Power Stabilization Technologies for Next-generation Transmission and Distribution Networks

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OVERVIEW: It is anticipated that power generation systems that use renewable energy such as solar power generation systems and wind power generation systems will provide an alternative source of energy to fossil fuels although the dependence of these systems on weather conditions means that stabilization systems are necessary to cope with the variation in their power output. An expectation for the positive introduction of these systems has been institutionalized at the government level. Hitachi is conducting extensive work on the development of technologies for next-generation power distribution networks, power network connection technologies, and demand-and-supply balance control technologies. The objective of this work is to provide solutions to the problems that arise from the large-scale introduction of renewable energy systems.

INTRODUCTION

INTEREST in power generating systems that use renewable energy such as wind power generation systems and solar power generation systems has risen because of concerns about negative impacts on the environment and dependency on fossil fuel. It is anticipated that a large amount of renewable energy will be introduced all over the world. For example, the Ministry of Economy, Trade and Industry of Japan has established an Advisory Committee for Natural Resources and Energy and Renewable Energy Departmental Meeting and has set a target of raising

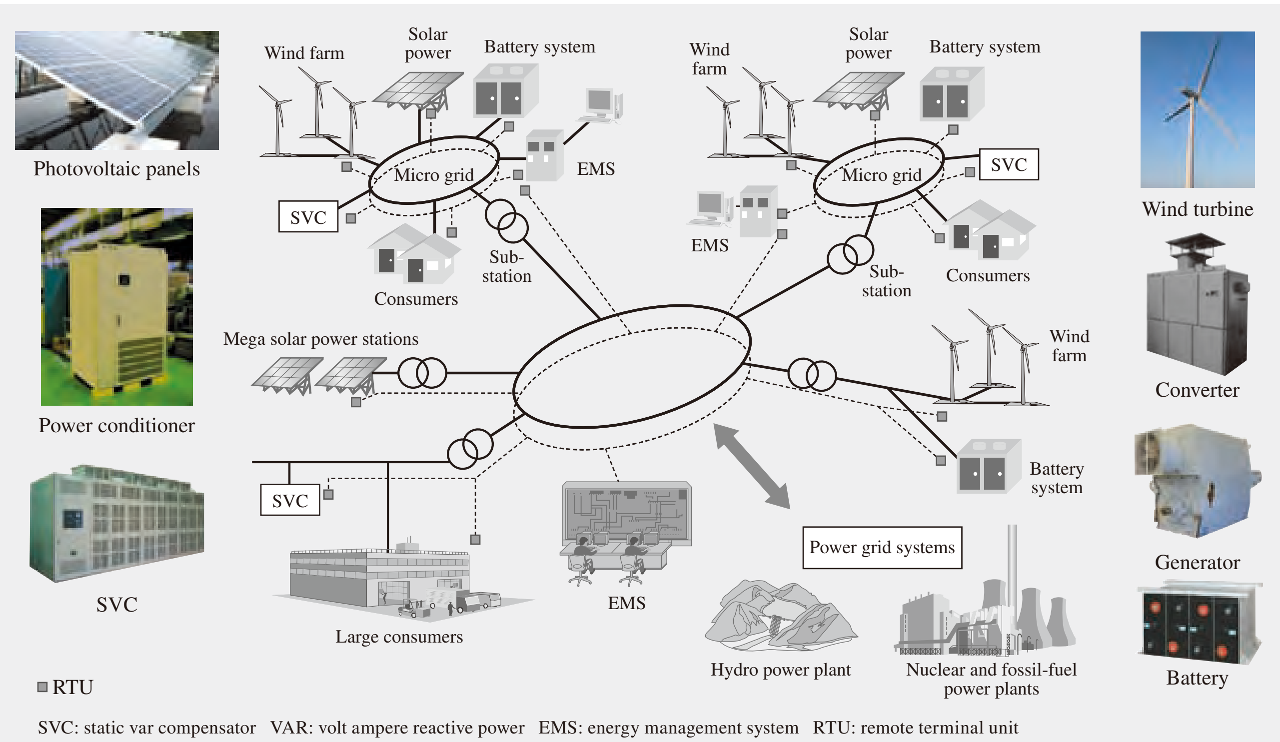

Fig. 1—Use of IT (information technology) Networks in Energy Management System for Electricity Grid.
High-quality electric power can be provided by using a local EMS to collect status information from a micro grid that may include renewable energy systems, battery storage systems, SVCs, and so on via RTUs and by transmitting supply-demand balancing instructions to each equipment.

