High-Accuracy Time Synchronization Technologies for Wide-Area Power Networks

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Abstract

With the rise of renewable energy resources, there is a concern over the negative impacts on grid stability due to sharp fluctuations of power output by the intermittent nature of such renewable energy resources such as wind and solar power, etc. In order to relieve such negative impacts caused by power output fluctuations from renewable energy resources, the use of constant output control using a storage battery is effective. For practical application, however, it is important to reduce the overall capacity of storage batteries due to the high cost.

For solutions, we started research in fiscal 2012 with the "Demonstrative Research Project on Wide-Area Operation System for Distributed Energy Resources Like Wind Power"(1), a project sponsored by the Ministry of the Environment in Japan. Under this project, the distributed renewable energy resources scattered around Hokkaido are centrally controlled by using a communication network. In so doing, we aimed to realize a substantial reduction of capacity for the storage battery.

1 Preface

With the rise of the use of renewable energy resources in Japan, intermittent energy resources are increased as a result of a grid-connection of renewable energy resources such as wind and solar power. As a result, it is noted that there is a risk of losing grid stability due to the loss of balance of power supply and demand in the grid.

To solve such an issue, the Japan Weather Association, HOKKAIDO UNIVERSITY, Hokkai Electrical Construction Co., Inc., and HOKUDEN SOGO SEKKEI Corporation and Meidensha Corporation collaborated and started the "Demonstrative Research Project on Wide-Area Operation System for Distributed Energy Resources Like Wind Power"(1) in fiscal 2012. This is a project sponsored by the Ministry of the Environment in order to reduce the required capacity for battery storage.

In order to reduce the overall capacity of a battery by central control of distributed renewable energy resources in a wide area, it is necessary to gather the outputs of energy resources and battery outputs measured with an accurate time stamp.

To keep time precisely synchronized in a wide-area network, we developed a smart meter in accordance with the IEEE1588 Standard and performed measurements and evaluation of time synchronization characteristics by smart meters distributed in a wide area through the communication network as a fiber optic network, ASDL, ISDN, etc. This paper introduces our technologies of precise time synchronization applying the IEEE1588 Standard.

2 Configuration of Wide-Area Operation System

Fig. 1 shows the configuration of a wide-area operation system. Under this project, it is important to compensate for the fluctuation of power outputs generated from distributed renewable energy resources in a wide area. It is also essential to eliminate the imbalance between the grid power demand and supply. In other words, it is necessary to examine if system stability control using energy storage batteries is property done in order to maintain the stability of the grid. This should be evaluated at the same time mode. For this purpose, we established a high-speed communication network so that preci-

