Development of Large-scale Photovoltaic Power Generation System

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OVERVIEW: Progress is being made around the world on introducing renewable energy sources such as solar and wind power as a response to the problem of global warming and to reduce dependence on oil and other fossil fuels. However, the outputs of these renewable energy sources are not constant and can be unstable because they depend on the terrain, level of sunlight, and other environmental factors at the installation site. There are concerns that if significant numbers of large-scale photovoltaic power generation systems are incorporated into the electricity grid in the future, they will cause voltage and frequency fluctuations that interfere with the operation of the grid. As a result, technologies are needed to deal with these problems. When developing a high-capacity power conditioning system for use with large-scale photovoltaic power generation systems, Hitachi incorporated two new functions that did not previously exist. These were a function for reducing grid voltage fluctuation and an FRT function for coping with transient voltage drops. A harmonic suppression function that reduces the flow of harmonic currents was also incorporated (see Fig. 1). These functions contribute to future-oriented large-scale photovoltaic power generation systems that can help maintain the stability of the power grid.

Fig. 1—Hokuto Site for Verification of Grid Stabilization with Large-scale Photovoltaic Power Generation Systems Operated by New Energy and Industrial Technology Development Organization (NEDO).
View of megasolar generation panels at a solar power generation system of approximately 2 MW under construction at Hokuto in Yamanashi Prefecture is shown.

INTRODUCTION

RECENT years have seen an increased adoption of solar, wind, and other forms of renewable energy around the world. In Europe in particular, construction of large-scale photovoltaic power generation systems ranging in capacity from several megawatts to several tens of megawatts continues at a rapid pace, primarily in Germany and Spain. This is to a large extent due to the existence of feed-in tariffs (a system whereby power utilities agree to long-term fixed-price arrangements that purchase renewable energy at a higher than usual tariff). Fig. 2 shows the amount of installed photovoltaic power generation capacity in leading countries.

The Action Plan for Achieving a Low-carbon Society agreed upon by the Japanese cabinet in 2008 set a target of increasing the quantity of power generated from photovoltaic energy to ten times the 2005 level by 2020 and 40 times by 2030. Given that the total installed capacity in 2005 was 1,420 MW and assuming the annual mean generating efficiency of a photovoltaic power generation system is 12%, this plan would increase photovoltaic power generation from less than 1,500 GWh in 2005 to 15,000 GWh by 2020 and 60,000 GWh by 2030. Assuming that total demand will be 1,057,500 GWh in 2020 and 1,125,800 GWh in 2030 (calculated based on a long-term energy demand forecast that assumes ongoing efforts for energy conservation), this will bring the proportion of total power demand supplied by photovoltaic power generation to approximately 1.4% in 2020 and 5.3% in 2030. The current proportion is approximately 0.2%.

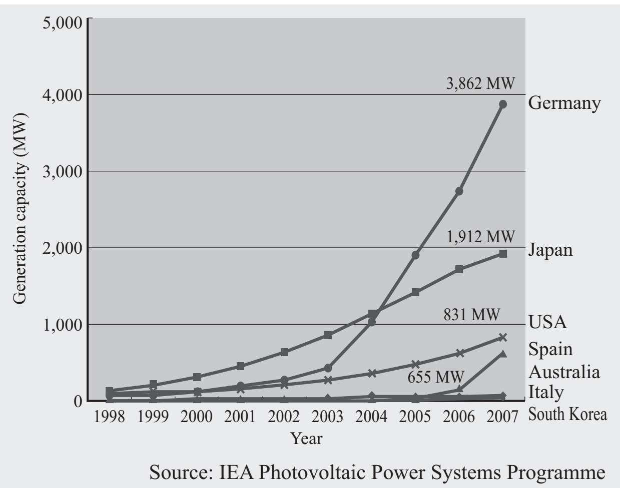

Fig. 2—Cumulative Installed Photovoltaic Power Generation Capacity in Leading Countries.
In recent years, fast growth has occurred in Germany and Spain.

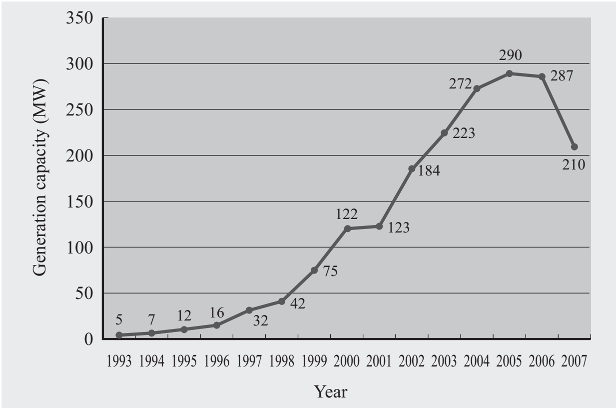

Fig. 3—Annual Photovoltaic Power Generation Capacity Installed in Japan.
The growth of photovoltaic power generation in Japan has mainly been on private homes.

