Core Components for Large-scale PV Generation Systems

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OVERVIEW: Recent years have seen the development and installation of renewable energy systems around the world, with considerable progress having been made on both system performance and cost reduction. Hitachi has been engaged in the development of key technologies for this sector, encompassing inverters for photovoltaic power generation, amorphous transformers, and all aspects of system engineering. The know-how needed to integrate these different elements is an important part of establishing a photovoltaic power generation business. Hitachi's experience includes the development of core components for utilizing renewable energy, and it is drawing on this to operate its business globally.

INTRODUCTION

THROUGHOUT the world, growing use has been made of photovoltaic, wind, and other forms of renewable energy generation in recent years. In Japan, in response to the Act on Special Measures Concerning the Procurement of Renewable Electric Energy Sourced by Electric Utilities passed in August 2011, a rapid expansion has taken place in plans for the installation of large photovoltaic power plants under the feed in tariff (FIT) scheme that started in 2012. Despite a reduction in the price offered by the FIT scheme from 40 yen/kWh (excluding tax) in FY2012 to 36 yen in FY2013, the construction of large power plants is continuing throughout the country.

Meanwhile, construction of photovoltaic power generation systems is also being planned overseas, both in Europe and in sunbelt countries such as those in the Middle East and Asia.

In addition to operating an engineering, procurement, and construction (EPC) business for large photovoltaic power plants in Japan, Hitachi is developing core components that maximize the amount of annual power generation, including highly efficient next-generation power conditioning systems (PCSs) and amorphous transformers with low standby power consumption.

EPC BUSINESS FOR LARGE PHOTOVOLTAIC POWER PLANTS

As a sub contractor to NTT Facilities, Inc. under the Verification of Grid Stabilization with Large-scale PV Power generation systems project of the New Energy and Industrial Technology Development Organization (NEDO), Hitachi has been working on the development of PCSs and of monitoring and measurement systems. The former converts the direct current (DC) from photovoltaic cells into alternating current (AC) and supplies it to the grid, and the latter monitors overall system operation. Hitachi has released heavy-duty PCSs for large photovoltaic power generation systems that it is marketing in Japan and overseas. These PCSs incorporate functions for minimizing voltage fluctuations, maintaining operation through short-duration voltage drops, and the suppression of harmonic currents.

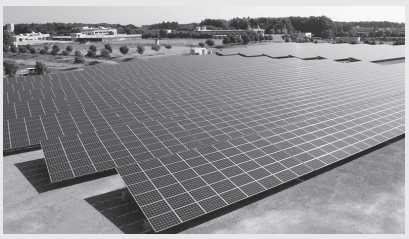
The Ohgishima Solar Power Station, which commenced operation in December 2011, was the largest "megasolar" power plant for commercial power generation in Japan at that time. It has a maximum output of 13 MW and delivers an estimated annual reduction in carbon dioxide (CO_2) emissions of about 5,800 t.

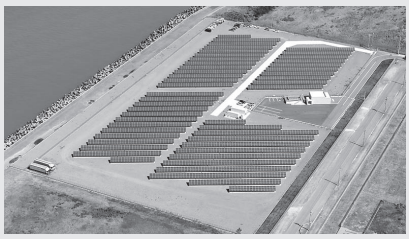
Also, a 1-MW photovoltaic power plant commenced operation in July 2011 for the Ibaraki Prefectural Public Enterprise Bureau. This plant was installed to reduce demand during peak summer hours (peak cutting) in response to the need to save power due to the shortage of power generation capacity in the region covered by Tokyo Electric Power Company, Incorporated (TEPCO) since the Great East Japan Earthquake in March 2011. Hitachi acted as an EPC supplier for this project, providing a complete package that extended from equipment design to manufacturing, site preparation, installation, and commissioning.

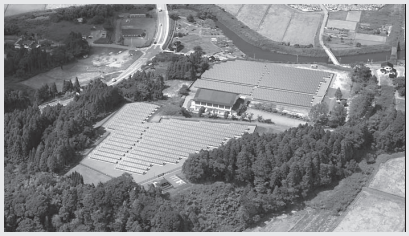
The system incorporates the following features to maximize power generation, and the system configuration is designed for generation efficiency and reliability.