the proportion of renewable energy in the primary energy supply in 2010 to 3%. In Europe, the European Renewable Energy Council (EREC) has published a roadmap in which it states its objective of increasing the amount of power generated by renewable energy in the European Union (EU) in 2020 to 20% of EU power demand in March 2008. The US government has announced its National RPS (Renewable Portfolio Standard) which sets the target for the amount of power generated by renewable energy in 2025 at 25% of total demand. Hitachi has been developing renewable energy system stabilization technologies, electric power systems, electric power infrastructure technologies, and telecommunications system technologies for more than several decades, and has a technology advantage over other businesses in this field.

This article describes the problems associated with the large-scale introduction of renewable energy systems, and the technologies that can solve these problems and enable these systems to be connected to the grid.

PROBLEMS ASSOCIATED WITH THE LARGE-SCALE INTRODUCTION OF RENEWABLE ENERGY SYSTEMS

Because, until a few years ago, the amount of renewable energy generation capacity connected to the power grid was relatively small compared with the total capacity, its influence on the grid was limited. Recently, however, large wind farms of several hundred megawatts have been installed in the EU and North America and approval has been granted for solar power systems of similar scale, meaning that these systems are now sufficiently large enough that their influence cannot be disregarded. A problem with systems that generate power using renewable energy is that, because their output varies greatly depending on the weather conditions and because they tend to be located a long way from load centers, they can cause the whole power grid system to become unstable in proportion to their installed capacity. For example, if lightning or some other event results in a grounding fault on a transmission line causing the grid voltage to drop, the conventional protection systems used in renewable power generation systems will cause them to disconnect all at once. This reduces the stability of the grid and leads to problems such as blackouts. To prevent such phenomena, various countries are establishing codes of practice for FRT (fault ride through) that regulate how systems are to disconnect from the grid. Hitachi has developed technologies to deal with these problems that can be used in various different applications.

GRID CONNECTION TECHNOLOGY

Grid connection technologies that use IT (information technology) to balance power generation supply with load demand have attracted attention as a way of allowing the use of renewable energy systems while still maintaining grid stability. This will involve greater use of interconnections between the conventional and renewable generation systems in each region and in the near future will also integrate the grid infrastructure into the management system. Fig. 1 shows an example in which a high-quality electricity distribution system is implemented by an EMS (energy management system) that uses RTUs (remote terminal units) to collect status information from a micro grid that includes renewable energy systems, battery storage systems, SVCs [static VAR (volt ampere reactive power) compensators], and other equipment and by transmitting supply-demand balancing instructions to each equipment. The following sections describe technologies for leveling generation output and for grid connection systems that can help resolve the problems associated with connecting renewable energy systems to the grid.

Generation Leveling Control for Wind Farms

A number of wind farms have been installed recently that have a capacity in the range of several hundreds of megawatts. Whereas the output of a wind farm with only a small number of turbines is directly related to the weather conditions, the output from different turbines in wind farms in the several-hundred-megawatt range can differ considerably from each other because they are spread over a much wider area of land. Hitachi supplies a wind farm control

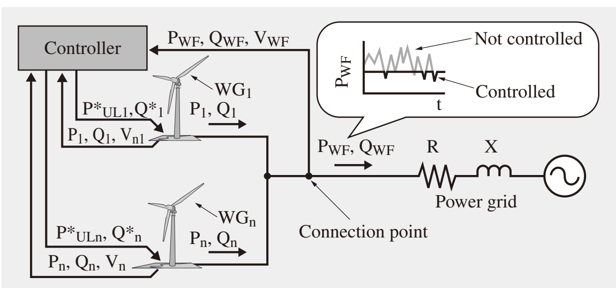

Fig. 2—Generation Leveling Control for Wind Farm.
The wind farm control method regulates the maximum output of each wind turbine by providing an upper limit reference value to each generator to stabilize the total output of the wind farm.

