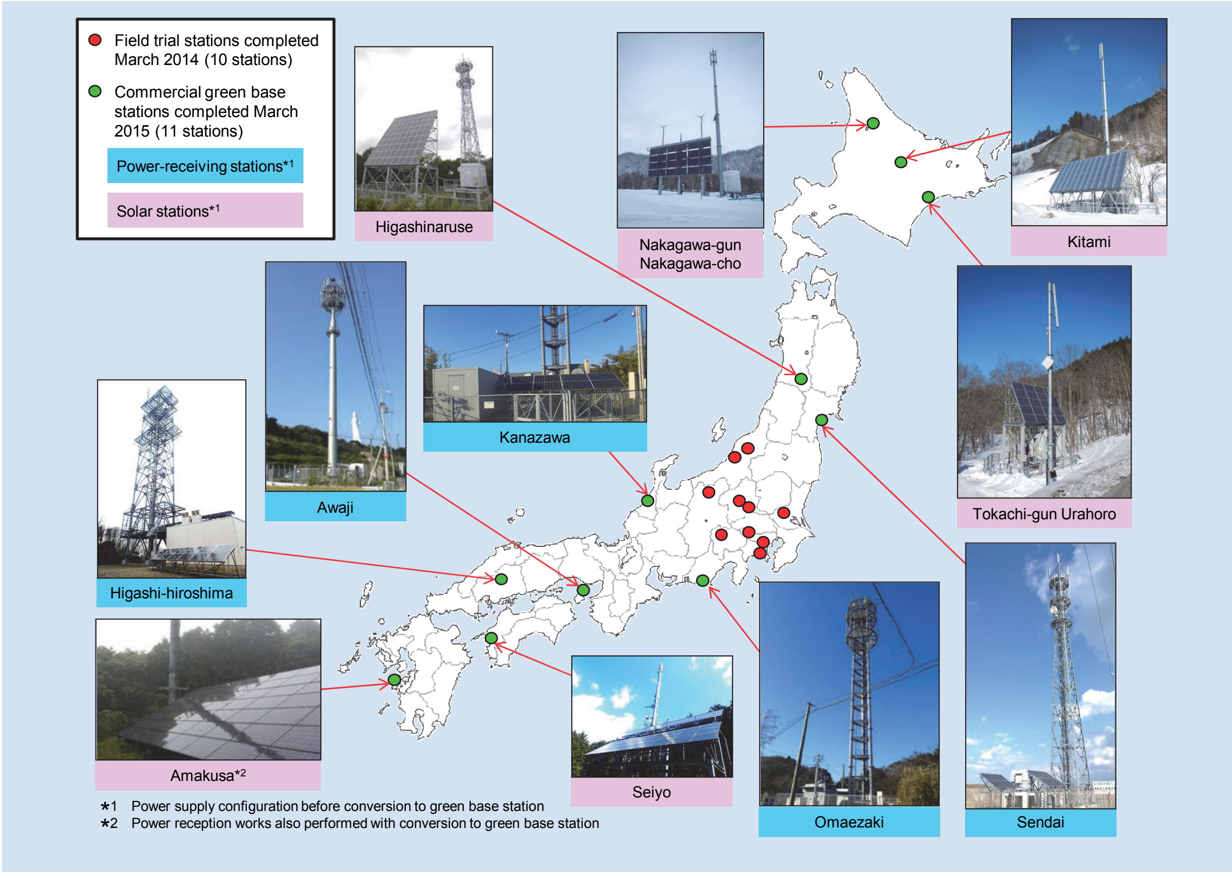

Figure 6 Green base station locations

Table 2 Example of data collection from commercial green base stations (averages for June 1-10, 2015)

Branch	Area	Daily amount of power generated by PV (kWh)	Power consumed by load (kW)	Self-sufficiency rate (%)
Hokkaido	Kitami	1.3	0.3	18.1
	Tokachi-gun Urahoro	4.2	0.3	58.9
	Nakagawa-gun Nakagawa-cho	0.7	0.1	30.5
Tohoku	Sendai	13.2	2.4	23.0
	Higashinaruse	11.8	0.5	98.2
Hokuriku	Kanazawa	5.41	4.3	5.3
Tokai	Omaezaki	10.22	8.2	5.2
Kansai	Awaji	13.44	2.2	25.5
Chugoku	Higashi-hiroshima	8.39	1.7	20.6
Shikoku	Seiyo	10.6	0.7	63.3
Kyushu	Amakusa	5.49	0.7	32.7

Blue: Power-receiving stations* Pink: Solar stations*

*Power supply configuration before conversion to green base station

5. Conclusion

This article has described the basic structure of green base stations set up for field trials, optimal design patterns for commercial green base station installation (for stations receiving power, and solar-powered stations), monitoring methods using an integrated monitoring system that enables visualization of PV power generation data, and examples of data acquisition. Remote monitoring and control of power is possible with green base stations, and they also provide better environmental and disaster-resilient functions. We have also established optimized design methods for selecting and installing additional components, and wiring in facilities etc. for each pattern of green base station installation. By deploying these advanced technologies throughout Japan, we have contributed to the progress of ecological management business. NTT DOCOMO will continues to convert its nationwide commercial base stations to green base stations while bringing down costs of parts, construction and operations.

References

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