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Smart Grid Demonstration Project at Kyushu Electric Power

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OVERVIEW: Given the likely future installation of large amounts of renewable energy capacity, the balancing of supply and demand will rely heavily on supply and demand planning and control technologies for predicting power output, and the effective utilization of batteries to cope with the excess power or fluctuating outputs that result when renewable energy is connected to the grid. Grid operation, meanwhile, will require optimal voltage control techniques to maintain power quality and ensure that existing equipment continues to operate efficiently. Hitachi is developing supply and demand planning and control techniques and optimal voltage control techniques that will contribute to maintaining an efficient power supply with high quality and reliability even under future scenarios involving widespread use of distributed renewable energy sources with variable output, such as PV power generation.

INTRODUCTION

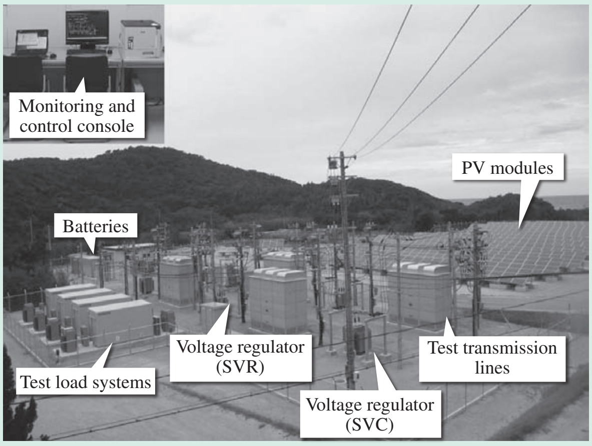
INCREASED demand for reductions in carbon dioxide (CO_2) emissions as a countermeasure to global warming has seen growing momentum in recent years behind moves to make greater use of renewable energy sources such as photovoltaic (PV) power generation. This has led to concerns about voltage deviation on the grid due to reverse power flows from PV power plants. At Kyushu Electric Power Co., Inc. in particular, which has a high proportion of PV capacity, there will be a need for measures to deal with voltage rises on transmission lines and complications to future supply and demand planning caused by the use of large amounts of PV power. In response, Kyushu Electric Power has embarked on a smart grid demonstration project whereby it has installed test equipment, including PV modules and batteries, at Genkai Town in Saga Prefecture and at Satsumasendai City in Kagoshima Prefecture. The aim of the project is to verify the effectiveness of the smart grid in practice, and to identify the associated challenges, the technologies needed, and the operational requirements.

Hitachi is participating in joint research with Kyushu Electric Power and has been running the demonstration project at Satsumasendai since October 2013.

This article describes the progress to date of this demonstration project.

OVERVIEW OF SMART GRID DEMONSTRATION PROJECT EQUIPMENT

The demonstration project equipment installed at Satsumasendai commenced operation in October 2013. It consists of a PV power plant, batteries, and a test transmission line system (see Fig. 1), as well as an energy management system for the measurement, monitoring, and control of voltage, current, and other equipment output parameters.



SVR: step voltage regulator SVC: static var compensator

Fig. 1—Demonstration Project Equipment at Satsumasendai.
The demonstration project was configured using equipment from the Kyushu Electric Power Co., Inc. grid.

