Power System Stability Solutions for Low-carbon Society

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OVERVIEW: As greater use is made of distributed power sources, how to deal with issues such as frequency and voltage fluctuations, fault response, and excess electric power will become increasingly important considerations for the power grid of the future. Hitachi supplies grid control systems that utilize adjustable-speed pumped-storage generation systems, online transient stability control systems, FACTS equipment, and power storage systems to provide solutions for grid stability that are effective for resolving these issues.

INTRODUCTION

THE introduction of large amounts of wind, solar, and other forms of distributed power generation is one of the measures being considered to help create a low-carbon society. Overseas, particularly in Europe, wind farms consisting of large numbers of wind turbine generators have been installed. In Japan, in addition to wind power, it is also anticipated that the future will see vigorous progress on photovoltaic (solar) power installation. The government has set targets for photovoltaic power generation capacity equivalent to 28 GW in 2020 and 53 GW in 2030 to help reduce CO_2 (carbon dioxide) emissions.

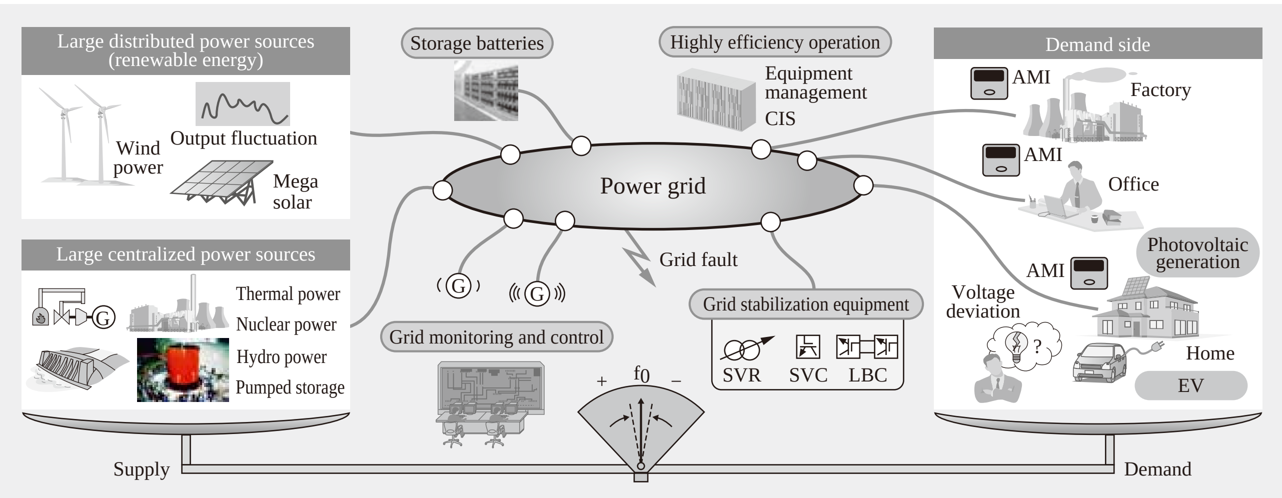
Because the output of wind and photovoltaic power generation is strongly influenced by weather conditions, power grids to which distributed power sources are connected experience larger voltage, frequency, and other fluctuations. They are also at risk of problems such as more complex fault recovery and instabilities caused by large numbers of distributed power sources dropping out when transient voltage drops occur due to lightning strikes or other events.

To counter these instabilities, it is anticipated that various types of transient stability control system will need to be installed.

This article describes power grid stabilization solutions being developed by Hitachi.

