Hitachi Review
Volume 63 Number 7 September 2014

HITACHI
Inspire the Next

# Renewable Energy Solutions

www.hitachi.com/rev

Hitachi Review
Volume 63 Number 6 August 2014

## From the Editor

This edition of *Hitachi Review* describes our work in the fields of photovoltaic, wind, and other forms of renewable energy.

The large-scale installation of renewable energy was triggered in Japan by the introduction in July 2012 of a feed-in tariff (FIT) scheme that guarantees purchase prices for renewable energy. The market is also becoming increasingly global, with the active participation of overseas investors and equipment suppliers.

Meanwhile, Japan has revised its primary energy plan, using the "3E+S" concept (which seeks to balance energy security, economic development, and environmental protection while maintaining safety as a key prerequisite) as a basis for looking at how to achieve a best mix of energy sources given their availability in Japan, and how to improve the balance of supply and demand while also giving consideration to energy efficiency. While renewable energy presents challenges in terms of reliability of supply and cost, the field can expect ongoing government support because of its role as a promising and diversified form of domestic energy production that can help ensure energy security without the need for fuel, while also reducing emissions of greenhouse gases. Forecasts such as those made by The Institute of Energy Economics, Japan anticipate steady ongoing growth in the field out to 2030 or 2050.

Making more effective use of renewable energy will require smart grids that can combine energy saving and advanced systems for balancing supply and demand together with measures for strengthening the power distribution system. If energy saving and energy storage systems can also be combined with the use of distributed generators to provide electric power to the local community during emergencies, this will deliver added benefits. Also important will be ways of utilizing heat, including geothermal and solar thermal energy. While the focus for renewable energy following the introduction of the FIT scheme will be on improving its economics to achieve grid parity, Hitachi also believes it is important to utilize the distinctive characteristics of renewable energy through a mix of technologies. Renewable energy can also be expected to play a role in robust and eco-driven urban development.

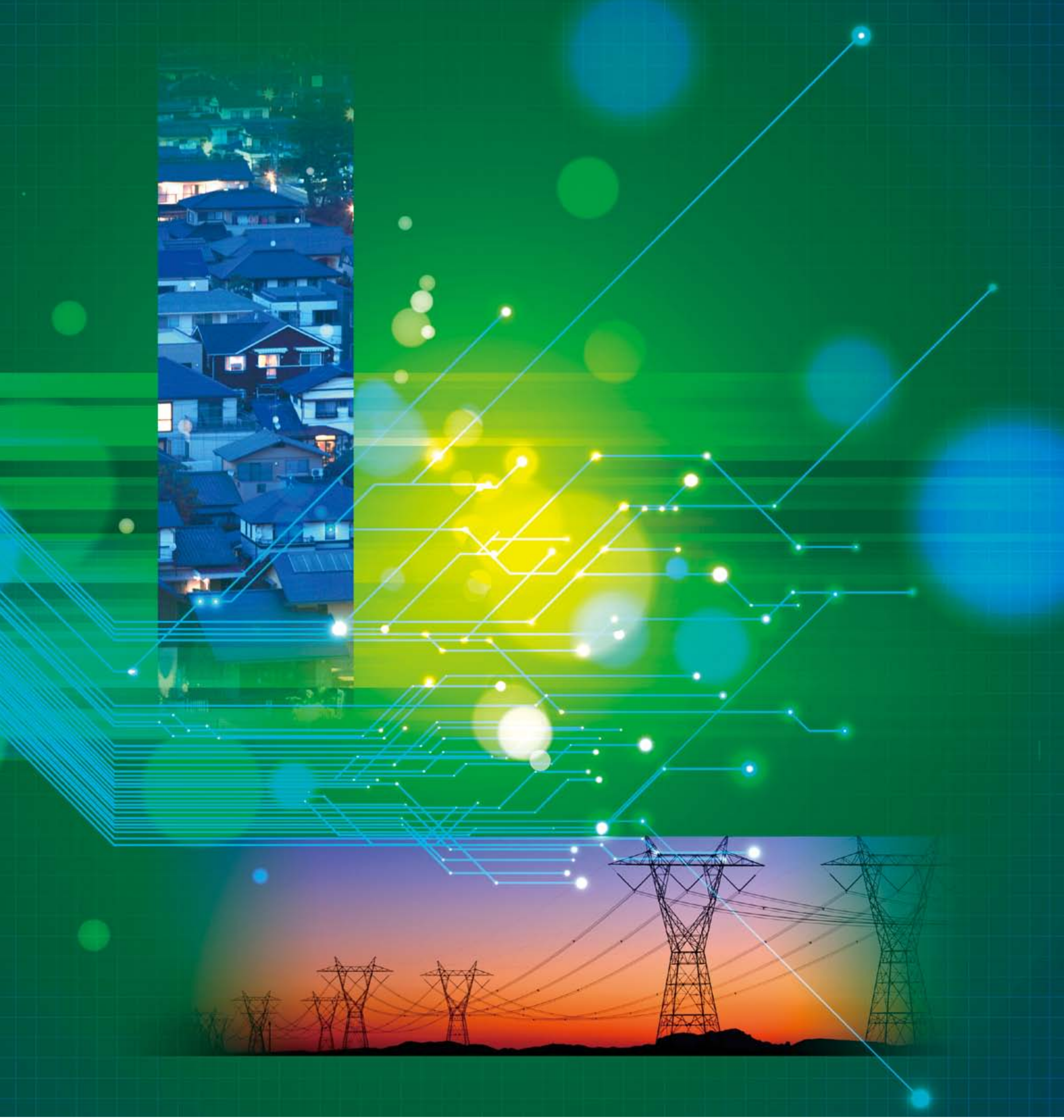
Because renewable energy and smart grids are part of an international trend, Hitachi not only pays careful attention to policy developments in Japan and elsewhere, its business operations also encompass partnerships with numerous overseas customers. The lead article in this issue of *Hitachi Review* provides insight into this. Other articles describe how Hitachi is drawing on its broad-based capabilities as an electrical equipment manufacturer (which include power system, power distribution and control, and information technologies) to encourage the wider adoption of renewable energy, including not only the development of renewable forms of electric power generation, but also multifaceted renewable energy systems that incorporate measures for strengthening power grids and electric power storage systems along with control and other technologies. Through these technologies, Hitachi intends to help create a low-carbon society by contributing to the next generation of structural improvements in the energy sector.

Editorial Coordinator,
Renewable Energy Solutions Issue

**Yasuo Takashima**
General Manager
Renewable Energy & Smart Grid Division
Power Systems Company
Hitachi, Ltd.

* Wind turbine photograph courtesy of Ministry of the Environment Floating Offshore Wind Turbine Demonstration Project

# Renewable Energy Solutions



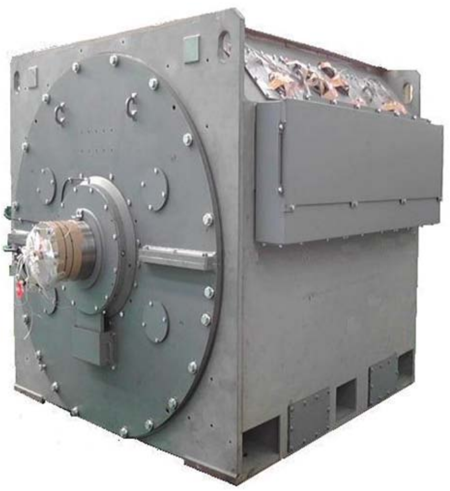
The pace of installation of renewable energy is accelerating around the world, motivated by aims such as cutting use of fossil fuels and improving energy security.
However, in addition to photovoltaic, wind, and other power generation technologies, greater use of renewable energy also creates a need for improvements across the entire power system, including measures for ensuring grid stability.
Based on its knowledge and experience with power systems technology built up over many years, Hitachi is supporting the widespread adoption of renewable energy with a wide variety of solutions, including photovoltaic power generation systems ranging from household systems up to megawatt-class power plants, efficient wind power generation systems that satisfy the need for larger turbines, energy monitoring systems and grid stabilization techniques, and energy-efficient technologies for household appliances.

Oita Solar Power Plant

Super Amorphous X ce Series


Power Distribution and Utilities Monitoring System


Container-type Energy Storage System



Permanent Magnet Generator for 5-MW Wind Turbine

Fukushima Floating Offshore Wind Turbine
(Photograph courtesy of Fukushima Offshore Wind Consortium)

Home Heat Pump Water Heater (BHP-FV46ND)

LED Ceiling Light (LEC-AHS1410B)

LED Light Bulb (LDA17L-G)

Refrigerator-freezer [R-G6700D(XT)]

Products Awarded the 2013 Grand Prize for Excellence in Energy Efficiency and Conservation for their Contribution to Power Saving in the Home

Technotalk

# Contributing to Realization of Low-carbon Society through Total Solutions Incorporating Various Technological Capabilities


**Nobuo Tanaka** Global Associate for Energy Security and Sustainability, The Institute of Energy Economics, Japan

**Tatsuro Ishizuka** Representative Executive Officer, Executive Vice President, Executive Officer, President and CEO of Power Systems Group, President and CEO of Infrastructure Systems Group, Chief Transformation Officer (CTrO), and Deputy General Manager of Smart Transformation Project Initiatives Division, Hitachi, Ltd.

**Yasuo Tanabe** Vice President and Executive Officer, Deputy General Manager of Legal and Communications Group, and General Manager of Government & External Relations Division, Legal and Communications Group, Hitachi, Ltd.

**Yasuo Takashima** General Manager Renewable Energy & Smart Grid Division, Power Systems Company



*Amid concerns about ongoing global warming and a growing frequency of abnormal weather events throughout the world, such as localized heavy rain or cold snaps, there are calls for measures dealing with warming to be taken seriously, with the report of the IPCC of the UN having stated that future warming is inevitable. Renewable energy sources that do not emit $CO_2$ in the generation process are seen as having an important role in countering warming. In its development of renewable energy technology, Hitachi is striving to apply the power system technologies and know-how it has built up through its extensive experience with energy equipment and systems. To help realize a low-carbon society, Hitachi intends to contribute to the wider adoption of renewable energy through total systems that are underpinned by these technological capabilities.*


## Energy Technology Innovations Essential to the World's Future

**Takashima:** Renewable energy is gaining an increasing presence against a background that includes global climate change and a changing energy resource situation. Today, we have invited Nobuo Tanaka, the Global Associate for Energy Security and Sustainability at The Institute of Energy Economics, Japan to discuss what form renewable energy should take in the future and what role equipment suppliers should play. Mr. Tanaka was Executive Director of the International Energy Agency (IEA) for four years (2007 to 2010). In particular, he was instrumental in devising scenarios for reducing carbon dioxide($CO_2$), one of the main missions of the IEA, and presented the Blue Map scenarios. These scenarios are used as reference models throughout the world.

**Tanaka:** The IEA produces two major publications, the annual World Energy Outlook, and Energy Technology Perspectives, which is published every two years. The Blue Map scenarios are included in the latter publication. They focus on the problem of global warming from a long-term perspective, presenting scenarios for halving the level of global carbon dioxide($CO_2$) emissions by 2050 (relative to 2005), with different versions being presented with each new issue of Energy Technology Perspectives. These scenarios are based on a broad international consensus on the need to reduce carbon dioxide($CO_2$) emissions to limit the rise in temperature over the 21st century to no more than 2°C. In terms of energy mix, the IEA has put forward its vision for achieving this in its "450 Scenario" (for stabilizing the level of carbon dioxide($CO_2$) in the atmosphere at 450 ppm), which was published in the World Energy Outlook. The purpose of the Blue map scenarios is to look at the technical aspects of how this can be achieved.

If the level of carbon dioxide($CO_2$) emissions is to be halved, the priority in the short term is to use low-cost technologies to improve energy efficiency. In the long-term, on the other hand, energy technology innovations will be needed to remove carbon from the electric power generation process. The target for the Blue Map scenarios is an energy mix of 50% renewable energy, 25% nuclear energy, and 25% thermal power generation with carbon capture and storage (CCS). The scenarios play an important role as a basis for debate and study, providing a road map for achieving this outcome at minimum cost and considering the technological innovations that will be needed to reduce carbon dioxide($CO_2$) emissions, while also maintaining energy security and economic growth.

**Takashima:** The fact that the IEA has extended its role beyond its previous focus on oil and the maintenance of energy security to include presenting a vision of a future energy mix for minimizing global warming is an impressive achievement.

**Tanaka:** In that context, the energy situation is currently undergoing major changes, the shale gas revolution being one example. Although a shift from coal to natural gas reduces carbon dioxide($CO_2$) emissions, it is not an ultimate solution to the problem. The key issue at present is how we can quickly and sustainably invest in the development of carbon-free technologies.

**Takashima:** In this regard, what are you looking for in equipment suppliers such as ourselves?

**Tanaka:** To achieve a low-carbon or carbon-free society, we need the comprehensive deployment of usable technologies, including more efficient thermal power generation, the commercialization of CCS technology, and energy efficiency improvements across various different types of equipment. There remains considerable scope for the development of renewable energy technology. In the field of nuclear power generation, all of humanity could benefit from the wider adoption of the latest technologies with a high degree of intrinsic safety, such as the integral fast breeder reactor and dry reprocessing techniques using electrolysis that General Electric Company (GE) of the USA has plans to commercialize.

The importance of energy management technologies is also growing. Whereas energy security in the 20th century was all about the stockpiling of oil, in the 21st century it is about the sustainable supply of electric power, requiring technologies for the optimal control of supply and demand.

