Operation Test of Solar Photovoltaics Power Remote Control using 920MHz Radio Multi-hop Network

Kentaro Yanagihara **Masayuki Nishikawa**
Motohiro Tanabe **Takeshi Okamoto**

The use of renewable energy such as solar photovoltaics is currently on the rise. However, to maintain a stable power supply, management of supply and demand is required. The Japanese Cabinet passed the Strategic Energy Plan in June 2010 that states, "As early as possible in the 2020's aim at the construction of the world's most advanced next-generation power transmission and distribution network capable of two-way communication in principle with all power sources and consumers." In order to meet these challenges, R&D and operation tests are underway.

Based on these circumstances and situation, The Ministry of Economy, Trade and Industry's Agency for Natural Resource and Energy carried out the Demonstration Projects for Next Generation Power Control Systems by Two-Way Communications[1)] from 2011 to 2013.

Along with the development of solar photovoltaic devices whose output can be controlled according to external communication signals, the project carried out verification tests of the device/communication combination in preparation for the large-scale introduction of solar photovoltaics power.

Using the 920MHz wireless multi-hop communication as the means of two-way communication, OKI participated in an operation test conducted at Rokkasho Village in Aomori Prefecture and carried out experiments from December 2012 through November 2013.

This article presents an overview and results of those experiments followed by comments on the feasibility.

Background of the Operation Test

Large-scale introduction of solar photovoltaics brings numerous technical issues to the operation of power systems including reverse power flow resulting from surplus power generation and rise in distribution line voltage. Resolutions for these issues are being sought and among them, the need for a solar photovoltaic output control as a system stability measure has been pointed out. In order to control output, information exchange between the system (electric power company) and consumers (homes) is necessary.

There are several means to perform the aforementioned communication. Wide-area services provided by telecom operators (mobile phone, WiMAX), specified low power wireless (900MHz band, 400MHz band) and power line carrier are some of the possible methods. At the demonstration project, the transmission and reception characteristics of the same command were measured for each of the communication methods proposed by the participating companies. OKI was responsible for the experiments using the 920MHz wireless multi-hop communication. Details of the entire demonstration project can be found in Document 3 listed in the References section of this article.

Device Configuration of the Operation Test

The device configuration of the Aomori Operation Test is shown in **Figure 1**. Center server is for processing information on the system side (power company side). Communication server was prepared for each communication method and enabled communication in accordance with the characteristics of the method. The 920MHz wireless system consisted of a concentrator, relay stations and DCEs. The concentrator and relay stations were attached to utility poles. The DCEs were installed at consumers' premise (each home). Control signals received at the DCE are sent to the PCS via a communication adapter.

PCS output control is assumed as the simultaneous control of all devices satisfying certain conditions such as area and/or type of device or as the control of an individual device. The former is defined as multicast communication and the latter as unicast communication.

Message format used in the test was ECHONET Lite[2)]. Since commands for the output control of solar photovoltaics did not exist, the commands were newly defined.

OKI's scope of development was from the communication server to the DCE (surrounded section in **Figure 1**).

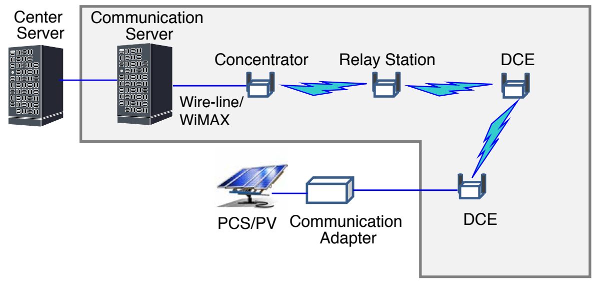

Figure 1. Device Configuration of Operation Test

Connections between the concentrator and DCE's are established with wireless multi-hop communication. The routing for this section utilizes the Many to One & Source Routing mechanism developed by OKI. An overview of the mechanism operation is given below. A more detailed description can be found in Reference Document 4.

