Next-generation SCADA and Control Technologies for Large-scale Use of Photovoltaic Generation on Electric Power Grid

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OVERVIEW: How to maintain the quality of electric power on the grid in terms of voltage and other parameters and ensure that equipment operates efficiently will be important considerations if large quantities of solar power generation are to be connected. In response, Hitachi is working on technology development with the aims of introducing equipment such as section switches with built-in sensors and advanced metering infrastructure, developing control equipment, and enhancing monitoring and control. In particular, research and development of SCADA system technologies and voltage control equipment that help maintain power quality on the grid are helping to speed up preliminary investigations into how to maintain power quality and minimize the cost of adapting the grid to cope when large amounts of photovoltaic and other distributed power resources are introduced, thereby helping achieve reductions in CO_2 emissions.

INTRODUCTION

THE installed capacity of PV (photovoltaic) power generation is increasing year by year and the government of Japan has set capacity targets equivalent to 28 GW in 2020 and 53 GW in 2030. Of the 2020 target, it is anticipated that 70% will be installed on domestic dwellings and the majority of this connected to the distribution grid. Connecting large amounts of PV capacity to the grid raises the following issues that need to be considered and progress made on developing technical solutions.

(1) Power quality: Voltage rises caused by variation in PV output, measures for controlling variation

(2) Grid operation: The difficulty of estimating PV generation makes management of power flows more complex and makes it more difficult to determine the actual load at consumer premises.

(3) Protection and maintenance: Preventing misoperation of protection relays, preventing individual running (generator continuing to run after disconnection from grid)

This article describes SCADA (supervisory control and data acquisition) system technologies that help maintain power quality on the grid with a focus on voltage control techniques for managing grid voltage, something that will become an important issue in the future.

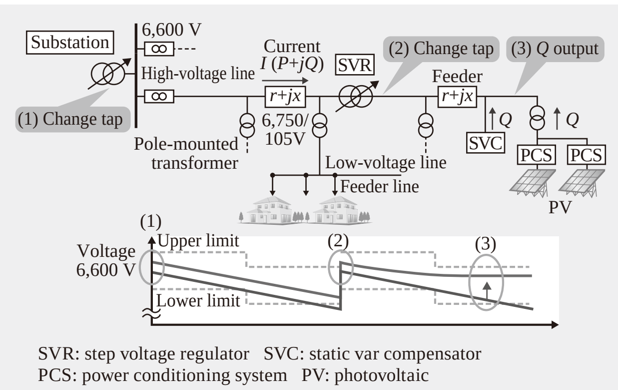

Fig. 1—Overview of Grid Voltage Control.
The voltage is adjusted using the substation transformers, changing SVR taps, and by control of SVC reactive power (Q).

CONCEPTS BEHIND NEXT GENERATION OF SCADA AND CONTROL

Overview of Grid Voltage Control

The electric power grid in Japan supplies power to homes through high-voltage distribution lines that originate at substations and then via pole-mounted transformers to low-voltage distribution lines and feeder lines (see Fig. 1). On a grid with no distributed power sources, the voltage drops the closer one gets to the edge of the grid. Voltage regulation is performed by switching of LRTs (load ratio transformers) located at substations and tapped control at SVRs (step voltage regulators) located on the power lines. Because fluctuations in voltage are likely to occur due to variations in output if a significant amount of PV generation is introduced, it is anticipated that, in addition to making good use of the LRTs, SVRs, and other existing equipment, systems such as SVCs (static var compensators) able to make rapid changes in voltage and PCSs (power conditioning systems) that are able to perform PV reactive power control will also prove effective in suppressing voltage fluctuations on the high-voltage lines. Meanwhile, it is also anticipated that low-voltage grids incorporating PV installed on homes will experience similar voltage fluctuations and that this voltage problem will become the greatest challenge for distribution grids in the future.

Future Directions for SCADA

Two approaches can be taken to the monitoring and control of grid voltage.

