Our Approaches to the Wide-Area Operation System for Distributed Energy Resources like Wind Power, Low Carbon Technologies Development, and Verification Projects

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Keywords Renewable energy, Energy storage system, System stabilization, High-speed WAN network, Generation plan

Abstract

For three years from Fiscal 2012 to 2014, we joined the "Experimental Study on Wide-Area Operation System for Distributed Power Sources Like Wind Turbines" carried out as part of the Low Carbon Technologies Development and verification projects sponsored by the Ministry of the Environment. We have been working on technical developments to promote the wider introduction of renewable energy resources. In this "Verification Project," a system was created to centrally monitor renewable energy resources distributed in a wide area through high-speed WAN network and to stabilize the power network system by using an energy storage system in a single location. At the same time, we worked hard to resolve the practical problems through a verification and evaluation process. While there are some concerns about negative impacts of power quality and the instability of renewable energy on the utility grid, the above technologies are expected to contribute to the amount of increasing acceptance of the interconnection of renewable energy resources to the utility grid.

1 Preface

Under the trade system of Feed-in Tariff (FIT) that began in Fiscal 2012, the interconnection capacity of Renewable Energy resources (RE resources) mostly by photovoltaic power generation has rapidly increased. Consequently, there is concern that power quality and power system instability of RE resources may adversely affect the utility grid. In fall 2014, the power produced by a power utility at authorized facilities exceeded the minimum demand from the utility grids, and the request for interconnection with utility grids was suspended temporarily. In this way, challenges with supply and demand began to surface. These adverse influences of RE resources to utility grids are caused by short-term output fluctuations, unreliability in generation output, or concern regarding the generation of surplus power. If the generation output of the RE resources is predicted in advance and short-term output fluctuations can be suppressed in combination with energy storage systems, system management conforming to the generation plan may be realized and it is expected that most of the aforementioned problems may be eliminated. In a system where storage batteries are installed in each power station to secure system stability, however, there is a limit of forecast accuracy for generation output that is the basis for the planned system management. This will create a problem such as the capacity of necessary storage batteries may become too excessive.

To solve this problem, the "Experimental Study on Wide-Area Operation System for Distributed Power Sources Like Wind Turbines" (the "Verification Project") was carried out for three years during Fiscal 2012-2014 as a demonstrative research project sponsored by the Ministry of the Environment in Japan. This project is intended to smooth the generation output through virtual integration of widely distributed RE resources. In addition, further improvement of accuracy is attempted by canceling mutual forecast errors among generation sites so that the total capacity of storage batteries in kW considered necessary for the system as a whole can attain 50% of the total capacity of RE resources. **Fig. 1** shows an overall image of this Verification Project and **Fig. 2** shows its concept.

For this Verification Project, we oversaw the wide-area operation system building including the control of storage battery system. We conducted technical development to realize real-time control through high-speed WAN network. This paper introduces the contents of the wide-area operation system and the results of the technical development.

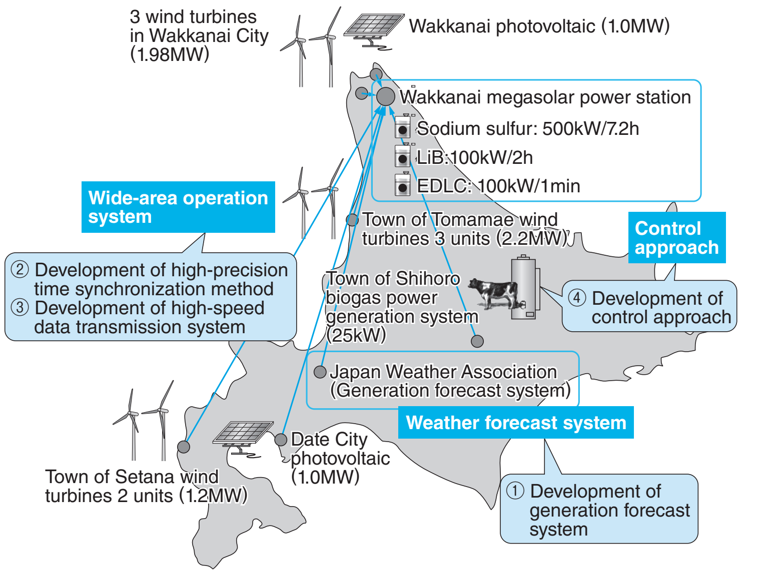

Fig. 1 A Whole Image of the Verification Project

Renewable energy power that has been distributed to various places in the Hokkaido and intensive monitoring in the wide-area information communication network, to stabilize in one place of the power storage system.