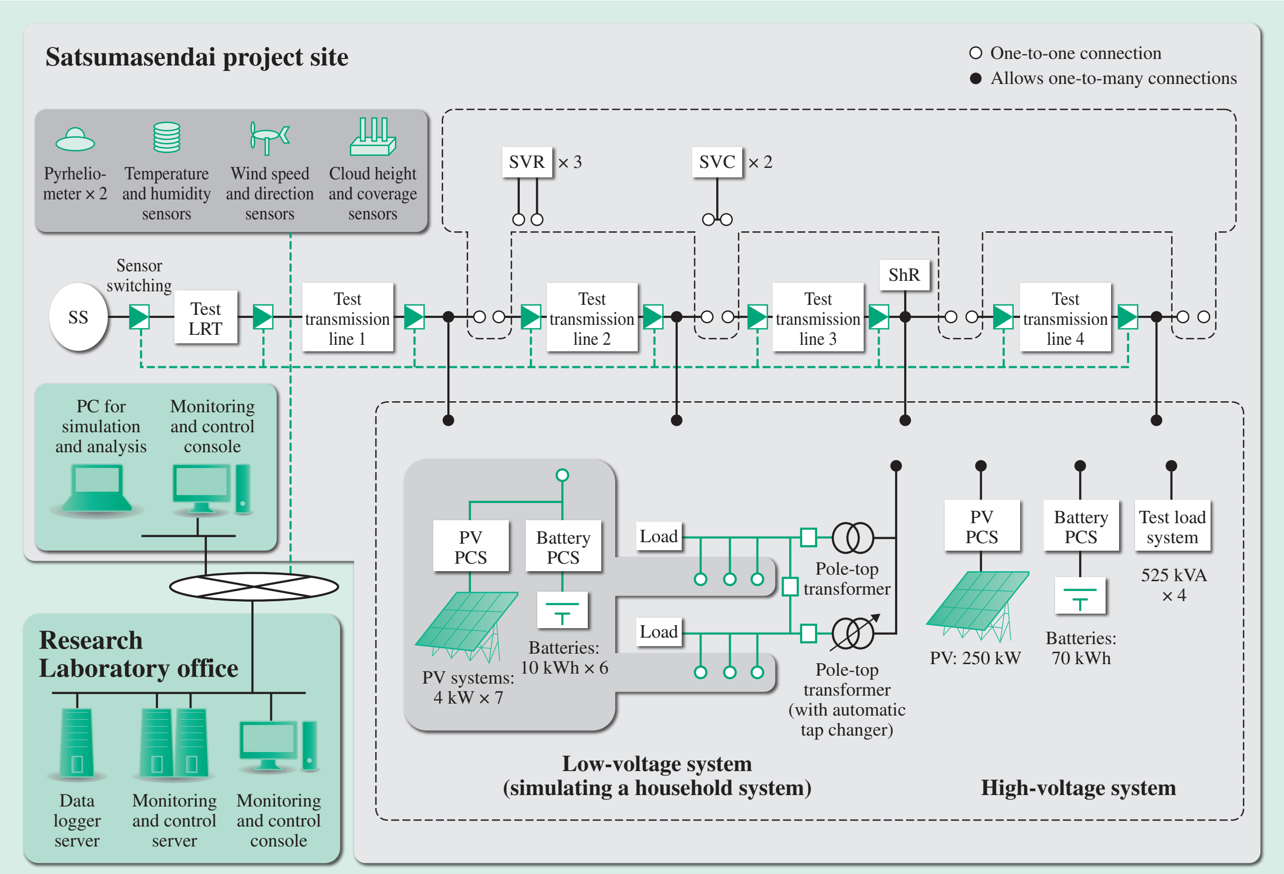
TABLE 1. Components of Test Transmission Line System
The table lists the specifications of the main components of the test transmission line system.

Component	Specifications
Test LRT	2,000 kVA × 1, short-circuit impedance: 3%
Static voltage regulators	SVR × 3, SVC × 2, ShR × 1
Test transmission lines	4 × 10 km of 6.6-kV distribution lines (400 sq/200 sq) Line length: 0, 2.5, 5, 7.5, 10 km
Test load systems	525 kVA × 4, active and reactive power control, with bidirectional operability
PV modules	Connected to high-voltage system (simulating a commercial-scale system): 250 kW × 1 Connected to low-voltage system (simulating a household system): 4 kW × 7
Batteries	Connected to high-voltage system (simulating grid use): 100 kW (70 kWh) × 1 Connected to low-voltage system (simulating a household system): 3 kW (10 kWh) × 6