(1) Determine situation on grid (improve observability)

Whereas grids in the past have been limited to slow-rate measurements of a subset of data from automatic switches on the high-voltage lines, utilities in recent years have been working toward improvements such as collecting measurements from each phase using switches with built-in sensors and increasing the speed of grid telecommunications. The widespread adoption of automatic metering and future monitoring of the status of PV generation, electric vehicles, and other new technologies will also become important factors in improving the accuracy of grid status monitoring.

(2) More sophisticated voltage control (improve controllability)

Another approach is to install additional voltage control equipment to complement the existing LRTs and SVRs and help maintain the voltage either through autonomous or coordinated operation. Potential voltage control equipment includes distribution SVCs and pole-mounted transformers with a voltage control capability as well as the use of the batteries in electric vehicles and PCSs for distributed power sources to perform control of reactive and active power. DSM (demand-side management) to control the operation of consumer equipment is also being considered.

In this way, by improving observability and controllability to allow detailed monitoring and control, it is possible to implement voltage management measures that can cope efficiently with an increase in load equipment of different types when PV generation is introduced. What will be important to achieving this will be the development of various instrumentation, communications, grid status monitoring techniques, and control equipment along with techniques for autonomous, coordinated, and centralized control.

Along with the above improvements in control performance, it is anticipated that control techniques

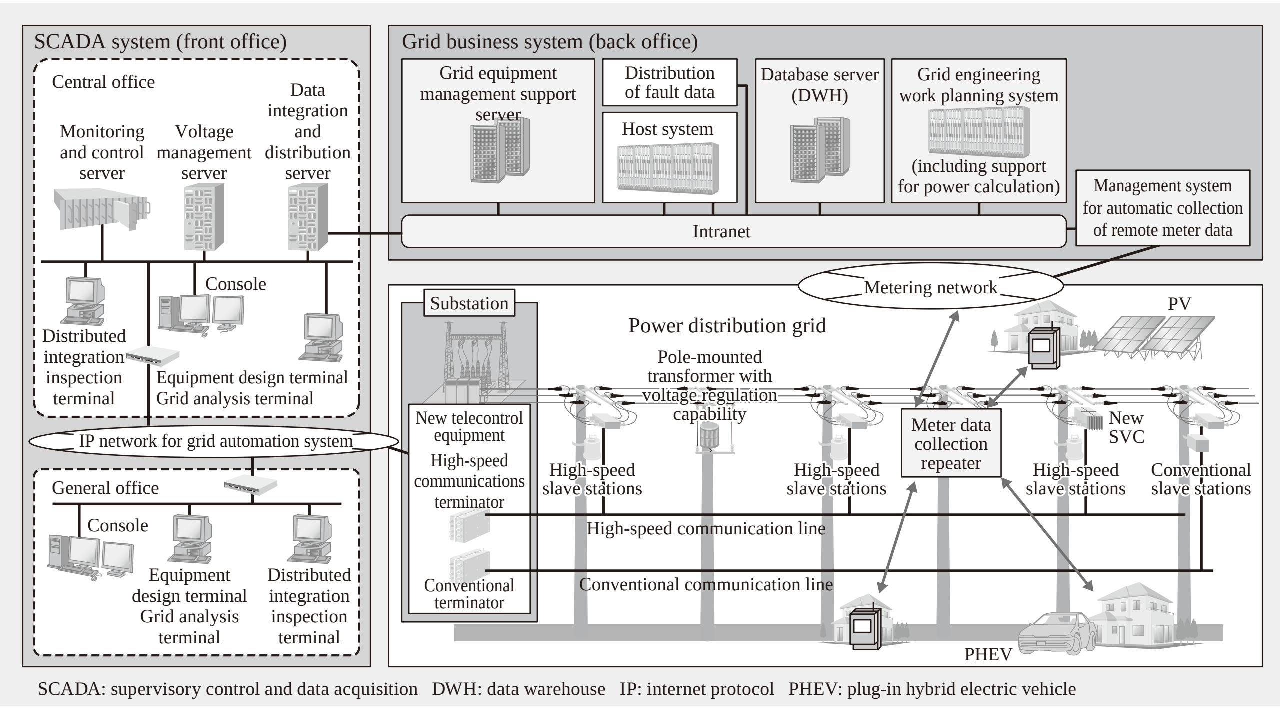

Fig. 2—Example Configuration of SCADA System.
Efficient management of voltage and equipment can be achieved by adopting a comprehensive system configuration and by interconnecting the front office and back office computer networks systems from sensors, slave stations, and a communication network.

will evolve as follows.