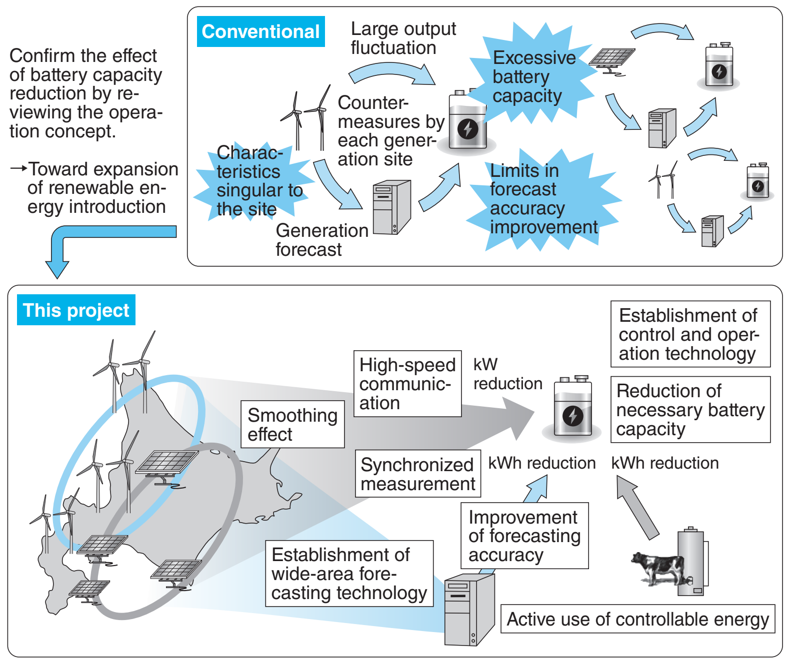

Fig. 2 Concept of the Verification Project

The conventional operation concept was significantly reviewed and the capacity of the batteries in kW needed for the entire system was reduced to increase the volume of introduced renewable energy.

2 Wide-Area Operation System Building

2.1 System Configuration

For this Verification Project, three existing wind farms and two solar farms installed in Hokkaido were chosen as the measuring targets, all systems of which we built. **Fig. 3** shows an image of system configuration. With help from Wakkanai City Government, our output constant control equipment was installed on the premises of the Wakkanai Megasolar Power Station (Wakkanai MS) constructed under the title of the "Verification of Grid Stabilization with large-scale PV Power Generation Systems" sponsored by the New Energy and Industrial Technology Development Organization (NEDO), a national corporation for research and development.

2.2 Energy Storage System

In the energy storage system, three types of energy storage devices with mutually different characteristics were adopted to verify the effect of improvement of control performance through coordinated control and examined the effect of reducing the battery capacity. For sodium sulfur batteries, existing facilities installed at the Wakkanai MS were utilized. Lithium-ion Batteries (LiB) and Electric Double Layer Capacitors (EDLC) were newly installed. With a hope of further reducing the battery capacity, a biogas power generation system was installed in Town of Shihoro as a controllable RE resource. For the biogas power generation system, a gas container was used as a means for energy storage. In this manner, although somewhat inferior in terms of fast-

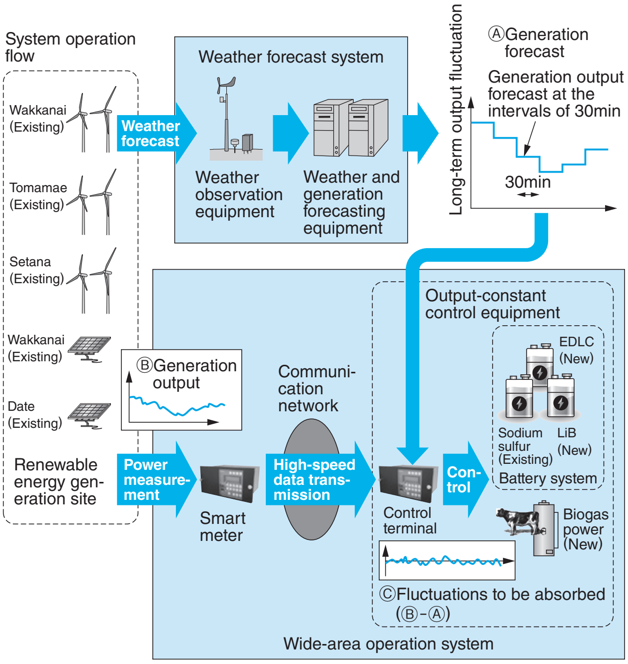

Fig. 3 **Image of System Configuration**

The RE generation output is obtained from each site through smart meters and, a wide-area communication network, and a differential component (fluctuation) from the computed generation goal value is compensated by using batteries and biogas power based on the result of the weather forecast.