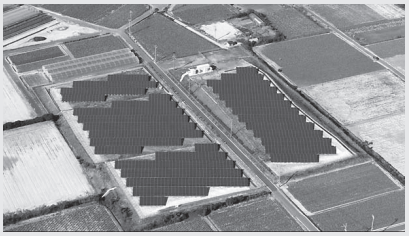
(1) Lightweight mountings achieved through optimal design


Power plant of SGET Ashikita Mega Solar LLC (output: 8 MW)


Central District Waterworks Office of the Ibaraki Prefectural Public Enterprise Bureau (output: 1 MW)


Mikuni Photovoltaic Power Station, Hokuriku Electric Power Company (output: 1 MW)


Suzu Photovoltaic Power Station, Hokuriku Electric Power Company (output: 1 MW)


Solar Farm Toyohashi, C-TECH Corporation (output: 1 MW)


Megasolar power plant of Oita Solar Power Co., Ltd. (output: 82 MW)

Fig. 1—Large Photovoltaic Power Generation Systems.
In addition to undertaking large photovoltaic power generation projects under EPC contracts, Hitachi also supplies core components that include highly efficient next-generation PCSs and amorphous transformers with low standby power consumption.

(2) PCSs with high conversion efficiency even at low output levels
(3) Use of modular construction for quick installation
(4) Low standby power consumption due to use of amorphous transformers

Drawing on this development experience, operation has commenced at the Mikuni and Suzu photovoltaic power stations of Hokuriku Electric Power Company, the Solar Farm Toyohashi of Ctec Corporation, and the Ashikita Megasolar plant operated primarily by SGET Ashikita Megasolar LLC, a public-private infrastructure fund run by Tokyo Metropolitan Government. When planned plants are included, plants with a total capacity of several hundred megawatts are in the pipeline (see Fig. 1).

The megasolar power generation system for Oita Solar Power Co., Ltd. will be the largest such system ordered from a supplier in Japan. The plant is to be operated by Oita Solar Power Co., Ltd. and is being constructed in Oita City, Oita Prefecture in readiness for operation to commence in spring 2014. The plant covers 105 ha and has a capacity of 82 MW. Annual power production is estimated at 87,000 MWh, roughly equivalent to the electric power needs of 30,000 homes. If all of the panels were laid out in a line, they would extend for about 500 km, similar to the distance from Tokyo to Osaka.

The system will reduce CO_2 emissions by about 36,000 t annually. The site also features a layout that takes account of the surrounding natural environment.

These generation systems use highly efficient PCSs (capacity: 500 kW, maximum DC input voltage: 660 V, maximum conversion efficiency: 98.0%) to increase generation efficiency significantly across a wide range of load conditions, from sunny to cloudy days. By utilizing amorphous transformers with high efficiency under low load, the system is designed to increase the amount of power generated under weather conditions in Japan.

Since FY2013, Hitachi has been building power plants that use highly efficient PCSs. Described later in this article, these PCSs have a maximum DC input voltage of 1,000 V and a maximum conversion efficiency of 98.8%.

Hitachi coordinates all aspects of highly reliable megasolar power generation systems that feature the highest levels of efficiency available in Japan. This extensive support includes manufacturing the PCSs and other core components used in megasolar power generation systems, providing assistance with gaining the necessary permits prior to construction, construction work from design and fabrication through to commissioning, and a remote monitoring service after the plant enters service.

DEPLOYMENT OF MEDIUM-SIZED PHOTOVOLTAIC POWER GENERATION SYSTEMS

The period since the introduction of the FIT scheme in 2012 has seen a stream of new entrants to the photovoltaic power generation business from many different industries, together with considerable activity in the construction on unused land of medium-sized photovoltaic power generation systems in the 1-MW to 2 MW range. In response to this new demand, Hitachi has developed its photovoltaic power generation system packages, which provide the key equipment needed for power generation, and which are designed to maximize annual power generation.

Because photovoltaic power generation operates under constantly changing conditions (including the weather), with good power output only possible on a small number of days each year, it is important to consider how to increase total annual production efficiently to allow sale of electric power. This package not only reduces the work associated with equipment selection during system configuration, it is also designed to allow the trouble-free construction of systems with a variety of desirable features, including highly efficient operation and low standby power consumption.

Specifically, the standard configuration, which includes photovoltaic panels, PCS, amorphous transformer, and switchgear, is available in 1-MW and 2-MW models. These have panel capacities of 1.3 MW and 2.6 MW, respectively. Based on the relation between sunlight levels and annual power generation, the systems are designed to maximize power generation under conditions in Japan, making maximum use of operating ranges in which the PCS and amorphous transformer are most efficient.