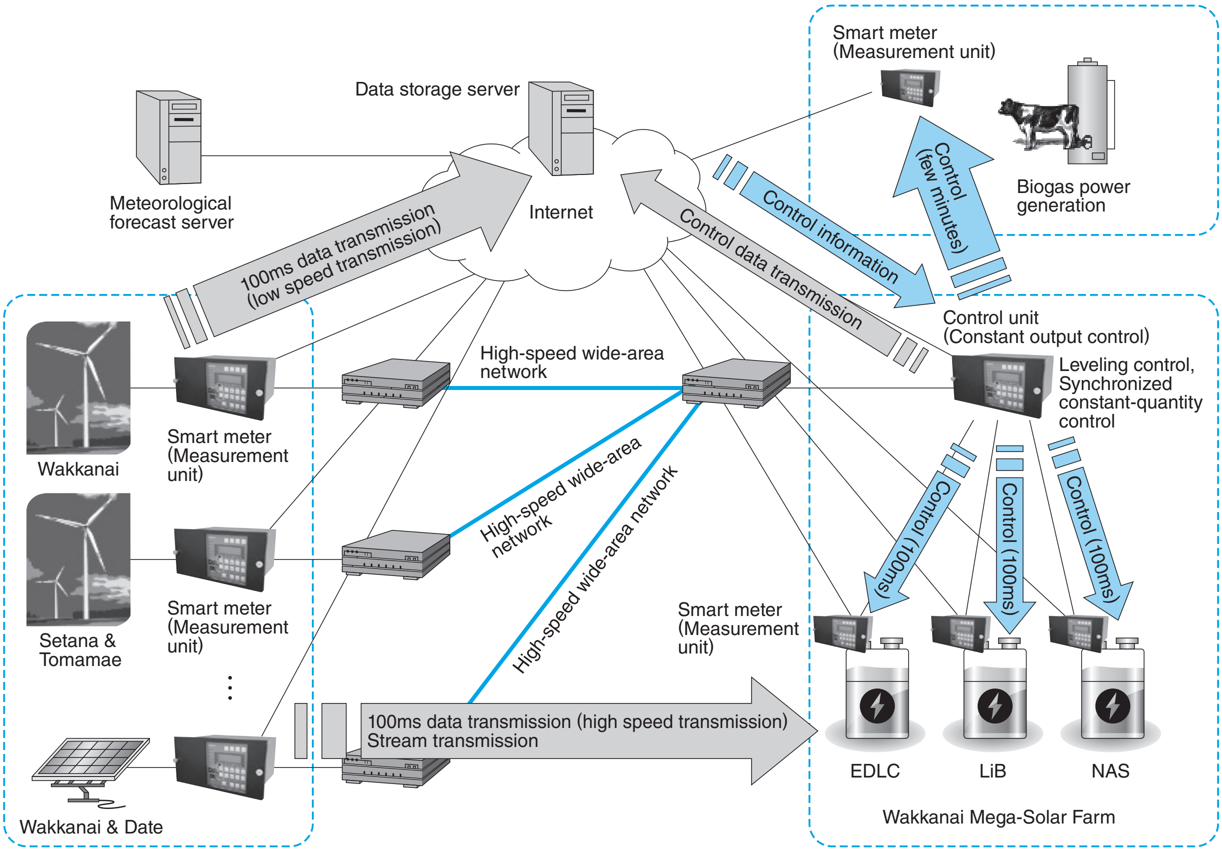

Fig. 1 **Configuration of Wide-Area Operation System**

The total power generation of widely distributed power generation sites and charge-discharge outputs of energy storage batteries are logged by the control smart meters in precision time synchronization mode so that energy storage battery banks and a biogas generator can be adequately controlled.

sion time synchronization can be performed to control the telemetry values of power generation and charge-discharge outputs of storage batteries at each power generation site distributed in a wide area.

In a wide-area power management system, it is necessary to establish two things simultaneously: transmission of high-speed data for real-time control, and communication of large-capacity data in order to evaluate the control results on the grid. Accordingly, the bandwidth of the communication is divided into two sections: the “real-time transmission network” and the “management network.” Fig. 2 shows an image of a logical configuration of a wide-area network.

At the time of verification of a wide-area operation system in Hokkaido, we cover three wind farm sites (Wakkanai, Tomamae and Setana) and two mega-solar sites (Wakkanai and Date). The energy storage system was built inside a mega-solar site in Wakkanai. The Wakkanai Mega-Solar Site has sodium-sulfur (NAS) battery banks with a capacity

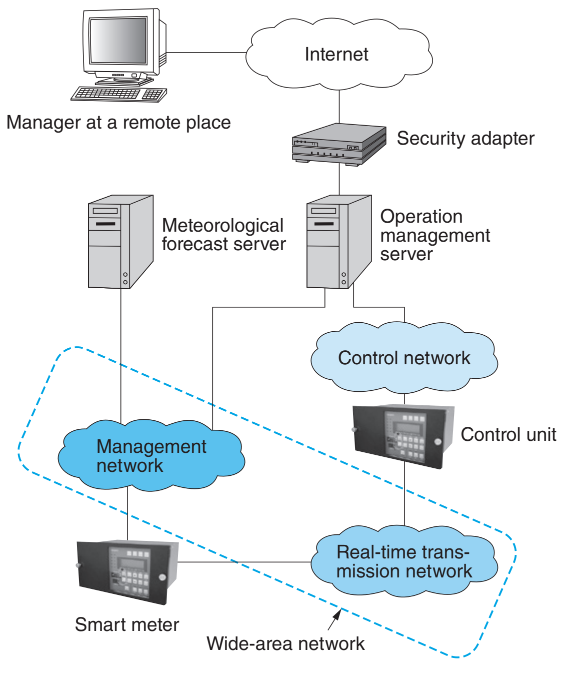

Fig. 2 **Image of a Logical Configuration of a Wide-Area Network**

A wide-area network configuration is shown. It is split into two sections: a real-time transmission network and a Network for control.

