Next-generation SCADA/EMS Designed for Large Penetration of Renewable Energy

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OVERVIEW: The penetration of renewable energy is on the rise worldwide. When interconnecting renewable energy sources with grids, various problems in rotor angle stability and voltage stability could occur. As penetration of renewable energy becomes increasingly larger in energy sources, the potential for grid instability that leads to major power outages increases, creating a need for heightened awareness among SCADA/EMS operators. Phasor measurement units are gaining attention as a technology that can provide operators with the situation awareness they need. Hitachi is developing grid status monitoring technology using phasor measurement units, and working on initiatives related to this technology in markets throughout the world.*

INTRODUCTION

RENEWABLE energy sources have recently been growing in penetration throughout the world, but the output of renewables such as wind and photovoltaic power may fluctuate due to changing weather conditions. Besides, phenomena such as lightning strike can result in instantaneous voltage drops, causing renewables to trip out. And both renewable and non-renewable energy sources are always subject to the risk of major power outages caused by events such as grid failures. To ensure power grid stability, these problems need to be identified and prepared for in advance.

This article describes the work Hitachi is doing in markets throughout the world to promote grid status monitoring technology using phasor measurement units (PMUs).

PROBLEMS AND SOLUTIONS RELATED TO LARGE PENETRATION OF RENEWABLE ENERGY AND GRID FAILURES

This section discusses problems and solutions related to the large penetration of renewable energy, in areas such as rotor angle stability, voltage stability, and major power outages caused by grid failures.

(1) Problems with rotor angle stability when adopting renewable energy sources

Rotor angle stability is a measure of how well operating synchronous generators can continue to maintain stable operation without stepping out when a disturbance in the power grid occurs such as a transmission line failure. The inertia of conventional thermal power generators makes them highly proficient at restoring their original synchronous state after a grid failure occurs (strong synchronizing power). But wind and photovoltaic power generators are generally interconnected and via inverters therefore lack synchronizing power. Increasing the proportion of wind or photovoltaic power sources and decreasing the proportion of thermal power makes the power grid unstable due to this loss of ability to maintain synchronization.

(2) Problems with voltage stability when adopting renewable energy sources

Conventional thermal power generators operate with stable output and enable appropriate control of reactive power, so they help keep the grid voltage within the appropriate range. But since renewable energy sources can have their output affected by weather conditions, they are less stable than thermal power sources. If energy providers prioritize output of active power to maximize power generation and not provide reactive power, grid voltage maintenance will be adversely affected.

Possible measure for these problems is to maintain grid voltages and inhibit voltage fluctuations during accidents by controlling reactive power with flexible alternating current transmission system (FACTS) devices such as static var compensators (SVCs) and static synchronous compensators (STATCOMs). But the problem of who should be responsible for implementing these methods remains.

* EMS: energy management system

TABLE 1. Major power outages throughout the world

There have been successions of wide area major power outages in both the developed and emerging economies. There has been recent discussion on whether to incorporate economic losses from power outages into power costs.

Date	Area affected	Accident statistics	Description
August 14, 2003	Northeastern USA	Power lost: 61.8 million kW Affected area: Eight U.S. states and one Canadian province Affected users: About 50 million Total damage: 4 to 10 billion U.S. dollars	Tree contact caused a transmission line shutdown that cascaded into a wide area power outage.
September 28, 2003	Italy	Power lost: 27.7 million kW Affected area: All of Italy except Sardinia	Tree contact caused shutdown of an interconnecting line with Switzerland.
November 4, 2006	Europe	Power lost: 17 million kW Affected area: Eleven countries including Germany, France, Belgium, Italy, Austria and Spain Affected users: About 10 million	A transmission line safety shutdown to enable safe passage of a ship caused an overload shutoff in the German-controlled zone.
February 26, 2008	USA	Power lost: About 3.4 million kW (lost generation capacity) Affected area: Southern Florida Affected users: About 580,000	Fires caused shutdowns of nuclear and thermal power plants.
November 10, 2009	Brazil Paraguay	Affected area: Eighteen Brazilian states and all of Paraguay Affected users: About 67 million	Transmission equipment short-circuit accident
September 8, 2011	USA Mexico	Affected area: California, Arizona and part of Mexico Affected users: About 5 million	Substation work error
September 15, 2011	Korea	Affected area: Seoul and other areas Affected users: About 4 million	Manual overload restriction caused by poor demand forecast
September 24, 2011	Chile	Affected area: Wide area including Santiago Affected users: About 10 million	Transmission equipment failure
July 30 and 31, 2012	India	Affected area: Northern, eastern and northeastern India Affected users: Over 600 million	An accident occurred in a transmission line linking the north and west of the country, and subsequently cascaded into a wide area event.