(1) Local control

Control based on local information (existing techniques), dual heavy-load/light-load setting, etc.

(2) More sophisticated equipment setting

Optimize equipment control parameters based on measured data.

(3) Autonomous, coordinated, and centralized control

Wide-area control using data from other locations obtained via communication links, coordinated control that takes account of operation of other equipment, control for overall optimization based on data from wide area, etc.

Example SCADA System Configuration

System configurations need to be designed so that measurement data can be collected and utilized for control. A comprehensive system with tight integration of measurement data can potentially be configured from grid sensors, slave stations, communication networks, and front office (monitoring and control systems) and back office (grid business systems) computer network systems.

Fig. 2 shows a block diagram of such a system.

The front office system consists of a high-speed communication network in which various data for each phase are collected from switches with built-in sensors by a monitoring and control server at high speed and utilized to determine the status of the grid. Meanwhile, meter data from consumer premises are collected by an automatic remote meter reading system via the metering network. The grid equipment management support server that acts as an intermediary between the front and back office systems collects this data along with various equipment data for each pole-mounted transformer and grid section. By allowing load estimation to be performed for each grid section, for example, and when used in conjunction with other systems including commercial design systems and grid analysis techniques for automating power distribution, this provides benefits which include more appropriate grid operation and distribution equipment configuration and, in particular, more detailed grid voltage management.

POWER DISTRIBUTION EQUIPMENT TECHNOLOGIES

Static Var Compensator

Hitachi is developing grid voltage regulators including self-commutated SVCs and transformers with a voltage regulation capability.

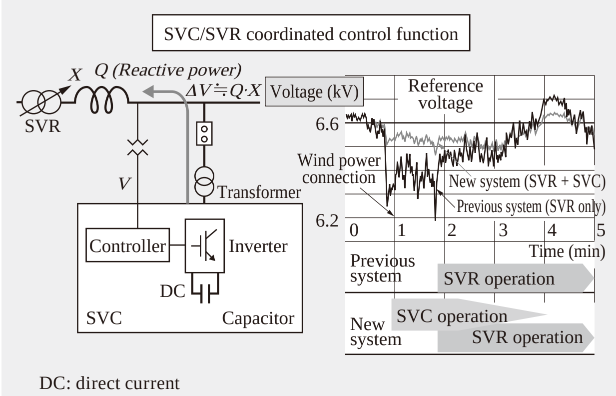

Fig. 3—Self-commutated SVC for Use on Grid (300 kVA).
The system can coordinate operation with an SVR using local data.

Fig. 3 shows an overview of a self-commutated SVC for use on power grids.

Through joint research with Tohoku Electric Power Co., Inc. and Tohoku Electric Manufacturing Co., Ltd., Hitachi has already commercialized a 300-kVA grid SVC capable of coordinated operation with SVRs using local data. The system works by using the SVC to handle short-duration voltage fluctuations (from several tens of milliseconds up to several tens of seconds) and the SVR to handle the variation in load through the day and other long-period fluctuations. Although the main focus during the initial development was dealing with transient voltages caused by the in-rush current that occurs when induction-motor-type wind power generators are linked to the grid, the system can also be effective for dealing with voltage fluctuations caused by the rapid changes in output that occur with PV generation. Work is continuing on utilizing the latest power electronics to reduce the size and cost of the systems.

Transformers with Voltage Regulation Capability

One way of performing voltage regulation on low-voltage grids is to incorporate a voltage regulation capability into the transformers used to convert from the high-voltage grid voltage to 100 or 200 V. Using a converter to apply a variable voltage to a series winding on the low-voltage side of the transformer can feed the low-voltage transmission lines and perform continuous voltage regulation. Fig. 4 shows a prototype transformer with a voltage regulation capability designed for installation on the ground which was developed jointly with The Tokyo Electric Power Co., Inc.