LIKELY RISKS FOR FUTURE ELECTRIC POWER GRIDS

In addition to large-scale centralized power sources such as thermal, hydro, and nuclear power plants, it is anticipated that power grids in the future will also connect large distributed power sources such as wind



SVR: step voltage regulator SVC: static var compensator LBC: loop balance controller EV: electric vehicle CIS: customer information system
AMI: advanced metering infrastructure G: generator f: frequency

Fig. 1—Overview of Next Generation of Power Grid Systems.
Because greater use of distributed power sources and EVs will increase the variation in power flow across the grid, appropriate grid operation will be needed to maintain its stability.

farms and mega-solar while on the user side small-scale solar panels installed on household roofs and EVs (electric vehicles) will also become more common (see Fig. 1).

This grid of the future will not only face variations in the output of large distributed power sources such as wind farms and mega-solar installations as they are influenced by changing weather conditions, it will also be subject to output variations from small distributed power sources installed in homes and increasing regional load variations due to changes in things like the timing or location of EV recharging. This will result in unanticipated power flows occurring on the grid which risks causing the various problems described below.

Two other articles in this issue entitled “Convergence of Advanced Information and Control Technology in Advanced Metering Infrastructure (AMI) Solution” and “Next-generation SCADA and Control Technologies for Large-scale Use of Photovoltaic Generation on Electric Power Grid” cover measures for dealing with the problem of voltage fluctuations on power distribution systems caused by distributed power sources and describe AMI (advanced metering infrastructure), a remote automatic meter reading system that uses bidirectional communications.

Loss of Generation Efficiency and Inadequate Frequency Regulation Capacity

In the past, power systems were operated by forecasting electric power demand through the day and ensuring that sufficient frequency regulation capacity was available to prevent the generated power from being insufficient. An optimum schedule was determined for the startup and shutdown times of generators that combined thermal power generators, pumped-storage power plants, and other systems in a way that minimized costs such as fuel and losses in transmission lines. In the future, however, it is likely that wider use of distributed power sources will result in large variations in power demands depending on differences between the actual and forecast weather. This brings a risk that power generation efficiency will drop if the way in which frequency regulation is performed involves making rapid changes in thermal generator output or urgent startup or shutdown in response to these variations.

Voltage Fluctuation

Because it is anticipated that most photovoltaic power generation in Japan will be for home use, the power distribution system will require voltage fluctuation countermeasures located close to homes. Currently, the grid voltage is maintained by switching between transformer taps to regulate the voltage at the transformers located in substations and on power poles. As greater use is made of home photovoltaic power in the future, however, voltage regulation is likely to become more difficult as excess power not consumed within the home flows back into the power grid causing the grid voltage to rise.

Large-scale Blackout Due to Cascading of Faults

When events such as lightning strikes occur on the grid, protective relays and circuit breakers are triggered to isolate the fault from the rest of the grid quickly. In the event of a major fault, further measures such as shedding of generators or loads are used to prevent cascading faults.

If photovoltaic power generation becomes widespread, there will be a high likelihood of shutdowns in power generation equipment due to transient voltage drops caused by lightning strikes or other incidents and this may trigger further problems including instability (loss of synchronism) in the operation of existing large-scale generators, fluctuations in the grid frequency, and large rises or falls in the grid voltage. The risk is that this may lead to blackout over wide areas.

There is also a risk that local imbalances in power demand due to changes in local weather conditions will increase in frequency making it more likely that incidents will occur in which lightning strikes or other grid faults cause overloads on transmission lines, transformers, or other equipment in locations where they are not expected leading to wide-area blackout. As described below, these problems are already emerging in Europe because of its extensive use of wind power.

CASE STUDIES

German Case Study

An incident occurred in Germany in November 2006 in which an overload in a transmission line caused by human error resulted in the eastern and western areas of the European grid being disconnected from each other as the fault spread over a wide area. A feature of this incident was that the recovery was slowed by the effect of wind power generation. Because generation capacity exceeds demand in eastern areas, the splitting of the grid caused the grid frequency to rise, shutting down many wind generators. To recover from the fault, the frequencies of both the eastern and western areas of the grid were brought close to the rated frequency so that the lines linking the areas could be connected. The outputs of thermal generators were adjusted to start restoring the grid frequency to its rated value, but as the eastern grid was brought back toward its rated frequency the shut-down wind generators started coming online again and the resulting increase in generation capacity caused the frequency of the eastern grid to rise once more, impeding the task of connecting the lines between the eastern and western grids.