(3) Problems occurring during major power outages

Many large power outages have occurred recently throughout the world (see Table 1). One of the largest was a failure in the northeastern part of the USA in 2003. High-load operation combined with a line failure led to a power outage from a lengthy accident, lasting between 1 and 2 hours after the initial accident indications. Although it took nearly one hour for power transmission to stop, the problem was the inability to obtain detailed realtime monitoring.

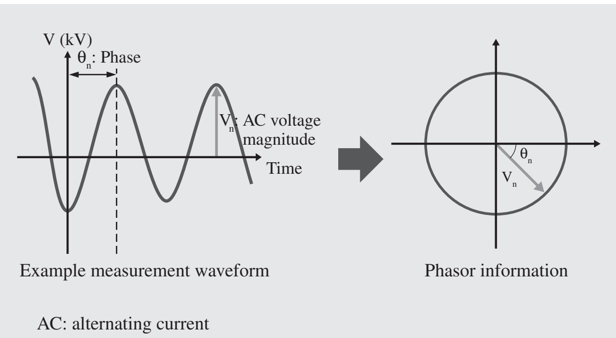

Fig. 1—Measurement waveform example and phasor information

Data is actually acquired as discrete values, but for simplicity is represented here as a waveform graph. The phasor information shown in this example diagram represents AC voltage magnitude and phase as a single vector.

Adopting wide area monitoring across multiple power companies and measurement systems enabling detailed realtime grid monitoring may provide effective solutions in the future to the problems discussed in Sections (1) through (3). There is a need to improve measurement systems, raise operator awareness and implement advance readiness measures to prevent grid instability and accidents. The use of wide area measurement systems (WAMSs) that use PMUs to enable more detailed monitoring has also been gaining global popularity recently.

GRID MONITORING/CONTROL SYSTEM TECHNOLOGIES

PMU-driven grid status monitoring

PMUs are devices that measure time-series measurement information (see Fig. 1) in realtime by appending absolute times obtained from global positioning system (GPS) data to power grid measurement information such as phase, voltage, and current.

Conventional grid status monitoring is done with a supervisory control and data acquisition (SCADA) system. But SCADA systems can only measure the magnitude of parameters such as voltage and current. It can’t measure phase directly, and requires separate data acquired from oscilloscope devices installed in substations to measure information needed to analyze