Table 1 Capacity Table of Each Power Generation Site

Capacity table at each power generation site is shown.

Power generation site		Generator capacity	
Wind power	Wakkanai	660kW × 3	1980kW
	Tomamae	600kW × 2 1000kW × 1	2200kW
	Setana	600kW × 2	1200kW
	Subtotal		5380kW
Photovoltaic power	Wakkanai※1	250kW × 4	1000kW
	Date※2	250kVA × 5	1000kW
	Subtotal		2000kW
Total			7380kW

Notes:
※1. This project deals with total capacity of 1000kW only among 4990kW-the facility capacity of Wakkanai Mega-Solar Farm.
※2. Because of its reactive power control, the power generating capacity of Date Solar Farm is rated at 1000kW although this farm has a total facility capacity of 1250kVA.

Table2 Capacity Table of Power Sources for Grid Control

A capacity table of power sources for grid control is shown.

Classification	Installation place	Rated capacity	Duration of discharge
NAS	Wakkanai	500kW	7.2h
LiB	Wakkanai	100kW	2h
EDLC	Wakkanai	100kW	60s
BG	Shihoro	25kW	—

of 1.5MW in total as an existing facility.(2) A 500kW battery bank has been used to control the output under this project. In addition, as a new facility, we added a set of Electric Double Layer Capacitor (EDLC) and a Lithium-ion Battery (LiB). In addition, we introduced a Biogas Generator (BG) in Shihoro as an energy resource. This region has many dairy farms and biogas is easily available. **Table 1** shows a capacity table of each power generation site and **Table 2** shows a capacity table of power sources for grid control.

3 Wide-Area Communication Network

In a wide-area operation system, the quality of data transmission in the applied communication network becomes a very important factor. In a case where the value of the communication network quality is paramount, the use of dedicated lines would be an ideal choice. In this case, however, cost is an issue. In this project, we use public communication networks and made a virtual private network using fiber optic lines. The required bandwidth of the fiber optic line is guaranteed. Since many power sites of renewable energy resources are located far from urban areas, in many cases it is difficult to secure fiber optic lines. Considering the future rise of distributed energy resources, it is also important to consider the low-speed communication networks using public lines. As such, we conducted communication performance evaluation. We adopted an ADSL line for a wind farm in Tomamae and an ISDN line for a BG site in Shihoro.

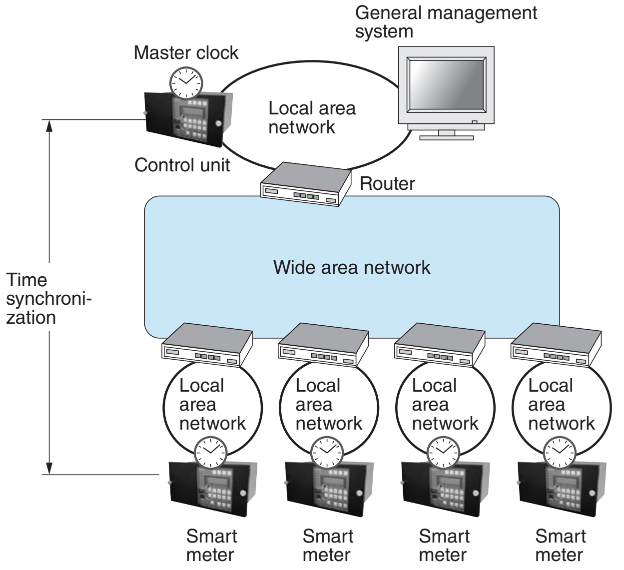

Fig. 3 Configuration Image of Time Synchronization

An image of configuration of time synchronization is shown.

4 Building a Time Synchronization System

Each smart meter adopted the IEEE1588 Precision Time Protocol (PTP) by which precision time synchronization can be secured through a communication network. The PTP makes it possible to maintain precise time synchronization in such a manner that any communication lag caused in a network is correctly identified and the detected delay time is adjusted precisely. **Fig. 3** shows a configuration image of the time synchronization.