method that can stabilize the total output of a wind farm by setting an upper-limit reference value to each turbine to regulate its maximum output. Fig. 2 shows the proposed wind farm control concept[1]. The controller reads the real power (P_n, P_{WF}), reactive power (Q_n, Q_{WF}) and voltage (V_n, V_{WF}) at the point of connection for each WG_n (wind turbine generator) and sends back an upper-limit reference value (P^*_{ULi}). Under this control scheme, the total leveled output of the wind farm (P_{WF}) may never reach the sum of the outputs of each WG. The end result is to maintain a constant output from the wind farm. The voltage at the point where the wind farm connects to the grid (V_{WF}) is controlled by applying an appropriate reactive power setting (Q^*_n) based on the system impedance.

Leveling System Using Battery Storage

Despite the use of measures such as leveling control, there are times during sustained periods of low output when control-based measures alone are insufficient to keep the total output of the renewable energy system constant. Because they are easy to install and have no moving parts, battery-based power storage systems can assist with grid stabilization including frequency stabilization. Recent developments in battery technology mean that batteries have become available that have a sufficiently long life for use in large-scale storage systems and can sustain 3,000 to 4,000 charge/discharge cycles. However, such battery-based storage systems have not been used widely up to now because large systems are not economic. To reduce the cost, battery storage systems designed to level the output of a wind farm, for example, allow a margin within which the output is permitted to vary and which is set based on what the grid can cope with (see Fig. 3). Fig. 4 shows the output from a system that allows a margin of several percent of the rated power (2% for example) which is determined from historical trends.

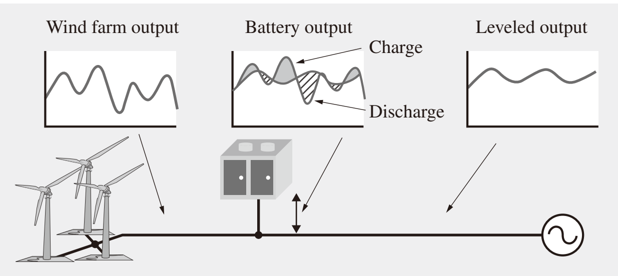

Fig. 3—Wind Farm and Battery Storage Systems.
The output of the wind farm is leveled by charging and discharging a battery storage system.

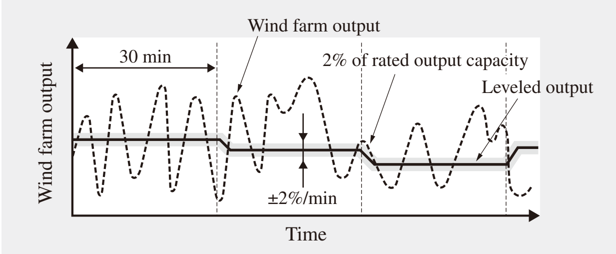

Fig. 4—Constant Output Achieved Using Battery Storage System.
The method controls the output to be within a 2% margin of the rated power, which is determined from historical trends, and keeps the output within this band over a 30-minute period.

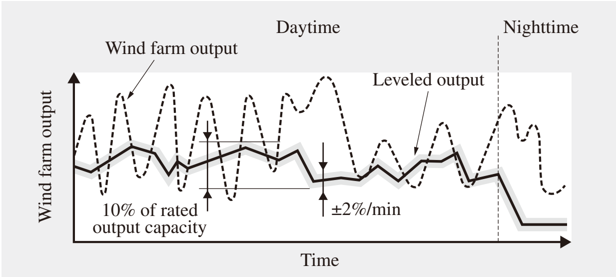

Fig. 5—Variation in Output Using Battery Storage System with Large LFC Margin.
If the grid's LFC (load frequency control) has sufficient margin for adjustment and some amount of variations in output band can be tolerated (about 10%) by smoothing the output fluctuation (dP/dt), the storage batteries of less capacity can be used to build a system.