Table 1 **Capacities of Storage Batteries and Biogas Power**

In fluctuation components, short-term output fluctuation of EDLC, middle-term output fluctuation of LiB, and long-term output fluctuation of sodium sulfur batteries are respectively regarded as compensation targets. The biogas power is designed to play a role of maintaining 50% state of charge in sodium sulfur batteries.

Classification	Capacity (kW)	Battery capacity
Sodium sulfur batteries	500	7.2h
LiB	100	2h
EDLC	100	1min
Biogas power	25	—

response speed, it can be used as a source of capable regulation like that of storage batteries. Table 1 shows the capacities of storage batteries and biogas power generation system. Fig. 4 shows an external appearance of the energy storage system.

2.3 High-Speed WAN Network

In a high-speed WAN network, it is necessary to integrate the generation outputs of widely distributed RE resources through a wide-area communication network. Accordingly, data transmission delay and instability in transmission cycles in communication networks are the subject of some issues. For this reason, we decided to adopt a virtual dedicated line with a secured bandwidth for the wide-area communication network. Since many RE resources are distant from urban areas, optical lines without any concern in performance are not always available. We therefore selected three types of lines such as optical lines, ADSL lines, and ISDN lines, for our evaluation. Since telemetry data for the RE resources at each power generation site call for time synchronization, a time synchronization method conforming to IEEE1588 was adopted because this method has recently been getting increased attention. Thus, a high-accuracy timestamp could be assigned. Due to adopting this method, a time synchronization accuracy within ±50ms in conjunction with the master clock device was realized only

(a) Sodium sulfur battery

(b) LiB・EDLC

Fig. 4 **Energy Storage System**

In regard to sodium sulfur batteries for this verification project, 500kW was borrowed from existing batteries with a total capacity of 1500kW (switched over in accordance with the right of control). LiB and EDLC were individually accommodated in the dedicated containers.

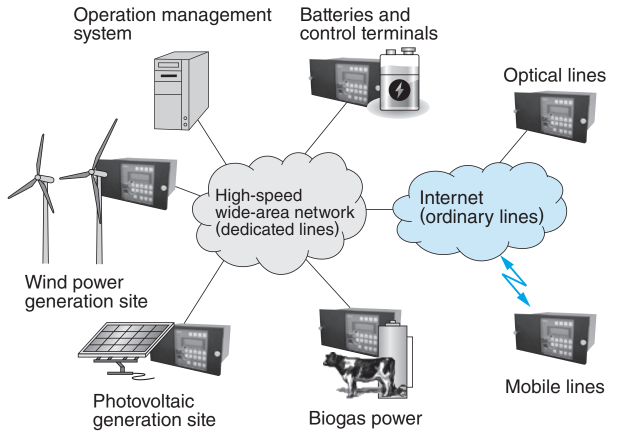

Fig. 5 Image of High-Speed WAN Network

For high-speed data transmission, each site was connected through dedicated optical lines. In consideration of possible various issues during the commercialization process, ordinary lines (optical and mobile) were also applied through ADSL, ISDN, and Internet.

through network communications. Realizing this goal accuracy is significant because it is essential to evaluate the experimental test results and it is also a means to prove system control performance.

Meanwhile, considering the commercialization steps, its expected use of dedicated lines demand might be a cost burden. For this reason, control response characteristics by using ordinary lines were also verified and evaluated. In this case, two types of lines, both optical and mobile, were adopted. Fig. 5 shows an image of a high-speed WAN network.

