Electric-power-supply Systems for Coexistence of Power-distribution Systems and Distributed Resources

Noriyuki Uchiyama
Tomoharu Nakamura
Yasunori Ono
Masahiro Watanabe

OVERVIEW: As a result of the increased concern for environmental issues and system improvement, distributed resources utilizing renewable energy are being introduced. In the case that multiple distributed resources are connected to a power system, the influence of such connection on power quality and supply reliability is a cause of much concern. Accordingly, it is hoped that new power-supply systems that combine implementation expansion of distributed resources and stable operation of power systems will be established. Hitachi is continuing technical development that will contribute to realizing next-generation power-supply systems aimed at achieving coexistence of power systems and distributed resources. Aiming at power systems, in collaboration with the Central Research Institute of Electric Power Industry (CRIEPI), we are grappling with development of a supervision and control system for power-distribution systems, and we have developed such a system for use in demonstrative project of New Energy and Industrial Technology Development Organization (NEDO). Furthermore, as for "microgrids"—which are drawing much attention as an implemented form of distributed resources—we are developing a system with functions such as operation scheduling, demand and supply control, and power-quality monitoring. In addition, a request was received from NTT FACILITIES INC. for such a system, so a system for use at NEDO's demonstrative project was developed and constructed.

INTRODUCTION

OVER recent years, the environment surrounding electric-power systems, such as the continuing deregulation of power utilities and the popularization of distributed resources, has been changing rapidly. In particular, as a result of implementation of the RPS (renewables portfolio standard) law and others, the introduction of distributed resources utilizing renewable energy has been stepped up. When many distributed resources are connected to a power system, however, problems concerning power quality and supply reliability (i.e. voltage and frequency variation due to power variation and voltage rise due to reverse power flow to the system) come to a head.

In light of these circumstances, at Hitachi, we are developing supervision and control systems for
(1) power-distribution systems needed for maintaining power quality from the viewpoint of the operation side of power systems, and
(2) for "microgrids" (which are in the spotlight as an implemented form of distributed resources that is well-suited to power systems) from the viewpoint of users of distributed resources.

In this paper, characteristics of next-generation power-supply systems aimed at coexistence between power systems and distributed resources, voltage and var control system for distribution system, and supervision and control system for microgrids are described, and some examples of their applications are presented.

NEXT-GENERATION POWER-SUPPLY SYSTEMS

The concept behind next-generation power-supply systems for handling mass implementation of distributed resources in power systems is shown schematically in Fig. 1. As for the form in which distributed resources are connected to power systems, in the case that individual distributed resources are either dispersed around or concentrated in a