The system keeps the output within this band for a specified period of time (30 min for example) based on the capacity of the batteries to absorb variations in output. If the grid's LFC (load frequency control) has sufficient margin for adjustment[2] and some amount of variations in output band can be tolerated (about 10%) by smoothing the output fluctuation (dP/dt), the storage batteries of less capacity can be used to build a system. The leveled output of the wind farm is shown in Fig. 5.

Continuity of Operation during Instantaneous Voltage Sags

If a grounding fault on a transmission line triggered by lightning or some other event causes voltage sag to occur across the grid, the protection systems used in renewable power generation systems may cause them to disconnect. To prevent such phenomena, various countries are establishing codes of practice[3], [4] such as for FRT that regulate how systems are to disconnect from the grid and stipulate the permitted voltage and frequency variations (see Fig. 6). In the past, regulations

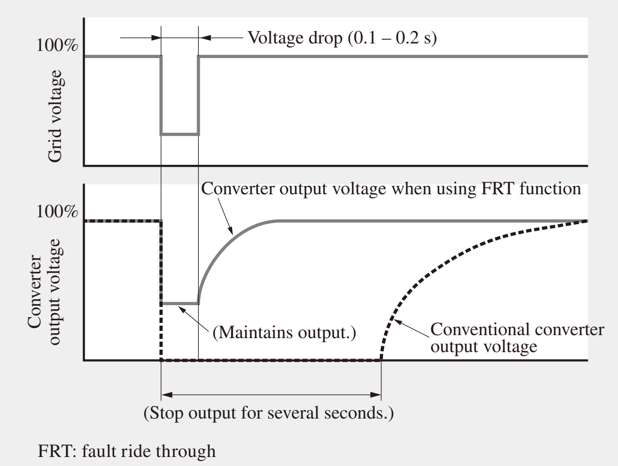

Fig. 6—Voltage Sag and Converter Operation Range.
The converter output waveforms when low voltage (voltage sag) is detected for the cases when the FRT function is and is not used.

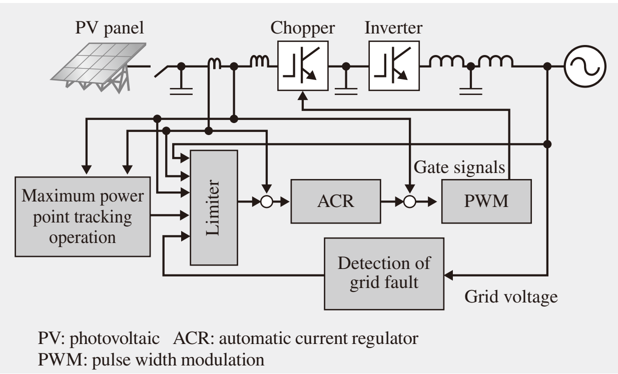

Fig. 7—Converter Control Block Diagram.
The converter controller detects the grid voltage and regulates the maximum power via a limiter.

