# Application of Economical 920 MHz Wireless Network to Power Flow Control in Power Networks

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## Abstract

Current problems related to the power grid in Japan include the large-scale introduction of natural energy resources and summertime peak power cutting and shifting. Data centers face similar problems with concern for instability in the power supply system caused by sharp changes in load such as server power consumption and diversification in server power consumption patterns. As a solution to such problems, we have investigated a method for switching power flow by power semiconductors via economical 920 MHz band wireless communication to control the rise and fall in power in real time has been studied. We have fabricated a mini-model and used it to test the basic operating sequence. We report basic guidelines for using this system to improve the real-time performance of an economical wireless communication system and a source routing technique for improving reliability.

## 1. Introduction

The problems currently faced by the power grid in Japan include the large-scale introduction of renewable energy production, the cutting and shifting of summertime peak power, and conversion to an energy infrastructure that is strong and resilient against earthquakes. However, the difficulty of solving those problems simultaneously in the existing power grid has motivated a proposal for introducing a multi-function power conversion module that uses advanced power devices to construct a next-generation power grid that is like an energy internet. That proposal has stimulated research around the world [1], [2], [3].

A testbed for constructing next-generation direct current (DC) power networks in data centers and office buildings is illustrated in Fig. 1. Silicon carbide (SiC) semiconductor switches that are inserted at the nodes of a mesh power network [4] make it possible to halt or pass power flow at each node, thus implementing DC power routing. We began investigating a highly convenient next-generation power system that uses economical wireless communication for control such as shown in Fig. 1, focusing on the 920 MHz band for good access even inside buildings. We designed a mini-model to evaluate the real-time performance and reliability of current wireless control systems.

## 2. Experimental system configuration

This power system has three components: control software, a two-way communication system, and a DC power network.

### 2.1 System overview

The sequence control program is run by software prepared in advance on the computer used for control. An open or close command is sent to each semiconductor switch according to the execution of that program. Communication is accomplished by using low-power 920 MHz wireless communication modules (compliant with ARIB STD-T108). The transmission output is 1 mW or 20 mW, and the communication speed is 20 kbps or 50 kbps. The testing reported here was done with the transmission power set to 1 mW and the communication speed set to 50 kbps. The communication speed for the wired connection (RS232C) between the terminal station and the controlled device is 19.2 kbps.

The control computer and base station module and the semiconductor switches and their terminal station module are respectively connected by RS-232C cables. The part that is equivalent to one of the power lines in the upper part of the mini-model shown in Fig. 1 corresponds to the experimental system shown in Fig. 2. On the power line between the constant voltage power supply (Kikusui Electronics PWX1500ML) and the load resistance (TAMAOHM hollow cylinder resistor) four semiconductor switches are connected in series. The current flow can be stopped or passed by opening and closing those switches in order. The system is described in detail below.

### 2.2 Structure of the monitoring and control software

The configuration of the monitoring and control system of the mini-model is shown in Fig. 3. Various types of calculations and instructions can be performed by running prepared command scripts for sequential control of the power routing switches. The states of operation such as voltage, current flow, received signal strength, packet loss rate and statuses of the switches can be checked in real time in the status display window.
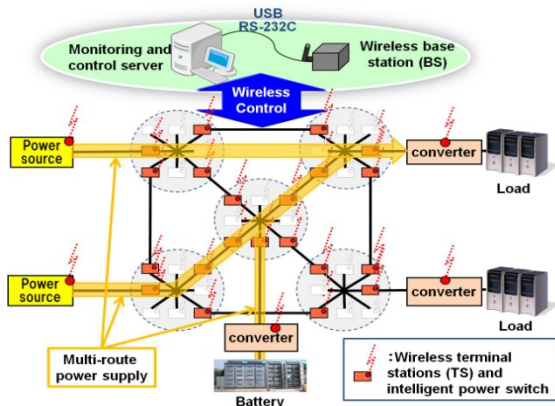
Figure 1. Mini-model for investigating next-generation DC power networks
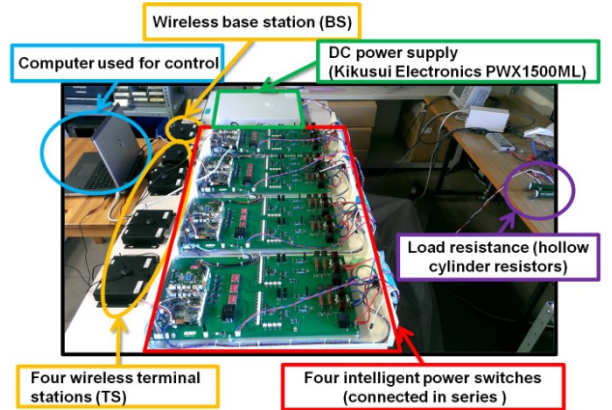