LRT: load ratio control transformer   ShR: shunt reactor

Table 1 lists the components of the test transmission line system. The test load ratio control transformer (LRT) has 11 taps, with voltage settings that range from 6,180 V to 7,020 V in increments of 84 V. It is controlled from a static voltage regulator panel that is part of the operating grid. Each of the four test transmission lines has the same impedance (R + jX) as the cable sizes used by Kyushu Electric Power, and can be configured to have a length of between 0 and 10 km, in increments of 2.5 km. That is, it is possible to simulate a long-distance transmission line of up to 40 km by connecting the lines together in a series. The four test load systems can be configured to act as either loads or generators, and are able to provide an output of up to 500 kW (active power) with a response time of 1 s. This means the systems can regenerate a power flow of up to 2,000 kW, and simulate a reverse power flow. The voltage regulators consist of step voltage regulators (SVRs), static var compensators (SVCs), and other components that are the same as those used on the Kyushu Electric Power grid. Also included in the equipment are PV modules and batteries.

Fig. 2 shows the system configuration. A feature of the Satsumasendai project site is that it can configure a



SS: substation   PC: personal computer   PV: photovoltaics   PCS: power conditioning system

Fig. 2—Demonstration Project Equipment Configuration.
Testing can be conducted under a wide variety of conditions by swapping in and out the various components at the demonstration project site (areas enclosed by black dotted lines).

wide variety of different grid conditions. This is done using the 35 section switches that can swap in and out the various components of the system (including PV modules, batteries, test load systems, and voltage regulators). Measurement data from around the site is collected on a data logger server or monitoring and control server to allow realtime monitoring of parameters such as transmission line voltages and currents or outputs from PV modules and batteries. Functions such as PV output prediction and battery charging and discharging control are performed from monitoring and control consoles. A supply and demand planning function that uses these systems is also included.

The demonstration project is using this equipment to test techniques for supply and demand planning and control, and for optimal voltage control.

TESTING OF SUPPLY AND DEMAND PLANNING AND CONTROL TECHNIQUES

Demonstration Project Overview

With the aim of overcoming the challenges associated with techniques for planning and control of supply and demand on grids with a large PV capacity, the project will test methods for optimal battery control using PV modules and batteries. The objective of optimal battery control is to make effective use of the power generated by PV modules and to minimize the battery capacity needed to achieve this. This includes two types of tests, a long-term fluctuation suppression test and a short-term fluctuation suppression test. The following section describes the supply and demand planning and control techniques used to test the suppression of long-term fluctuations.

Verification of Supply and Demand Planning and Control Techniques

Hitachi has previously developed energy management systems (EMSs) for the planning and control of supply and demand across entire grids or parts thereof. The EMS used by the demonstration project is one designed to manage a specific region, with additional functions that incorporate know-how built up from past experience.

Supply and demand planning functions generate output schedules for generation plants by calculating the balance between supply and demand in the area being managed. Because it is intended for use with PV modules and batteries, the supply and demand planning function in the demonstration project system includes both a PV module output prediction function and a planning function for battery charging and discharging.

The demonstration project is based on the possibility that EMSs for specific regions will be installed in the future, and that the batteries in each of these regions will be operated independently. Accordingly, two new functions have been added to allow independent energy management of a number of regions using the demonstration project system on its own.

The first of these is a function that allows supply and demand plans to be generated for designated equipment only. Past EMSs for specific regions have only considered their own region, and have not had to deal with more than one region at a time. In contrast, the concept of dividing the equipment to be managed by region was introduced in the demonstration project system to allow the generation of multiple independent plans. Fig. 3 shows the equipment covered by a