Spanish Case Study

Spain has installed significant wind power generation capacity and this has caused problems with large numbers of wind generators shutting down at the same time due to transient voltage drops caused by lightning strikes or other faults. The risk when this happens is that the resulting rise in Spanish demand will cause the power flow through the link to the French grid to exceed its capacity, triggering protection relays and disconnecting Spain from the rest of the grid.

In response to this problem, the Control Centre of Renewable Energies (CECRE) was established to monitor the status of wind farms with capacities of 10 MW or more. The CECRE performs preventive control to regulate the output of distributed power sources by simulating the effects of transient voltage drops caused by grid faults to determine how much wind generation capacity to shut down.

GRID STABILIZATION SOLUTIONS

A number of different measures can be used to prevent instability in the electric power grid caused by the uncertain behavior of distributed power sources.

Adjustable-speed pumped storage, which can rapidly absorb or supply electric power over comparatively long periods of time, provides an effective way of suppressing frequency fluctuations. For maintaining stability during grid faults or other transient incidents, large high-density storage batteries, as well as flywheels and superconductor energy storage systems are considered to be effective because they can supply electric power immediately even if only for short periods of time. Large-capacity batteries and pumped-storage power generation systems are also useful for absorbing excess power from distributed power sources.

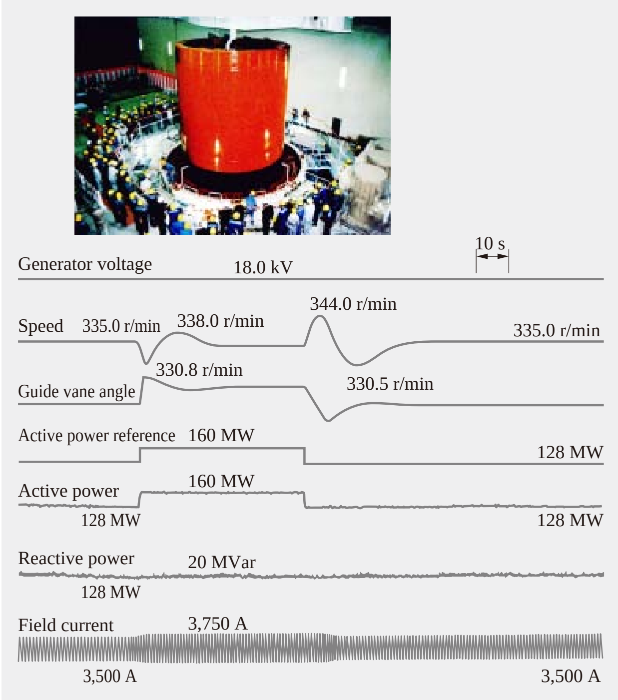


Fig. 2—Adjustable-speed Pumped-storage Generation System Supplied to Okawachi Power Plant of The Kansai Electric Power Co., Inc.
Increasing the desired (reference) level of active power causes flywheel energy to be released resulting in a rapid increase in the actual active power.

Adjustable-speed Pumped-storage Power Generation System

Adjustable-speed pumped-storage power plants use generators that are able to vary their power levels rapidly and it is anticipated that they will provide an effective way of suppressing grid frequency fluctuations caused by variations in the output of distributed power sources. Hitachi has demonstrated that a practical adjustable-speed pumped-storage generator can rapidly vary its active power output by using a technique called active-power-based control to absorb and release flywheel energy[(1), (2)]. It is anticipated that this technology will have major benefits for keeping the frequency stable during grid faults because it can provide active power rapidly in response to the sudden rise in demand that might occur when home photovoltaic power generation systems drop out all at once in response to a lightning strike or other incident causing a voltage drop on distribution lines (see Fig. 2).