When you consider these challenges, the world's future will depend on such things as research and development capabilities, technical skills, and the ability to innovate. These are areas where suppliers like Hitachi have a very important role to play.

## Multi-faceted Contribution to Wider Adoption of Renewable Energy

**Ishizuka:** Hitachi has built up extensive experience and technology in the energy sector, including generation, transmission, distribution, and demand-side management. In the case of renewable energy, we are able to contribute not only through the development and supply of our own technologies and products, but also through collaboration with corporate partners across all stages from planning and engineering to construction, and through business management aspects such as earning a return on investment.

Because renewable energy has a highly variable output, power system management technologies will be essential if it is to become more widely used. These include grid stabilization technologies for maintaining power quality (including frequency and voltage), technologies for efficient transmission and distribution, smart grids, and demand-side management (controlling the demand for electric power as well as its supply). Hitachi also supplies solutions that draw on its technology and experience in these areas.

Along with generation systems, management functions for interconnecting with the grid will be key to the wider use of renewable energy. Having taken over its wind power generation system business from Fuji Heavy Industries, Ltd. in 2012, Hitachi has established the capability to provide total solutions that incorporate grid interconnection and stabilization as well the development of wind turbine systems and their manufacture, delivery, and maintenance services.

One of the major features of our systems is the wind turbine itself. In 2003, Hitachi and Fuji Heavy Industries, Ltd. jointly developed a downwind turbine, a configuration rarely used elsewhere in the world. Although more difficult technically than other types of wind turbines, the

**Nobuo Tanaka**

**Global Associate for Energy Security and Sustainability, The Institute of Energy Economics, Japan**

Joined the Ministry of International Trade and Industry in 1973. Following appointments as Minister for Energy, Trade and Industry at the Japanese embassy in the USA; Vice President of the Research Institute of Economy, Trade and Industry; Director-General for the Multilateral Trade System Department of the Ministry of Economy, Trade and Industry; Director for Science, Technology and Industry at the Organisation for Economic Co-operation and Development (OECD); and Executive Director of the International Energy Agency (IEA), he took up his current position in September 2011.

**Tatsuro Ishizuka**

**Representative Executive Officer, Executive Vice President, Executive Officer, President and CEO of Power Systems Group, President and CEO of Infrastructure Systems Group, Chief Transformation Officer (CTrO), and Deputy General Manager of Smart Transformation Project Initiatives Division, Hitachi, Ltd.**

Joined Hitachi, Ltd. in 1978. Following appointments as manager of Hitachi Works in the Power Systems Group, President and CEO of the Power Systems Company, and Executive Officer and CEO of the Power Systems Group, he took up his current position in April 2014.

development was able to draw on the knowledge built up by the aeronautical division of Fuji Heavy Industries, Ltd. for the blades, tower, and other turbine components, and also on Hitachi's expertise in the design and manufacture of generators and other power system control equipment.

**Tanaka:** What is meant by a downwind configuration?

**Ishizuka:** It means a wind turbine with the rotor on the downwind side of the tower. Most wind turbines have the rotor on the upwind side. Turbines are designed with the rotor tilted so as to prevent the flexing of the blades under wind load from causing them to collide with the tower. With a downwind rotor, this tilting means that the rotor is oriented downward in the direction opposite to the incoming wind. That is, a feature of downwind turbines is that they can make more efficient use of wind energy than an upwind configuration at sites where updrafts are common, such as the mountainous terrain where most wind turbines in Japan are located, because they can align themselves perpendicular to the wind direction.

Also, having the blades downwind of the tower is safer in strong winds, meaning this configuration is seen as being more suitable for conditions in Japan, where typhoons are common.

Along with their use in Japan and in other parts of Asia and elsewhere with similar environmental conditions, the downwind configuration will also offer superior generating efficiency in future floating offshore wind power generation systems because of its ability to make efficient use of wind energy even when the tower is tilted. We also aim to satisfy demand for larger turbine sizes by taking advantage of the fact that everything from design onwards is handled in-house.

**Takashima:** What about large (megasolar) photovoltaic power plants?

**Ishizuka:** An important factor in photovoltaic power generation is to have total system integration encompassing a layout that maximizes generating efficiency, power conditioners and other equipment, and grid interconnection technology. In our role as a plant supplier, Hitachi has built up engineering technologies that are both efficient and reliable, and we are applying these technologies to the construction of megasolar power plants.

Other important factors for power generation businesses that use renewable energy are obtaining the required land and ensuring the best possible connection to the grid.

In addition to providing consulting services, we can help expedite the adoption of renewable energy in a variety of different ways, not only through technology, but also through schemes, which also include finance, offered by Hitachi Capital Corporation, one of our group companies.

**Tanaka:** There has been growing interest over recent years in the local production of energy for local consumption (distributed generation). Does Hitachi also have a model for supporting this approach?

**Takashima:** The different parts of Hitachi have worked together to satisfy the recent growth in demand from customers who want to implement local production of energy for local consumption, including local governments installing renewable energy or seeking to attract data centers. We also offer support for the development of smart farms, including the use of renewable energy and information technology (IT) in dairy farming and other forms of agriculture.

## New Energy Systems that will be the Envy of the World

**Takashima:** It is recognized that the wider adoption of renewable energy needs to be underpinned by government policy in a variety of ways. Based on your experience, which includes both policy development and working for an equipment supplier, what is the best way

### Yasuo Tanabe

**Vice President and Executive Officer, Deputy General Manager of Legal and Communications Group, and General Manager of Government & External Relations Division, Legal and Communications Group, Hitachi, Ltd.**

Joined the Ministry of International Trade and Industry in 1978. Following appointments as Manager of the International Affairs Division of the Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry; Vice President, Research Institute of Economy, Trade and Industry; and Minister's Secretariat Council (Economics Affairs Bureau), Ministry of Foreign Affairs, he took up his current position in October 2013.

### Yasuo Takashima

**General Manager Renewable Energy & Smart Grid Division, Power Systems Company**

Joined Hitachi, Ltd. in 1971. Following appointments as Vice General Manager Chubu Area Operation, Vice General Manager Renewable Energy & Smart Grid Division, he took up his current position in 2012.

Mr. Takashima is a member of The Institute of Electrical Engineers of Japan.

to coordinate policy with the role of a supplier?

**Tanabe:** I recently read a very interesting report from the Institute of Energy Economics, Japan. It concerned the limit on the total capacity of wind power that can be installed due to its highly variable, wind-dependent output, which it estimated at 10 GW assuming nothing is done to deal with this variability. However, given the ability to limit output by 5% based on wind conditions, and a 5% margin for using demand response to control demand, this limit could be raised to 51 GW. This five-fold increase represents a very large potential.

When electric power pricing is based exclusively on sale through a feed-in tariff (FIT) scheme, however, it makes sense for generators to produce as much power as possible regardless of what is happening on the grid. Achieving the above level of output fluctuation control requires not only technology, but also the policy incentives to use it. What is needed is to combine both policy and business considerations.

**Tanaka:** This means designing a framework that puts a price on flexibility as well as capacity. This has been the subject of much debate in Europe, and is something that Japan should be considering in the future.

**Ishizuka:** In technical terms, there remains considerable potential for progress on grid management to help ensure grid stability. In developed economies, load dispatch offices and other similar facilities currently manage the grid with reference to changes in the weather and fluctuations in supply and demand. There has also been interest recently in grid management technology based on high-speed computation that uses computers to provide continuous estimates of demand fluctuation so that the system can know in advance where to shed generator output or which load to turn off when a given situation arises. At Hitachi, we are developing a management system that can perform high-speed calculations to determine the state of supply and demand across the entire grid at 30-second intervals, make predictions 30 seconds in advance, and take the necessary steps. The system is now undergoing customer trials.

In addition to automatic regulation of output and providing the ability to utilize large amounts of renewable energy without the need for storage batteries, we also see these leading-edge technologies as being able to help optimize supply and demand in emerging economies and elsewhere.

**Tanabe:** Given the ongoing changes in the world's energy situation, I believe that energy policy considerations demand that we improve resiliency, both at a national level and in terms of corporate practices. At Hitachi, meanwhile, although we are improving coordination between operating divisions to pursue renewable energy initiatives, we also need to demonstrate greater effort and speed in the future in both our operations and technology development.

While energy policy in Japan has been a success when viewed in global terms, the aftermath of the Great East Japan Earthquake has raised numerous issues. Through efforts by companies to resolve these issues, and through policies that encourage such efforts, I hope we can once again develop new energy systems that will be the envy of the world.

**Tanaka:** I agree. As I said earlier, technology is the key to creating a low-carbon society, and we need to expedite measures for achieving this by having policies that take technology into account. I have learned much from today's discussion and would like to thank you for inviting me. I look forward to Hitachi utilizing its comprehensive capabilities to improve energy security, not only in Japan, but around the world.

**Takashima:** By combining Japanese technology, our own Hitachi technology, and effective policies, we can contribute globally to the creation of a low-carbon society. Thank you for your time today.

Expert Insights

# CCS Technology Powering the Future in Saskatchewan, Canada

**Robert Watson**
President & CEO, SaskPower

Imagine transforming a coal-fired power plant more than a half-century old into a model of environmental sustainability, where a fuel both bountiful in supply and predictable in price generates cleaner, greener energy than ever thought possible.

Saskatchewan is a dynamic place to be right now. The province's strong economy is providing a wealth of opportunity, and the population continues to climb. As the province's Crown electrical utility, SaskPower is right in the middle of the excitement.

As the province grows, so does demand for electricity. In 2013, demand for power increased 6.4 % — the highest annual growth in 20 years. Demand is expected to increase by more than 30% over the next 20 years and double between now and 2050.

From now to 2017, SaskPower will add up to 1,300 MW to the provincial power system through new projects and initiatives as well as investments in current infrastructure. The piece of this puzzle that has captured the world's attention, the Boundary Dam Integrated Carbon Capture and Storage Project, is at center stage as SaskPower prepares for the province's future.

## PROJECT OVERVIEW

SaskPower is the developer of the world's largest and most significant post-combustion carbon capture and storage (CCS) project—the first to fully integrate CCS technology with commercial-scale coal-fired generation unit. The project involves transforming a coal-fired power turbine nearly 50 years old into a model of environmental sustainability. The aging coal-fired Unit #3 at Boundary Dam, near Estevan, Saskatchewan, is being converted into a reliable, long-term producer of 110 MW of baseload electricity.

The capture facility is now constructed and testing is underway to ensure safety and functionality. The power facility rebuild is on track for completion in 2014. The work remaining involves piping around the unit for water, oil and steam. More than 450 regulatory inspections are currently being carried out to bring the project to completion. To date, the project represents five million man-hours of work without a single lost-time injury.

In the very near future, carbon dioxide($CO_2$) emissions from Boundary Dam Unit #3 will be reduced by up to 90%, as one million tons of post-combustion $CO_2$ emissions are captured annually. The captured $CO_2$ will then be sold to Cenovus for its use in enhanced oil recovery projects. Some of the $CO_2$ will also be stored in a deep saline formation known as Aquistore.

## WHY CCS, AND WHY NOW?

Coal is an abundant energy source in Saskatchewan, and SaskPower has traditionally relied upon it as a cost-effective power supply option that is secure and affordable.

Environmental impact, however, also needs to be taken into account as we move forward. New federal $CO_2$ regulations, which will take effect on July 1, 2015, have eliminated conventional coal-fired generation without $CO_2$ capture as a future option.

The new federal performance standard will affect both new coal-fired units and units that have reached the end of their useful life. To continue to keep coal as a viable fuel source, SaskPower has taken a leadership role in incorporating CCS technology.

In choosing the technology, we evaluated a number of options and looked at factors such as plant size, location, cooling processes, new builds vs. rebuilds, and the different capture technologies available. We ultimately determined that the most economically viable option, for a first project, was to use post-combustion technology on a refurbished, end-of-life power unit and sell the captured $CO_2$ for enhanced oil recovery. Revenue from the $CO_2$ was essential to the business case.

The Cansolv aqueous amine scrubbing technology was selected following a rigorous Request for Proposal process that considered factors such as performance, cost, and technological risk.

## BEYOND BOUNDARY DAM

SaskPower's investment in CCS technology does not end when Boundary Dam Unit #3 begins commercial operation in 2014. In collaboration with Hitachi, SaskPower is leading the development of a carbon capture test facility to validate carbon capture technologies.

Adjacent to SaskPower's Shand Power Station in southeastern Saskatchewan, the facility will offer a neutral platform for vendors to verify and improve post-combustion technologies in a commercial setting. Dozens of pilot plants worldwide are testing post-combustion carbon capture. Often, these are smaller scale facilities producing results that tend to be more qualitative than quantitative.

The Shand Carbon Capture Test Facility is unique as it has been sized to manage measurement uncertainty and is the only facility emerging from a full-scale commercial carbon capture project. SaskPower will be able to use the knowledge gained from this facility to broaden our experience base and, in turn, further support the Boundary Dam project.

What have we learned so far? Coal CCS can be both technically and commercially viable, provided that sufficient due diligence is completed, regulations are defined, and value can be obtained for $CO_2$. We look forward to showing the world what can happen when all of these factors fall into place.

As we continue to innovate in carbon capture and storage technologies, we look forward to working with Hitachi and finding new opportunities for partnership.

## LESSONS LEARNED

When you're the first to try something new, inevitably there are challenges to face along the way. The Boundary Dam project has been no exception.