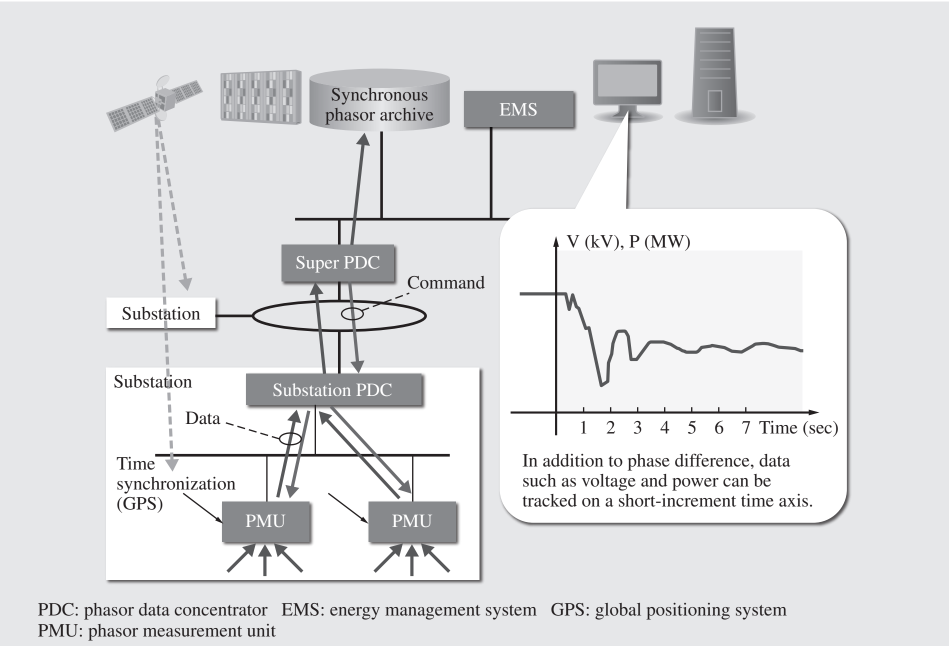

Fig. 2—PMU data transmission route
PMUs have a short measurement cycle, enabling measurements on a short-increment time axis. Measured information is compiled by a PDC.

transient phenomena. Monitoring grid status with a PMU and the transmission route shown in Fig. 2 enables online information measurement from the PMU, with information gathered in realtime as short-cycle, time-series waveform information. It enables instant tracking of power grid transient status, which is not measurable with conventional grid status monitoring systems.

Data gathered by PMUs has a short measurement cycle and is synchronized using absolute time. These advantages mean that even when an accident occurs, waveform information from multiple locations gathered at the time of the accident (caused by generator trip or a transmission line failure) can be used in detailed accident analysis to create prevention measures for future accidents. Table 2 compares grid status monitoring using SCADA systems and PMUs.

TABLE 2. Comparison of SCADA systems and PMUs
PMUs can have a shorter data-gathering cycle than SCADA systems, and can measure phase.

	SCADA systems	PMUs
Sampling cycle	2 to 4 seconds per snapshots	10 to 60 snapshots per second
Measurement items	Magnitudes of parameters such as voltage and power flow	Magnitudes of parameters such as voltage and power flow; phase
Ensuring data synchronization	Not possible	Possible (using absolute time)
Scope of use	Local operating area	Wide area extending beyond local operating area

SCADA: supervisory control and data acquisition

PMUs are becoming increasingly popular worldwide. North America and India have already created PMU measurement infrastructure and installed WAMSs[(1), (2)] (see Fig. 3 and 4).

Use of PMU measurement information

The advantages of PMUs give PMU measurement information a variety of applications. Hitachi initiatives that make use of PMU measurement information are described below.

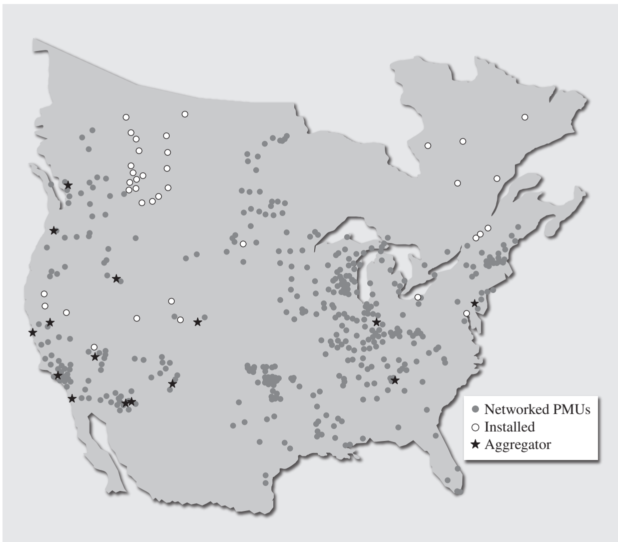

Fig. 3—PMU installation in North America (2012)
Five hundred PMUs had been installed in North America in 2012, and the figure is expected to reach about 1,000 by the end of 2014.

