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Hitachi's Involvement in Mid-range Photovoltaic Power Generation Systems

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OVERVIEW: Along with the greater use being made of renewable energy in the shift to a low-carbon society, installation of generation plants that use this energy has expanded rapidly in Japan since the introduction of a feed-in tariff scheme for renewable energy in 2012. Against this background, Hitachi has been developing a variety of technologies for generating photovoltaic power. This includes contributing to further expansion in the use of photovoltaic power generation through the development of technology for mid-range power plants, which are seen as having an important role in the future.

INTRODUCTION

THE installation of generation plants that use renewable energy has accelerated since 2012, when a feed-in tariff scheme for renewable energy was introduced as part of a special measures law concerning the purchase by electric power utilities of electricity generated from renewable energy. There has been significant growth in photovoltaic power generation in particular, with new plant approvals by the Ministry of Economy, Trade, and Industry during the period from July 2012 to October 2013 totaling about 24,500 MW(1).

This article describes the development by Hitachi Industrial Equipment Systems Co., Ltd. of equipment for mid-range solar power plants (industrial plants with a capacity of 100 kW to 1 MW), which are expected to be in greater demand in the future.

DEVELOPMENT OF 100-KW POWER CONDITIONER

For mid-range solar power plants, Hitachi has developed the HSP900-1000LFH power conditioning system (PCS) with an isolation transformer operating at utility frequency and a rated output capacity of 100 kW. To satisfy the requirements of a PCS for mid-range solar power plants, the development concept for the HSP900-1000LFH was to satisfy the following three groups' requirements.

(1) Users: Maximize overall power generation.
(2) Technical staff: Ensure PCS is easier to work on.
(3) System designers: Improve ability to work with different panel characteristics and layouts.

To maximize the overall power from the photovoltaic power generation system, it is necessary both to design the conversion efficiency curve based on the actual distribution of solar radiation intensities, and to improve its ability to respond to sudden changes in intensity, such as when a cloud passes over the plant.

Data from the Automated Meteorological Data Acquisition System(2) (AMeDAS) in Sapporo, Tokyo, and Osaka indicates that a greater increase in total annual power generation can be achieved by improving the efficiency under partial load rather than the efficiency at 100% output (see Fig. 1).

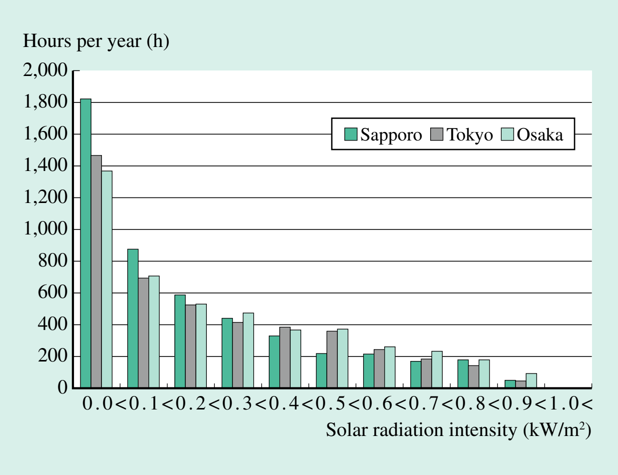


Fig. 1—Time Distribution of Solar Radiation Intensity.
Distribution of hourly mean solar radiation intensities (kW/m²) measured by AMeDAS. The data was collected from January 1 to December 31, 2009. (Times with zero solar radiation were excluded).

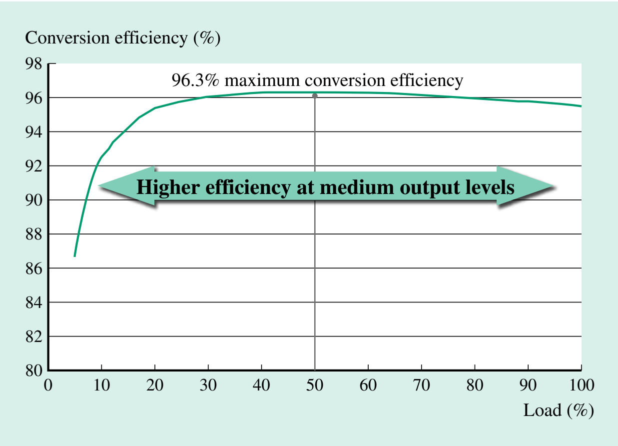


Fig. 2—Conversion Efficiency.
The graph shows the conversion efficiency of the HSP900-1000LFH DC345 V. Hitachi designed the conversion efficiency curve to maximize overall power generation.