2.4 Wind Turbine Operation State Monitoring System

In this Verification Project, the measuring subject window power generation systems are small scale and three wind turbines are installed. In addition, there is no installation of a Supervisory Control And Data Acquisition (SCADA) system for the control of this wind farm. It is, therefore, difficult to grasp the state of operation accurately. Meanwhile, weather forecasting equipment is used to estimate the wind velocity based on weather forecast data the following day, and estimates the next-day generation output based on the past generation record. For this reason, it is essential to grasp the state of operation of RE resources correctly. At the stage of operation and in the case of wind turbine stoppage is due to system malfunction, it is necessary to make adequate adjustment of power yield forecast data per the availability state. Against such background,

Table 2 Wind Turbine Operation State Monitoring Approach and Result of Evaluation

The surveillance camera requires maintenance such as periodic removal of contaminants from the lens. Since the precision sound level meter and Charge Coupled Device (CCD) camera can have obstructive factors like weather, it is necessary to use technologies to eliminate various disturbances (examples: noise-producing moving objects, birds, airplanes, etc.).

Monitoring approach	Detection object	Judgment method	Evaluation
Surveillance camera	Image of whole wind turbine	Visual	Obstructive factor: Weather, etc.
Precision sound level meter	Wind noise	Frequency analysis	Obstructive factor: Individual difference
CCD camera	Blade image	Image differential	Obstructive factor: Slight movement
Vibration sensor	Tower vibration acceleration	Frequency analysis	No obstructive factor (Adopted)

we examined the monitor system building to grasp the state of the wind turbine operation. Table 2 shows our state of wind turbine operation monitoring approach and the result of the evaluation.

According to the result of our preliminary investigation, we constructed a wind turbine operation state monitoring system assuming in which “vibration acceleration” is a detection target with which the state of wind turbine operation can be identified most effectively. Each wind turbine is generally installed at a separation distance of a few hundred meters. As a result, at the existing power station, it is difficult to secure a wired communication route between wind turbines. We then decided to install a multi-hop type monitoring network that employs a small-power wireless device. Such a system does not require any large-scale modification in existing facilities. Fig. 6 shows the wind turbine operation state monitoring system and an installation image.

3 Evaluation of Wide-Area Operation System

3.1 Control Response Characteristics

Table 3 shows the result of performance evaluation for the high-speed WAN network used in a wide-area operation system that has been installed for this Verification Project. It was confirmed that high-speed and steady communication performance can be attained irrespective of the line type used, if dedicated lines are employed. If ordinary lines are used, however, it was verified that a sufficient level of communication performance can be attained in the case of optical lines, but mobile lines

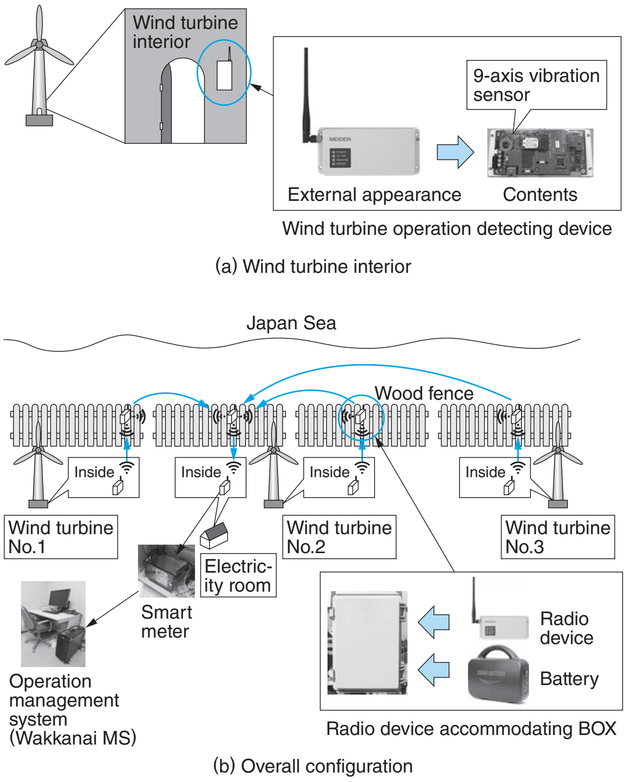

Fig. 6 **Wind Turbine Operation State Monitoring System and Installation Image**

An integrated unit of a vibration sensor and radio was installed on the inner wall of wind turbine tower No.1～No.3. Each unit was used to transmit detected information to a radio master device for data collection via the closest radio relay device (outdoor).

Table 3 **Result of Performance Evaluation for High-Speed WAN Network**

Target performance was realized with all types of lines except an ordinary mobile line.