Figure 2. Experimental system

## 2.3 Power line and semiconductor switch specifications

In these experiments, a constant voltage DC power supply that has a 48 V output was used and 80 Ω fixed hollow cylinder resistors served as the load resistance (200 W heat capacity). The circuit diagram for the semiconductor switch is shown in Fig. 4. High-voltage silicon carbide static induction transistors (SiC-SITs) that are applicable to next generation 400-V dc distribution systems [4] were used for the switches. The power route interface has two terminals, one for input and one for output. The communication interface is RS232C and a LAN. Switching (stop or pass) can be done by a remote control operation as well as manually.
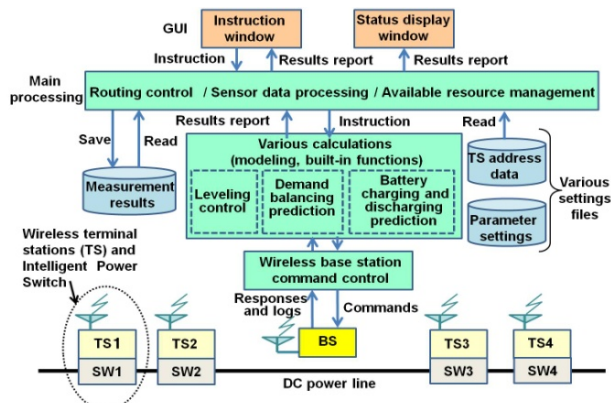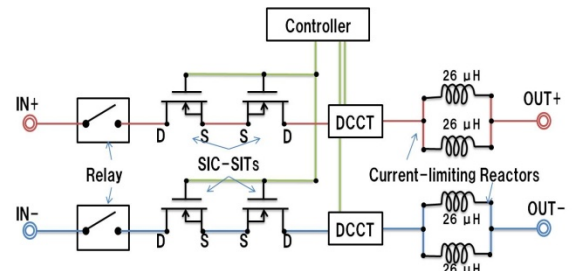


Figure 3. Configuration of the control system



Figure 4. Circuit diagram for the semiconductor switch

## 2.4 Control flow in the experiments

For the system shown in Fig. 2, we wrote a program for the sequence for beginning supply of power from the DC power supply to the load resistance and the sequence for ending the power supply. The control order for opening and closing the semiconductor switches is to start supply of power by turning switches on in order from upstream to downstream (the DC power supply side is regarded as upstream) and stopping power supply by turning switches off in order from downstream to upstream. The interval was set to 1 sec.

## 3. Basic operating results
## 3.1 Sequential control

As described in the configuration of the experimental system, wireless communication is used to execute the on/off control sequence. First, the change in the operating waveform of the semiconductor switch over time is presented in graph form as the execution result in Fig. 5. The voltage waveforms of the four semiconductor switches for when the power supplying is started and when the power flow is stopped are shown in the figure. It is thus possible to achieve the desired operation. A data logger (YOKOGAWA DL850) and differential probe (Agilent Technologies N2791A) connected to the two output terminals of each switch were used for the measurements.

## 3.2 Analysis of control delay factors

A communication sequence for single instruction power control is shown in Fig. 6. Although the control delay can be divided into the computation time, communication time, and transient response time, we argue here that the sum of the communication time and the transient response time sufficiently determines the control delay.

The transient response time of 18 μs was experimentally obtained. For the communication time, we used the theoretical value. The calculations were done with the transmitted data fixed at 20 bytes. For the wired communication, the transfer speed is calculated at 19.2 kbps, with 1 stop bit and a data length of 8 bits, a one-way delay of 9.4 ms occurred. For the wireless communication, calculations for the transfer speed of 50 kbps with a 144 bit preamble, 16 bit synchronizing word, 16 bit CRC, and carrier sense time of 5 ms produced a one-way delay of 11.7 ms. We can thus neglect the transient response time, so the control delay can be estimated as 61 ms. The wireless communication delay accounts for 38% of the control delay, which is lower than for wired communication.

However, that does not take into account variations such as resending and processing time (for example, the carrier sense time is about the same as this). Accordingly, we can expect the actual times to be longer than the above time estimates. The average control delay without resend requests was confirmed to be 154 ms using actual software.



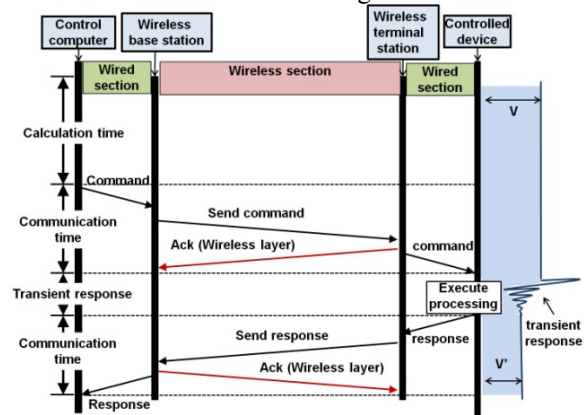**Figure 5. Switch operating waveforms for when power is started and stopped**