Each node periodically transmits a Hello packet to confirm connections with neighboring nodes. The Hello packets contain a path cost to the concentrator, and a node selects a neighboring node that will have the least cost to reach itself as the parent node.

- Each node transmits upstream data to the parent node. If transmission to the parent node fails, another neighboring node appropriate for the transmission is selected.
- Each node periodically transmits a RREC (Route Record) packet to the concentrator. Nodes along the path add their own address to the RREC packet's address list before relaying the packet.
- The concentrator identifies the path to each node from the address list contained in the received RREC packet. When the concentrator transmits data downstream, it includes an address list in the data.
- A node receiving downstream data removes its own address from the address list. It determines the next node from the list and proceeds to forward the data.

Operation Test Field

The operation test was carried out at Rokkasho Village in Aomori Prefecture. Devices were installed within a one square kilometer block. Five units were located outdoors and 31 units were placed indoors. The map of the installations is shown in **Figure 2**. Installation sites of the indoor units are divided into four main locations and through the outdoor units, the entire installation constitutes a single network. The straight lines in the figure show the main transfer paths that were used. In determining the installation sites, preliminary measurements were taken to confirm the propagation conditions of the wireless signals.

To conduct testing under conditions that were close to real life, majority of the DCEs were installed inside actual homes with the cooperation of residents. Except at one home actually connected to a solar photovoltaic generator and another only connected to a communication adapter, the pseudo-PCS function implemented in the DCE create/send response signals and the practicality of the communication portion was evaluated.

Signal output from each wireless device during the test was 20mW. External view and specifications of the used wireless devices are shown in **Figure 3**.

Views of the installations are shown in **Figure 4**. Outdoor units were installed on utility poles at a height of about 6m. Indoor units were attached to walls or on top of curtain rails where they will not interfere with daily life. The structures of the unit-installed houses were wooden single-family home and reinforced concrete housing (company housing in **Figure 2**).

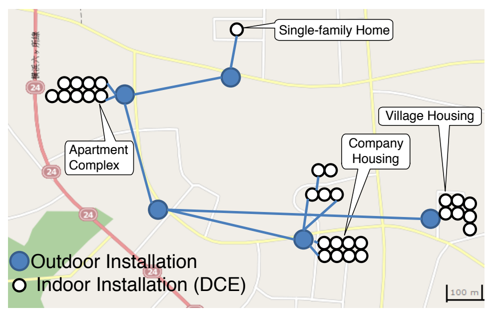

Figure 2. Unit Installation Sites

Modulation Scheme	GFSK
Transmission Rate	Maximum 100kbps
Frequency Channel	Output maximum 20mW 926.5 ~ 927.7MHz
External Interface	Connects to RS485, RS232C via UART×1 IF-BOX
Internal Sensors	Temperature, humidity, illuminance (unused in test)
Power Source	USB charging 5V
Environmental Condition	-20 ~ 60°C
Maximum Power Consumption	100mA (3.3V)
External Dimensions	30×60×20mm (Antenna 190mm)

Figure 3. Wireless Unit Specifications

Figure 4. Views of Installations

Test Results

Installation work was performed in September 2012 and after confirming the installation, operation test was conducted from December 2012 to November 2013.

The continuous operation test lasted more than a year, but no operational glitches were observed in the devices including those installed outdoors.

Center server transmitted control signals according to a schedule that assumed actual use. Communication server accumulated the messages from the center server, performed conversions/retransmissions as necessary and delivered the messages to the DCEs. Return of response signals from the DCEs to the center server determined the success or failure of the communication. Furthermore, each DCE periodically transmitted signals to measure the communication status with neighboring communication-capable devices. Shown below are the results for the command signals sent by the center server.

Communication success rates by installation site are shown in **Table 1** and by weather condition in **Table 2**. These figures indicate the final success rates including the retransmissions by the center server, which is described later. Since additional functions were added and changes were made to the operating parameters during the test, the conditions did not remain the same throughout the testing period.