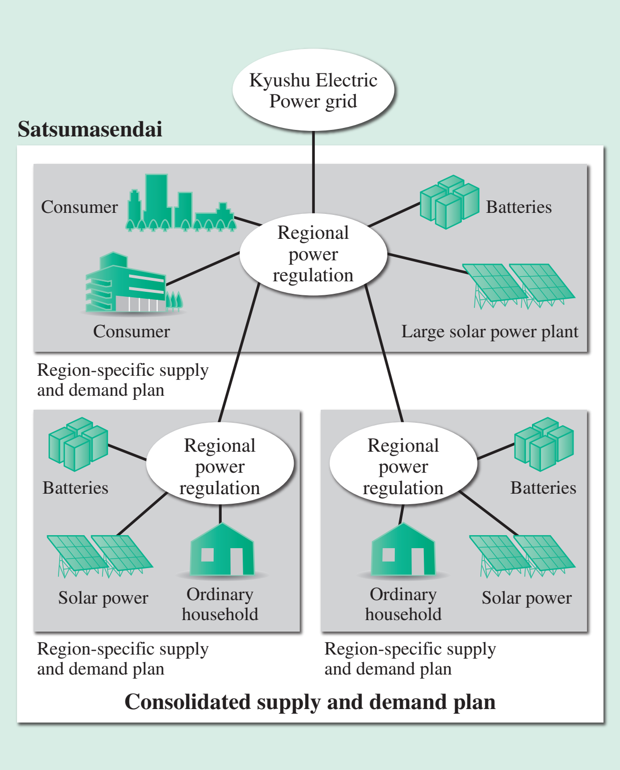


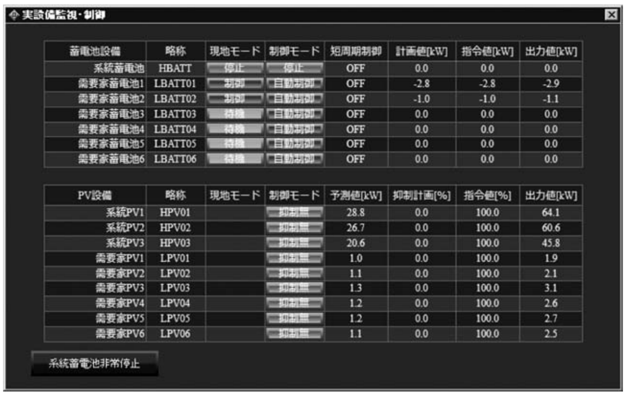
Fig. 3—Example of Equipment Covered by Consolidated and Region-specific Supply and Demand Plans.
The white box encloses the equipment covered by the consolidated supply and demand plan, and the grey boxes enclose the equipment covered by the respective region-specific supply and demand plans. Whereas the consolidated plan covers all equipment, the region-specific plans only cover equipment from their region.

consolidated supply and demand plan, and the equipment covered by the region-specific plans. Whereas the consolidated plan provides for integrated operation of all of the equipment managed by the demonstration project system, the region-specific plans only specify the operation of equipment from their own region. This function allows optimal battery control techniques to be verified under both scenarios in which energy management is consolidated across regions and scenarios in which it is handled within each region.

The other function is the coordination of consolidated and region-specific supply and demand plans. This allows for the case in which some regions use region-specific operation while operation of the remainder is consolidated. This updates the supply and demand plan for the consolidated regions so that their operation is coordinated with the supply and demand plans for those regions operating independently. This function allows optimal battery control techniques to be verified under scenarios in which region-specific and consolidated operation occurs at the same time.

These additional functions provide the flexibility to generate a wide range of different supply and demand plans. Based on the generated supply and demand plan, the demonstration project system sends instructions to the test equipment via the control functions. Fig. 4 shows an example control screen. The screen is used to display a list of equipment setting values and to issue control instructions.

The demonstration project will record and collect the results of supply and demand planning and control, and analyze and verify how these influence load patterns, optimal battery control, and where batteries are installed.



蓄電池設備	略称	現地モード	制御モード	短周期制御	計画値[kW]	指令値[kW]	出力値[kW]
系統蓄電池	HBATT	停止	停止	OFF	0.0	0.0	0.0
需要家蓄電池1	LBATT01	制御	自動制御	OFF	-2.8	-2.8	-2.9
需要家蓄電池2	LBATT02	制御	自動制御	OFF	-1.0	-1.0	-1.1
需要家蓄電池3	LBATT03	待機	自動制御	OFF	0.0	0.0	0.0
需要家蓄電池4	LBATT04	待機	自動制御	OFF	0.0	0.0	0.0
需要家蓄電池5	LBATT05	待機	自動制御	OFF	0.0	0.0	0.0
需要家蓄電池6	LBATT06	待機	自動制御	OFF	0.0	0.0	0.0