Circuit classification		Time synchronization (ms)	Transmission delay (ms)	Performance evaluation
Dedicated line	Optical	±0.3	10	Target attained
	ADSL	±0.7	16	Target attained
	ISDN	±8	38	Target attained
Ordinary line	Optical	±7	25	Target attained
	Mobile	±17	102	Conditional

caused a large communication delay. As shown in Fig. 7 and Fig. 8, it was also confirmed that the communication speed of an ordinary line tends to cause unstable changes. Since the transmission quality and communication cost of the dedicated and ordinary lines have a relationship of trade off, it is necessary to choose an adequate communication line according to the control performance to be secured in operation.

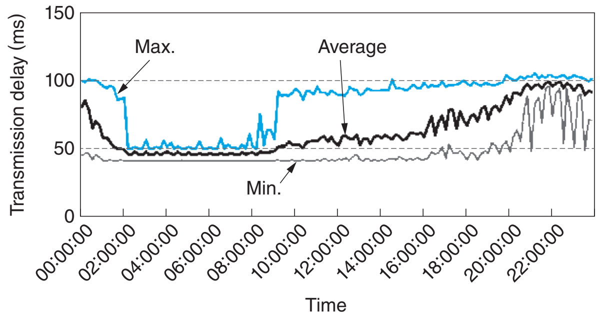

Fig. 7 **Instability in Ordinary Optical Lines**

Although the transmission speed tends to change greatly in a time frame from evening to next morning, we confirmed that optical lines can be used in almost same way as dedicated lines.

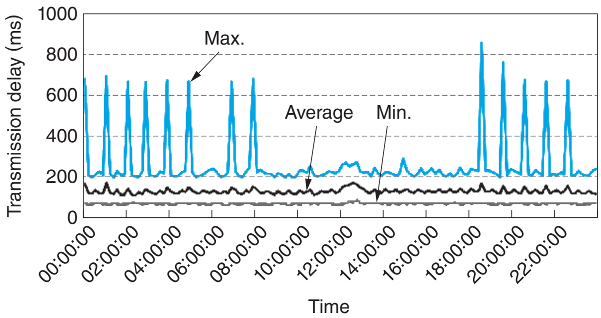

Fig. 8 **Instability in Ordinary Mobile Lines**

Like optical lines, the transmission speed tends to change greatly in a time frame from evening to the next morning. Target performance cannot be attained. Mobile lines are, therefore, applicable to areas where high-speed control is not required and where biogas power or wired lines are not available.

3.2 Wind Turbine Operation State Monitoring System

For the wind turbine operation state monitoring system, we confirmed its operating conditions by gathering necessary data for one month. Fig. 9 shows the result of judgment on wind turbine power yield, wind velocity, and running. In the time zone where power generation is 0kW, a judgment of non-operation (OFF) is correctly indicated. In regard to a part marked by an arrow in the figure, however, it was identified as a record caused by false detection. As a result of our analysis on the test data, we concluded that judgment accuracy can be improved further by reviewing the detection threshold value and improving the judging method.

3.3 Result of Long-Term Continuous Operation Test

For this Verification Project, we carried out a long-term continuous operation test for about two

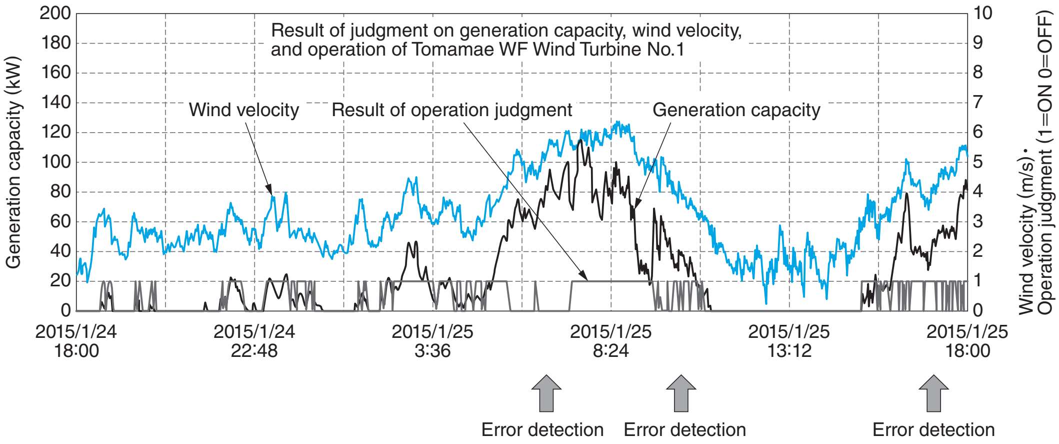

Fig. 9 **Result of Judgment on Wind Turbine Generation Capacity, Wind Velocity, and Operation**