Online Transient Stability Control System

Recent years have seen a series of large-scale blackout occurring in different parts of the world that were triggered by grid faults and involved disturbances spreading across the entire power grid. A 1965 grid fault in Japan provided the impetus for research and development of grid stabilization techniques aimed at preventing major blackout and this has contributed to the high level of supply security the country now enjoys.

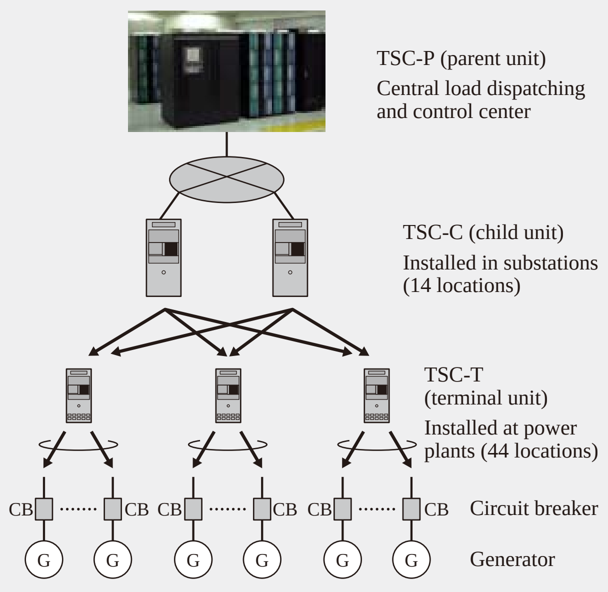
A system for maintaining grid stability called the online TSC (transient stability control) system is now in commercial operation and is a typical example of a transient stability control system that uses the latest IT (information technology). A system using the latest blade servers for control applications called TSC-P (parent) units commenced operation in 2009[3] (see Fig. 3).

This system produces a grid model that accurately reflects the state of the grid at 30-s intervals in the TSC-P units installed at the central load dispatching and control center. It then calculates the level of stability for the case when a lightning strike or other grid fault occurs, determines what measures to take to restore stability in response to a fault that destabilizes the grid (such as shedding of generators), and transmits this information to the TSC-C (child) units located in substations every 30 s. If an actual grid fault occurs, the TSC-C units and TSC-T (terminal) units perform stabilization control in realtime.

Because the online transient stability control system can determine the status of the grid at 30-s intervals, it is believed that this will allow more flexible stabilization measures to be provided in the future even if increased use of distributed power sources means various different types of unanticipated power flow occur. To ensure appropriate countermeasures against the disturbances after an actual fault occurs, Hitachi is also working on developing the ISC (integrated stability control) system which combines advance predictive control based on the online stability calculation with corrective control based on the actual situation on the grid after a fault occurs[4].

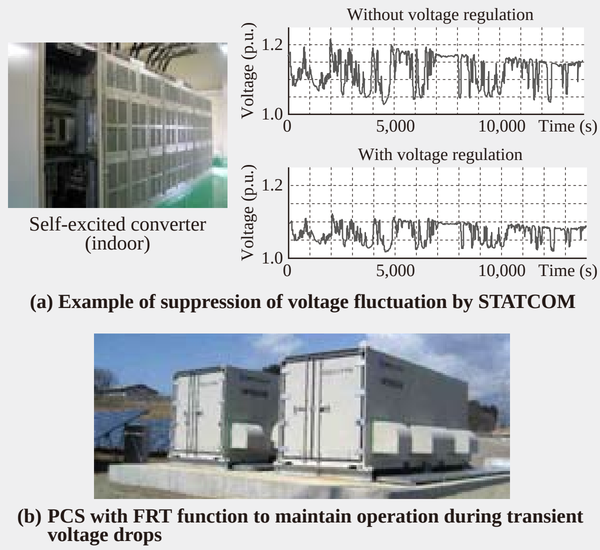
FACTS Equipment

Hitachi is developing a range of FACTS (flexible alternating current transmission system) equipment that utilizes power electronics to improve grid stability, suppress voltage fluctuations, and otherwise improve the quality of electric power. Typical examples include a STATCOM (static synchronous compensator) with a high degree of tolerance to grid disturbances