Receiving approvals to undertake a technology that had never been done before on a commercial scale was the first, and largest, step we had to take. A strong business case, extensive study, and education were required before our executive, board, and provincial government felt that pursuing a CCS solution was the right course to follow.

Today, commissioning has begun and our focus is increasingly shifting to understanding what it will take to operate the plant, both from a technical and a "people" perspective.

Operating a carbon capture plant is a whole new world for SaskPower. To prepare our employees, we've brought in an unprecedented classroom training program and a simulator training system that mimics the exact control systems of the future power island and capture island control rooms in order to bring familiarity with the control system, eliminate operator error, and reduce training time.

We've learned many lessons along the way, but two in particular stand out to us—and they come right from the beginning of the project.

Lesson one: You can't overstaff in situations like this. A large project team brought together from the start is a must.

Lesson two: Investment of significant dollars into the evaluation phase of a project is essential for ensuring success after project approval in terms of design, construction, and commissioning.

Organizations can be hesitant to commit significant financial resources to estimate and design a solution prior to project approval. We spent approximately $50 million (CAN) evaluating this undertaking. This allowed us to do our homework, evaluating feasibility and setting out a target to capture up to 90% of emissions, or a million tons of $CO_2$ annually, and meet (or surpass) federal regulations.

## SHARING WHAT WE KNOW

Industry interest in the Boundary Dam project has been strong. Later this year, SaskPower will host a CCS Symposium from Sept. 30 – Oct. 2, 2014, to bring governments and organizations together from around the world.

Participants will be given the opportunity to see the project first hand and learn about SaskPower's CCS initiatives.

Based on the knowledge gained from the Boundary Dam CCS project, preliminary estimates suggest that SaskPower could save 20 – 30% on future carbon capture projects. These savings are coupled with the knowledge and efficiencies gained on budgets, time and human resources, risk and regulatory management, and CCS technology selection and integration.

More information can be found at www.saskpowerccs.com.

Expert Insights

# Lietuvos elektros skirstymo bendrovė investuoja į taupymą

English translation appears on page 16

**Mantas Vaskela**
AB LESTO
Inovacijų skyriaus vadovas

Lietuvos elektros skirstymo bendrovė AB LESTO šalyje aptarnauja daugiau nei 1,6 mln. klientų ir užtikrina, kad kiekvienas jų galėtų patikimai naudotis elektros energija, gautų aktualias paslaugas. Bendrovei, rinkoje užimančiai natūralią monopolinę padėtį, tenka ir socialinis vaidmuo – ugdyti racionalaus elektros energijos vartojimo tradicijas ir skatinti energijos taupymą

2013 m. elektros skirstymo bendrovės AB LESTO buvo išskirtiniai – prie bendrovės tinklų prijungta beveik 1700 naujų elektrinių – tai 5 kartus daugiau nei prieš metus ir net 46 kartus daugiau nei 2011 m. Didžiąją dalį (1646 objektai) visų naujai prijungtų elektrinių sudarė saulės jėgainės – instaliuota maksimali jų galia sudaro 55,6 megavato (MW). Taip pat pernai prijungta 40 vėjo jėgainių, kurių bendra instaliuota galia sudaro 7,3 MW, ir 7 biomasės elektrinės – jų galia sudaro 4,19 MW.Bendra prie LESTO tinklų prijungtų saulės jėgainių galia šiuo metu sudaro 68 MW, vėjo – 59 MW (taip pat papildomai 223 MW vėjo jėgainių Lietuvoje prijungta prie perdavimo tinklo operatoriaus AB „Litgrid“).

„Saulės elektrinių plėtotojai praėjusių metų pradžioje skubėjo pasinaudoti itin palankiu buvusiu teisiniu reglamentavimu, užtikrinusiu galimybę gauti palankius elektros energijos supirkimo tarifus. Šiais metais dėl pasikeitusių teisinių aplinkybių rinkoje tikimasi mažesnio aktyvumo“, – teigia Mantas Vaskela, AB LESTO Inovacijų skyriaus vadovas.

Didėjantis šalies ekonominis aktyvumas augina naujųjų vartotojų prijungimo projektų skaičių. Per 2013 m. LESTO prie skirstomųjų tinklų prijungė apie 21 tūkst. naujųjų vartotojų objektų – 14 proc. daugiau nei 2012 m., kuomet prijungta 18 130 naujų vartotojų objektų. Naujų vartotojų prijungtų objektų leistinoji naudoti galia sudarė 297,4 MW – tai 25,6 proc. daugiau nei 2012 m., kuomet leistinoji naudoti galia sudarė 236,8 MW.

2013 metai elektros skirstomojo tinklo operatoriui AB LESTO buvo itin sėkmingi – grupė pirmą kartą nuo veiklos pradžios dirbo pelningai ir uždirbo 47,646 mln. Lt grynojo pelno. Taip pat pasiekti aukščiausi iki šiol elektros energijos tiekimo patikimumo, klientų pasitenkinimo rodikliai. Taip pat ir pats skirstomasis tinklas veikė efektyviausiai iki šiol – bendrovė patyrė mažiausias skirstymo technologiniuose įrenginiuose sąnaudas ir daugiau elektros energijos patiekė vartotojams.

Nevertinant stichinių reiškinių („force majeure“) poveikio, vidutinė neplanuotų elektros energijos persiuntimo nutraukimų trukmė (SAIDI) per 2013 m. vienam vartotojui siekė 72,67 minutes, o vidutinis neplanuotų ilgų nutraukimų skaičius vienam vartotojui (SAIFI) 2013 m. per ataskaitinį laikotarpį siekė 0,96 karto. Palyginimui, 2012 m. šie rodikliai sudarė atitinkamai 76,67 min. ir 1,06 karto. SAIDI, įskaičiuojant „force majeure“ poveikį, per 2013 metus sudarė 153,9 min. (2012 m – 288,1 min.), o SAIFI – 1,43 karto (2012 m. – 1,83 k.).

LESTO kasmet nutiesia daugiau nei po 1000 km požeminių kabelių linijų. Per 2013 m. LESTO nutiesė 1326 kilometrus 10/6/0,4 kV įtampos kabelių linijų. Kabelių linijos itin sumažina gedimų skaičių eksploatacijos metu, pati linijų eksploatacija tampa pigesnė, be to, oro linijas pakeitus kabeliais gražėja kraštovaizdis.

### Siekia efektyvumo

LESTO ilgalaikė strategija iki 2020 m. numato bendrovės siekį būti efektyvia, optimaliai išteklius naudojančia, į kliento pasitenkinimą besiorientuojančia ir visuomenės pasitikėjimą turinčia bendrove. LESTO savo veikla siekia prisidėti prie Europos Sąjungos iniciatyvų taupyti energiją, saugoti aplinką, integruotis į bendrą elektros energijos rinką, tiekti saugią, patikimą ir prieinamą energiją, dinamiškai prisitaikyti prie besikeičiančios vidinės ir išorinės aplinkos.

„Bendrovė siekia didinti savo vertę dirbdama šiomis kryptimis: didindama klientų aptarnavimo efektyvumą ir kokybę; kurdama modernią, į pokyčius orientuotą organizacinę kultūrą, taikyti šiuolaikinius vadybos metodus, efektyvinti veiklos procesus; mažindama nuostolius elektros energijos tinkle, užtikrindama naujų vartotojų prijungimą ir patikimą tinklo veikimą“, – teigia M. Vaskela.

Europos Sąjunga yra numačiusi šalims narėms, įskaitant ir Lietuvai, energijos vartojimo efektyvumo įpareigojimus. Pagal ES direktyvos reikalavimus yra apskaičiuotas privalomas sutaupyti energijos kiekis Lietuvoje 2014–2020 m. Ši direktyva LESTO reiškia įpareigojimus kiekvienais metais investuoti į naujas energijos taupymo ir efektyvumo didinimo priemones.

LESTO didelį dėmesį teikia veiklos efektyvumo didinimui. Šiuo metu peržiūrima ilgalaikė investicijų strategija, apimanti skirstomojo tinklo modernizavimą, kabelių linijų, kurios yra atsparios gamtos stichijų poveikiui, tiesimą, išmaniųjų apskaitų diegimą, informacines technologijas ir kitas veiklai svarbias sritis. LESTO efektyvinant bendrovės procesus, ne tik mažėja bendrovės sąnaudos, bet ir gerėja klientams teikiamų paslaugų ir aptarnavimo kokybė.

Jau šiuo metu LESTO investuoja į elektros energijos apskaitos prietaisų modernizavimą bei jų automatizavimą – nuotoliniu būdu bendrovė gauna informaciją iš daugiau nei 20 tūkst. verslo klientams įrengtų elektros energijos skaitiklių, tai leidžia nuotoliniu būdu apskaityti daugiau nei pusę LESTO persiunčiamos elektros energijos. Investicijos į apskaitos prietaisų modernizavimą sudarė prielaidas plėtotis Lietuvos elektros biržai, formuotis laisvai elektros energijos rinkai, kurioje vartotojai gali pasirinkti mažiausią kainą ir geriausias paslaugas teikiančius nepriklausomus elektros tiekėjus, gali geriau kontroliuoti suvartojamos elektros energijos kiekius.

LESTO bendradarbiaudama su koncernu “Hitachi” planuoja diegti naujos kartos oro linijas, kuriomis galės efektyviau perduoti elektros energiją. Taip pat vertina galimybę į perdavimo tinklą integruoti elektros energijos kaupimo sprendimus, kurie naudodami atsinaujinančios energijos išteklius ir baterijas aprūpintų tam tikras tinklo dalis elektros energija net ir sutrikus skirstymo tinklo veiklai. Konsultacijos bus teikiamos ir norint išsiaiškinti kaip galima pagerinti SAIDI ir SAIFI rodiklius Lietuvoje bei pasiekti patikimesnį elektros energijos tiekimą.

## Kviečia prisijungti prie iniciatyvų

Racionalaus elektros energijos naudojimo skatinimas yra viena iš prioritetinių LESTO socialinės atsakomybės krypčių, prisidedanti prie aplinkos ir energetinių išteklių tausojimo bei šalies įsipareigojimų vykdant Europos Sąjungos klimato kaitos programą. Vykdomas projektas „Tiek, kiek reikia“ – skirtas kurti racionaliai gyvenančios visuomenės tradicijas – čia ieškoma racionalaus elektros energijos vartojimo būdų tiek buičiai, tiek verslui.

Verslo įmonės jau trečius metus kviečiamos prisijungti prie LESTO įsteigto „Žaliojo protokolo“ – tai vienintelis šalyje susitarimas, kuriuo įmonės ir organizacijos patvirtina, kad yra susipažinusios su aplinką tausojančiomis idėjomis, skatinančiomis racionalų elektros energijos vartojimą, šioms idėjoms pritaria ir pasižada jas taikyti praktikoje.

2013 metais LESTO įteiktas Nacionalinis atsakingo verslo apdovanojimas – bendrovė pripažinta „Metų bendruomeniškiausia įmone“ Lietuvos didelių įmonių kategorijoje.

LESTO įžvelgia didelį potencialą elektromobilių plėtrai ateityje – efektyviau energiją vartojančios naujos technologijos ir jų diegimas automobilių pramonėje tampa vis konkurencingesnis rinkoje, ypač lyginant su senais, tradicinį iškastinį kurą naudojančiais automobiliais. Įveikti 100 km elektromobiliu kainuoja tik apie 4-8 Lt, todėl elektra yra santykinai pigesnė ir efektyviau vartojama, lyginant su iškastiniu kuru. Bendrovė viena pirmųjų šalyje įsigijo elektromobilį – „Nissan LEAF“.

Viena didesnių bendrovės patiriamų problemų – vagystės iš skirstomojo tinklo įrenginių. Vagysčių apimtys iš skirstomojo tinklo įrenginių 2013 m. buvo panašios kaip ir 2012 m. – nors patirti praradimai buvo 1,3 proc. didesni ir sudarė beveik 1 mln. Lt, vagysčių skaičius sumažėjo 1,7 proc. – užfiksuotos iš viso 825 vagystės. Net 83 proc. visų vagysčių nuostolių patirta dėl transformatorių aušinimo alyvos vagysčių.

2013-ieji metai buvo itin reikšmingi, kovojant su įsisenėjusia vagysčių iš elektros skirstomųjų tinklų įrenginių problema – LESTO, bendradarbiaudama su policija ir kitomis institucijomis, išaiškino 63 nusikalstamas veikas, sulaikyti 39 jas padarę asmenys, vagims skirtos pirmosios realios laisvės atėmimo bausmės. Bendrovė kviečia vietos gyventojus būti budrius ir visais atvejais informuoti apie pastebėtus įtartinus veiksmus šalia elektros įrenginių.

LESTO, atlikdama misiją patikimai tiekti elektros energiją, ir toliau dės visas pastangas didinti akcininkų, visuomenės, ir darbuotojų gaunamą vertę. LESTO vizija – būti pavyzdine įmone, turinčia visuomenės pasitikėjimą.

Expert Insights

# Lithuanian Electricity Distribution Company Invests in Savings

**Mantas Vaskela**
Head of Innovation
AB LESTO

The Lithuanian electricity distribution company AB LESTO serves more than 1.6 million customers in the country, and ensures that each of them can reliably use electricity and receive relevant services. The company, enjoying a natural monopoly in the market, also plays a social role by promoting the traditions of rational use of electricity and energy conservation.