Accordingly, by matching the conversion efficiency characteristics of the amorphous transformer with those of the inverter, Hitachi achieved an efficiency curve with particularly high conversion efficiency in the 20 to 80% output range.

The maximum conversion efficiency using an amorphous isolation transformer is 96.3% (at 50% load) (see Fig. 2).

Also, Hitachi has developed its own binary search method for maximum power point tracking (MPPT). The method searches for the maximum power point (MPP) using an iterative procedure that first divides the power-voltage (P-V) curve in two by measuring three points, and then determines which side contains the MPP (see Fig. 3).

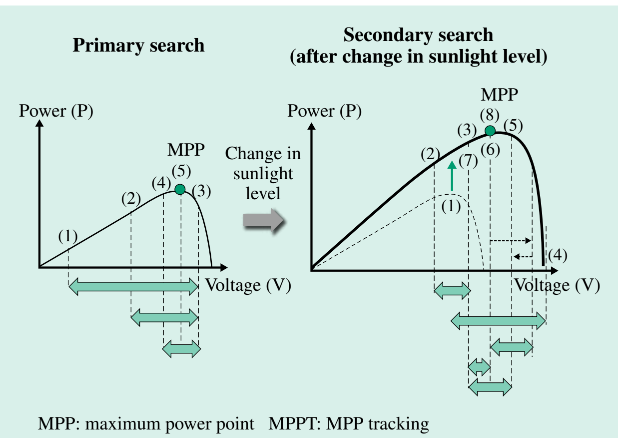


Fig. 3—Binary Search Method.
Developed by Hitachi Industrial Equipment Systems Co., this method provides highly responsive MPPT that is good at dealing with partial shadows.

This method is faster than the conventional hill-climbing method at responding to changes in the level of sunlight and is resistant to MPP misdetection caused by partial shadows, which is a common problem for mid-range photovoltaic power plants.

This combination of a conversion efficiency curve optimized for actual levels of solar radiation and an MPPT function that responds rapidly to changes in the level of solar radiation satisfies the above objective [development concept (1): Users] of maximizing overall power generation. To satisfy the second objective [development concept (2): Technical staff] of making the equipment easier to work on, on-site work has been facilitated by providing adequate space (height) for the busbars used to fasten the direct current (DC) and alternating current (AC) cables, with up to 200 mm^2 of space provided for running DC cables. To satisfy the third objective [development concept (3): System designers] of improving the ability to work with different panel characteristics and layouts, the PCS has a DC input voltage range of 0 to 650 V (operating range: 315 to 600 V) to support different panel outputs and provide flexibility in how panels are connected together.

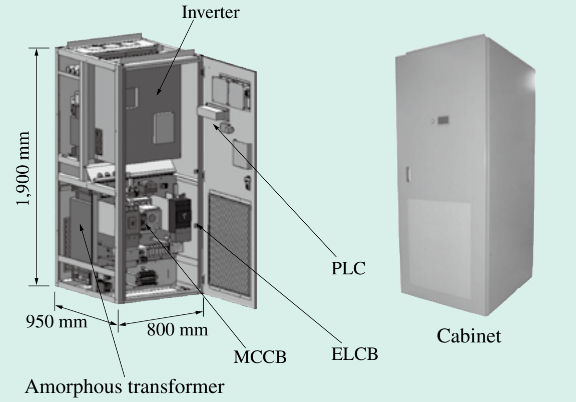
Fig. 4 lists the specifications and shows photographs of the newly developed HSP900-1000LFH.