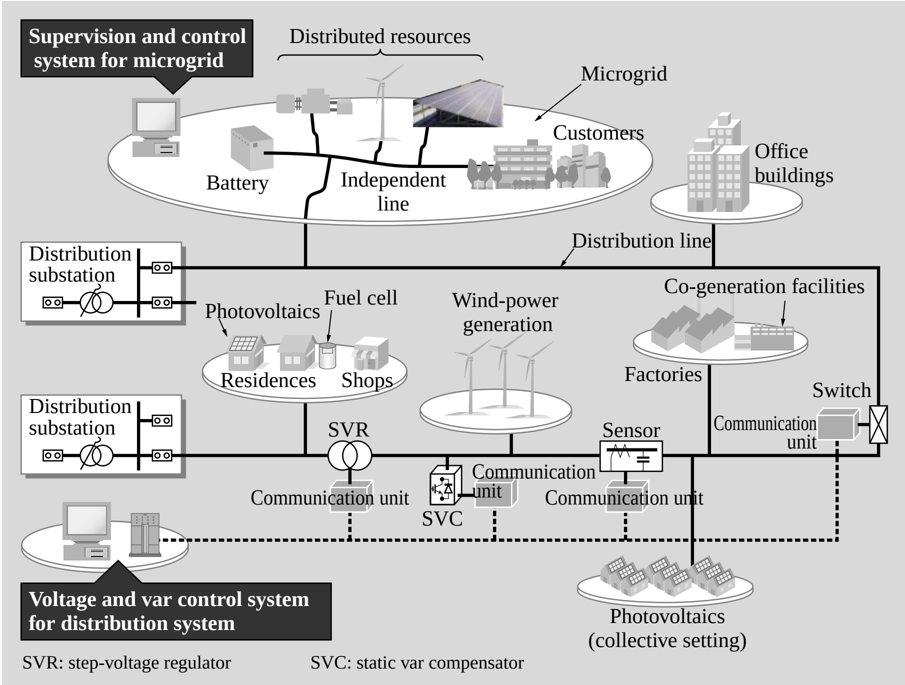


Fig. 1—Example of Next-generation Power-Supply Systems.
As for the implementation form of distributed resources, it is assumed there are two cases: independent connection of distributed resources, and connection is linked loads and multiple distributed resources in a "microgrid." For the sake of maintaining power quality, a supervision and control system for the distribution-system equipment and microgrid is needed.

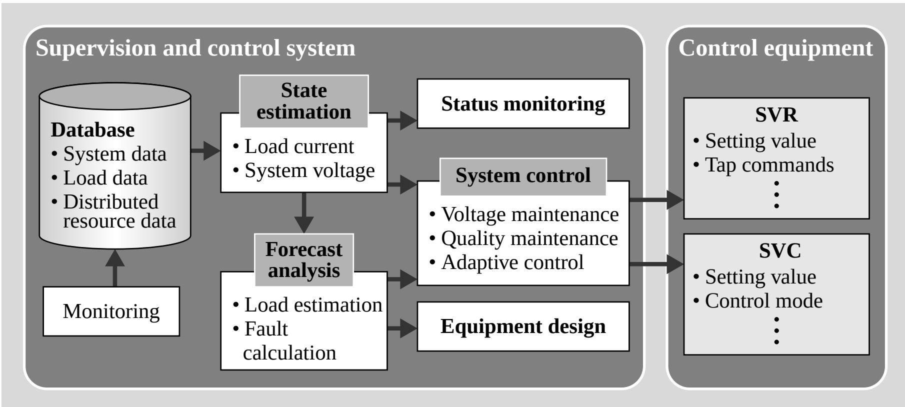


Fig. 2—Concept behind Voltage and Var Control System for Distribution Network.
Instructions are given to system control devices such as SVRs by means of system-monitoring, status-estimation, forecasting analysis, and system-control technologies, and voltage of systems is maintained properly.

distribution system and independently connected, multiple distributed resources and customer demand are bundled together to form a connected structure called a "mirogrid." In the case that distributed resources are each set up independently and connected to power systems, the possibility of voltage rise and variation (due to reverse power flow to the system and power variation, respectively) arises. To attain stable operation of power systems, measures such as installing devices for maintaining power quality from distribution systems [such as an SVR (step-voltage regulator), and an SVC (static var compensator), which are operated in coordination] are needed. In contrast, as for microgrids, they have become an important technology for controlling the distributed resources and power-storage devices in such a way to prevent the above-mentioned problems occurring, thereby absorbing power fluctuations within the grid and maintaining a balance between supply and demand.

VOLTAGE AND VAR CONTROL TECHNOLOGIES FOR DISTRIBUTION SYSTEMS

The concept behind the supervision and control system—combining state estimation and prediction analysis—for power-distribution systems is shown in Fig. 2. First, setup information about systems, loads, and distributed resources and on-line monitoring information (such as voltage and current statuses) is used to estimate the current status of the distribution system. After that, change of state of the system is estimated by load-forecasting and assumed-fault calculations, and system devices like SVRs and SVCs are operated in an integrated manner in such a way as to maintain supply reliability and power quality.