Fig. 3 shows the actual quantity of photovoltaic power generation capacity installed in Japan. About 80% of this is installed on private homes. As meeting the targets described above would require 70% of all new homes to be fitted with photovoltaic power generation by 2020 and 80% by 2030, there is a limit to how far these targets can be met using home-mounted generation alone and in practice large-scale photovoltaic power generation systems (referred to below as "megasolar") will be needed.

As a step toward large-scale photovoltaic power generation, Hitachi is developing a PCS (power conditioning system) that converts the DC (direct current) power generated by solar panels into AC (alternating current) to allow interconnection with the electricity grid and a monitoring and instrumentation system that monitors the overall operating status of the system, having been re-commissioned by NTT Facilities, Inc. to undertake this work as part of the Verification of Grid Stabilization with Large-scale Photovoltaic Power Generation Systems project run by New Energy and Industrial Technology Development Organization (NEDO).

This article focuses on the development of this large-scale PCS which minimizes any influence on the grid.

GRID INTERCONNECTION ISSUES WHEN INTRODUCING LARGE-CAPACITY RENEWABLE ENERGY

Because the output of renewable energy sources such as wind and solar fluctuates depending on the strength of the sunlight or the speed of the wind, it presents the following problems for the electricity grid to which it is connected.

(1) Voltage fluctuations in the grid caused by varying output

Because conditions such as the movement of clouds cause the amount of sunlight reaching a photovoltaic power generation system to vary, the electric power output varies and voltage fluctuations occur at the point where the power plant connects to the grid. As megasolar projects connect a large number of photovoltaic power generation units to the grid at a single interconnection point, the effect of voltage fluctuations on the stable operation of the grid is of concern.

(2) Frequency fluctuations caused by varying output

As with voltage fluctuations in (1) above, large fluctuations in the level of power generation cause an imbalance between demand and supply, and this causes the frequency to vary.

(3) Voltage and frequency fluctuations caused by simultaneous drop-outs during disturbances in the electricity grid

Inverter power supplies typically shutdown if the AC voltage drops by about 20%. A large number of megasolar plants may all drop out (stop operating) together when disturbances such as short-duration voltage drops (referred to below as "transients") occur in the electricity grid. This influences the grid's demand balance and causes voltage and frequency fluctuations. In some cases this may affect the stability of the grid. Considering the possibility of megasolar plants becoming widespread in the future, there is a need to improve tolerances to prevent simultaneous drop-outs occurring unnecessarily.

(4) Increased harmonics due to greater use of inverters

As megasolar plants are added, the proportion of output capacity produced from photovoltaic energy using inverters will rise relative to the capacity of the grid to which they are connected and this will increase the effect of harmonics on the grid. Therefore, more effective suppression of harmonic current flows will be needed.

DEVELOPMENT OF PCS FOR LARGE-SCALE PHOTOVOLTAIC POWER GENERATION SYSTEMS

A PCS is an inverter that converts the DC power produced by the solar panels to AC so it can be supplied to the electricity grid. Hitachi decided to incorporate functions for dealing with grid stability issues into its large-capacity PCS for use with megasolar plants.

Specifically, Hitachi developed a 400-kW PCS incorporating function for reducing grid voltage fluctuation, FRT (fault ride through), and harmonic suppression functions. This PCS is designed to have a high AC voltage output (420 V), improved efficiency achieved by a transformer-less design, and the ability to operate at high efficiency even under partial load. The design of the unit also aims to reduce production costs by using general-purpose components for its main circuit-switching elements and switches, and by selecting an operating capacity that takes maximum advantage of the capacity of each component.

Large-capacity PCS

The features of the PCS are that it incorporates functions specifically intended for high-capacity grid interconnection, that it is designed for low cost through the use of general-purpose components, and that it delivers high efficiency, large capacity, and high reliability based on UPS (uninterruptible power supply) technology. Fig. 4 shows diagrams of the large-capacity PCS and its internal configuration.