It is also possible that the flow of power through the transformer will reduce due to the power produced

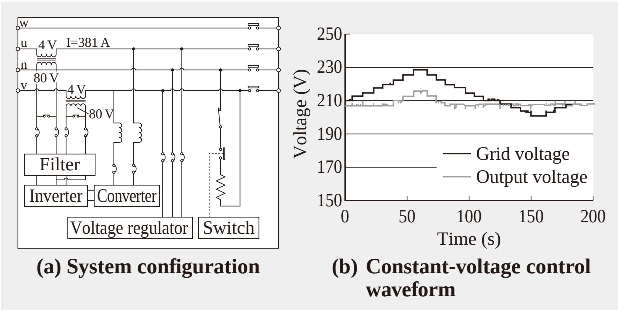

Fig. 4—Voltage Regulation Unit on Transformer with Voltage Regulation Capability.
The grid voltage can be controlled to the desired value by applying a voltage in series with the grid.

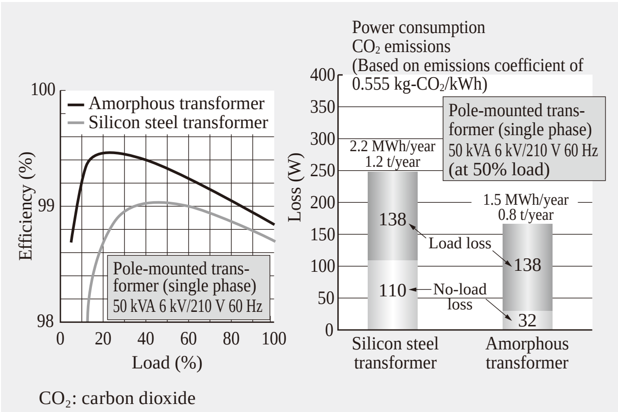

Fig. 5—Reduction in Loss from Use of Amorphous Transformer.
Use of an amorphous transformer reduces loss under low load such as when PV power is being generated.

by PV generation. Amorphous transformers which have low loss under low load can be effective in cases like this.

Fig. 5 shows the reduction in loss achieved by using an amorphous transformer. The use of an amorphous alloy with low loss as the transformer core reduces no load loss.

TECHNOLOGIES FOR GRID VOLTAGE CONTROL AND ANALYSIS

Grid Voltage Control System

The following section describes a control system for coordinating the operation of multiple voltage regulation devices.

Fig. 6 shows an example SCADA system for trial research equipment at the New Energy and Industrial Technology Development Organization (NEDO). The monitoring and control technology is from a SCADA system supplied to the Akagi Testing Center of the Central Research Institute of Electric Power Industry for use in the "Demonstrative Project on New Power