DEVELOPMENT OF AMORPHOUS STEP-UP TRANSFORMER

Transformer losses can be broadly divided into no-load and load losses. No-load losses remain the same regardless of the load ratio (actual load as a proportion of transformer capacity) and correspond to the power consumption when the transformer is idle. Load losses, in contrast, are caused by the load current and are proportional to the square of the load current (or load ratio).

The utilization of photovoltaic power generation systems is only about 15 to 25% because of the times, such as at night, when they are unable to generate any power. However, they continue to consume electric power (standby power) during these times when they are not generating power. This means that the best transformers for photovoltaic power generation systems are those with high efficiency at low loads. Accordingly, the dedicated transformer used to step-up the voltage from the photovoltaic system to the grid needs to have minimal standby power consumption and low loses, both when power is and is not being generated. Special designs are also required to deal

Model		HSP900-1000LFH
Rated output		100 kW
Isolation		Utility frequency isolation transformer
DC input	Rated input voltage	DC345 V
	Input voltage range	DC 0 V to 650 V
	Input operating voltage range	DC 315 V to 600 V
AC output	Phases	Three-phase, three-wire
	Rated output voltage	AC202 V
	Rated frequency	50 Hz/60 Hz
	Rated output current	286 A
	Electrical conversion efficiency	95.3%
Structure		Freestanding, indoor, lockable cabinet
External dimensions		800 mm (W) × 950 mm (D) × 1,900 mm (H) (excluding base and ceiling protection cover)
Weight		1,100 kg



DC: direct current AC: alternating current
PCS: power conditioning system PLC: programmable logic controller
MCCB: molded case circuit breaker
ELCB: earth leakage circuit breaker

Fig. 4—PCS Specifications.
The HSP900-1000LFH (product specifications and photographs shown above) achieves high conversion efficiency using a utility frequency isolation transformer.

with grounding or with the harmonic components of the output electric power, which depend on the PCS specifications. In response, Hitachi has developed the Super Amorphous X ce series of transformers that satisfy the required step-up transformer specifications, which include basing the design on an amorphous transformer that features significantly lower standby power consumption while also incorporating measures for dealing with the harmonic components. Fig. 5 shows a photograph of a Super Amorphous X ce series transformer, Fig. 6 shows the efficiency curve, and Fig. 7 shows a transformer installation.

The main features of the Super Amorphous X ce series transformers are as follows.

(1) The transformer core is made of amorphous alloy. This reduces no-load losses (due to standby power consumption) by approximately 70%.

(2) They are designed specifically for photovoltaic power generation systems, with higher system efficiency in the actual operating range.

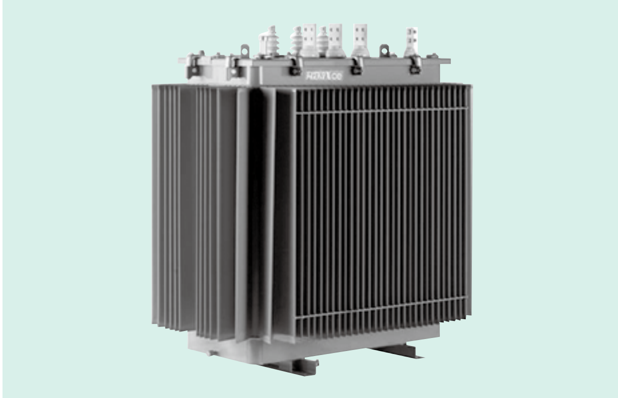


Fig. 5—Super Amorphous X ce Series.
The transformer is designed specifically for photovoltaic power generation systems, using an amorphous transformer with low standby power consumption as a base.

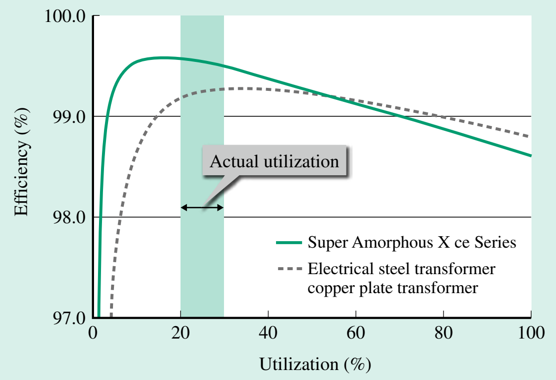


Fig. 6—Comparison of Efficiency Curves.
Achieving high efficiency in the actual utilization range used in photovoltaic power generation helps maximize the amount of power generated.