Under this project, we set up the target performance values for the control to be realized in the wide-area operation system: target response time of monitoring and control systems, target transmission delay time of monitoring and control information, and target time synchronization accuracy of the measured data. Considering the fluctuation characteristics of renewable energy resources and response characteristics of the grid, it is considered sufficient if the control-to-response time is within a few seconds. As such, the target value was set as “within 500ms.” In order to realize this control-to-response time, the control cycle time was set as a target value of 100ms and the target transmission delay time was set as 50ms or shorter. This is half of the control cycle time. The target value for time synchronization accuracy was set at 10ms or less. This is 1/10 of the control cycle time.[3]

5 Development of the IEEE1588-Compliant Time Synchronization-Based Smart Meters

We developed three types of smart meters in this project: a monitoring type to measure outputs from the each power generation site or outputs from energy storage systems, a type to measure and individually control biogas generator outputs, and a type to make an overall control of wide-area operation systems. **Fig. 4** shows the external appearance of a smart meter.

The smart meter for measurement is installed in Renewable Energy (RE) sites and energy storage systems performs the computation for various power outputs based on input values at each Voltage Transformer (VT) and Current Transformer (CT). At the same time, it conducts time synchronization in accordance with the IEEE1588 protocol. It transmits the computed result of each smart meter for control at the interval of 100ms based on the UDP protocol. In addition to the processing of the smart meter for measurement, the smart meter for BG mediates communication of control commands and status updates of data between the smart meter for control and the BG. The smart meter for control

Fig. 4 Smart Meter

For the smart meter we adopted our unit type of digital protective relay.

performs real-time collection of measured values from each smart meter aforementioned above. It computes and sends the control command of output values of the energy storage system and BG so that target output values can be maintained based on the power output prediction.

6 Time Synchronization Technologies

Fig. 5 shows how time synchronization works by the IEEE1588.[4] In this case, a slave unit in charge of time adjustment attempts to retrieve time-related information from the master unit that always carries the correct time. This exercise will cause a time delay which is caused by network transmission time. To compensate for this delay, a synchronization packet with a record of transmission time and reception time is exchanged so that the slave unit can calculate the dual transmission delay to compensate for its own time based on a time deviation from the master unit.

The reason why the IEEE1588 is considered “high precision” is because of its hardware support. Since the hardware send-receive time is recorded in the synchronization packet, there is no impact of processing time for software. This is an advantage to exclude an unnecessary error factor.

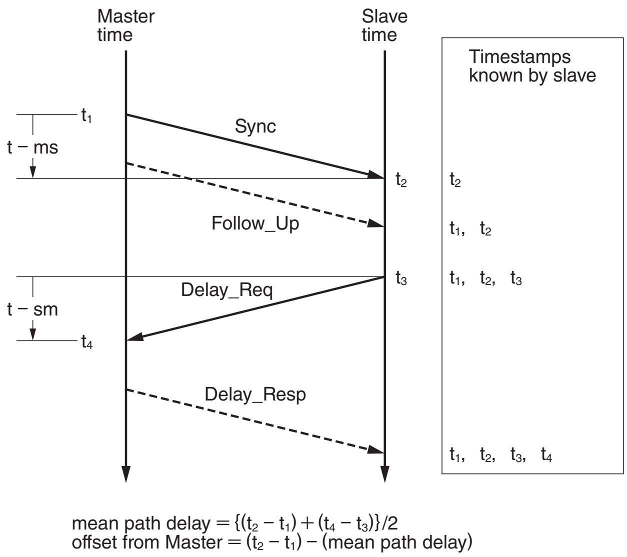

Fig. 5 How Time Synchronization Works by IEEE1588

An example (calculation procedure for transmission delay time and time variance) of the PTP protocol is shown. In the IEEE1588 Standard, any concrete compensation procedure is not specified. The basic approach, however, is the determination of time variance deriving from a mean dual transmission delay time (based on the hypothesis that out-bound transmission delay time is equal to in-bound delay time).

