

Highly Efficient Power Conditioning System for Large Photovoltaic Generation Systems

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OVERVIEW: Installation of photovoltaic power generation systems is accelerating around the world, driven by factors such as the introduction of feed in tariff schemes for renewable energy. Photovoltaic power is characterized by long periods of time during which equipment is operating under partial load, and inverters play an important role in ensuring generation efficiency and power system stability. Hitachi has released a new generation of PCSs based on three-level PWM inverters that are designed to be more efficient than past models. Hitachi intends to contribute to the wider adoption of photovoltaic power generation systems with the objective of increasing annual power generation, and with a view to developing systems with excellent long-term reliability.

INTRODUCTION

TO help reduce emissions of carbon dioxide (CO₂), countries around the world have been taking advantage in recent years of renewable energy sources such as photovoltaic and wind power, which do not use fossil fuel and produce no CO₂ in the generation process.

In June 2008, the Japanese government announced a target of installing 14,000 MW of photovoltaic power generation capacity by 2020. The target was subsequently raised to 28,000 MW. In response, the Federation of Electric Power Companies has announced a “Mega Solar Power Generation Plan” that aims to install large photovoltaic power plants at about 30 sites around Japan with a total capacity of approximately 140 MW, and has commenced construction and operation of these megasolar power plants.

Also, in response to the “Act on Special Measures Concerning Procurement of Renewable Electric Energy by Operators of Electric Utilities” passed in August 2011, a rapid expansion has taken place in plans for the installation of photovoltaic power plants under the feed in tariff scheme that started in July 2012, with construction of large power plants currently underway in various parts of the country (see Fig. 1).

Meanwhile, construction of photovoltaic power generation systems is also proceeding overseas where similar schemes have been introduced, particularly in sun belt countries including those in the Middle East and Asia. Hitachi has developed a next-generation power conditioning system (PCS) that helps maximize

the amount of annual power generation based on its experience and past success as a system integrator for the construction of megasolar systems in Japan where its role extended from equipment design to commissioning. As part of its global strategy, Hitachi is also proceeding with plans to manufacture its PCSs in overseas markets as well as in Japan.

This article describes two new PCS models that Hitachi has developed and commercialized for large photovoltaic power generation systems.

OVERVIEW OF PHOTOVOLTAIC POWER GENERATION

Photovoltaic power generation systems use the rays of the sun as a source of electric power. Accordingly,



Fig. 1—Large Photovoltaic Generation System (Ibaraki Prefectural Public Enterprise Bureau).

The construction and operation of large photovoltaic power plants commenced in Japan due to the introduction of a feed in tariff scheme and an expansion in its adoption. The construction of photovoltaic power generation systems is also proceeding in places such as the Middle East and Asia that experience high solar radiation intensity, where similar schemes have been adopted.

the amount of power generated is strongly influenced by the weather conditions that determine how much sunlight gets through.

Solar Radiation Intensity and Power Output

The power output of a photovoltaic panel is normally rated based on a solar radiation intensity of 1 kW/m^2 falling on a panel at a temperature of 25°C . Because the angle of incidence of sunlight varies depending on the season and the time of day, the power generated from a panel on a fixed platform typically starts to increase from dawn, peaks when the sun reaches its zenith for the day, and then decreases again toward sunset.

Accordingly, photovoltaic panels only generate their rated maximum output around noon and during that part of the year when sunlight is strong and the temperature comparatively low. Therefore, power plant equipment such as photovoltaic panels, PCSs, and step-up transformers operate at partial loads of between 20% and 80% of their rated capacity for significant periods of time. This makes it essential that the equipment be able to generate power with high efficiency even under partial load.

Role of PCS

A PCS is an inverter connected to the electric power grid that converts the direct current (DC) from the photovoltaic panel into alternating current (AC) (see Fig. 2). A feature of photovoltaic panels is that the current they generate varies depending on factors such as the level of sunlight and the voltage across their terminals. Therefore, the output power (the product of the current and the voltage across their terminals) depends on these same factors. The PCS is equipped with a maximum power point tracking (MPPT) function that improves the efficiency of power generation by optimizing the voltage across the panel terminals to maximize the generated power based on the level of sunlight.

Large-capacity PCSs for megasolar power generation systems also require functions for power system stabilization. Working through demonstrations and other projects run by the New Energy and Industrial Technology Development Organization (NEDO), Hitachi has already developed and implemented functions that include minimizing grid voltage fluctuations, maintaining operation during short-duration voltage drops, and suppression of harmonics.