Fig. 7—Super Amorphous X ce Series Installation.
Safety is improved by enclosing live parts inside a terminal box.

(3) They can be used with a variety of PCSs, including PCSs that do not require an isolation transformer.

DEVELOPMENT OF INTEGRATED SOLUTION FOR MID-RANGE PHOTOVOLTAIC POWER PLANTS

Hitachi has developed and commercialized the Solar Inverter Package, a compact and low-cost grid connection system designed to use the 100-kW PCS described above along with a dedicated amorphous transformer, which are supplied in a cubicle housing. Hitachi also conducted market research, beginning in December 2010, aimed at clarifying the basic concept. At that time, the Japanese government was considering a special measures law (the Act on Special Measures Concerning Procurement of Renewable Electric Energy by Operators of Electric Utilities) to encourage the development of renewable energy and its wider adoption. Its objectives included international initiatives aimed at reducing emissions of carbon dioxide (CO_2) in order to help prevent global warming, and encouraging the installation of more photovoltaic, wind, and other clean power generation systems. The feed-in tariff scheme differed from the previous scheme for purchasing excess electric power in that it obliged the electric utility to purchase all the power generated. In order to segregate the generated electric power from other electric power, this required dedicated connection points to a new high-voltage (6,600-V) grid separate from the existing low-voltage (200 to 400 V) distribution systems. Accordingly, operators needed to obtain new grid connection systems (see Fig. 8).

Against this background, Hitachi embarked on development with a focus on equipment efficiency and with the aim of integrating systems to make them more compact, setting the following development targets for its 100-kW system.

(1) Manufacturing cost: Reduce total cost of existing high-voltage distribution equipment, PCSs, and PCS housings by 10%.

(2) Installation footprint: Reduce installation footprint of existing high-voltage distribution equipment and PCS housings to 76.5% of existing footprint.

(3) Conversion efficiency: Improve efficiency to 94.5% (including step-up transformer), higher than the combined efficiency of existing PCSs and transformers.