PV設備	略称	現地モード	制御モード	予測値[kW]	抑制計画[%]	指令値[%]	出力値[kW]
系統PV1	HPV01		抑制無	28.8	0.0	100.0	64.1
系統PV2	HPV02		抑制無	26.7	0.0	100.0	60.6
系統PV3	HPV03		抑制無	20.6	0.0	100.0	45.8
需要家PV1	LPV01		抑制無	1.0	0.0	100.0	1.9
需要家PV2	LPV02		抑制無	1.1	0.0	100.0	2.1
需要家PV3	LPV03		抑制無	1.3	0.0	100.0	3.1
需要家PV4	LPV04		抑制無	1.2	0.0	100.0	2.6
需要家PV5	LPV05		抑制無	1.2	0.0	100.0	2.7
需要家PV6	LPV06		抑制無	1.1	0.0	100.0	2.5

Fig. 4—Equipment Operation Screen.
Control settings are sent to the batteries and PV systems based on a plan generated by the supply and demand planning function.

TESTING OF OPTIMAL VOLTAGE CONTROL TECHNIQUES

Demonstration Project Overview

With the aim of overcoming the challenges associated with optimal voltage control techniques on grids with a large PV capacity, the project includes a variety of testing using the test transmission lines. The project is focusing on the following two types of testing in particular.

(1) Use of test transmission lines for operational verification of voltage regulators

Determine the limit on installed PV capacity, operational limits of voltage regulators, and the benefits of upgrades to grid equipment and the installation of voltage regulators on the transmission line model.

(2) Study optimal voltage control techniques

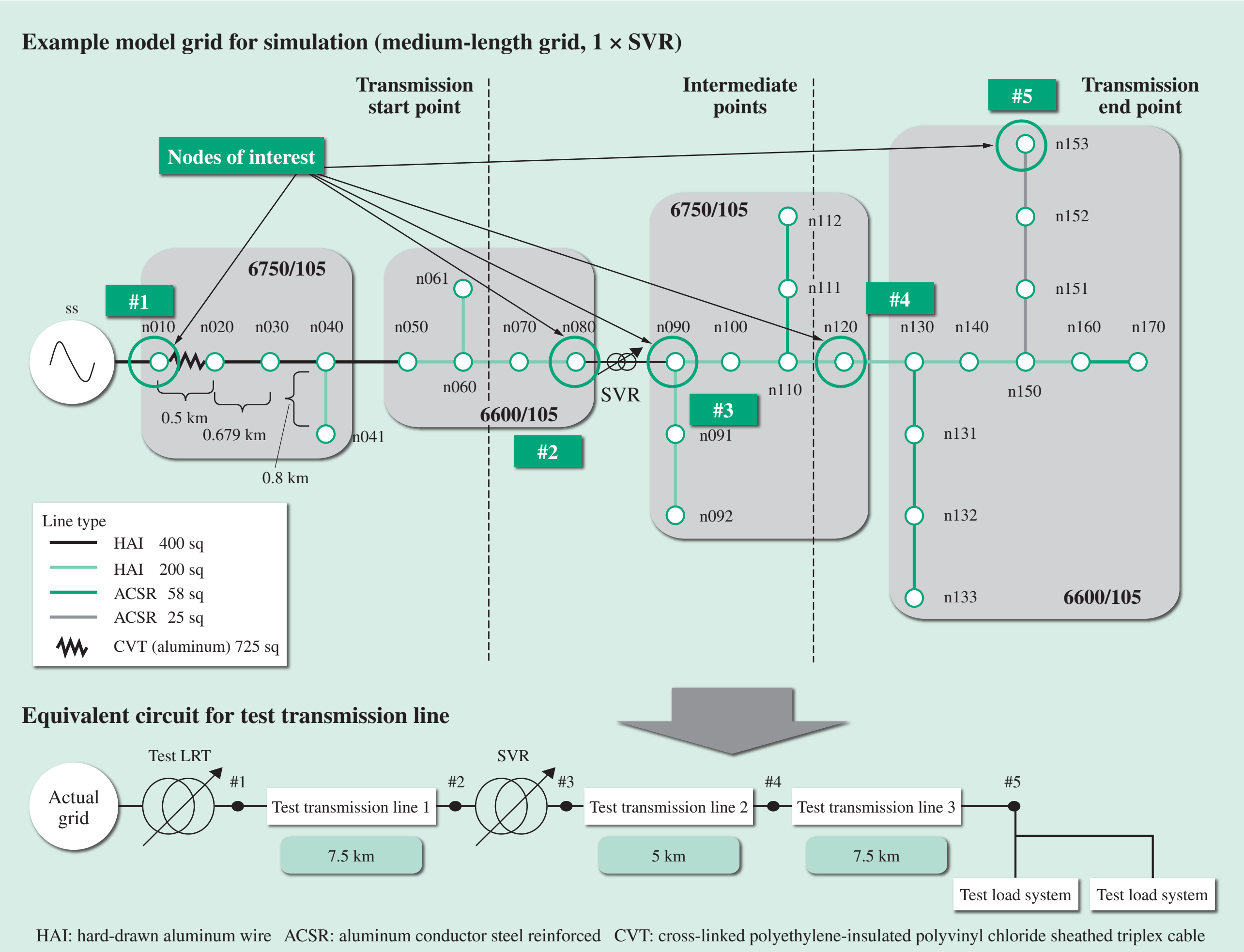
Determine the benefits of optimal settings for voltage regulators and consider the potential for use of technologies such as advanced techniques for autonomous and distributed control.