Generally, in the case of distribution systems,

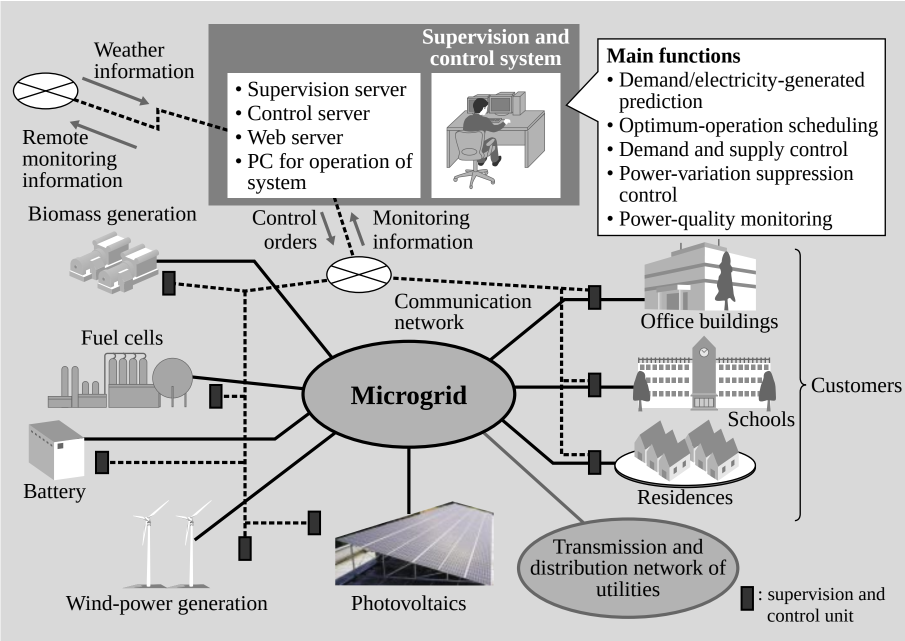


Fig. 3—Outline of Supervision and Control System for Microgrids.
A microgrid is a power-supply system connecting multiple customers with distributed resources in specific areas in the form of relatively small-scale power networks. By utilizing the supervision and control system, it is possible to operate and control microgrids in order to reduce environmental load and influence on power systems.

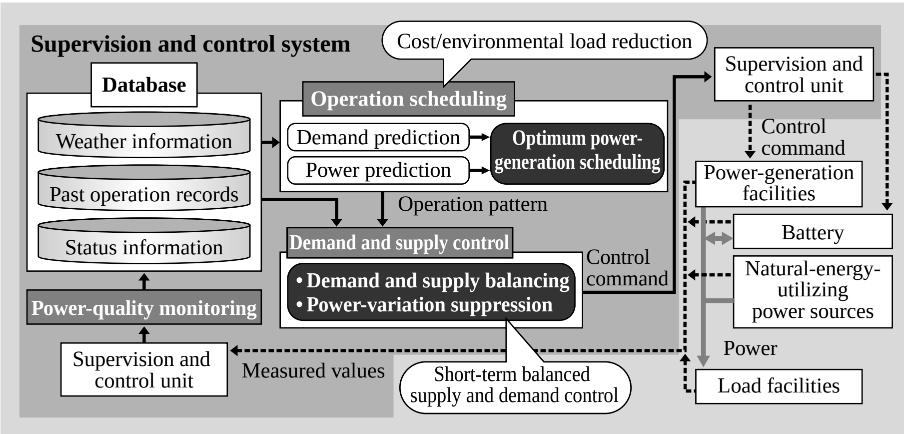


Fig. 4—Main Functions of Supervision and Control System for Microgrids.
The system is mainly composed of the following functions: database, operation scheduling, demand and supply control, and power-quality monitoring.

measurement data of voltage and current is insufficient, and information on the power load corresponding to customer demand is unclear. As regards the developed state-estimation method[1], by performing optimization calculation based on limited measurement data and load-power data, the number of setup sensors can be curtailed, and distribution-line number, load, current and voltage of distributed resources, and active power and reactive power can be estimated. The processing steps of the developed state-estimation method are explained below:
Step 1: Initial setup of system status; node voltage and line current are calculated from power flow of lines, load patterns, and electricity-generation pattern of distributed resources by means of power flow calculation.
Step 2: The difference in values for monitoring data and initial-setup data is estimated.
Step 3: Load and generated-power adjustment; power flow and voltage sensitivity for handing changes in load and generated power are used, and load and generated power are adjusted so as to minimize the difference obtained in step 2.
Step 4: System-state estimation; adjust the load and generated power, and estimate the system state using the power-flow calculation.