The year 2013 was exceptionally good for AB LESTO with nearly 1,700 new power plants being connected to the company's grid, five times more than the previous year and 46 times more than in 2011. The majority (1,646) of the newly connected plants were solar power plants with a maximum installed capacity of 55.6 MW. Also, last year the company connected 40 wind turbines with a total installed capacity of 7.3 MW, and seven biomass power plants with a capacity of 4.19 MW. The total capacity of solar power plants currently connected to the LESTO network is 68 MW, with 59 MW of wind power (moreover, an additional 223 MW of wind power plants in the Republic of Lithuania were connected to the power transmission grid of operator Litgrid AB).

Early last year, solar power developers were eager to take advantage of the former highly favorable legal regulations supporting high purchase rates of electricity. This year, due to legislation changes, we expect lower market activity.

The country's growing economic activity has led to an increase in the number of new customer connection projects. During 2013, about 21,000 new consumer facilities were connected to the LESTO distribution network. This is 14% more than in 2012, when 18,130 new user facilities were connected. The permissible power of new user facilities was 297.4 MW, 25.6% more than in 2012, when the permissible power was 236.8 MW.

The year 2013 was particularly successful for the electricity distribution network operator LESTO: for the first time since the inception of operations the group was profitable and earned 47.646 million litas of net profit. The company also achieved its highest level of electricity supply reliability and customer satisfaction so far. Similarly, the distribution network has been the most effective so far—the company had the lowest distribution costs in process facilities, and supplied more electricity to customers.

Excluding the effects of natural phenomena (force majeure), the average duration of unscheduled interruptions of supply (SAIDI) during 2013 per user was 72.67 minutes, and the average long unplanned interruptions per customer (SAIFI) during the 2013 reporting period amounted to 0.96 times. By comparison, the figures for 2012 amounted to 76.67 minutes and 1.06 times respectively. The SAIDI, including the force majeure effects, amounted to 153.9 minutes during 2013 (288.1 minutes in 2012) and SAIFI was 1.43 times (1.83 times in 2012).

Every year LESTO lays more than 1,000 km of underground cable. During 2013, LESTO laid 1,326 km of 10/6/0.4 kV cable. Cable lines significantly reduce the number of failures during operation, while the line operation itself is less expensive. Moreover, replacement of overhead lines with cables makes the landscape even more attractive.

## Seeking Efficiency

LESTO'S long-term strategy until 2020 entails the company's efforts to be an efficient company enjoying public confidence, to use resources optimally, and to be focused on client satisfaction. In its activities, LESTO aims to contribute to the European Union's initiatives to save energy; protect the environment; integrate into a single market for electricity; supply safe, reliable, and affordable energy; and dynamically adapt to the changing internal and external environments.

The company aims to increase its value by working in the following areas: increasing customer service efficiency and quality; building a modern, change-oriented corporate culture that applies modern management techniques, and improves business efficiency processes; and reducing losses in the electricity grid, ensuring the connection of new customers and the reliable operation of the network.

The European Union has imposed energy efficiency obligations on its member states, including Lithuania. The EU directive envisages the energy binding savings for Lithuania for the period of 2014-2020. For LESTO, this directive imposes an obligation to invest in new energy-saving and efficiency improvement measures each year.

LESTO is focused on ensuring operational efficiency. Currently the company is engaged in a long-term investment strategy that covers the modernization of the distribution network, the construction of cable lines resistant to the effects of natural disasters, the installation of smart metering and information technology, and other important areas of activity. By increasing the efficiency of its processes, LESTO not only reduces the company's costs, but also improves customer satisfaction and the quality of service.

LESTO already invests in the modernization and automation of electricity metering equipment. The company remotely receives information from more than 20,000 electricity meters installed for business clients, allowing the remote accounting of more than half of electricity transferred by LESTO. Investments in the modernization of meters created the prerequisites for the development of the Lithuanian power exchange, building a free electricity market where consumers can choose independent power suppliers offering the lowest price and the best service, and can better control their consumption of electricity.

In cooperation with Hitachi, LESTO has plans to introduce a new generation of overhead lines for more efficient transmission of electricity. The company also appreciates the opportunity to integrate energy storage solutions into the transmission network that can use renewable energy sources and batteries to supply certain parts of the network with power, even in cases of natural failures. Consulting will be provided to figure out how to improve the SAIDI and SAIFI indicators in Lithuania and achieve a more reliable supply of electricity.

### Invitation to Join the Initiatives

Promotion of rational energy use is another priority area for corporate responsibility at LESTO, contributing to the conservation of the environment and energy resources and the country's obligations under the European Union's climate change program. The company is engaged in an "As much as needed" project to build a society based on rational living practices, and to look for rational energy consumption patterns for both households and businesses.

For the third consecutive year, businesses are invited to join LESTO'S Green Protocol, the only concord in the country through which companies and organizations can demonstrate their environmental awareness, promote the rational use of energy, support such ideas, and promise to apply them in practice.

In 2013, LESTO was awarded the National Responsible Business Awards, recognizing it as "The Best Socially Oriented Company of the Year" in the category of large Lithuanian companies.

LESTO sees great potential for the development of electric vehicles in the future. Implementation of energy-efficient technologies in the automotive industry is becoming increasingly competitive in the market, especially compared to the obsolete vehicles that use traditional fossil fuel. It only costs about 4-8 litas to travel 100 km in an electric vehicle, indicating that electric power is relatively cheaper and more efficient than fossil fuels. The company was one of the first in the country to acquire electric cars (the Nissan LEAF*).

One of the major problems faced by the company is theft from distribution network devices. While the volume of theft from distribution network equipment in 2013 was the same as in 2012, with the actual loss being 1.3% higher and worth nearly 1 million litas, the number of thefts declined by 1.7% to 825 thefts. As many as 83% of all losses due to theft were incurred because of the theft of transformer cooling oil.

The year 2013 was very important in the fight against the chronic problem of theft from the electricity distribution network. LESTO, in collaboration with the police and other authorities, investigated 63 offenses and arrested 39 perpetrators. For the first time, thieves have been given prison sentences. The company calls on local residents to be vigilant and report all cases of suspicious activity in the vicinity of electrical equipment.

In its mission of ensuring a reliable power supply, LESTO will continue to make every effort to increase added value for shareholders, the public, and employees. LESTO's vision is to be a model company with the confidence of the public.

* Nissan LEAF is a trademark owned by or licensed to Nissan Motor Co. Ltd.

Expert Insights

# Сотрудничество компании Хитачи лтд., и ОАО "Российские сети" в рамках политики инновационного развития

English translation appears on page 19

**Бердников Роман Николаевич**

Первый заместитель Генерального директора по технической политике ОАО "Россети"

ОАО «Россети» – крупнейшая в мире электроэнергетическая компания, являющаяся стратегическим активом государства. «Россети» объединяют межрегиональные, региональные распределительные электросетевые компании (МРСК/РСК) и магистральный сетевой комплекс. Всего в зоне ответственности холдинга сосредоточено 70 % распределительных и 90 % магистральных сетей от основных активов электросетевого комплекса Российской Федерации.

Внедрение инновационных решений и технологий для повышения надежности электроснабжения и повышения доступности сетевой инфраструктуры являются стратегическим приоритетом для ОАО «Россети» и одним из основных приоритетов на ближайшую перспективу, заложаенных Стратегией развития электросетевого комплекса Российской Федерации.

ОАО «Россети» при выборе объектов инновационной программы применяет сбалансированный подход. Есть мероприятия, необходимость которых очевидна, исходя из текущих, операционных задач – к примеру, автоматизация и энергоэффективность, или перспективные технологические направления – такие, как мультиагентные системы. Компания самостоятельно инициирует подобные работы, однако для их обсуждения и экспертизы максимально широко привлекаются партнёры, преподаватели ВУЗов и академий, учёные, эксперты – все те, кого принято называть экосистемой инновационного развития. Одновременно, в компании чутко прислушиваются к предложениям российских и международных научных и производственных организаций – они составляют основной блок НИОКР.

Одним из таких примеров поиска различных инновационных решений в области снижения потерь при передаче электроэнергии в сетях, снижения всех видов ресурсов для эксплуатации объектов и административных зданий и развитие системы управления учета энергоэффективностью является сотрудничество с Hitachi Ltd.

В соответствии со Стратегией развития электросетевого комплекса к 2017 году, потери электроэнергии по сравнению с 2012 годом должны быть сокращены на 11%. Планируется, что они составят 8,79%. Положительная динамика изменений данного показателя подтверждает верность расчетов и возможность достижения заявленных показателей: с 2009 по 2012 годы потери сократились на 8,5 %, а в 2013 по отношению к 2012 году на 2,1 %.

В связи с этим в рамках Соглашения о сотрудничестве между ОАО «Россети» и Hitachi Ltd, заключенного 20 июля 2013 года, была организована совместная работа по разработке первой в мире комбинированной установке на базе солнечных панелей и аккумуляторов большой мощности.

По результатам всестороннего технико-экономического анализа рассматривается возможность реализации пилотного проекта по установке солнечной станции в Бурятии. Район обусловлен длинной одноцепной линией 35 кВ протяженностью более 150 км. Установка позволит району получать электроснабжение без перерыва, работая в изолированном режиме без использования дизель-генератора. Такое технологическое решение с применением «солнечных технологий» на базе распределенной генерации и интеллектуального управления повышает надежность сети, снижает потери на передачу электроэнергии на больших расстояниях, и позволяет в гибком графике выводить одноцепные линии в ремонт, для проведения их обслуживания и модернизации.

Expert Insights

# Cooperation between Hitachi, Ltd. and JSC Russian Grids within the Framework of the Innovative Development Policy

**Roman Nikolaevich Berdnikov**

First Deputy General Manager for Rosseti JSC Technical Policy

Rosseti JSC is the world's largest electric power company, and a strategic asset of the state. Rosseti is comprised of interregional and regional distribution grid companies (IDGCs/RDGCs), as well as the bulk electric power system. In terms of power grid capital assets in the Russian Federation, the corporate area of responsibility covers 70% of distribution and 90% of bulk transmission networks.

Innovative solutions and technology implementation for power supply reliability improvement and increased network infrastructure availability are the strategic priorities of Rosseti JSC, and one of the main priorities for the near future established by the Power Grid Development Strategy of the Russian Federation.

Rosseti JSC uses a balanced approach to select targets for its innovation program. Judging by the current operational targets, we can define some obviously necessary activities, such as automation and increasing energy efficiency, as well as the development of technologies with strong potential for the future such as multi-agent systems. Being the promoter of such activities, the company calls on its partners, university and college professors, scientists, experts, and those who are known as the ecosystem of innovation development to participate in this dialogue and provide expert examination. Furthermore, the company considers proposals from Russian and international scientific and industrial organizations and draws on these to a large extent in its research and development.

Cooperation with Hitachi, Ltd. is one such example of seeking innovative solutions for reducing electric power losses in transmission networks, reducing the use of resources in the operation of facilities and administrative buildings, and developing an accounting management system for energy efficiency.

The Power Grid Development Strategy has set a target of reducing electric power losses by 11% (relative to 2012) by 2017. The anticipated reduction is 8.79%. The progress made on this index confirms the calculation accuracy and the ability to achieve the target. Losses were reduced by 8.5% between 2009 and 2012, and by 2.1% in 2013 (relative to 2012).

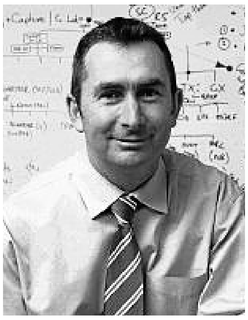
In this regard, within the framework of the Cooperation Agreement concluded between Rosseti JSC and Hitachi, Ltd. on July 20, 2013, an agreement was reached to develop the world's first integrated plant powered by solar panels and high-capacity batteries.

Drawing on the results of comprehensive technical and economic analyses, the feasibility of a pilot solar plant installation project in the Republic of Buryatia is being considered. The area is served by a 35-kV single-circuit line that is over 150-km long. The plant will supply electric power to the area without interruption, working in standalone mode without the use of a diesel generator. This technological solution, which includes "solar technologies," is based on distributed generation and intelligent control. It improves the reliability of the network, reduces the losses of electric power transmission over long distances, and allows the single-circuit lines to be taken out of operation on a flexible schedule for improvements, maintenance and modernization.

Expert Insights

# SMART Energy

## —One Eskom view of the future highlighting the need for strategic partnerships.



**Barry MacColl**

General Manager, Research, Testing and Development, Group Sustainability,
Eskom Holdings (SOC) Ltd. South Africa

There is surely no more exciting place to be at the moment than in the energy industry. An industry faced with enormous challenges but also technology opportunities that threaten to revolutionise the business model and operations of a traditional power utility such as Eskom. Climate change, finite fossil reserves, rising prices, societal inequalities and global economics are amongst the many macro drivers pressurizing utilities to relook their strategies. As they do they are looking to distributed generation, energy storage, metering, ubiquitous communications and the internet of things (amongst others) to become 'smarter'.

Eskom is quick to point out that current networks and operations are not dumb but acknowledges there is major room for improvement towards more intelligent networks. There are seemingly as many definitions of Smart Grids as there are people prepared to offer one so it does not add a lot of value to focus on one particular view, or indeed one particular technology. I have often described Smart Grids as supervisory control and data acquisition (SCADA) on steroids. Fundamentally, all applications involve some form of control and data acquisition through a telecommunications media. Whether it is controlling and visualizing a 400kV circuit breaker or a household appliance, the principles and challenges are the same. What speedy advances ininformation and computer technology (ICT) bring to the power grid however are opportunities to connect devices in the 'internet of things'. This brings endless possibilities. Imagine a world in which every single electrical energy device is 'connected' and every device has the ability to communicate and respond to outside stimulus and commands. Right down to light bulb level – current light-emitting diode (LED) bulbs could rely on universal serial bus (USB) sockets and internal processors to bring intelligence to this the most basic of appliances. Is it possible to control every light bulb on the planet simultaneously? Technically yes but the back end systems and processes as well as the infrastructure, standards, protocols etc. are a long way behind.