The following section provides an overview of this testing, which will start with the type (1) tests.

Evaluation Using Simulations and Test Transmission Lines

The power system and load curve settings (for heavy loads and light loads) for the demonstration project use four average model power systems representing the actual Kyushu grid and loads at a macro level. The testing assumptions cover both distributed (throughout an entire region) and centralized (distributed between transmission start, intermediate, and end points) PV and load distributions, and different combinations of connected capacity and connection points for PV modules.

Because of time and equipment-related constraints, the project has been set up to allow digital analyses of the test cases for the test transmission lines to be performed beforehand using a voltage analysis simulation tool. Because the test transmission lines have fewer nodes than the model grid used for simulation, the test grid needs to be replaced with an equivalent circuit that can be replicated using the test transmission lines. To assess issues such as rises or fluctuations in the voltage on the test transmission lines when a PV module is connected to the grid, the equivalent circuit for the test was configured by adjusting the line impedances on the respective transmission lines and the outputs of the



HAI: hard-drawn aluminum wire ACSR: aluminum conductor steel reinforced CVT: cross-linked polyethylene-insulated polyvinyl chloride sheathed triplex cable

Fig. 5—Equivalent Circuit for Model Grid and Test Transmission Lines.
Because of constraints on the load capacity, number of loads, number of nodes, and length of the test transmission lines, they were replaced by a simulation equivalent circuit for preliminary testing.

test load systems so that the amplitudes of the voltage fluctuations at the equivalent circuit nodes on the transmission lines matched the amplitudes of the fluctuations at each node on the model grid used for simulation shown in Fig. 5 (see Fig. 6).

Issues to be Studied during Testing

When a large amount of PV capacity is connected to a transmission line, reverse power flows occur at times of low load causing the voltage on the transmission line to rise. Meanwhile, because existing voltage regulators were not designed to cope with reverse power flows and PV output fluctuations, there is a need to identify and verify the issues associated with these situations. There is also a need to clarify the issues associated with having a number of different voltage regulators with different operation time limits connected to the same transmission line, and the effectiveness of such configurations.

The demonstration project will determine the operational limits of existing voltage regulators (their adjustment limits and interference with other equipment) by including testing of extreme cases involving reverse power flows and transient output fluctuations caused by PV modules, and cases in which a number of different voltage regulators are installed.