TSC: transient stability control CB: circuit breaker

Fig. 3—Online Transient Stability Control System Supplied to Chubu Electric Power Co., Inc.
The TSC-P parent unit collects grid data at 30-s intervals, performs stability calculations based on about 100 potential grid faults, and determines what countermeasures to use. In the event of an actual grid fault, the TSC-C units and TSC-T units act to maintain stability by shedding generators within 150 ms after the fault occurring.



Results of “Verification of Grid Stabilization with Large-scale PV Power Generation” run by the New Energy and Industrial Technology Development Organization (NEDO).

p.u.: per unit STATCOM: static synchronous compensator
PCS: power conditioning system FRT: fault ride through
PV: photovoltaic

Fig. 4—Products that Use Power Electronics.
These systems are used in applications such as AC (alternating current) converters for distributed power sources and reactive power voltage control for the electric power grid.

that uses high-speed IGBTs (insulated-gate bipolar transistors) and a PCS (power conditioning system) AC (alternating current) conversion system with an FRT (fault ride-through) function that can keep large distributed power sources operating through transient voltage drops[5] (see Fig. 4). These demonstrate how power electronics technology can be used to enhance grid stability.

Grid Control Systems that Use Electric Power Storage

Investigations are being conducted into the use of electric power storage devices such as batteries to absorb excess power generation and regulate voltage, frequency, and other fluctuations caused by variation in the output of distributed power sources. Hitachi has already commercialized a system for smoothing the output of wind power generation that uses long-life lead-acid batteries[6]. Hitachi is now utilizing this technology to develop high-density lithium-ion batteries and research and development is also in progress aimed at commercializing techniques such as how to control battery charging and discharging so that it can be used for grid stabilization.

One example of a future grid control technique is to treat the grid as a hierarchical collection of small cells of demand. This approach uses storage batteries to compensate for the difference between the total load in a demand cell and the output of the distributed power sources in that cell and autonomously controls the power flow through the point of connection to the higher level grid (see Fig. 5).

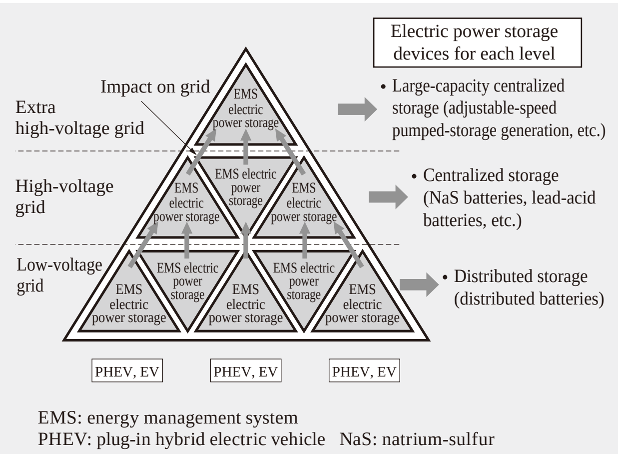


Fig. 5—Concept of Electric Power Storage for Future Grid.
The concept is to maintain stability and power quality for the entire grid by utilizing storage batteries to localize the influence of photovoltaic power and EVs within each demand cell.

CONCLUSIONS

This article has described power grid stabilization solutions being developed by Hitachi.

The future widespread adoption of technologies like distributed power sources and EVs has the potential to create a variety of different grid problems. Hitachi is developing adjustable-speed pumped-storage generation systems, online transient stability control systems, FACTS equipment, and other products that it believes will provide effective solutions to these problems along with grid control systems that use electric power storage devices.

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