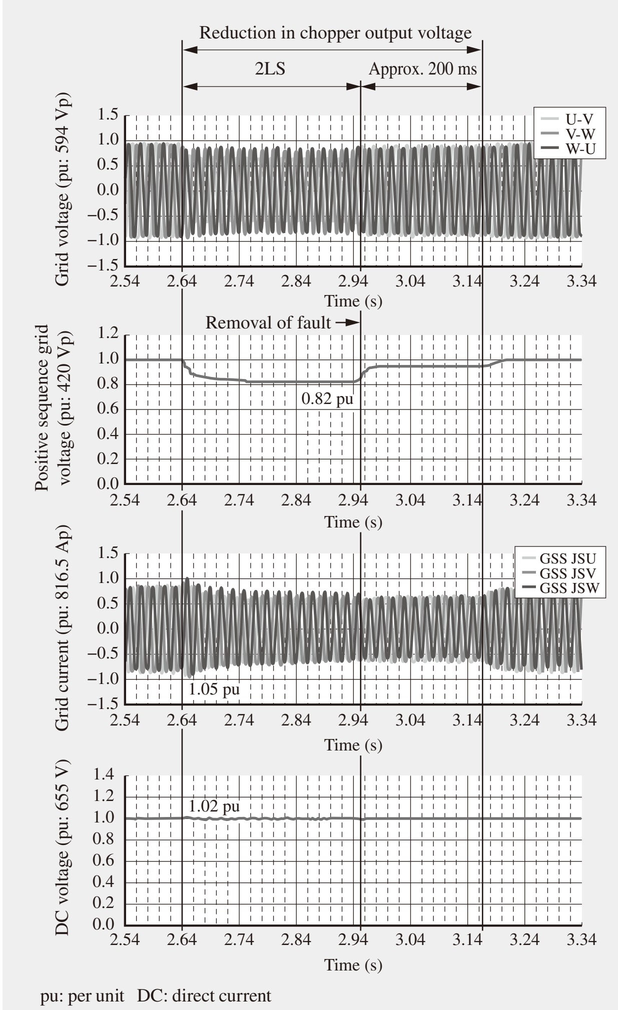

Fig. 8—Output Waveforms for Line-to-line Short Circuit.
The output waveforms for a line-to-line short circuit at a grid connection point are shown.

concerning voltage sag stipulated that the output was to be interrupted for a predetermined time after detecting the voltage sag, then restarted. In recent years, it is necessary to continue operation even when the voltage sags for 200 ms and to increase output proportionally to track the grid voltage. The power conditioners used in solar power systems require such a function. Fig. 7 shows a power conditioner control block that detects the grid voltage and regulates the output via limiters. Fig. 8 shows the output waveforms when a line-to-line short circuit occurs at the grid connection point. The figure shows that the positive sequence voltage at the connection point is 0.82 pu (per unit) and the output current remains continuous without overcurrent at the connection point. The figure also shows the output voltage tracking the recovering grid voltage for about 200 ms after the removal of the fault.

SVC

In the past, conventional wind generator systems used induction generators which were relatively small. Systems in this size range are still widely used for wind turbines in hard-to-access locations. The disadvantages of induction generators, however, are that they supply unnecessary reactive power to the grid and the level of this reactive power changes with output power which itself fluctuates with the wind strength. For these reasons, wind power generation systems require an SVC to stabilize the grid voltage at the connection point (see Fig. 9). SVCs are also used to improve the power quality on the grid in situations that include: (1) a large number of power generating systems that use renewable energy are connected to the grid, (2) the transmission capacity is small, or (3) the nearby load is variable.

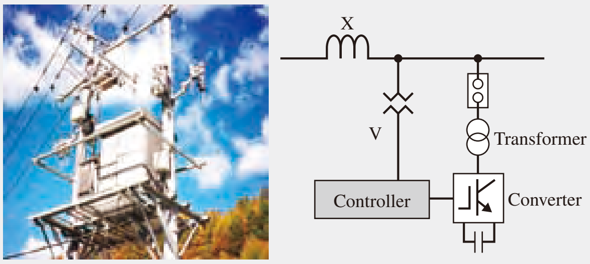

Photo courtesy of Tohoku Electric Manufacturing Co., Ltd. (5)

Fig. 9—SVC Circuit Configuration [±300 kvar (constant), 400 kvar (short time)].
The system has been miniaturized to allow installation on power poles.

CONCLUSIONS

This article has described the problems associated with the large-scale introduction of renewable energy systems, and given several examples of technologies that can solve these problems. Renewable energy systems such as wind power generation systems and solar power generation systems are important systems for reducing the impact on the environment and dependency on fossil fuel. Hitachi has developed various types of electrical power systems up to now, and has considerable experience and know-how in equipment technologies and system technologies. It intends to continue contributing to the promotion of renewable energy systems.

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