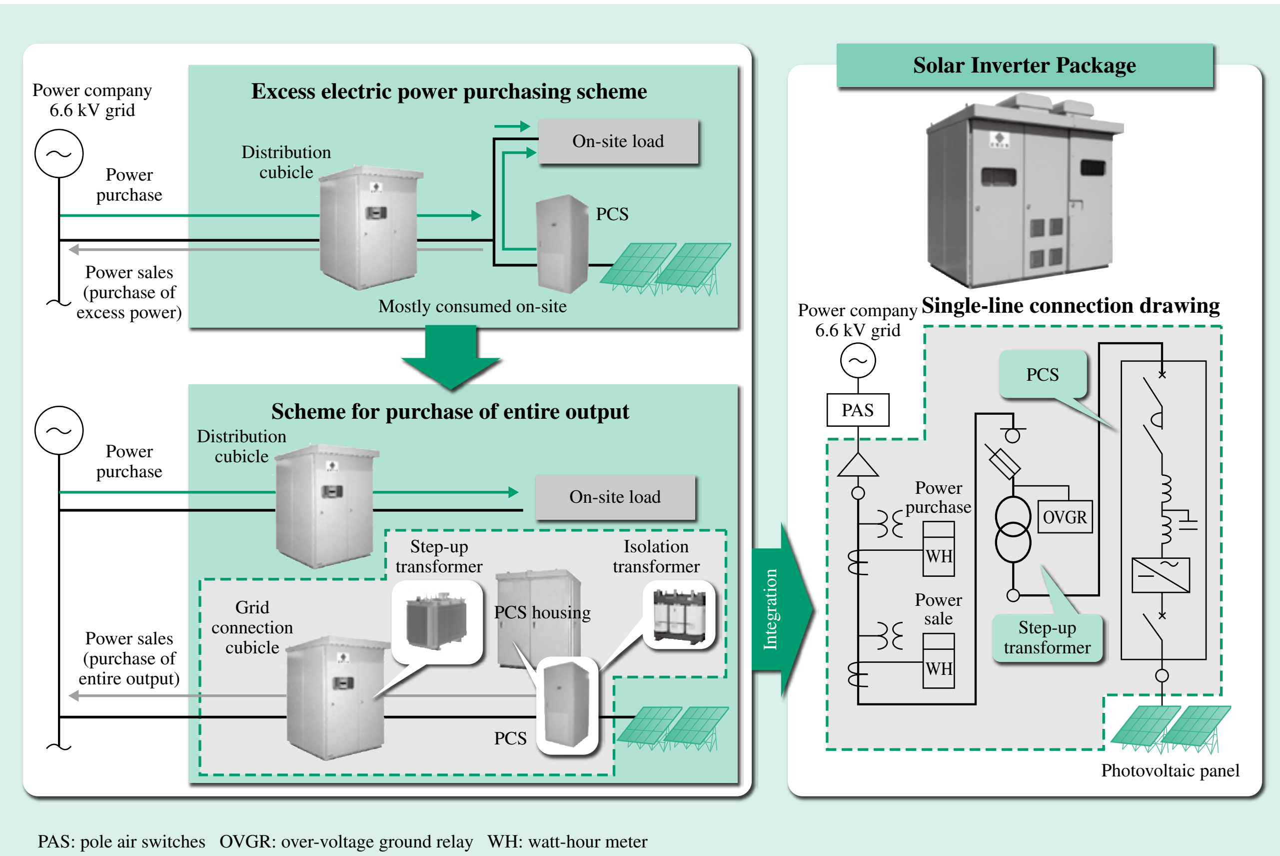


Fig. 8—Grid Connection for Feed-in Tariff Scheme.
Under the feed-in tariff scheme, power generation equipment connects directly to the power company grid.

When working on the equipment design, Hitachi paid particular attention to the following aspects of equipment selection.

(a) Main circuit breaker: A study was conducted to compare a high-voltage load break air switch (LBS) and high voltage, current-limiting power fuse (PF) against a vacuum circuit breaker (VCB) and disconnecting switch (DS), resulting in the lower-cost LBS+PF combination being selected, with short-circuit protection being provided by fusing the PF.

(b) Cooling: Cooling performance is important for PCSs because they generate significant amounts of heat and contain a large number of electronic components. Hitachi ultimately chose to use a fan for mechanical cooling.

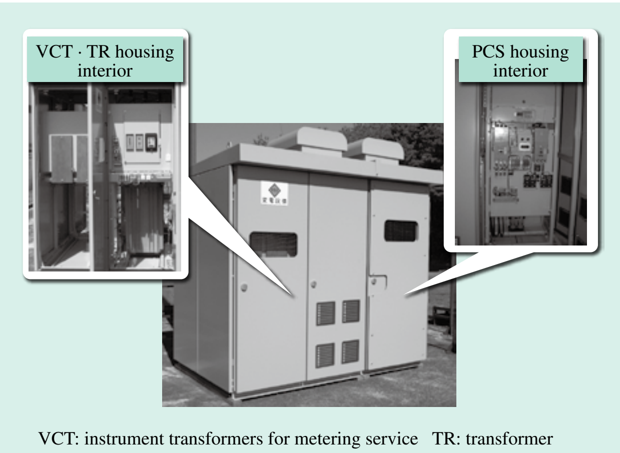


Fig. 9—100-kW Solar Inverter Package.
Integration of the high-voltage distribution equipment and PCS has reduced space requirements to 76.5% that of previous models.

Fig. 10—300-kW Solar Inverter Package.
The product range includes 100-kW, 200-kW, and 300-kW models.

(c) Ventilation design: Because many of the electronic components used in a PCS are rated for indoor use, keeping dust out is important. For the ventilation design, Hitachi fitted a dust filter in the door grill.