PCS

A PCS is an inverter that converts the DC power generated by the photovoltaic panels to AC power and supplies it to the grid. A characteristic of photovoltaic panels is that their output current varies depending on factors such as the incident sunlight and terminal voltage. These same factors also cause the output power (the product of the terminal voltage and current) to vary. To improve generation efficiency, the PCS includes a maximum power point tracking (MPPT) function that adjusts the voltage across the photovoltaic panel terminals to maximize the output power for different levels of sunlight (see Fig. 2).

In addition to these functions, the heavy-duty PCSs used by megasolar power generation systems also require grid stabilization functions. Through work that includes the NEDO research project referred to earlier, Hitachi has developed and commercialized a number of

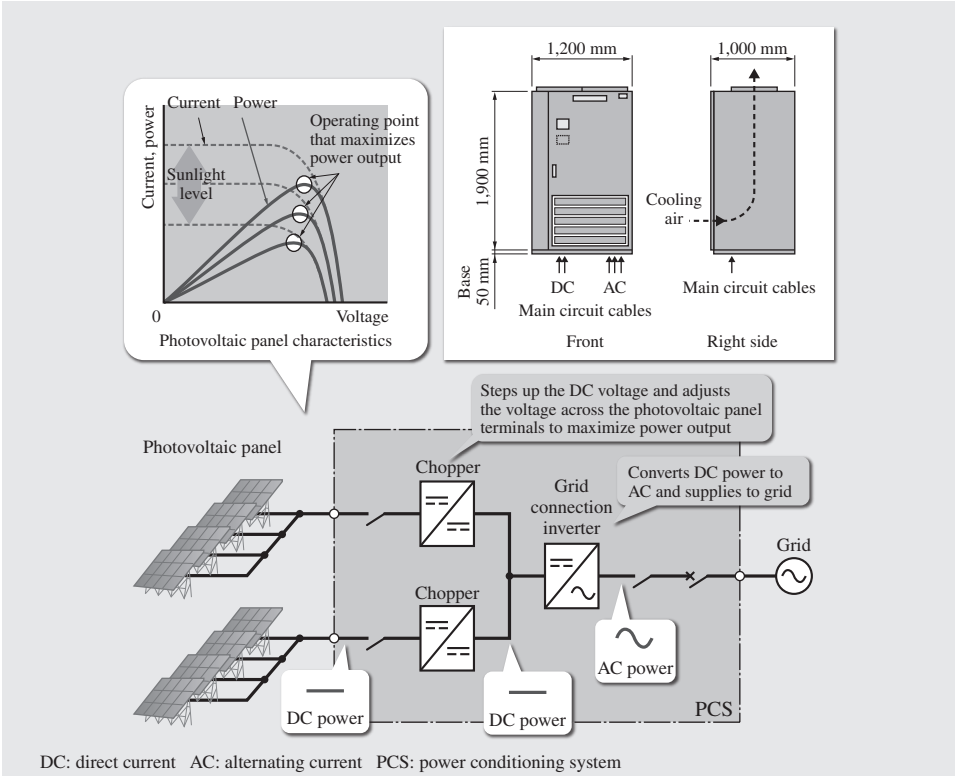


Fig. 2—PCS for Photovoltaic Power Generation Systems. The PCS adjusts to the sunlight conditions to perform efficient conversion of the DC power generated by the photovoltaic panels to AC power.

such functions, including those for minimizing voltage fluctuations, maintaining operation through short-duration voltage drops, and suppressing harmonics.

Hitachi initially supplied PCSs in Japan and overseas that used two-level pulse-width modulation (PWM) inverters and achieved small size and high efficiency through features that included a transformer-less configuration and high output voltage (400 V). Hitachi then went on to develop and commercialize PCSs designed for even greater efficiency, and is currently releasing a new high-efficiency model with a maximum DC input voltage of 1,000 V to complement the previous model, which has a maximum input voltage of 660 V.

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 and large motor drives. However, insulated-gate bipolar transistor (IGBT) modules for three-level inverters in the 600- to 1,200-V class have become commercially available in recent years, thereby allowing three-level inverters to be implemented without requiring a significant increase in the component count. Accordingly, Hitachi has gone ahead with the commercialization of next-generation PCSs that use three-level PWM inverters to improve conversion efficiency further.

The anticipated benefits of using three-level PWM inverters include lower switching loss, the ability to use smaller and lighter filter reactors with lower losses, less high-frequency electrical noise, and quieter operation. These lower losses are expected to make a major contribution to increasing annual power output (see Fig. 3).