Eskom Research, Testing and Development (R,T&D) is working on various projects that all have an element of 'smart' to them. Online Coal Analysis allows the combustion characteristics of the fuel to be known before it enters the plant and thus enables better operational decision making. It also assists in contract management issues with suppliers. Similarly real time analysis of pulverized fuel boiler operating conditions allows improvements in efficiency and reduction in boiler tube wear rates and failures. Rooftop photovoltaic (PV) and other distributed generation technologies offer promise to the utility if their characteristics can be controlled en masse and today's inverters can be managed to provide many benefits to the power system operator. Most utilities have smart metering projects and Eskom is no different. We are focusing on functionality and pushing for open source solutions and standards. In a country struggling to meet electrical demand the need for real time demand-side management (DSM) is paramount and appliance control and real time pricing are just two ways to achieve this, both enabled by smart technologies. Visualisation, simulation, and data management are also key areas of study with cyber security rapidly rising in importance as a research area.

The list is seemingly endless and it is often harder to decide what areas of smart grid not to pursue than to succumb to the temptation to try a bit of everything. Research management becomes even more difficult when offered such a sumptuous array of options and focussing on a few critical areas is required if results are to be of significant value. Partnerships with industry allow research groups to cover a lot more ground than they could do if they went it alone. No group has the skills and expertise in all these environments and by working with suppliers such as Hitachi the results can be delivered a lot more quickly. It is part of Eskom's strategy to work with firms that are at the cutting edge of what is possible and we are happy to confirm that Hitachi is in this category. It is a healthy relationship in which the utility brings a need or a vision and the supplier brings the expertise and possible solutions. Of course it is not this simple in practice and many smart research projects end up looking very different in the final solution than they did at conceptualization.

There are four fundamental principles which Eskom looks for in all smart solutions. Firstly, as far as possible, it must be open source. We prefer common functionality which is not device or supplier specific. If a particular device fails, it should be replaceable from a number of sources. This relies on strong protocol based specifications and standardization where possible. My favorite example of this is USB – from printers to cameras to memory sticks – plug it in and it works. First time. This also implies backend software and systems should be similarly open and that brings the second principle into play. The power of the solution is in the app. Just like a tablet is pretty useless without applications so too the smart backend. And similar to tablet applications, anyone who has the training and inclination can write one. In the utility of the future it is highly likely that customers will write or purchase apps that meet their requirements. That access to energy and billing data will be open and that apps based on this data will be plentiful. The third aspect is that of integration – most smart apps and systems suffer from a failure to adequately backward integrate into legacy systems. This is crucial in the power sector given the size and scope of the applications – large investment has gone into developing these systems (billing, customer care, and work management, etc.) into which smart solutions must seamlessly integrate. And lastly but most importantly from a management point of view is the all-important business case, or more simplistically – why do it? Here we find that the answer lies less in one or two applications that stand alone but in the idea of sequential value add at declining investment cost. Take smart metering as an example. The upfront cost of the meter and its installation are the biggest components in the life of the asset. If the inherent technology is chosen wisely however, it is possible to build on this initial investment at very low additional cost. Adding appliance control, real time pricing, load limiting, power buy back schemes etc, to an installed platform is usually a firmware upgrade that can be downloaded to millions of devices from a central point and thus the incremental cost is very small for a large functionality increase. So taking a life time approach to the strategy is key to the success of the business case but also probably the hardest thing to do technically. To design a future proof, open source, standards based technology platform for a whole suite of apps to run on. But apply this through the electricity supply chain and you have the promise of a true smart grid.

We look forward to a continued relationship with Hitachi on the journey towards such a future as we know we cannot do it alone. Planning the future today in an uncertain world requires that all factors are considered and that best practices are fully understood so that confident decisions can be made. Our relationship with Hitachi builds our confidence and our understanding of the future – inspiring the next!

## Expert Insights

# 台灣發展風力發電產業的現況與前景

English translation appears on page 23

**許文都**
台灣風力發電產業協會 理事長

有感於 2011 年日本 311 大地震引發海嘯及福島核電廠輻射外洩等重大災難，台灣開始省思能源方針，同年 11 月 3 日台灣馬總統公布新能源方針，主軸為「確保核安、穩健減核」與「打造綠能低碳環境、逐步邁向非核家園」，其中全力推動再生能源、穩定電力供應及降低碳排放為打造綠能低碳環境的推動重點。2012 年公布「千架海陸風力機」目標，先開發陸域風場，再擴展離岸海域風場；2030 年風力裝置容量合計達 4,200 MW（其中離岸風力機裝置容量為 3,000 MW）。2012 年 7 月經濟部公告離岸風力發電示範系統獎勵辦法 :2015 年前完成 2 個民營及 1 個台灣經營示範風場，共計 6 架示範風力機，惟台電配合台灣機組製造可延長至 2020 年；2020 年前完成 3 個示範風場共計 300 MW 離岸風力機裝置容量。

近來台灣陸域風場開發受到居民及環保團體的強烈抗爭，本島設置量恐接近上限，隨著千架海陸風力機計畫及離岸風電示範獎勵辦法的啟動，台灣期透過內需離岸風場帶動大型風力發電產業鏈發展。現台灣之風力發電產業鏈結構雖略具雛型，然尚無實際參與離岸風電之經驗，亦缺乏相關技術能力，需與海外合作藉以提高自主能量。由於離岸風場開發難度更甚陸域，民營得標商目前以海外成熟風機系統為優先考量，台灣業者目前缺乏運轉實績，暫難切入市場。目前，為能讓台灣當地業者確立自行生產風機系統的自主能力，台灣運用工業合作計畫資源協助業者自海外引進相關技術，然 3 GW 離岸風場開發尚面臨環評法規、漁業補償、躉購電價及航運安全等課題，加上整機、海事工程施工船舶設備投資規模高達百億元以上，亟待台灣在風場開發方針及產業基礎建設方面予以積極協助。

中鋼公司長期為台灣金屬工業領頭羊，已累積相關土木及海事船舶工程技術的堅實基礎，且具充份能力供應風力機機組、塔架、船體所需鋼材，本身亦具備優良企業形象，加上台灣順應世界綠能趨勢推動離岸風電能源方針，積極規劃投入離岸風力發電產業，希望能建構離岸風力發電產業的整體供應鏈。2013 年 12 月中鋼董事會通過成立「風電事業發展委員會」，下設風電業務處、工程處及技術處。為配合台灣的自行生產整機示範案，中鋼將自海外引進風電整機技術。日立目前積極開發 5 MW 離岸風力機，其設計係考量日本所處地域之多颱風、多地震以及雷電易生等自然環境因素。2013 年中鋼與日立已簽署合作備忘錄，因日本與台灣地處環境相近，日立的離岸風力系統如能引進台灣，將對台灣風能電力供應有極大效益，也期望未來台日合作能為台灣創造新興產業。

Expert Insights

# Current Status and Future Prospects of the Wind Power Industry in Taiwan

**Hsu, Wen-du**

President, Taiwan Wind Turbine Industry Association

In the wake of the 2011 Great East Japan Earthquake and tsunami that caused radiation leaks at the Fukushima Nuclear Power Station, Taiwan began a rethink of its energy policy. On November 3 of the same year, a new energy policy was announced by President Ma Ying-jeou that included, "ensuring nuclear safety, steadily reducing dependence on nuclear energy" and "creating a low-carbon environment and gradually progressing toward a non-nuclear homeland." The push to create a low-carbon, green energy environment focuses on adoption of renewable energy, a stable power supply, and carbon emissions reduction. A target of "1000 marine and terrestrial wind turbines" was announced in 2012. The development of terrestrial wind farms will take place first, before expansion to include offshore marine wind farms. By 2030, total installed wind power capacity will reach 4,200 MW (with offshore wind turbines having an installed capacity of 3,000 MW). In July 2012, the "Incentive Program of Offshore Wind Power Demonstration System" was announced by the Ministry of Economic Affairs. These called for the completion of one government-run and two private sector demonstration wind farms with a total of six demonstration wind turbines by 2015, though the Taiwan Power Company project can be extended to 2020 if it uses Taiwan-built turbines. Three additional demonstration wind farms with a total offshore installed wind power capacity of 300 MW are also to be completed by 2020.

The development of terrestrial wind farms in Taiwan has recently been met with intense opposition by residents and environmental groups, so the number of installations on main island of Taiwan is probably reaching its upper limit. With the launch of the Thousand Wind Turbines Project and the Offshore Demonstration Incentive Program, Taiwan will use domestic demand from offshore wind farms to drive the development of a large wind power industry chain. Though the wind power industry chain in Taiwan is beginning to take shape, it does not have any actual experience in offshore wind power operations and lacks necessary technical skills. Overseas assistance is therefore necessary to improve self-sufficiency. As the development of offshore wind farms is far more difficult than terrestrial farms, the private operators who submitted winning bids have given priority to mature overseas wind turbine systems. Taiwanese operators lack actual operating experience so will find it difficult to enter the market for now. To help local Taiwanese businesses establish homegrown wind turbine system production capabilities, Taiwan is drawing on the resources of the Industrial Cooperation Program to introduce relevant technologies from overseas. The development of a 3-GW offshore wind farm, however, faces issues such as environmental impact assessment regulations, fisheries compensation, feed-in pricing, and navigational safety. Investment in turbine units marine engineering ships, and equipment will also exceed NTD 10 billion. Government support is therefore necessary for wind farm and infrastructure development.

China Steel Corporation (CSC) has long been the leader of Taiwan's metal industries and has accumulated extensive experience in civil and maritime engineering technology. It is also fully capable of providing the steel needed for turbine units, towers, and ship hulls. CSC also has a good corporate image. With Taiwan's push to promote offshore wind power in line with global green energy trends, CSC has been actively planning to enter the offshore wind power industry and hopes to establish a complete supply chain for the industry. In December 2013, the CSC Board of Directors approved the formation of a "Wind Power Business Development Committee" to oversee the Wind Power Business Office, Engineering Office, and Technology Office. To support Taiwan's turbine production demonstration project, CSC will introduce overseas technology for the manufacture of complete wind turbine units. Hitachi is currently working to develop a 5-MW offshore wind farm. Its design takes into account the fact that Japan's geographic location means it experiences frequent typhoons, earthquakes, and lightning strikes. CSC signed a memorandum of understanding with Hitachi in 2013. Due to the similarities between the physical environments of Taiwan and Japan, if the Hitachi offshore wind power system can be introduced to Taiwan as planned, this will be very beneficial to wind power supply in Taiwan. It is also hoped that future Taiwan-Japan cooperation will help create a new emerging industry for Taiwan.

Report

# Outlook for Installed Capacity of Solar Photovoltaic Power Generation in Japan up to 2020

*OVERVIEW: The Institute of Energy Economics, Japan has developed a model for projecting future installation of solar PV power generation capacity and has used it to estimate the installation capacity in Japan up to 2020. The institute projects that cumulative installed capacity will rise from 6,890 MW in 2012 (5,350 MW residential and 1,540 MW non-residential) to between approximately 31,200 MW and 32,500 MW in 2020 (14,900 to 16,300 MW residential and 16,200 MW non-residential). Residential system prices are anticipated to fall from 460,000 yen/kW in 2012 to between 290,000 and 300,000 yen/kW, and non-residential from 410,000 yen/kW to 260,000 yen/kW. As a result, the feed-in tariff (price paid for generated power) will fall to between 10 and 17 yen/kWh for residential generation and 25 yen/kWh for non-residential. The total cost from 2012 to 2020 is projected to be between 3 trillion and 3.2 trillion yen, with a average surcharge of between 0.37 and 0.39 yen/kWh.*

## INTRODUCTION

AN expansion in the installation of solar photovoltaic(PV) power generation capacity has been anticipated since the introduction in Japan of a feed-in tariff scheme for renewable energy in July 2012. Although this appears to have led to a short-term boost in installation, the long-term outlook is clouded by the potential for policy changes prompted by energy mix considerations. Despite this, projecting the extent of installation capacity over the medium-term is crucial to business strategy planning by Japan's solar PV power industry.

In response, The Institute of Energy Economics, Japan has developed a model for projecting the future installation of solar PV power generation capacity and has used it to estimate the installation capacity in Japan up until 2020. This article presents its predictions. Because installation capacity is heavily influenced by the economic benefits of installing solar PV power generation systems, the model estimates installation based on factors that include the system price and feed-in tariff.

## OVERVIEW OF PROJECTION MODEL FOR SOLAR PV POWER GENERATION SYSTEM INSTALLATION

For reasons including the extensive availability of actual data and the short lead time between commencing installation and starting generation, a regression equation was used to estimate annual new residential capacity in terms of explanatory variables such as gross domestic product (GDP) and economic factors. For the non-residential case, on the other hand, the paucity of available data and the need to consider the time lag between commencing construction and starting generation led the institute to decide to use an existing model to project future installation.