Study of Optimal Voltage Control Techniques

With reference to the results of testing to ascertain the limit on PV module installation capacity when using existing methods on existing voltage regulators, Hitachi investigated ways of calculating the optimal settings for these methods. The test transmission lines were also used to check how well voltage regulators worked when operated using these optimal settings. The next step is a plan to verify the potential for increasing the limit on PV module installation capacity

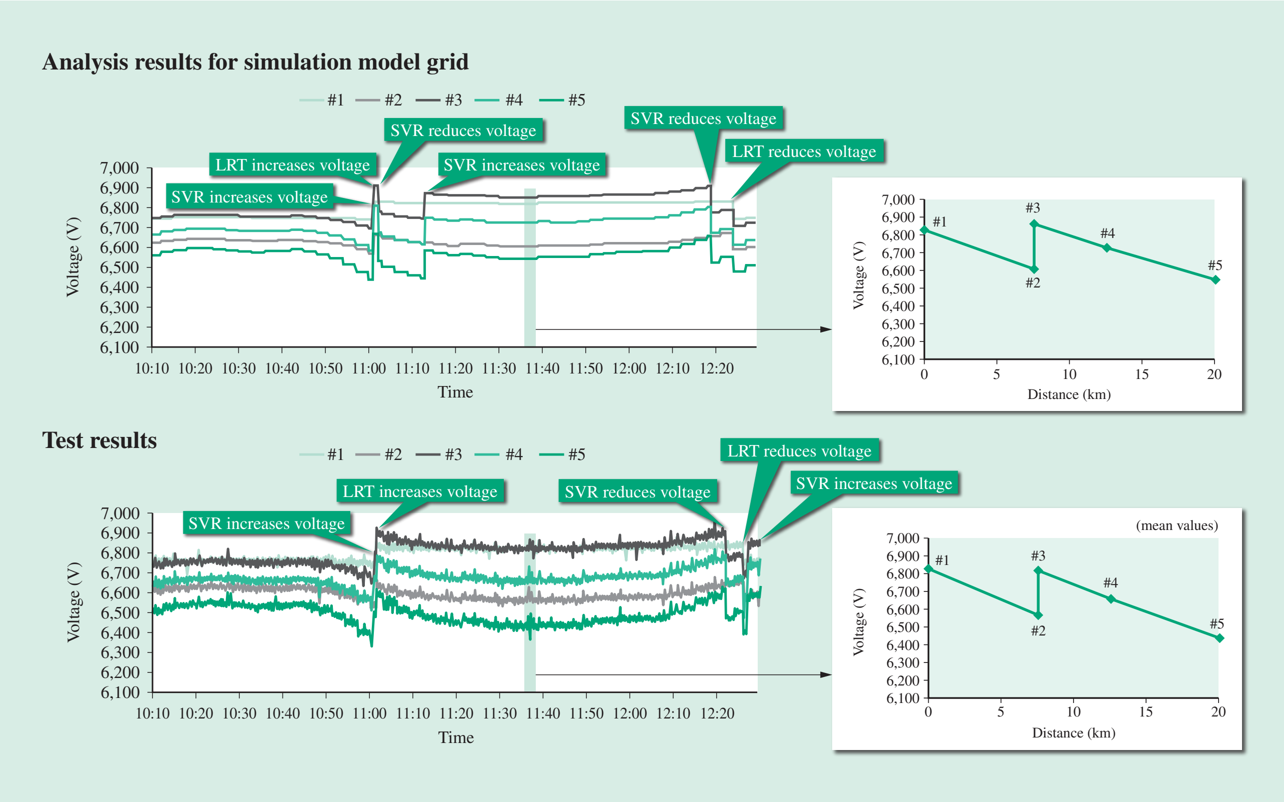


Fig. 6—Analysis Results for Model Grid and Test Transmission Lines.
The validity of the equivalent circuit used in testing was confirmed by adjusting the amplitude of the voltage fluctuations on the simulation model grid and test transmission lines to be the same.

when using existing methods by using different settings at different times, for example.

Based on the results of the above testing, Hitachi also plans to investigate the use of control methods that use communication links and advanced techniques for autonomous distributed control that are currently under development.

CONCLUSIONS

This article has described the testing conducted to date for Kyushu Electric Power's smart grid demonstration project, and its plans for the future.

To support the greater use of renewable energy and help establish a low-carbon society, Hitachi plans to continue with the verification and development of optimal battery control and optimal grid voltage control techniques.

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