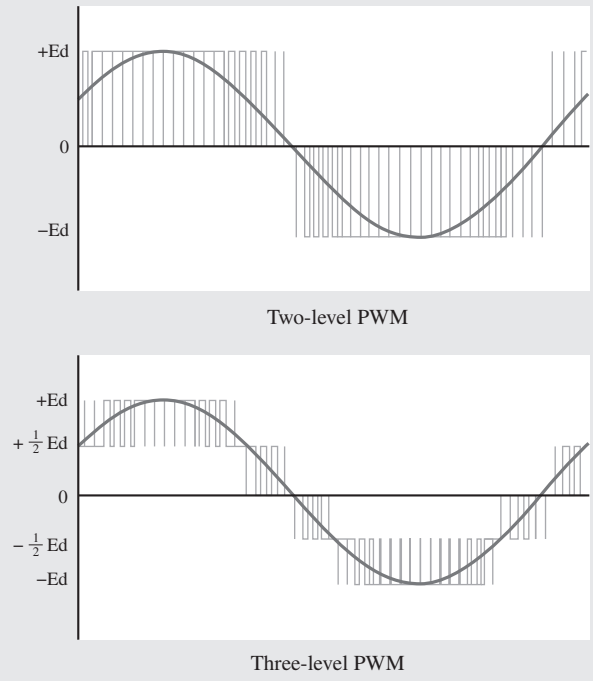


Fig. 3—Comparison of Two-level and Three-level PWM.
Compared to two-level PWM, the three-level PWM waveform is closer to a sine wave and therefore allows use of a smaller AC filter.

Features of HIVERTER NP203i (500-kW)

The HIVERTER NP203i 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. The step-up chopper consists of two circuits, each of which has an input capacity of 250 kW and supports MPPT operation (see Fig. 4 and Table 1).

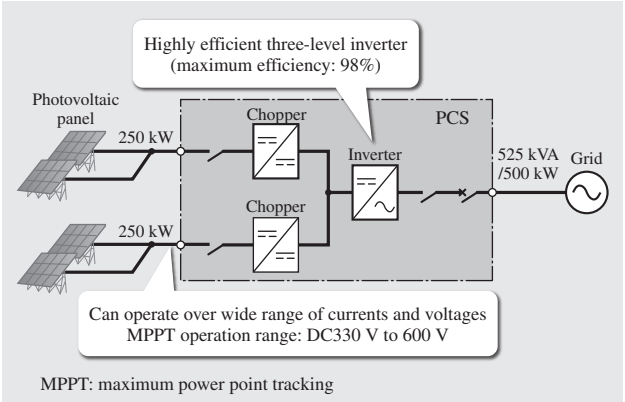


Fig. 4—Single-line Wiring Connection Drawing for PCS (HIVERTER NP203i).
The HIVERTER NP203i has a step-up chopper input circuit to perform MPPT control over a wide range of voltages.

Table 1. HIVERTER NP203i Specifications
The table lists the main HIVERTER NP203i specifications.

Parameter	Specification
Maximum output	500 kW/525 kVA
Maximum DC input voltage	660 V
Operating DC voltage range	DC 230 V – 600 V
Rated AC output voltage	AC 420V/440V (±10%)
Rated frequency	50/60 Hz (±6%)
Conversion efficiency	98% (max.) (DC 500 V, AC 420 V, PF = 1.0)
Dimensions (mm)	1,200 (W) × 1,000 (D) × 1,900 (H)
Weight	1,350 kg

PF: power factor

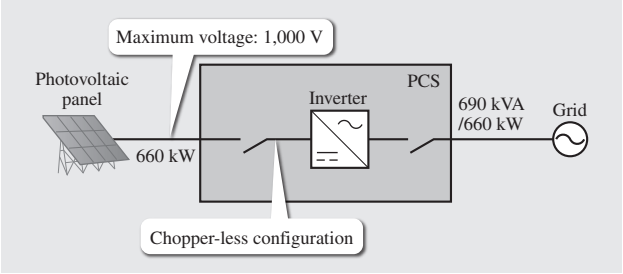


Fig. 5—Single-line Wiring Connection Drawing for PCS (HIVERTER NP213i).
The HIVERTER NP213i has a maximum DC input voltage of 1,000 V and achieves maximum conversion efficiency of 98.8%.