**Figure 6. Communication sequence for control**

## 3.3 Relation of the received signal strength to the data reception rate

The communication from the base station to the terminal stations is one-to-one. The terminal station and switch positions were in fixed locations and the base station was moved to various locations for measurement of the terminal station received signal strength (RSSI) and data reception rate. The terminal station has a function for returning an Ack signal and the received signal strength to the base station. The transmitted data was 16 bytes repeated 1000 times. The transmission output was 1 mW, the communication speed was 50 kbps, a monopole antenna was used, and the height above the floor was 90 cm. The experiments were conducted on floors 4 and 5 of Building 7 on the Matsugasaki campus of the Kyoto Institute of Technology. The dependence of the measured data reception rate on the received signal strength is shown in Fig. 7. From the results, we can see the correlation between the RSSI and the data delivery rate. The data confirms that semiconductor switch instruction delay occurs when the RSSI is roughly -100 dBm or less. Improvement can be obtained by either raising the transmission output or increasing the antenna gain, but if the base station and terminal station are both in the same room, the data reception rate is 99.9% or higher, and communication is possible within tens of meters radius, even between floors.

## 3.4 Higher reliability with source routing

In a power control network, it is necessary to know the location of the communication failure and the route of the received data. As a means of improving the reliability of wireless communication, research is beginning to focus on the source routing method, in which multiple alternate routes are set in advance for look-up when a communication failure occurs. The effect of source routing in power control wireless communication is illustrated in Fig. 8. The state transition diagram for routing task processing implemented between the application programming interface (API) layer and the MAC layer is shown in Fig. 9. We set the system so that the alternate routes can be changed remotely via wireless communication. Specifically, the MAC layer routing table of a particular terminal station can be rewritten from the base station. We have implemented that function in a 920 MHz wireless device and confirmed that a route on which communication failure has occurred can be avoided and the data can be sent by a different route and also that the routing data can be changed remotely. In further work, we plan to evaluate the data delay when a communication failure occurs and the time required to change the routing.
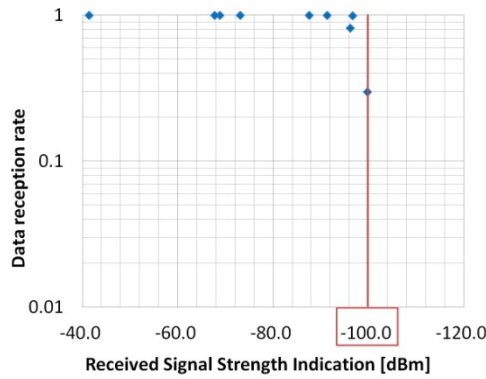
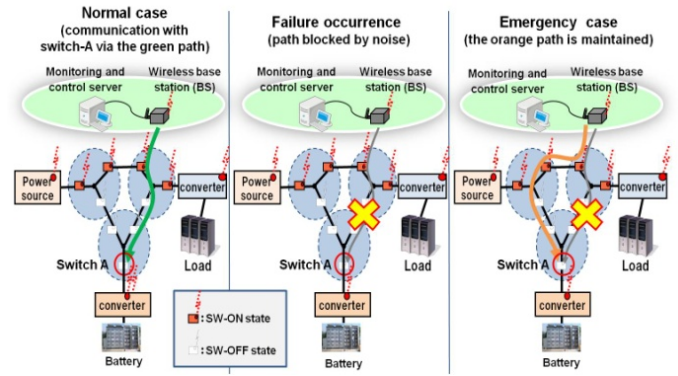**Figure 7. Dependence of the data reception rate on the received signal strength**



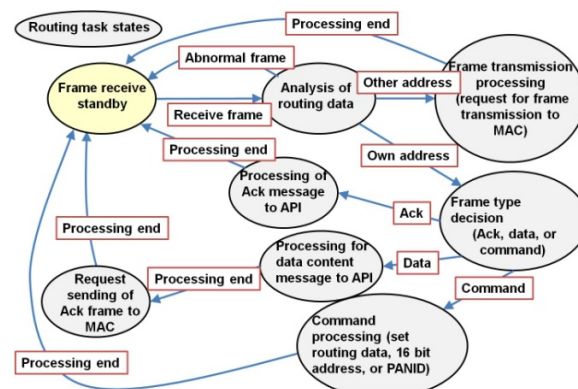**Figure 8. Effect of source routing in wireless communication for power control**



**Figure 9. State transition diagram for the routing task**

## 4. Issues in applying an economical wireless system for control

The purpose of our experiments was to analyze the factors of control delay. In future work, we must greatly reduce the current communication delay (154 ms) for application to power system control that requires real-time performance. Currently, the wired communication sections are bottlenecks, so we must first replace the RS232C connections with Ethernet or other faster communication specification.

For the wireless communication, we used an economical 920 MHz band low-power system, but we are investigating shortening of the back-off time as a way to substantially reduce communication delay. Also, to raise communication reliability, we are investigating the practicality of a source routing technique for changing the routing path in response to sudden occurrences of noise in the use environment.

## 5. Conclusion

We are investigating a sequential control system for semiconductor switches that uses 920 MHz wireless communication. We have constructed a partial mini-model for evaluation and used that system to evaluate the real-time performance and reliability of using an economical wireless communication system for control. In future work, we will proceed with investigation of improving the real-time performance and improving reliability by applying source routing in a multi-node, multi-hop system.

## 6. References

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