Table 1. Communication Success Rates by Installation Site

	Single-family Home	Company Housing	Village Housing	Apartment Complex	Overall
December	99.3%	93.9%	99.6%	96.9%	96.2%
January	98.3%	96.2%	99.2%	96.4%	97.0%
February	98.5%	96.4%	99.2%	97.5%	97.4%
March	100.0%	98.8%	100.0%	99.7%	99.4%
April	100.0%	99.9%	100.0%	100.0%	100.0%
May	99.7%	100.0%	100.0%	99.3%	99.8%
June	99.2%	99.4%	99.7%	96.1%	98.5%
July	99.4%	100.0%	99.8%	99.0%	99.7%
August	100.0%	100.0%	99.7%	99.5%	99.8%
September	98.5%	99.6%	99.8%	97.4%	99.0%
October	100.0%	100.0%	99.8%	99.7%	99.9%
November	100.0%	100.0%	100.0%	100.0%	100.0%

Table 2. Communication Success Rates by Weather Condition

	Sunny	Cloudy	Raining	Snowing	Overall
December	93.0%	96.7%	97.1%	95.5%	96.2%
January	96.8%	97.7%		96.2%	97.1%
February	98.3%	97.0%		97.6%	97.5%
March	99.8%	99.1%	100.0%	100.0%	99.4%
April	99.9%	100.0%	100.0%		100.0%
May	99.7%	99.9%	99.3%		99.8%
June	98.6%	98.7%	98.1%		98.6%
July	99.4%	99.8%	99.6%		99.6%
August	99.8%	99.7%	99.7%		99.8%
September	99.5%	99.0%	97.1%		99.0%
October	100.0%	99.6%	99.9%		99.8%
November	100.0%	100.0%	100.0%	100.0%	100.0%

Table 3. Distribution of the Number of Retransmissions

	None	1 Time	2 Times	3 Times	4 Times	Failed
March	93.14%	5.61%	0.64%	0.00%	0.00%	0.61%
April	95.88%	3.33%	0.67%	0.04%	0.04%	0.04%
May	92.93%	4.95%	1.24%	0.40%	0.29%	0.20%
June	83.38%	8.92%	3.94%	1.53%	0.78%	1.45%
July	90.49%	6.83%	1.55%	0.47%	0.14%	0.52%
August	91.86%	5.75%	1.28%	0.59%	0.31%	0.22%
September	85.89%	8.59%	2.47%	1.26%	0.76%	1.04%
October	94.61%	4.46%	0.61%	0.13%	0.04%	0.14%
November	96.98%	2.53%	0.37%	0.09%	0.01%	0.02%

From **Tables 1** and **2**, no correlation can be seen between the communication success rates and building structures or weather conditions.

The communication success rates are relatively lower during the initial stage of the test because the retransmission function for times of communication failure was added at the end of February. The function repeats the transmission from the communication server when there is no response from the DCE. In the operation test, transmissions were repeated at four-minute intervals for a maximum of five times.

Distribution of the number of retransmissions since March is shown in **Table 3**. Significant reduction in communication failures is possible by allowing retransmissions. The inter-equipment communication such as in this test does not involve mobile communication, however communication quality varies by changes in the surrounding environment. Variations in communication quality are shown in **Figure 5**. As the results in **Table 3** show, deterioration of communication quality can be dealt with delay tolerance of a few minutes.