The models also incorporated a "learning curve effect" to represent how the price of solar PV systems falls as more of such systems are installed. Since the

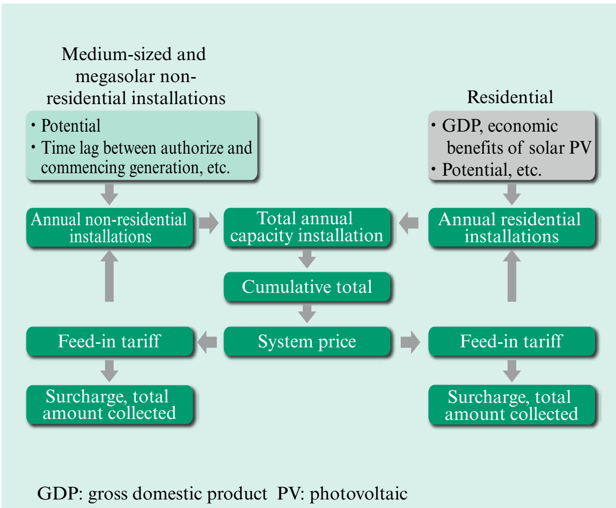



*Fig. 1—Overview of Projection Model for Installation of Solar PV Power Generation Capacity.*
*The model treats annual installation capacity as a function of economic benefits. Independent estimates are made for residential and non-residential installations, and the combined totals are used to calculate the value for cumulative installed capacity that is used to project the fall in system price due to the learning curve effect.*

cumulative installed capacity used for this purpose needs to include both residential and non-residential systems, the amount of installation for these two different types of systems are interrelated (see Fig. 1).

## PROJECTING NON-RESIDENTIAL INSTALLATION CAPACITY

### Structure of Projection Model

The model uses actual data as a basis for estimating authrized as a proportion of the total potential for solar PV installation. The capacity authorized for installation each year is calculated by multiplying this proportion by that year's residual potential. The lead time is represented by calculating a time lag coefficient from the capacity authorized for installation and the capacity that actually commenced operation. The time lag coefficient is then used to calculate how much capacity commences operation each year. These calculations are performed separately for medium-sized (up to 1 MW) and large "megasolar" plants (1 MW or more). The system price is calculated based on the learning curve effect, and the feed-in tariff for each year is calculated based on a simple payback period of 10.2 years (the current period used to calculate tariffs). Table 1 lists the assumptions.

### Projection

Fig. 2 shows the projection results. For non-residential generation, 1,030 MW of megasolar capacity was installed in FY2012. This is projected

Table 1. Non-residential Projections and Assumptions
*The potential is calculated from Ministry of Economy, Trade and Industry figures.*

| | |
|---|---|
| Potential installation | Medium-sized (up to 1,000 kW)<br>20,300 MW (public buildings, etc.) |
| | Megasolar (1,000 kW or more)<br>83,500 MW (unused/underused land + abandoned farmland, etc.) |
| Proportion of potential actually installed | 50% |
| System price | • 405,000 yen/kW (2012) (87% of residential price)<br>• Price in subsequent years calculated by modeling learning curve effect (based on total installations, including residential) |
| Feed-in tariff | • 42 yen/kWh (2012) → 37.8 yen/kWh (2013)<br>• Tariff in subsequent years calculated by model |
| Feed-in tariff period | 20 years |
| Simple payback period | 10.2 years |

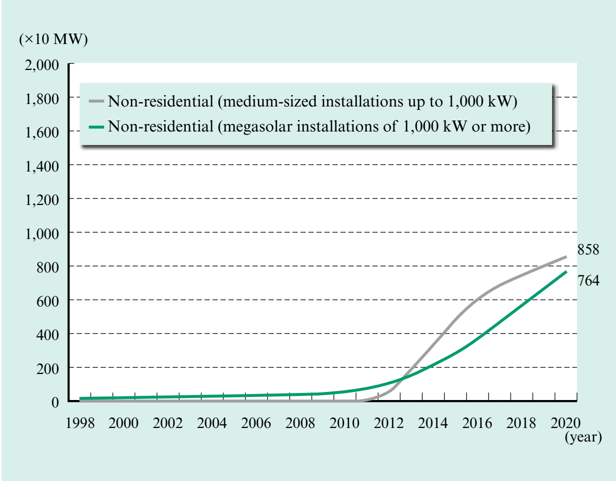



*Fig. 2—Projection of Cumulative Non-residential Installation of Solar PV Power Generation.*
*The rate of installation of medium-sized (up to 1,000 kW) plants is projected to begin falling in late 2015 due to the reduction in residual potential (availability of potential sites). The rate of megasolar plant installation, on the other hand, is expected to remain steady. However, the projection will need to be revised to take account of factors such as how many authorized projects are cancelled.*

to increase to 7,640 MW in 2020 with an annual average of 830 MW of new capacity commencing operation. For medium-sized power plants, capacity installation in FY2012 was 510 MW. This is projected to increase to 8,580 MW in 2020 with an annual average of 1,010 MW of new capacity commencing operation. That is, total non-residential capacity is projected to rise to 16,220 MW.

However, there remains little data on the time lag between project authorize and the commencement of generation. Also, because approvals include projects where land acquisition has yet to be completed, and because it is believed that, in some of these cases, there is no genuine likelihood of or intention to acquire the land, the proportion of authorized projects that will actually enter operation remains unclear. Accordingly, there is a need to revise the projections for future installation of non-residential capacity once more data has been collected on project approvals and how much of this capacity actually commences generation.

Due to the learning curve effect, which grows along with cumulative installed capacity (including the projections for residential capacity installation described below), the system price is projected to fall from 405,000 yen/kW in 2012 to 263,000 yen/kW in 2019 (the reference period for calculating the 2020 feed-in tariff). As a result, the feed-in tariff is

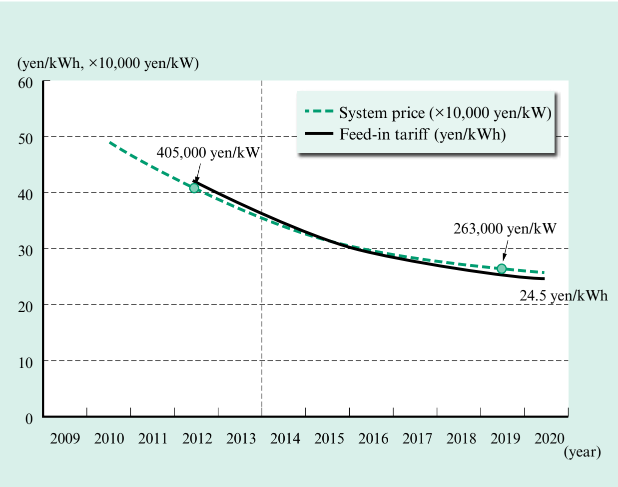



*Fig. 3—Projection of Cumulative Non-residential Installation of Solar PV Power Generation.*
*Projections for Non-residential Feed-in Tariff and System Cost. Because the entire output of non-residential power plants is sold to the utility, the system price and feed-in tariff will remain exactly proportional to each other assuming the simple payback period remains the same. Although this graph shows a small lack of proportionality, this is a consequence of the feed-in tariff for each year being calculated based on the system price for the previous year.*

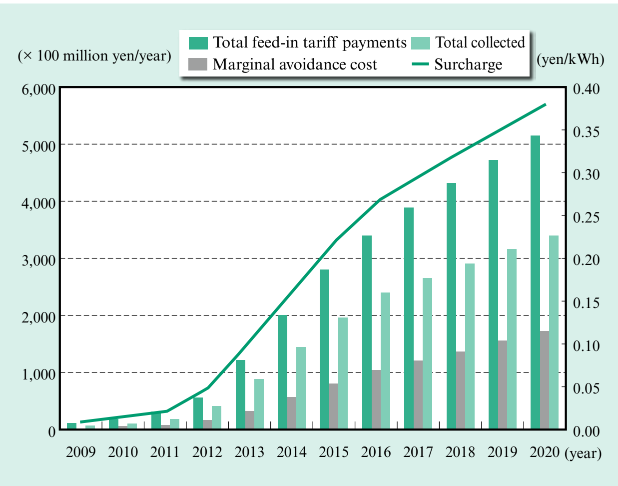



*Fig. 4—Projections for Total Non-residential Feed-in Tariff Payments and Surcharge.*
*Based on the feed-in tariff scheme, the marginal avoidance cost is 10.4 yen/kWh. The model also assumed electricity use, excluding in-house generation, of approximately 900 TWh.*

projected to fall from 37.8 yen/kWh in 2013 to 24.5 yen/kWh in 2020 (see Fig. 3). Note that, while the amount of residential installation also influences the non-residential system price, when a number of scenarios for different simple payback periods were considered for residential installation (as described below), the different scenarios did not result in large variations in system price. Accordingly, Fig. 3 shows only a single case for the above non-residential system price.

Fig. 4 shows total power purchases and the surcharge. The surcharge is projected to increase from 0.05 yen/kWh in 2012 to 0.38 yen/kWh in 2020, with the total annual cost rising from 42.2 billion yen to 340 billion yen. The cumulative total from 2012 will reach 1,900 billion yen.

## PROJECTING RESIDENTIAL INSTALLATION

### Structure of Projection Model

Fig. 5 shows the projection model. The model projects annual installation of solar PV power generation capacity from factors that include the economic benefits of system installation, per capita GDP, and time trends. However, rather than capacity installation, the model calculates the proportion of residual potential that is actually installed. Multiplying the residual potential by this installation ratio gives the annual capacity installation, and the sum of the annual values gives the cumulative installed capacity. Adopting this model structure expresses how the falling residual potential gradually becomes a constraint on installation, causing annual capacity installation to also fall.

**(1) Calculation of potential**

The potential was obtained by using statistics from the Housing and Land Survey (Ministry of

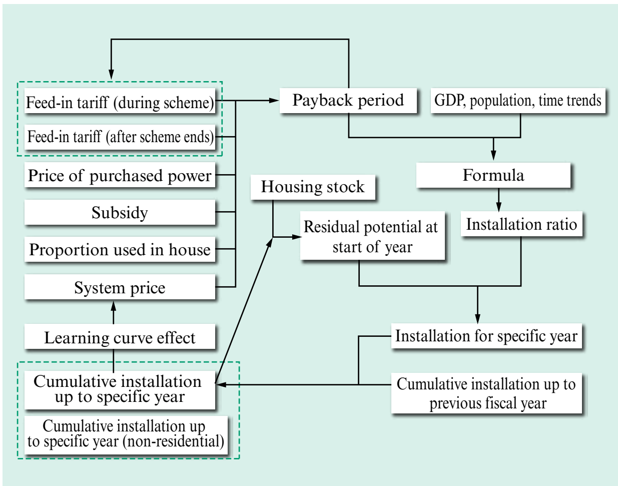



*Fig. 5—Structure of Projection Model for Installation of Residential solar PV Power Generation Capacity.*
*The annual capacity installed is calculated by multiplying the residual potential by the installation ratio. As more capacity is installed, the residual potential falls and the rate of new installation slows.*

Internal Affairs and Communications) to obtain separate figures for number of dwellings and degree of compliance with earthquake resistance standards (1981 and later) for detached house (including tenement housing) and apartment house respectively, and by estimating the total number of dwellings in the future with reference to a forecast of future dwelling numbers produced by the National Institute of Population and Social Security Research.

Based on factors such as roof shape and proportionate potential for rooftop installation, the potential for standalone dwellings was estimated to be 49,000 MW (figures from Cost Estimation and Review Committee). Although this potential is expected to increase further due to growth in the housing stock and the increasing number of dwellings that satisfy earthquake resistance standards as a result of renovations to existing houses, reaching 60,000 MW in 2030, it is expected subsequently to fall due to the falling total number of households.

While there have been cases of solar PV power generation being installed on existing collective housing, problems such as structural issues and the difficulty of getting consensus among residents mean that the numbers are very low. Similarly, while there is potential for installation on new collective housing, factors such as a jump in house prices and satisfying consumer needs remain an issue. Consequently, because of the high degree of uncertainty surrounding the outlook for installation of solar PV power generation systems on collective housing, it was excluded from this study.

**(2) Calculation logic**

The model estimates installation as a proportion of residual potential from per capita GDP and the simple payback period. It assumes a solar PV power generation system with rated generation output of 4 kW, 12% capacity factor, and that 40% of the generated power is used by the house. The simple payback period was calculated as follows.
Here, the equipment cost is taken from the previous period.

Annual income during feed-in tariff period (yen/year) = Tariff × Power sales + Consumer electricity tariff × Own consumption

Annual income after feed-in tariff period (yen/year) = Tariff after feed-in tariff ends × Power sales + Consumer electricity tariff × Own consumption

Simple payback period (years) = (Equipment cost - Annual income during feed-in tariff period × Duration of feed-in tariff period) / (Annual income after feed-in tariff period) + Duration of feed-in tariff period

The formula is shown below. The coefficient of determination (amount of variation explained by regression equation) is 0.92 and the t-statistic value is significant.

Installation as proportion of residual potential = -0.018912 + 0.000152 × (per capita GDP) - 0.001382 × (payback period)

## Projections

**(1) Assumptions**

A figure of 0.7% was used for annual real GDP growth from 2013 to 2020 based on the Asia/World Energy Outlook 2012 published by the Institute of Energy Economics, Japan. Based on predictions from the National Institute of Population and Social Security Research, population is expected to fall from 128 million in 2010 to 124 million in 2020. As a result, growth in per capital GDP up to 2020 is expected to average 1.0%.