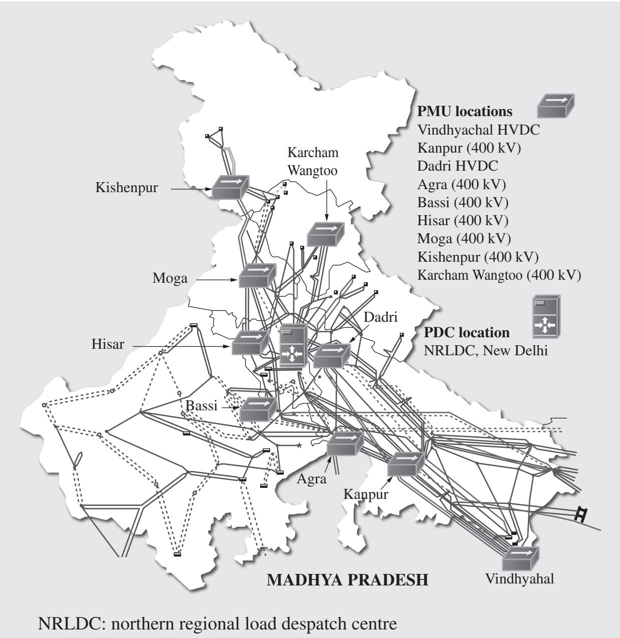

Fig. 4—PMU installation in northern India (2012)
PMUs have been installed in nine substations near large-output generators, scattered over several areas.

(1) Grid status monitoring

Power grid transmission lines must be operated within their total transfer capability (TTC) limits. Using PMU measurement information to monitor phase, voltage stability, frequency and power flow in realtime enables the current grid status to be viewed in detail and can assist transmission line operation.

(2) Wide area grid monitoring

PMUs enable easy measurement of information from wide areas spanning multiple operating areas, enabling tracking of status changes in external grids.

(3) Oscillation monitoring

Since short-cycle waveform information can be visualized in realtime, oscillations difficult to track with conventional systems can be monitored and reported to operators.

(4) Failure analysis

Analysis of waveform information when external disturbances such as grid failures occur enables visual display of accident phenomena and rapid feedback into preventive measures.

(5) State estimation precision improvement

Measurement data can be acquired from multiple measurement points without time lags, and phase data not measurable by SCADA systems can be measured, enabling state estimation with greater precision.

(6) Comparative verification of power grid models

Actual data can be compared and verified against existing power grid models used in analysis tools. This enables parameter adjustments for correction of analysis tool simulation results.

Although hardware for monitoring power flow and voltage is needed when the application is preventing overloading or maintaining grid voltage, PMUs are extremely effective since they enable short-cycle measurement. PMUs also enable actual phase measurement and data measurement ensuring synchronization, so they support high-precision state estimation.

For the future, the use of PMUs for more detailed monitoring will enable power grids to support large penetration of renewable energy sources. But although PMU-driven grid monitoring technology is on the rise worldwide, the only application that PMUs are currently being used for is grid status monitoring. Hitachi is planning to build on this status monitoring application with work on supervisory control applications that make effective use of PMU measurement information.

WORK IN GLOBAL MARKETS

Hitachi is working on multiple projects in markets throughout the world, in locations such as the USA, Europe and Asia.

For example, Hitachi is part of a joint research project titled “Research into Grid Stabilization Systems to promote widespread adoption of renewable energy.” The project is part of the FY 2013 Technology Innovation R&D program initiated by the Bonneville Power Administration of the U.S. Department of Energy. The project’s aim is to improve power quality by dynamically tracking and controlling the power flow of electricity. The project also aims to create an integrated grid stabilization system designed to popularize and make effective use of renewable energy by using data from PMUs, which are now widespread in the US. Anticipating the widespread use of renewable energy from sources prone to fluctuating output such as wind and photovoltaic generation, Hitachi plans to use the results of this research to create power transmission systems supporting renewable energy.

CONCLUSIONS

This article has presented PMU-driven grid status monitoring technology. It is used as grid monitoring/control system technology enabling solutions to various problems in power grids with large penetration of renewable energy.

The grid status monitoring systems described here enable realtime visual status displays, and make it possible to create advance readiness measures to prevent grid instability and accidents. In the years ahead, effective use of measurement information will result in technology leading to more advanced grid control.

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