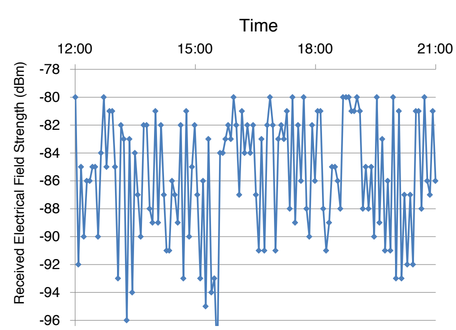

Figure 5. Example of Link Variation

Furthermore, part of the communication denoted as failed in **Table 3**, has reached the destination with retransmission from the center server (three hours after initial transmission). The final success rate of communications that were retransmitted from the center server was 100%. Of the 2,664 transmissions made, the number of retransmissions performed by the center server was 10 (0.37%). From this fact, it is believed that reliability of wireless communication can be adequately ensured through the increase of allowable delay.

Analyzing the previously mentioned communication status with the neighboring nodes, each device is ensured with multiple communication paths. If power loss or other failures occur, communication is maintained using an alternate path. Communication paths have actually changed during the test and through this process of selecting an appropriate path according to changes in communication environment, a more reliable communication was achieved.

At the site with the row of wooden-built houses, installation of the device was requested at every other home instead of the entire row. In the test, direct communication with the presence of non-device equipped home sandwiched in between was almost problem-free. Furthermore, there were many sites where communication was possible with the presence of several non-device equipped homes between the communicating devices leading to the conclusion that PCS control using wireless multi-hop communication is highly feasible.

Additionally, using the time during the installation and dismantling of the devices, the automatic reconfiguration of the network when devices are added or removed was confirmed. These results confirm the flexibility of the network configuration to cope with changes in environmental conditions and addition/reduction of wireless terminals.

Conclusion

Overview and results of an operation test using a 920MHz wireless multi-hop communication as the two-way communication to control the solar photovoltaics installed in each home were described. Judging from the results of the test, if solar photovoltaics are prevalent in many homes, use of wireless multi-hop communication to control solar photovoltaic output is sufficiently possible.

For this mechanism to exhibit true value, each wireless device must have communication access with several neighboring wireless devices and a certain density in the number of wireless devices is required. Instead of focusing on a standalone network for output control, future studies need to consider sharing of infrastructure with smart meter networks that are currently under construction.

Acknowledgment

This study was conducted as part of the "Demonstration Projects for Next Generation Power Control Systems by Two-Way Communications" sponsored by the Ministry of Economy, Trade and Industry's Agency for Natural Resources and Energy. In addition, test was carried out under the cooperation and support of Aomori Prefecture and Rokkasho Village. We at OKI wish to present our strongest gratitude to all who were involved. ◆◆

References

1) Ministry of Economy, Trade and Industry's Agency for Natural Resources and Energy, "Cost Subsidy Application Guidelines for Next Generation Power Control Systems by Two-Way Communications Demonstration Projects," June 2011
2) ECHONET Consortium, "ECHONET Lite Specification Ver.1.01 (In Japanese)," May 2012
3) Makoto Katagishi, "Demonstration Projects for Next Generation Power Control Systems by Two-Way Communications --Progress of Aomori Field Demonstration Project--," IEICE Technical Report, CS2013-32, pp. 37-42, September 2013
4) Masanori Nozaki, Hiroshi Nishimura, Yuki Kubo, Kentaro Yanagihara, Shigeru Fukunaga, "Evaluation and development of the reliable routing schemes for 950MHz band on large-scale wireless sensor networks," IEICE Technical Report, USN2010-24, pp.15-20, October 2010

Authors

Kentaro Yanagihara, Smart Solution Business Innovation Department, Corporate Research & Development Center

Masayuki Nishikawa, Smart Solution Business Innovation Department, Corporate Research & Development Center

Motohiro Tanabe, Software Development Department, Smart Communications Division, Telecom Systems Business Division

Takeshi Okamoto, Systems Integration Deaprtment-3, Intelligent Transport Systems & Safety Systems Division, Public Systems Business Division

TIPS

【Glossary】

DCE: Data Circuit terminating Equipment

PCS: (Power Conditioning System)

Device for converting direct current generated by the solar panels to alternating current. Additionally it adjusts the output of the solar photovoltaic power.