Because the input solar panels cover a wide area,

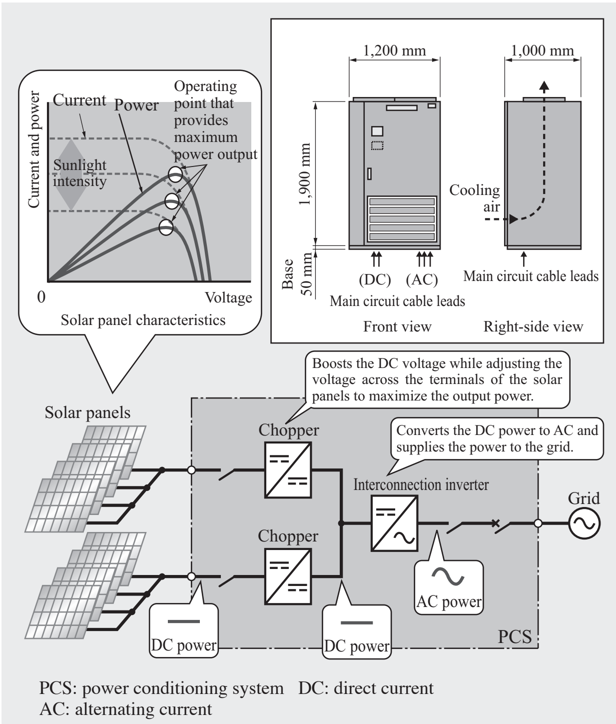

Fig. 4—Outline and Internal Structure of Large-scale PCS.
The large-scale PCS consists of a chopper that adjusts the voltage across the terminals of the solar panels to maximize the output power and an interconnection inverter that converts the DC power into AC.

the input is split into two circuits and the generation efficiency of the system is enhanced by using MPPT (maximum power point tracking) control for each chopper (a control system that adjusts the operating point of the photovoltaics to obtain maximum output power).

Grid Voltage Fluctuation Suppression

Potential methods for reducing voltage fluctuations caused by the varying output of the photovoltaic power generation system include limiting the generation output or using batteries or other components to charge and discharge rippled power. However, the former wastes useful energy and the latter entails significant equipment costs. Instead, Hitachi has developed a function to reduce the voltage fluctuations caused by the varying output of the photovoltaics by automatically adjusting the reactive power output from the interconnection inverter (also known as a "grid-tie inverter") to an appropriate level based on the state of the electricity grid together with the active power produced by the generation stage. Fig. 5 shows the effect of this system obtained by testing a mini model of the PCS. An output fluctuation equivalent to the rated power was generated from the PCS and then fluctuation reduction control was turned on with the initial value for reactive power set at zero. The result shows the reactive power output automatically adjusting to the appropriate level for the grid conditions with the voltage fluctuation at the interconnection point being kept down to only about 0.2%.

FRT

Previous PCS designs needed to block the PCS temporarily when short-duration voltage drops (transients) occurred to prevent over-current in the interconnection inverter. If large numbers of photovoltaic power generation systems come to be connected to the grid in the future, transients caused by grid faults or similar events could cause PCSs to drop off the electricity grid simultaneously over a wide area causing a sudden loss of power generation. In the worst case, this may result in a large power outage.

To reduce the effect on the electricity grid, the system needs to be able to continue operating even if transients occur and output as much of the generated power as possible. In response, Hitachi developed an FRT function that prevents over-current in the interconnection inverter and controls the generated power to keep it in balance with the amount of

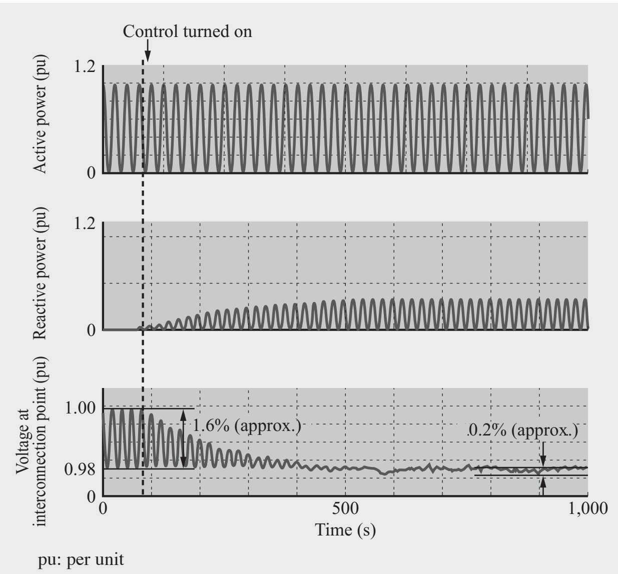

Fig. 5—Effect of Function for Reducing Grid Voltage Fluctuation.
The graphs show the results of testing the function for reducing grid voltage fluctuation on a photovoltaic power PCS for connecting to a 66-kV extra-high-voltage grid. The function reduces the amplitude of the voltage fluctuations to approximately 0.2% from approximately 1.6% prior to turning on control.