SUPERVISION AND CONTROL TECHNOLOGY FOR MICROGRIDS[2]

A schematic of the microgrid supervision and control system and its main functions are shown in Figs. 3 and 4. This system is composed of the following four main functions:
(1) a database for controlling and storing state-monitoring data of equipment and measurement data (such as power demand and generated output)

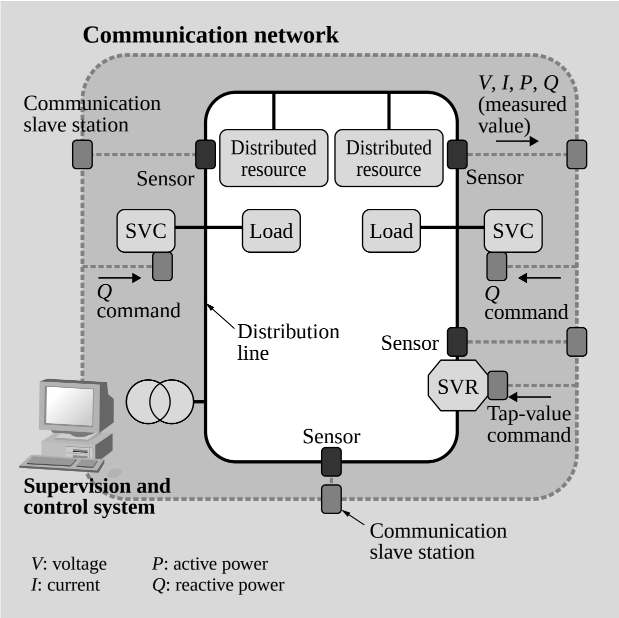
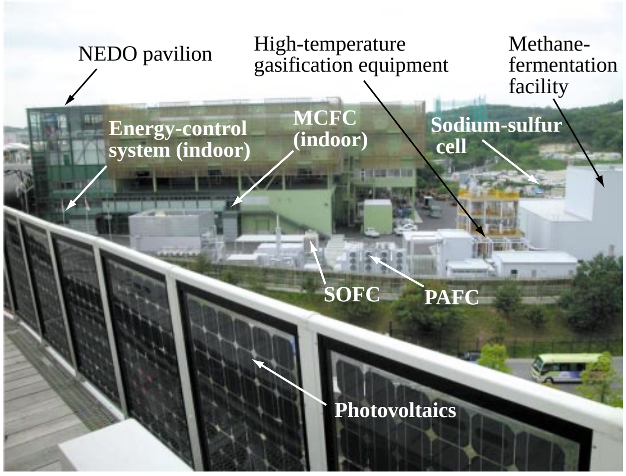


Fig. 5—Voltage and Var Control System for Demonstrative Project on New Electric Power Network System.
Measurement values from voltage and current sensors are sent to the primary station via optical-communication slave station. At the primary station, in addition to data monitoring, remote orders are given to the control devices (such as SVRs) via the communication slave station.



NEDO: New Energy and Industrial Technology Organization
MCFC: molten carbonate fuel cell
SOFC: solid oxide fuel cell
PAFC: phosphoric acid fuel cell

Fig. 6—NEDO-partnership New Energy Plant at EXPO 2005 AICHI JAPAN.
Functions for power-generation scheduling and power-quality measurement were applied to energy control systems.

transmitted from supervision and control units installed at load and power-generation equipment
(2) an operation-scheduling function for making operation schedule for distributed resources
(3) a supply-and-demand control function for controlling the balance between power demand and output generated
(4) a function for power-quality monitoring

Utilizing predictions of generated power amount of distributed resources and demand amount, the operation-scheduling function can create optimized plans operation to meet targets such as operating costs and CO_2 emission reduction. Moreover, by taking into consideration the prediction error in demand amount and generated amount as well as power fluctuation in distributed resources utilizing natural energy, this function can automatically determine the power purchased from power utilities.