(d) Sunlight exposure design: To prevent the heat of the sun from raising the temperature inside the cabinet, a shade panel proven in use with other outdoor cabinets was fitted around the PCS housing.

(e) Protection relays: Over-voltage ground relays (OVGRs) and directional ground relays (DGRs) were fitted to ensure that the protection relays for the grid connection complied with the applicable regulations. To meet the development targets, 100-kW prototypes were produced and subjected to a variety of tests during FY2011. This succeeded in meeting the targets for: (1) Manufacturing cost, (2) Installation footprint, and (3) Conversion efficiency (see Fig. 9).

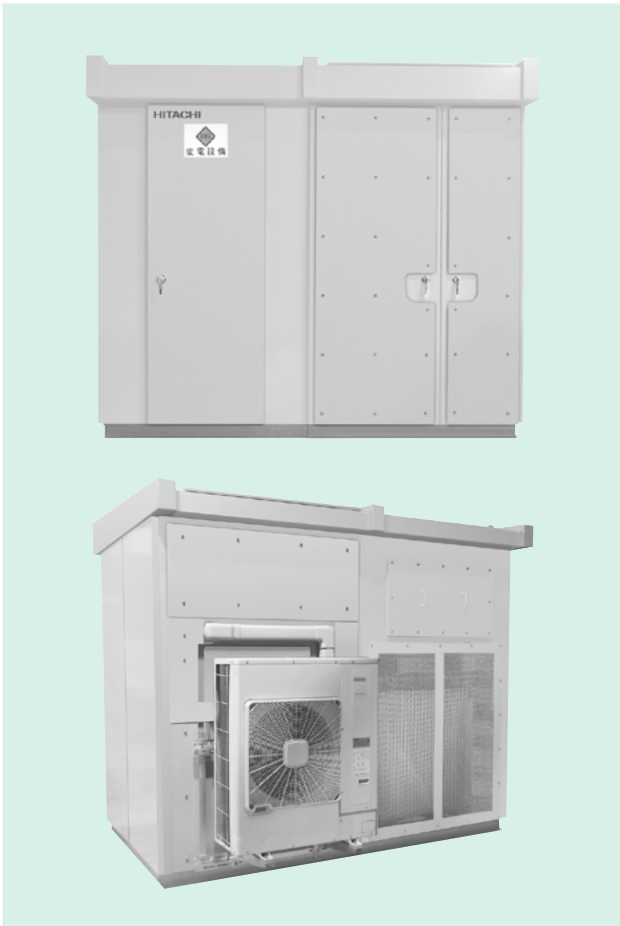


Fig. 11—100-kW Solar Inverter Package (Salt-resistant Model).
To allow installation at sites prone to salt damage, air conditioning is used to segregate internal and external air.

Development of the 100-kW solar inverter package, which is designed to provide reliable, trouble-free, and highly efficient grid connections was completed in April 2012, with 200-kW and 300-kW models following in January 2013 (see Fig. 10). This expansion in the range of available capacities was achieved by incorporating two 100-kW PCSs into a 200-kW system configuration and three 100-kW PCSs into a 300-kW system configuration.

The product range was further extended in November 2013 with the incorporation of a constant power factor control function and the addition of a salt-resistant model that could be installed at coastal sites prone to salt damage (excluding sites where seawater can be blown directly onto the equipment).

Like the standard models, these models were released in 100-kW, 200-kW, and 300-kW versions. To protect the PCS inside the cubicle, the salt-resistant model was fitted with air conditioning in place of the ventilation fan and grill used previously, thus successfully segregating internal and external air. As a result, installation in Okinawa was permitted, subject to conditions (see Fig. 11).

CONCLUSIONS

To achieve wider adoption of renewable energy and efficient energy use, Hitachi is active in a wide range of fields, including smart grids to micro grids.

Hitachi Industrial Equipment Systems Co. is contributing to CO_2 emission reductions and improvements in energy efficiency by drawing on the power electronics, grid connection, power distribution, and control technologies it has built up through the development of photovoltaic power generation components in order to develop equipment and systems in fields such as electric power storage systems and microhydro power generation.

REFERENCES

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