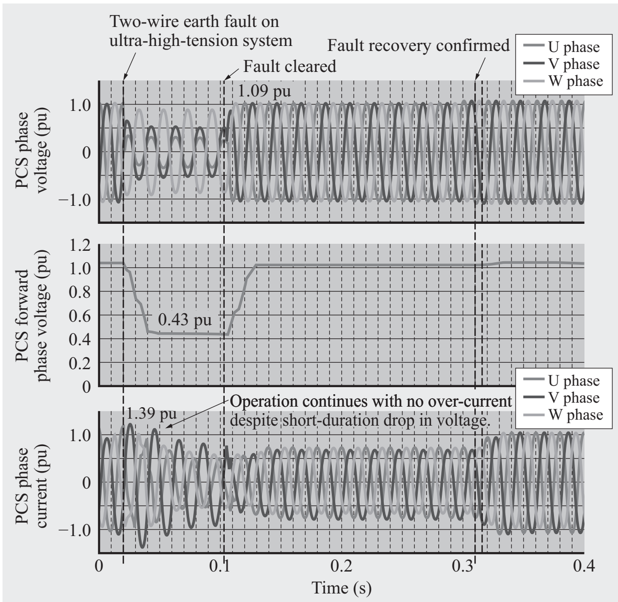

Fig. 6—FRT Function for Coping with Short-duration Voltage Drops.
The graphs show the results of using the mini model of PCS FRT (fault ride through) to test short-duration voltage drops caused by grid faults in ultra-high-tension systems. All of the available generated power is output even during short-duration voltage drops.

power able to be output to the grid using techniques such as high-speed current control and voltage phase detection that can operate at high speed and are tolerant of waveform distortion and other interference.

Experiments conducted on the mini model indicated that the system could continue to operate even if the AC positive phase voltage falls to approximately 35% of the rated voltage (see Fig. 6). This covers approximately 90% of all transients.

Suppression of Harmonics

Another concern if large numbers of PCSs are connected to the electricity grid is that harmonic currents will cause problems such as grid voltage distortion or abnormal overheating of equipment connected to the electricity system in the vicinity of a PCS. Although the lower-order harmonic currents output from PWM (pulse width modulation) inverters are comparatively small, there is the potential for harmonic currents that cause distortion of the grid voltage to flow. These harmonic currents are reduced by using control systems in the interconnection inverter that take account of the effect of grid voltage distortion. This achieved 80% or less of the new guidelines.

CONCLUSIONS

This article has described the development of a large-capacity PCS utilizing grid stabilization technologies suitable for megasolar power stations as part of the Verification of Grid Stabilization with Large-scale Photovoltaic Power Generation Systems project run by NEDO.

This research project is intended to promote the wider adoption of megasolar power generation, and aims to install a 2-MW class photovoltaic power generation system at Hokuto in Yamanashi Prefecture and implement a system that can connect to the electricity grid without causing any negative impacts. The research includes the development of a large-capacity PCS that helps stabilize the grid, evaluation of the characteristics of advanced photovoltaic modules, and the establishment of designs that are optimized in terms of economics and the environment. The research schedule covers five years from 2006 to 2010 and field testing of the overall system including the large-capacity PCS is planned for 2009 onwards (see Fig. 7).

It is anticipated that further megasolar projects will be undertaken in Japan by electric power companies or local government. Hitachi will continue to be involved in large-scale photovoltaic power generation in ways that take account of the effect of these systems on the electricity grid by utilizing its electricity distribution system, micro-grid, and other technologies built up through past experience.

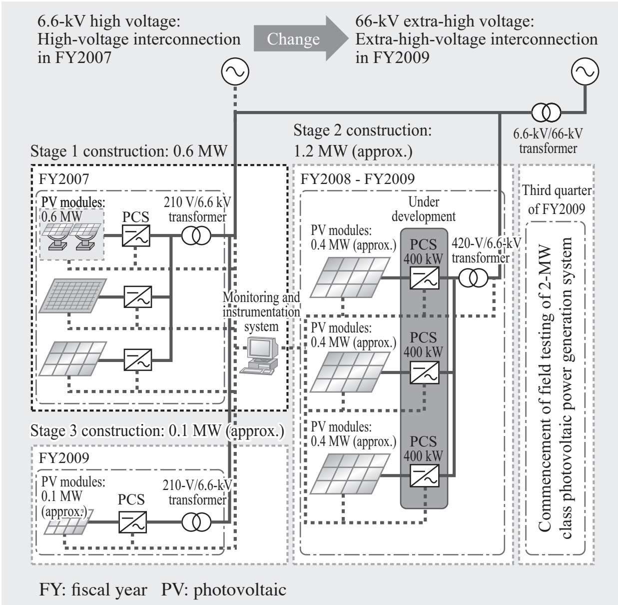

Fig. 7—Overall Configuration of Hokuto Project.
Field testing of the 2-MW class solar power generation system is to start during 2009.

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