The consumer electricity tariff (price charged by utility) was assumed to remain at its most recent actual level of 22.3 yen/kWh. Similarly, it was assumed that the feed-in tariff period would remain 10 years in the future.

Although government subsidies for solar PV power generation are falling, it was assumed they would remain at their current levels (17,500 yen/kW as of 2013).

Based on material from the Cost Estimation

TABLE 2. Assumptions for Residential Projections
*The purchase-related assumptions are based on the current feed-in tariff scheme.*

| | |
|---|---|
| Population | 128 million (2010) → 124 million (2020) (approx.) |
| Economic growth | 0.7%/year (2013 to 2020)<br>• Average annual increase in per capita GDP up to 2020: 1.0% |
| Consumer electricity tariff | Remain constant at FY2011 price (22.3 yen/kWh). |
| Subsidy | Assume current 17,500 yen subsidy will continue. |
| System price & learning effect | • 464,000 yen/kW (2012) (cells: 290,000 yen, associated equipment: 99,000 yen, installation: 75,000 yen)<br>• Future prices are calculated based on learning curve effect for each component (80%, 80%, and 100% respectively) (includes non-residential total) |
| Feed-in tariff | • 42 yen/kWh (2012) → 38 yen/kWh (2013)<br>• Subsequent tariffs calculated by model |
| Scheme duration | 10 years |
| After scheme ends | Assume excess power purchased at same rate as consumer tariff. Adjust if feed-in tariff falls below consumer tariff. |
| Simple payback period | 14 to 18 years (various scenarios are modeled) |

and Review Committee, the learning curve ratios that represent the cost reductions resulting from economies of scale were assumed to be 80% for cells and associated equipment, and 100% for equipment installation (see Table 2).

The future levels of mandated feed-in tariffs were calculated based on the assumption that the payback period assumed below will continue to apply. The feed-in tariff reverts to the consumer electricity tariff after the scheme period ends, and if the feed-in tariff falls below the consumer electricity tariff while the scheme is still in effect, the prices during and after the scheme will be adjusted so as to maintain the payback period and keep the two prices the same.

**(2) Scenarios (targets for economic benefits)**

An analysis was conducted in which the economic benefits of installing solar PV power generation capacity were varied in order to look at how future changes to the design of the feed-in tariff scheme would affect the amount of capacity installed. Given the likely fall in the price of solar PV power generation systems, future studies are likely to consider ongoing reductions in the feed-in tariff. Another possibility is to reduce the degree of favorable treatment to minimize the increases in the surcharge imposed on consumers that experience from Germany indicates are likely. Accordingly, anticipating that brakes will be imposed on any sudden increase in installation, alternative scenarios were considered with longer simple payback periods of 16 and 18 years (in contrast to the FY2013 period of 14.2 years) (see Fig. 6). However, because the feed-in tariff scheme states that "for the three year period after the law is enacted, special consideration shall be given to the profits of renewable energy suppliers to expand concentrated use of renewable energy," it was assumed that the simple payback period for FY2013 (14.2 years) will remain up until FY2014.

**(3) Capacity installation**

Fig. 7 shows the projection results. For the case when the simple payback period is kept the same as in FY2013 (14.2 years), it is projected that cumulative installation of residential solar PV power generation capacity will rise from 5,350 MW in 2012 to 16,300 MW in 2020. For the scenarios in which the simple payback period is raised to 16 years and 18 years, this projected total falls to 15,600 MW and 14,900 MW respectively. The projections for average annual capacity installation under the three scenarios are 1,370 MW, 1,290 MW, and 1,200 MW respectively, indicating that each year added to the simple payback period will reduce installation by 44 MW.

**(4) System price, feed-in tariff**

Fig. 8 shows a breakdown of income from residential solar PV power generation in FY2013 (calculated using the FY2012 system price as a base) and FY2020 (calculated using the FY2019 system price as a base) for the case when the simple

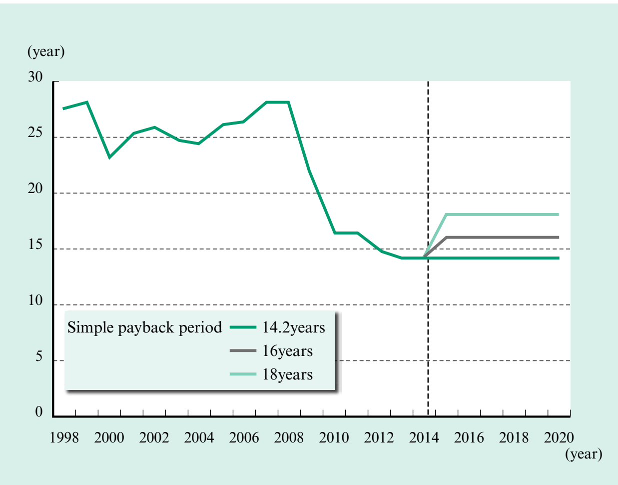



*Fig. 6—Simple Payback Period Scenarios (Targets for Economic Benefits).*
*Although the current simple payback period is 14.2 years, 16 and 18 year scenarios were also considered. However, all scenarios assumed that the simple payback period of 14.2 years would remain in force until 2014.*

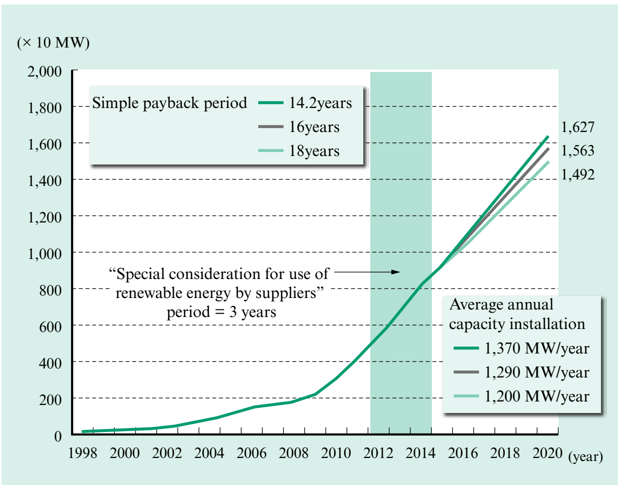



*Fig. 7—Projections for Cumulative Installation of Residential solar PV Power Generation Capacity.*
*The study projected that cumulative installation of residential solar PV power generation capacity would reach between 14,900 MW and 16,300 MW in 2020.*

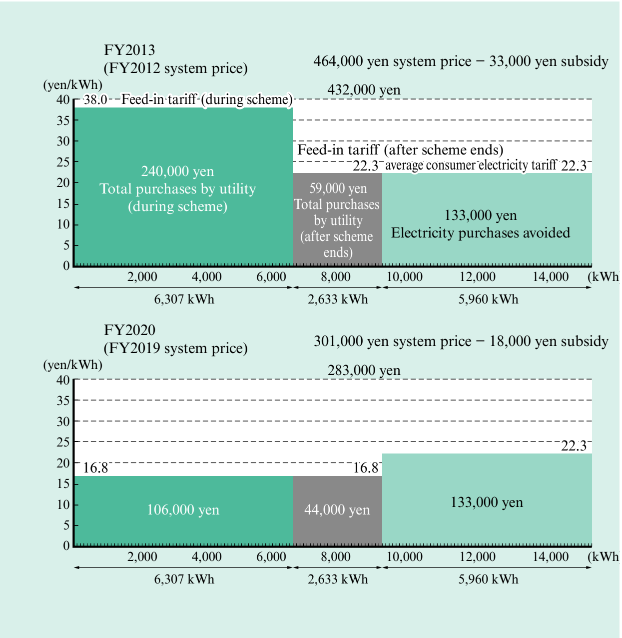



*Fig. 8—Income from Residential Solar PV Power Generation.*
*The feed-in tariff will fall significantly by 2020 because the falling system price will mean that electricity purchases avoided will represent a higher proportion of the system price.*

payback period is 14.2 years.

Assuming a feed-in tariff of 38 yen/kWh in FY2013, and its subsequent fall to the level of the consumer electricity tariff after the feed-in tariff scheme ends (after 10 years), the system price of 432,000 yen/kW (full price of 464,000 yen/kW less subsidy of 33,000 yen/kW) will be paid back over the 14.2-year simple payback period with income during the feed-in tariff scheme (240,000 yen), income from the scheme's end until the end of the payback period (59,000 yen), and avoided electricity purchases (133,000 yen). In 2020, the system price will have fallen to 301,000 yen/kW due to higher installation volumes, including non-residential systems (cumulative non-residential total of 16,220 MW by 2020), and the feed-in tariff will be 16.8 yen/kWh both during and after the feed-in tariff scheme. In this case, the price of 283,000 yen/kW (after deducting the 18,000 yen/kW subsidy) will be paid back over the simple payback period of 14.2 years with income during the feed-in tariff scheme (106,000 yen), income from the scheme's end until the end of the payback period (44,000 yen), and avoided electricity purchases (133,000 yen). Because the amount of electricity purchases avoided is independent of the system price, being dependent solely on the house's power use and the consumer electricity tariff, and because reductions in the system price will mean that these avoided purchases will be equal to a larger proportion of the system price, the feed-in tariff will drop significantly. That is, assuming a simple payback period of 14.2 years, the subsidy and the feed-in tariff scheme will no longer be needed once the system price falls to 133,000 yen/kW.

Fig. 9 shows the projections for feed-in tariff and system price. Because the installed capacities under the different scenarios are similar, the projected system prices remain roughly the same, falling from 460,000 yen/kW in 2012 to 300,000 yen/kW in 2019 (the reference period for calculating the 2020 feed-in tariff). The projected 2020 feed-in tariff is 16.8 yen/kWh for a payback period of 14.2 years and 10.3 yen/kWh for a payback period of 18 years.

**(5) Total surcharge collected**

Fig. 10 shows the feed-in tariff totals and surcharge amounts. The surcharge is projected to increase from 0.10 yen/kWh in 2012 to 0.16 yen/kWh, 0.13 yen/kWh, or 0.11 yen/kWh in 2020 under the 14.2-, 16-, and 18-year simple payback period scenarios respectively. The total annual surcharge collected under the three scenarios is projected to increase from 87.9 billion yen to 145.2 billion yen, 120.2 billion yen, and 102.4 billion yen respectively. Similarly, the cumulative total surcharge collected from 2012 is projected to increase to 1,200 billion yen, 1,100 billion yen, and 1,100 billion yen respectively.

Note that the reason why the total annual feed-in tariff decreases from 2019 to 2020 is because the

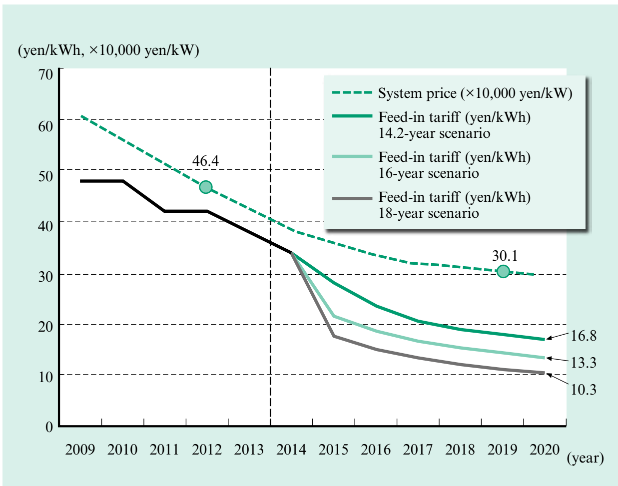



*Fig. 9—Projections for Residential Feed-in Tariff and System Price.*
*The system price is projected to fall from 460,000 yen/kW in 2012 to 300,000 yen/kW.*

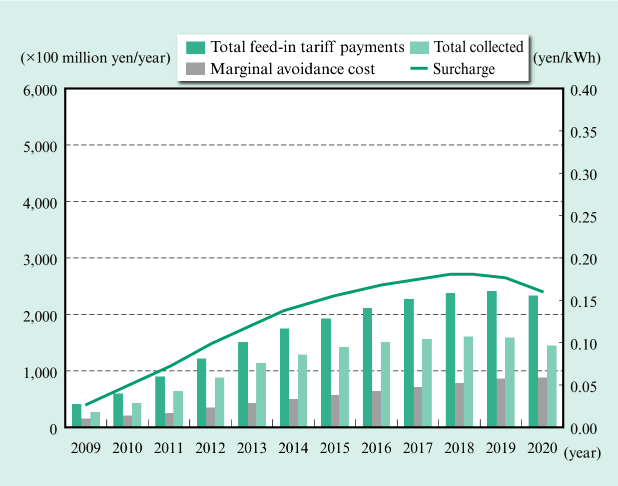



*Fig. 10—Projection for Total Residential Feed-in Tariff Payments and Surcharge.The cumulative total cost from 2012 is projected to exceed one trillion yen.*

amount for systems for which the (10-year) feed-in tariff scheme has ended (and for which the higher feed-in tariff applied) will exceed the amount for newly installed systems (for which a lower feed-in tariff applies).