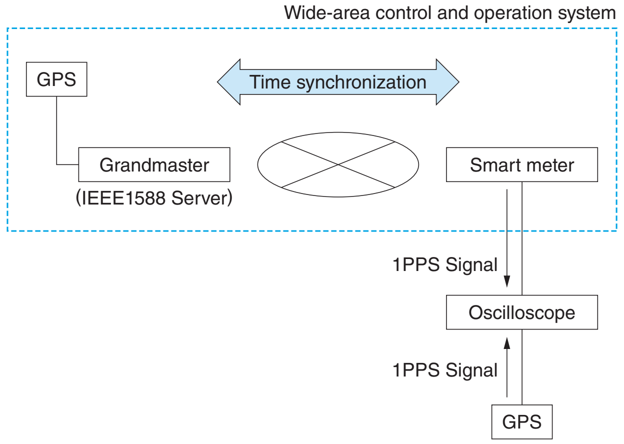

Fig. 6 **Circuit Configuration of the Verification Test for Time Synchronization Accuracy**

Time synchronization accuracy was evaluated based on the time difference from 1PPS signals of a GPS and smart meter.

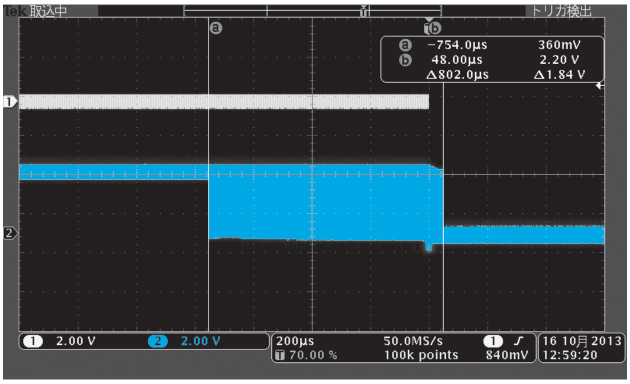

Fig. 7 **Result of a 1PPS Signal Measurement (Optical Line)**

An example of a 1PPS signal picked up from an actual smart meter is shown.

7 Time Synchronization Verification Test

In the wide-area operation system, real-time level of the measured values affects the final stabilizing performance against renewable energy resources. For this reason, it is very important to improve the accuracy of time synchronization. Accordingly, each selected power site is tentatively equipped with a Global Positioning System (GPS) unit in order to measure the time difference between a smart meter and the 1PPS signal. Time synchronization accuracy was verified. **Fig. 6** shows a circuit configuration of the verification test for Time Synchronization Accuracy. For example, **Fig. 7** shows the result of a 1PPS signal measurement performed at the smart meter installed in Wakkanai Wind Farm connected by fiber optic lines. Against the GPS, time at the smart meter changes within the range of 754μs leading to 48μs lagging. It is, therefore, clear that the center value of time change is approximately 400μs leading.

Table 3 **Result of Time Synchronization Accuracy Measurement**

A time synchronization accuracy measurement result is shown.

Line classification	Destination for connection	Delay (+lead/−delay)	Width of variation
Optical line	Wakkanai Wind Power Station	−400μs	±400μs
ADSL	Tomamae Wind farm	+1.6ms	±700μs
ISDN	Shihoro BG Power Station	−2ms	±3ms

8 Test Result

Table 3 shows the result of a time synchronization accuracy measurement. For optical fiber and ADSL lines, it was confirmed that the target performance (within 10ms) of time synchronization was achieved. For ISDN lines, the target performance was achieved, but variation of the communication speed seems to be greater as compared with other lines.

Because of how the IEEE1588 protocol works, it involves some difficulties such that fluctuation and asymmetry in network transmission delay time can directly affect the synchronization accuracy. In applying the IEEE1588 Standard to such lines, an original innovation is needed, such as presuming the transmission delay time by means of statistical approach.

9 Postscript

This paper introduced time synchronization technologies based on the IEEE1588 Standard. It was applied to the demonstrative research system for the “Demonstrative Research Project on Wide-Area Operation System for Distributed Energy Resources Like Wind Power.” This is a project sponsored by the Ministry of the Environment, Japan.

Going forward, we will continue to deepen our knowledge and experience on the IEEE1588 Standard. At the same time, we would like to contribute to the stabilization of renewable energy resources power output and the promotion of renewable energy resources.

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