The supply-and-demand control function enables control for containing the difference in demand-power amount and generated-power amount (in terms of unit-time) within a specified range and control for suppression of power fluctuation in the range of several seconds. Another characteristic point of this function is that it realizes high load-following capability by a combination of short-term demand prediction using a neural network method and accumulated-error correction in supply-and-demand balancing[(2)].

APPLICATIONS

The above-described technology has been applied to supervision and control systems developed for demonstrative project of New Energy and Industrial Technology Development Organization (NEDO). As regards supervision and control of distribution systems, as part of "Demonstrative Project on New Electric Power Network Systems," the developed supervision and control of system has been implemented at the Akagi Testing Center of the Central Research Institute of Electric Power Industry (CRIEPI). In regard to this implementation, the aim was to develop and demonstrate a system for coordinating multiple voltage-control devices and performing optimum voltage control of a distribution system (see Fig. 5).

As for microgrids, a request was received from NTT FACILITIES, INC., and an operation-scheduling system and power-quality measurement and evaluation system—aimed at the "Demonstrative Project of Regional Power Grids with Various New Energies" by NEDO—were constructed. In regard to the demonstrative project with these systems, in the site of the Expo 2005 AICHI JAPAN, photovoltaics, various fuel-cells, and sodium-sulfur cells were set up, and tests aimed at development and validation of new energy-supply systems combining new energy sources were carried out (see Fig. 6).

CONCLUSIONS

The characteristics of next-generation power-supply systems aimed at coexistence with distributed resources and distribution systems, supervision and control system for distribution system, and voltage and var control system for microgrids were described, and examples of their applications were presented. Aiming to support expanded utilization of distributed resources, thereby contributing to reducing environmental load and improving energy-utilization efficiency, Hitachi, from now onwards, will continue to develop supervision and control technology for distribution systems and operation and control technology aimed at practical application of microgrids.

ACKNOWLEDGMENTS

We would like to express our gratitude to the members of the Central Research Institute of Electric Power Industry (CRIEPI) and NTT FACILITIES, INC. for their valuable guidance in developing these super vision and control systems.

REFERENCES

(1) M. Watanabe et al., “Development of State Estimation Method for Distribution System Using Limited Observed Value,” The Papers of Technical Meeting on Power Engineering and Power Systems Engineering, IEE Japan, PE-04-91, PSE-04-91 (2004).

(2) Y. Ono et al., “Short-term Balanced Supply and Demand Control System for Microgrids,” *HITACHI REVIEW* **54**, No. 3 (Oct. 2005).

ABOUT THE AUTHORS

Noriyuki Uchiyama

Joined Hitachi, Ltd. in 1990 and now works at the Power Transmission & Delivery Systems Project, the Power & Industrial Systems R&D Laboratory, the Power Systems. He is currently engaged in the research and development on control systems of distributed generators interconnected with electric power systems. Mr. Uchiyama is a member of The Institute of Electrical Engineers of Japan (IEEJ).

Tomoharu Nakamura

Joined Hitachi, Ltd. in 1978 and now works at the Power & Industrial Systems Division, the Power Systems. He is currently engaged in the planning of solutions for operation and control systems of distributed resources. Mr. Nakamura is a member of the IEEJ, the Institute of Electrical and Electronics Engineers, Inc. (IEEE).

Yasunori Ono

Joined Hitachi, Ltd. in 1979 and now works at the Power Transmission & Delivery Systems Project, the Power & Industrial Systems R&D Laboratory, the Power Systems. He is currently engaged in the research and development on operation and control systems of distributed resources. Mr. Ono is a member of IEEJ.

Masahiro Watanabe

Joined Hitachi, Ltd. in 1991 and now works at the Power Systems Control Unit, the Second Department of Systems Research, Hitachi Research Laboratory. He is currently engaged in the research and development of analysis and control systems for distribution systems. Mr. Watanabe is a member of IEEJ and IEEE.