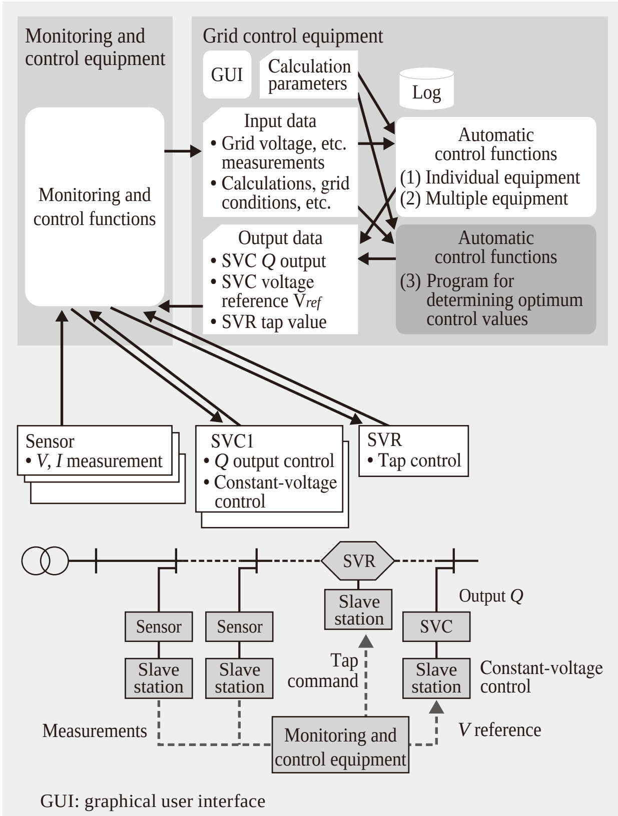

Fig. 6—Overview of Grid SCADA System.
Sensor data is collected via a network and used to calculate control settings for each device.

Network Systems (2004–2007 financial year)" project. The system sends data such as sensor measurements and data collected from control equipment to monitoring and control equipment via a high-speed network and can be used to study operating modes in which the control equipment uses the measurements from the points in the grid under the greatest stress to select the control values (simplified mode) or in which the overall grid voltage distribution is determined using a power flow calculation and optimization performed to select the control values for each device (optimum control value selection mode).

Optimum control value selection uses measurement data to estimate the load and a power flow calculation and the tabu search technique to obtain the optimum control values for each device. In addition to control values such as the reactive power output, the reference values for each control device can also include target voltages which each device can use as a basis for performing local constant-voltage control. This allows distributed control whereby individual devices handle short-period voltage fluctuations locally while the monitoring and control equipment is instructed to perform grid-wide optimization in response to long-

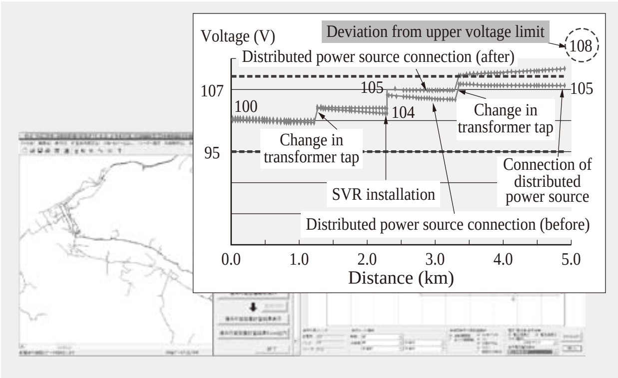

Fig. 7—Overview of High-voltage Analysis System for Distributed Power Sources.
The system collects sensor data via a network and calculates the control reference values for each device.

period fluctuations.

Based on these functions, Hitachi is currently investigating applications in systems using the communications infrastructure (communication speed and coverage) at various power companies.

Analysis of High-voltage and Low-voltage Grids and Systems for Managing Distributed Power Sources

Power grid simulation is essential for determining the status of the grid from measurements and for understanding how the grid status changes in response to the operation of control equipment.

Fig. 7 shows an overview of a high-voltage grid analysis system for distributed power sources which is one example of such simulation tools. The system uses a power flow calculation to determine factors such as the level of distributed power source capacity that can be connected to the grid, the voltage distribution when distributed power sources are connected, short-circuit capacity, and flicker. By incorporating measurement data from distribution automation systems, data from a variety of equipment such as power poles, high-voltage lines, switches, and voltage regulators can be collected automatically and used for analysis of the actual situation. This allows grid design and administration to be performed efficiently and on the basis of quantitative criteria based around investigation of whether or not distributed power sources can be connected and countermeasures to be used when distributed power sources are connected.

Hitachi is also developing systems for auditing the connection of PV power generated by domestic dwellings to low-voltage power lines, which will increase in the future.

CONCLUSIONS

This article has described SCADA system technologies that help maintain power quality on the grid with a focus on voltage control techniques for managing grid voltage, which will become an important issue in the future.

Through its future systems and equipment, Hitachi intends to continue contributing to reducing CO_2 (carbon dioxide) emissions and maintaining the same high level of power quality as in the past despite large-scale introduction of PV generation.

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