FEATURES OF NEW TYPE OF PCS

Hitachi already markets PCSs in Japan and other countries. The inverters in these PCSs use two-level pulse width modulation (PWM) and achieve small size and high efficiency through features that include a transformer-less configuration and high output voltage (400 V). Responding to recent market growth, Hitachi has now developed and commercialized a new type of PCS designed for even higher efficiency.

Use of Three-level PWM Inverter

Conventionally, three-level PWM inverters have only been used in applications that require the suppression of harmonics or a higher converter voltage, such as in railway rolling stock or large motor drives. However, with insulated-gate bipolar transistor (IGBT) modules for three-level inverters in the 600 to 1,200-V class having become commercially available in recent years, thereby allowing three-level inverters to be implemented without requiring a significant increase in the component count, Hitachi has gone ahead with the commercialization of next-generation PCSs that use this method to improve conversion efficiency further (see Fig. 3).

The anticipated benefits of using three-level PWM inverters include lower switching loss, the ability

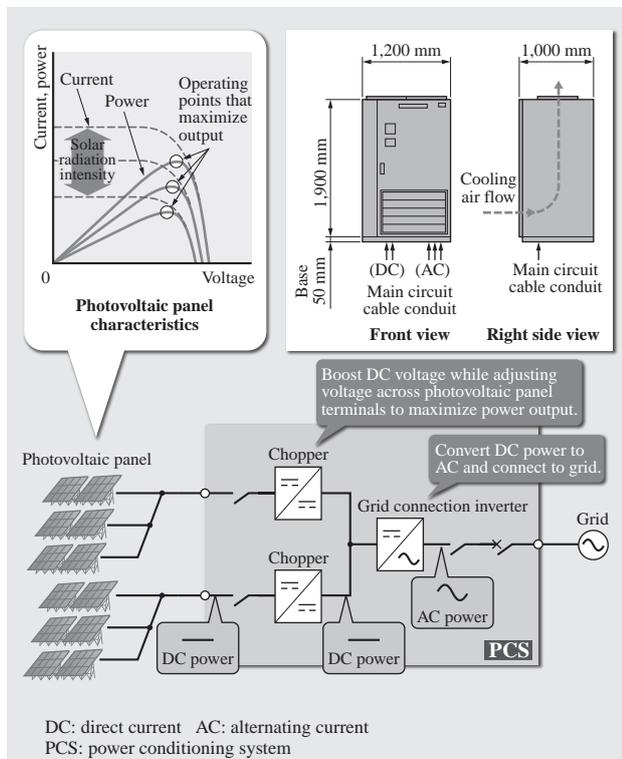


Fig. 2—PCS for Photovoltaic Power Generation System. A PCS is an inverter connected to the electric power grid that converts the DC electric power generated by the photovoltaic panels to AC.

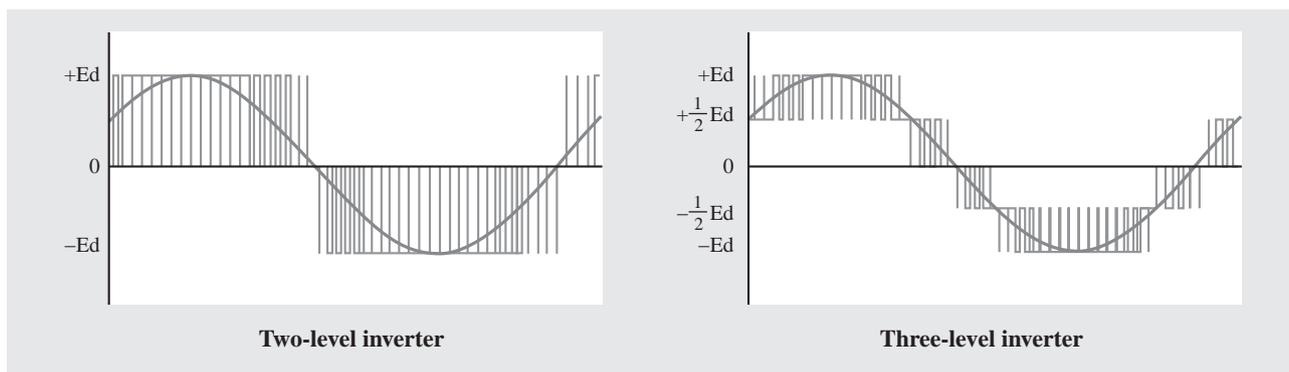


Fig. 3—Comparison of Two-level and Three-level Inverter Operation. Because a three-level inverter generates a pulse width modulation (PWM) waveform that more closely approximates a sine wave, a smaller AC filter can be used than on a two-level inverter.

to use smaller and lighter filter reactors with lower losses, less high-frequency electrical noise, and quieter operation. The lower losses make a major contribution to increasing annual power output.