When the wind turbine was in operation, vibration acceleration was dispersed (standard deviation became large). When it was out of service, the distribution of vibration acceleration was settled in a constant range with the standard value in the center. 9-axes of operation judgment was put into effect by vibration acceleration of the X, the Y and the Z axis detected by vibration sensor.

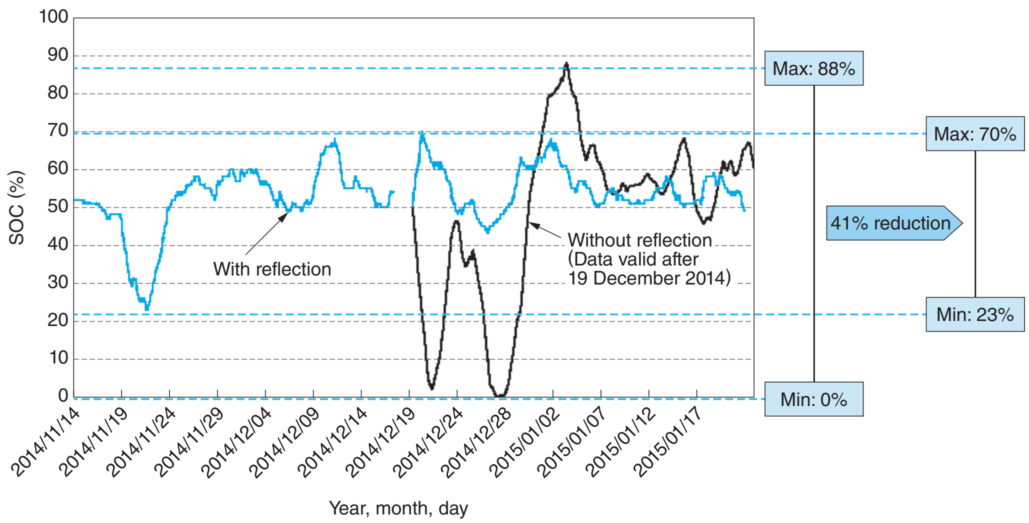

Fig. 10 **Effect of SOC Variation Range Reduction for Sodium Sulfur Batteries with or without Reflection by Wind Turbine Operation**

The SOC of batteries is considered ideal if it maintains around 50% consistently so that the batteries can respond in both cases of charge and discharge. In this testing, not only the result of weather forecast was used but also the wind turbine operation state was added in order to calculate the generation target value. In this manner, we could greatly reduce the SOC variation range of sodium sulfur batteries.

months since November 2014. Through this testing, we confirmed that the wide-area operation system built this time can deliver stable operation. During the test, we also carried out operation reflecting the conditions of the wind turbine operation, and made a comparison of control performance with a case when the state of wind turbine operation was not considered. As shown in **Fig. 10**, the result of the evaluation indicates that the State Of Charge (SOC) in the sodium sulfur battery can greatly reduce its variation range by reflecting the conditions of the wind turbine operation. This fact signifies that the required capacity of storage batteries can be reduced substantially.

4 Postscript

In this Verification Project, we could realize the original target performance for the wide-area operation system and confirmed that programmed operation of RE resources is possible in an effective and stable manner. By collecting the basic data about performance evaluation of the communication network and status monitoring of the conditions of wind turbine operation, we identified issues for future commercialization with a wider introduction of RE resources. We expect that our technologies will be actively used to increase the interconnection capacity of utility grids with RE resources.

Lastly, for the implementation of this Verification Project, we express our deepest gratitude to Wakkanai City Government and project-related organizations, such as Japan Weather Association (the chief representative of undertaker for contract research for this verification project), and joint implementation organizations: Hokkai Electrical Construction Co., Inc., HOKUDEN SOGO SEKKEI Corporation, and Hokkaido University. We appreciate your generous cooperation such as installation of test equipment at the existing RE resource power station and the acquisition of power generation data. Our special thanks to Hokkaido Telecommunication Network Co., Inc. for your cooperation in building the unprecedented high-speed WAN network.