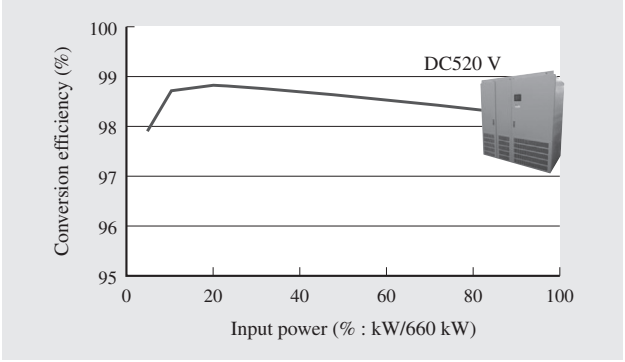


Fig. 6—PCS Conversion Efficiency Characteristics (HIVERTER NP213i).
The PCS helps maximize power production by delivering high conversion efficiency across the typical operating range for photovoltaic power generation.

Features of HIVERTER NP213i (660 kW)

Based on the 550-kW HIVERTER NP201i intended for the global market, the HIVERTER NP213i is designed for higher output. It features a chopper-less design and a three-level PWM inverter with a maximum input voltage of 1,000 V (see Fig. 5) to deliver a maximum conversion efficiency of 98.8%, giving it world-leading performance for a PCS in its class*. It is designed for small size and light weight, with efficiency characteristics that ensure high efficiency across the entire operating range (see Fig. 6 and Table 2).

TABLE 2. HIVERTER NP213i Specifications
The table lists the main HIVERTER NP213i specifications.

Parameter	Specification
Maximum output	660 kW/690 kVA
Maximum DC input voltage	1,000 V
Operating DC voltage range	DC 520 V – 900 V
Rated AC output voltage	AC 360V (±10%)
Rated frequency	50/60 Hz (±6%)
Conversion efficiency	98.8% (max.) (DC 520 V, AC 360 V, PF = 1.0)
Dimensions (mm)	1,400 (W) × 1,000 (D) × 1,900 (H)
Weight	1,400 kg

Outdoor PCS Package

The HIVERTER NP203i/NP213i product range includes outdoor packages suitable for large photovoltaic power plants (see Fig. 7). The ability to deliver the outdoor package to an installation site with two or three PCSs already fitted helps shorten installation time because it means that 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.

Fig. 7—PCS Outdoor Package.
The outdoor package can be fitted with up to three PCSs. Reliable long-term operation is facilitated by efficient cooling of the interior, which is isolated from the external atmosphere.

HITACHI'S SOLUTION BUSINESS

Large photovoltaic power generation projects require the plant operator to overcome a wide range of challenges, including not only equipment selection and design, but also permit procedures, power company grid connections, and operation and maintenance. In addition to the know-how it has built up in large photovoltaic power generation systems, Hitachi can also call on the comprehensive capabilities of the Hitachi Group to supply everything needed for these large systems to local governments or companies that are considering the construction of such projects on unused or under-used land.

Specifically, in addition to the selection and supply of the key equipment used in large photovoltaic power generation systems, including the photovoltaic panels and also ancillary systems such as highly efficient PCSs, transformer and distribution systems, and

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

remote monitoring systems, Hitachi can also handle permit procedures, power company grid connections, and also 20-year operation and maintenance plans arranged in conjunction with Hitachi Capital Corporation or other organizations.

Hitachi is also constructing a 1.8-MW photovoltaic power generation system on approximately 2 ha of land it owns in Hitachi City, Ibaraki Prefecture. By constructing and operating its own large system, Hitachi aims both to improve equipment quality and reliability and also to enhance its ability to assess business viability.

To achieve a major boost in generation efficiency over a wide range of sunlight levels (sunny and cloudy days), the system configuration will include a highly efficient PCS that went on sale in FY2013 (maximum voltage: 1,000 V, rated capacity: 660 kW, conversion efficiency: 98.8%) and an amorphous transformer with high efficiency at low load. Hitachi intends to sell all of the electric power generated by the system under the renewable energy FIT scheme. Work started in August 2013, and the plant is scheduled to commence generation in April 2014.

Hitachi has received turnkey orders (EPC contracts) for a considerable number of large photovoltaic power generation systems, including the large 82-MW photovoltaic power generation system for Oita Solar Power Co., Ltd. and the Ohgishima Solar Power Station (output: 13 MW) for Tokyo Electric Power Co., Inc. Hitachi's extensive experience also includes the supply of Megakits; ancillary equipment, particularly highly efficient PCSs, that contribute to cost savings; and remote monitoring systems.

CONCLUSIONS

This article has described Hitachi's involvement and experience with large photovoltaic power generation projects along with PCSs and other core components. Through the comprehensive use of these core components and other technologies in the renewable energy sector, and by working in collaboration with overseas production and engineering facilities, Hitachi believes it can supply solutions that suit regional needs, including for regions outside Japan.

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