Features of PCS for Overseas Markets

The PCS for overseas markets was developed to have a maximum input voltage of 1,000 V and went on sale in FY2012. Its three-level, transformer-less PWM inverter provides a maximum conversion efficiency of 98.7%, giving it world-leading performance for a PCS in its class* (see Fig. 4).

Fig. 5 compares the efficiencies of the new and previous PCSs, and Table 1 lists the main specifications of the PCS for overseas markets. Featuring superior efficiency across the entire operating range, including operation under partial load, the new PCS is smaller and lighter as well as delivering higher output from low to high levels of solar radiation.

* PCSs for large photovoltaic power generation systems in the 500-kW class. Based on Hitachi, Ltd. research as of October 2012.

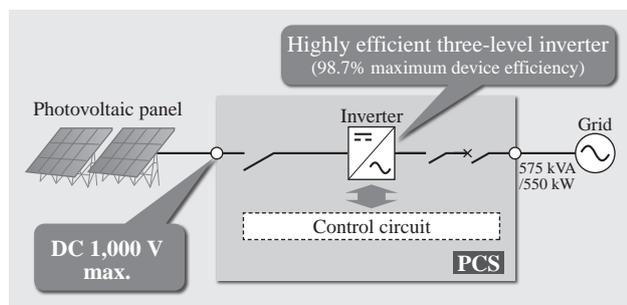


Fig. 4—Simplified PCS Wiring Diagram (PCS for Overseas Markets). This model uses a three-level, transformer-less PWM inverter to achieve a maximum conversion efficiency of 98.7%.

An expansion in use of 1,000-V systems is anticipated in Japan as a result of changes to regulations, and Hitachi also intends to utilize the new PCS in these systems.

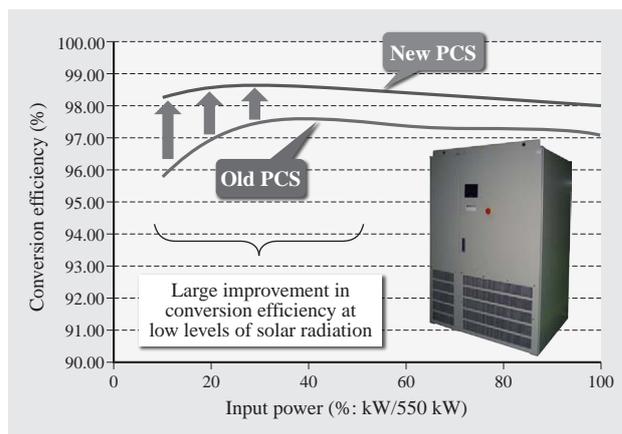


Fig. 5—Comparison of Conversion Efficiency for New and Old PCSs (Overseas Models).

This comparison shows the conversion efficiencies of the old and new PCSs.

TABLE 1. Main Specifications of PCS for Overseas Markets The table lists the maximum output and other key specifications of the PCS for overseas markets.

Maximum output	550 kW/575 kVA
Maximum DC input voltage	1,000 V
DC voltage range	DC450 to 900 V
Rated AC output voltage	AC300 V (±10%)
Rated frequency	50/60 Hz (±2%)
Conversion efficiency	98.7% max. (DC450 V, AC300 V, PF = 1.0)
Dimensions	1,400 (width) × 1,000 (depth) × 1,900 (height) mm
Weight	1,350 kg

PF: power factor

Features of PCS for Japanese Market

PCS for the Japanese market combines a transformer-less, three-level PWM inverter with a step-up chopper input circuit that enables MPPT control to be performed over a wide range of voltages (DC230 V to 600 V). It features enhanced conversion efficiency in the DC400 V to 500 V range (see Fig. 6). The step-up chopper consists of two circuits, each of which has an input capacity of 250 kW and supports MPPT operation.

Fig. 7 compares the efficiencies of the new and previous PCSs, and Table 2 lists the main specifications of the PCS for the Japanese Market.

This product range includes an outdoor package suitable for large photovoltaic power plants (see Fig. 8). The ability to deliver the outdoor package to the installation site with two PCSs already fitted helps shorten installation time because it means that

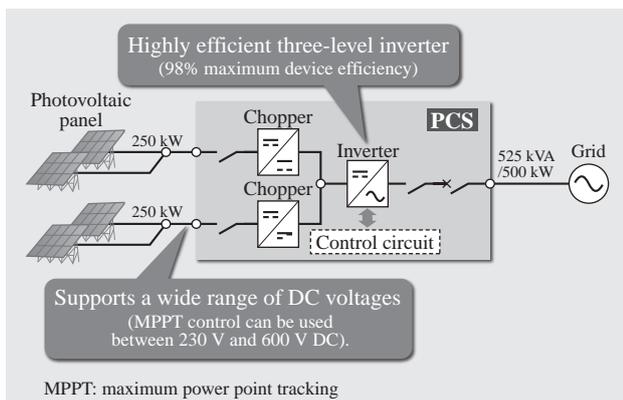


Fig. 6—Simplified PCS Wiring Diagram (PCS for the Japanese Market).

This model can use MPPT control over a wide range of voltages and features improved efficiency between 400 V and 500 V DC.

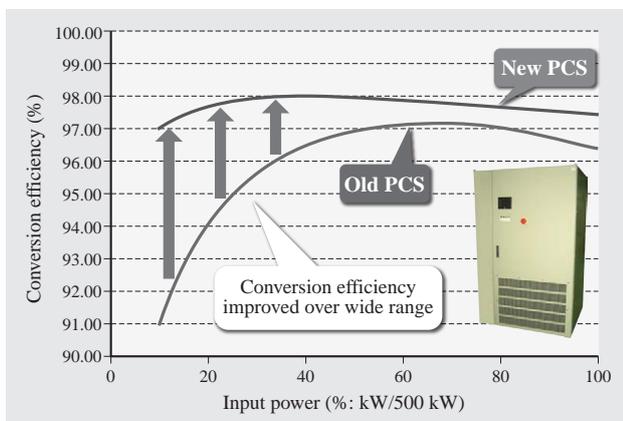


Fig. 7—Comparison of Conversion Efficiency for New and Old PCSs (Japan Models).

This comparison shows the conversion efficiencies of the old and new PCSs.

on-site setup work can be performed efficiently. The outdoor package isolates the PCSs from the external atmosphere and ensures that the PCSs operate reliably by using multiple air conditioning units to perform efficient internal cooling.

CONCLUSIONS

This article has described two new PCS models that Hitachi has developed and commercialized for large photovoltaic power generation systems.

Hitachi is developing a variety of renewable energy technologies based on its experience and past success in a wide range of fields, including power electronics and system control technology.

Regarding PCSs for large photovoltaic power generation systems, Hitachi has been involved in the development of PCSs with high efficiency and large capacity from an early stage, including participation as a sub-contractor to NTT Facilities, Inc. in the NEDO-sponsored “Verification of Grid Stabilization with Large-scale PV Power Generation Systems” project, and the PCS products described in this article represent the culmination of the work conducted to date.

TABLE 2. Main Specifications of PCS for the Japanese Market
The table lists the maximum output and other key specifications of the PCS for the Japanese market.

Maximum output	500 kW/525 kVA
Maximum DC input voltage	660 V
DC voltage range	DC230 to 600 V
Rated AC output voltage	AC420 V/440 V (±10%)
Rated frequency	50/60 Hz (±2%)
Conversion efficiency	98% max. (DC500 V, AC420 V, PF = 1.0)
Dimensions	1,200 (width) × 1,000 (depth) × 1,900 (height) mm
Weight	1,600 kg



Fig. 8—PCS Outdoor Package.

The product range includes an outdoor package suitable for large photovoltaic power plants.

In addition to conversion efficiency, long-term system reliability has also become an extremely important consideration for the large photovoltaic power generation systems that are anticipated to become more widely used in the future. This is to ensure that electric power can be generated reliably over long periods of time in combination with a diverse variety of different photovoltaic panels. Hitachi intends

to draw on the technologies and experience that it has built up in grid interconnection and renewable energy to work toward the wider adoption of systems with excellent long-term reliability. Hitachi also intends to contribute to the spread of smart grids through highly flexible systems that combine photovoltaic power generation systems with microgrids, energy storage systems, and other technologies.

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