## CONCLUSIONS

Assuming that feed-in tariffs will continue at a level that guarantees a payback period of between 14 and 18 years for residential installations and 10 years for non-residential installations, it is projected that cumulative total installation will increase from 6,890 MW in FY2012 (5,350 MW residential and 1,540 MW non-residential) to between approximately 31,200 and 32,500 MW in 2020 (14,900 to 16,300 MW residential and 16,200 MW non-residential). Residential system prices are anticipated to fall from 460,000 yen/kW in 2012 to between 290,000 and 300,000 yen/kW, and non-residential from 410,000 yen/kW to 260,000 yen/kW. As a result, the feed-in tariff will fall to between 10 to 17 yen/kWh for residential generation and 25 yen/kWh for non-residential. Assuming the simple payback period remains the same, the system price and feed-in tariff will remain in proportion for non-residential installations because these involve the sale of all power generated. For residential installations, on the other hand, which only sell excess power, the falling system price will result in avoided electricity purchases making up a larger proportion of the payback, and therefore cause a rapid fall in the feed-in tariff.

Also, the total cost from 2012 to 2020 is predicted to be between 3 trillion and 3.2 trillion yen, with a average surcharge of between 0.37 and 0.39 yen/kWh.

This article has used a model to project the future installation of solar PV power generation capacity up until 2020. Although the results show a steady increase in non-residential installations, caution is required as a number of factors remain that could stall this progress, including the cancellation of authorized projects, falling availability of land for plant construction, and constraints on grid connection. Similarly, while the results indicate that residential installations will also increase up until 2020, there is a potential for this to slow subsequently due to a falling number of dwellings suitable for installation. Given the inevitability of increases in the surcharge imposed on the public, another reason for caution is the potential for revisions to the feed-in tariff scheme.

This study was conducted under contract to Hitachi, Ltd.

## ABOUT THE AUTHORS

Yoshiaki Shibata
*New and Renewable Energy Group, The Institute of Energy Economics, Japan*
*He is currently engaged in studying measures for connecting renewable energy to the grid.*

Akira Yanagisawa
*Energy Data and Modelling Center, The Institute of Energy Economics, Japan*
*He is currently engaged in quantitative analysis of supply and demand and other aspects of energy markets.*

Featured Articles

# Japan's Largest Photovoltaic Power Plant

## —Turnkey Construction Contract and Commissioning of Oita Solar Power—

Yuichi Nagayama
Tetsuharu Ohya
Hiroaki Ota
Masayuki Sakai
Katsumi Watanabe
Yuki Kobayashi

*OVERVIEW: Hitachi won a turnkey (EPC) contract to supply a PV power generation system to Oita Solar Power Corporation, with the plant commencing operation in March 2014. With a PV capacity of 82-MW, it is the largest PV power plant in Japan (as of May 2014). The equipment selected for the plant, which was constructed in a very short time (16 months), includes highly efficient PCSs and amorphous transformers, thus ensuring the system will have a high level of efficiency. Hitachi also has a 20-year maintenance and operation contract to ensure the plant continues to operate reliably.*

## INTRODUCTION

HITACHI undertakes large ("megasolar") photovoltaic (PV) power plant projects under turnkey engineering, procurement and construction (EPC) contracts that include design and procurement. Hitachi is also involved in the supply of a wide variety of equipment and systems, extending from operation monitoring and instrumentation systems to highly efficient, heavy-duty power conditioning systems (PCSs), amorphous transformers that feature low power consumption during standby operation, and other key items of equipment used in megasolar power generation systems.

This article describes the Oita Solar Power Plant that Hitachi supplied to Oita Solar Power Corporation under a turnkey EPC contract, which commenced operation in March 2014.

## PROJECT OVERVIEW

Located in Oita City, Oita Prefecture, the Oita Solar Power Plant is situated on industrial land that had lain idle for many years.

The plant was constructed and will be managed by an operating company, Oita Solar Power Corporation, which is a subsidiary of Marubeni Corporation. The plant is Japan's largest, with a PV capacity of 82 MW, an estimated annual electric power production of 87,000 MWh (enough to power about 30,000 households), and a site area of 105 hectares (1,050,000 m$^2$). The system is very large, comprising 340,000 PV modules, which, if lined up, would stretch for approximately 500 km, roughly the distance from Tokyo to Osaka. It is estimated that the plant will deliver annual carbon dioxide ($CO_2$) emission savings of approximately 36,000 t. All of the power generated by the plant will be sold to the power company. Table 1 lists the project specifications.

Hitachi was awarded a turnkey EPC contract for the PV power generation system that encompassed design, procurement, fabrication, installation, and commissioning. Work started in December 2012 and the plant commenced operation in March 2014. Fig. 1 shows a photograph of the completed plant.

## FEATURES OF OITA SOLAR POWER

Direct current (DC) generated by the PV modules is converted to alternating current (AC) and stepped up to 6.6 kV at 61 subsidiary substations. It is then stepped up again to 66 kV by three high-voltage (extra-high tension) transformers and supplied to the transmission

TABLE 1. Project Specifications
*The table lists a summary of the project.*

| Project Summary | |
|---|---|
| **Operator** | Oita Solar Power Corporation |
| **Plant name** | Oita Solar Power |
| **Location** | Oita City, Oita Prefecture |
| **Site area** | 105 ha |
| **PV module capacity** | 82 MW |
| **Grid interconnection capacity** | 61 MW |
| **Grid interconnection voltage** | 66 kV |

PV: photovoltaic

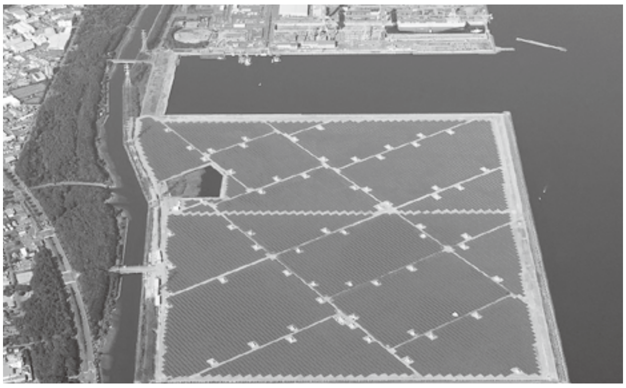


*Fig. 1—Oita Solar Power Plant.*
*The power plant is visible in the middle of the photograph, surrounded by the ocean and a river. The approximately 1 km² site is almost entirely covered with PV modules.*

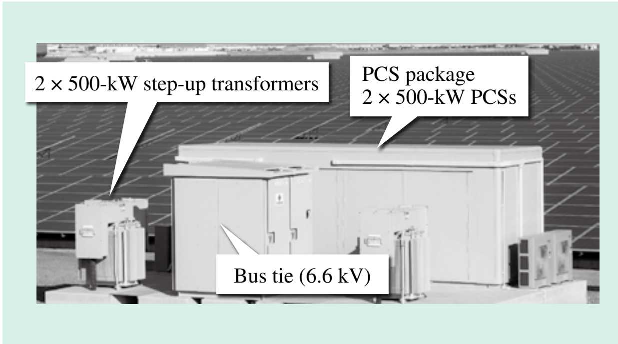



*Fig. 2—Subsidiary Substation.*
*Each subsidiary substation consists of a PCS package with two PCSs, two step-up transformers, and a bus tie. The PV modules are visible behind the subsidiary substations.*

pylons of the power company to which the power is sold. Table 2 lists the specifications of the main generation system equipment.

Each subsidiary substation is fitted with two 500-kW PCSs and two step-up transformers (1 MW per substation) (see Fig. 2). The extra-high-tension transformers are installed in three banks, each containing a 21-MW extra-high-tension transformer. The electric power stepped up by these three high-tension substations is consolidated at the extra-high-tension transformer closest to the grid connection point, from which it is connected to the power company's existing transmission pylons (see Fig. 3).

TABLE 2. Main Equipment Specifications
*The table lists the specifications of the PV modules, PCSs, step-up transformers, and high-voltage (extra-high tension) transformers.*

| | Parameters | Specifications | | |
|---|---|---|---|---|
| PV modules | | 240 W model | 245 W model | Total |
| PV modules | Maximum output/ panel | 240 W/panel | 245 W/panel | — |
| PV modules | No. of panels | 307,454 | 33,586 | 341,040 |
| PV modules | Total capacity | 73.8 MW | 8.2 MW | 82 MW |
| PCSs | **Parameters** | **Specifications** | | |
| PCSs | Capacity/unit | 525 kVA/500 kW | | |
| PCSs | Rated input voltage | DC 400 V | | |
| PCSs | Operating voltage range | DC 230 V – DC 600 V | | |
| PCSs | No. of units | 122 | | |
| PCSs | Total capacity | 61 MW | | |
| Step-up transformers | **Parameters** | **Specifications** | | |
| Step-up transformers | Voltage | 440 V (primary)/6.6 kV (secondary) | | |
| Step-up transformers | Capacity/unit | 500 kVA | | |
| Step-up transformers | No. | 122 | | |
| Step-up transformers | Total capacity | 61 MW | | |
| Extra-high-tension transformers | **Parameters** | **Specifications** | | |
| Extra-high-tension transformers | Voltage | 6.6 kV (primary)/66 kV (secondary) | | |
| Extra-high-tension transformers | Capacity/unit | 21 MVA | | |
| Extra-high-tension transformers | No. | 3 | | |
| Extra-high-tension transformers | Total capacity | 63 MVA | | |

PCS: power conditioning system DC: direct current

*Fig. 3—Extra-high-tension Substation (Grid Connection Substation).*
*The extra-high-tension transformer is located at the center of the extra-high-tension substation. The lines to the transmission pylon run via the gantry.*

## System Optimization

While the maximum output of the system's PV modules is 82 MW, the PCS capacity is 61 MW. This design was selected as optimal for Japanese weather conditions.

PV modules generate their rated output when the solar radiation is 1 kW/m². Unfortunately, over the period of a year, the total time during which solar radiation is at 80% or more of this value is less than 10% of the time during which solar radiation is less than 80% (see Fig. 4). This makes it important to operate at higher efficiency during periods of low solar radiation. Installing an excess number of PV modules results in a generation system with higher efficiency than one where the number of PV modules

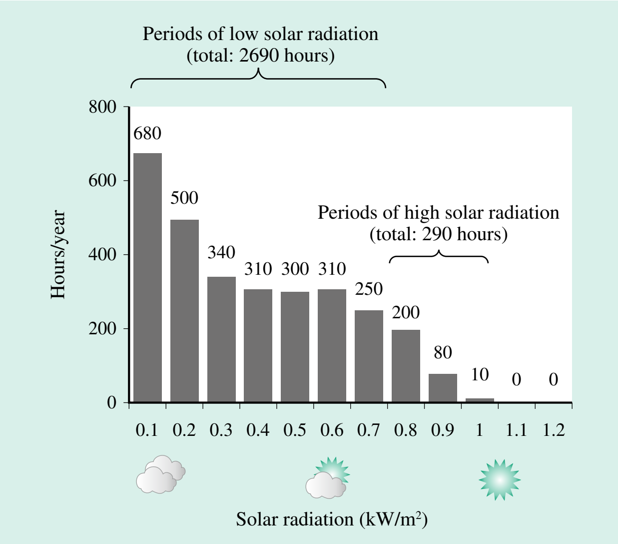



*Fig. 4—Annual Solar Radiation Distribution.*
*The graph shows how periods of low solar radiation are more common.*

**Typical transformer characteristics (three-phase, 500 kVA)**

| Parameter | No-load loss (W) | Load loss (W) | Efficiency (%) (@25% load) |
|---|---|---|---|
| Electrical steel transformer | 600 | 4,300 | 99.31 |
| Amorphous transformer | 160 | 6,900 | 99.53 |

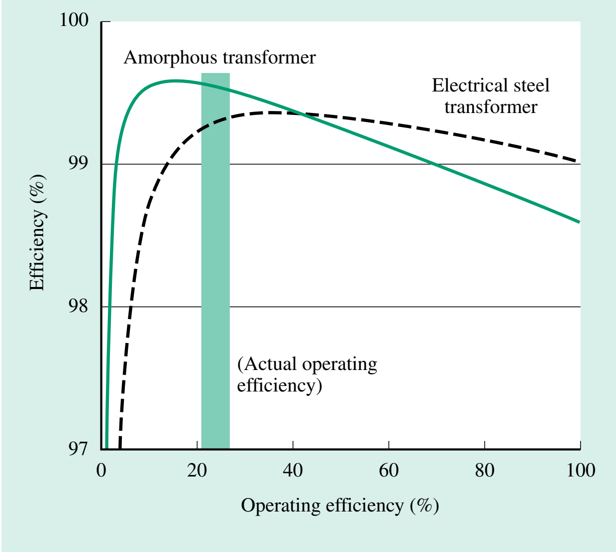



*Fig. 6—Characteristics and Efficiency Curve of Step-up Transformer (Amorphous Transformer).*
*The transformer features low no-load losses and operates efficiently at the low loads common in actual use.*

is set to match the PCS capacity. The higher efficiency means more power is generated overall. For this power generation system 82 MW of PV modules, the optimal system design is a PCS capacity of 61 MW.

## Highly Efficient Power Generation System

To improve the generation efficiency of the power plant, Hitachi selected highly efficient equipment and designed the system to have low losses.

More specifically, Hitachi selected highly efficient PCSs (capacity: 500 kW, maximum DC input voltage: 660 V, maximum efficiency: 98.0%) and designed the system to have a high generation efficiency over a wide range of solar radiation levels, including both sunny and cloudy days (see Fig. 5). It combined these features with amorphous step-up transformers (maximum efficiency: 99.6%), which have low standby power consumption (no-load losses) and high efficiency under light loads (see Fig. 6).

To shorten high voltage cable lengths, and thus minimize cable power losses, Hitachi also designed the system to have three extra-high-tension substations (see Fig. 7).

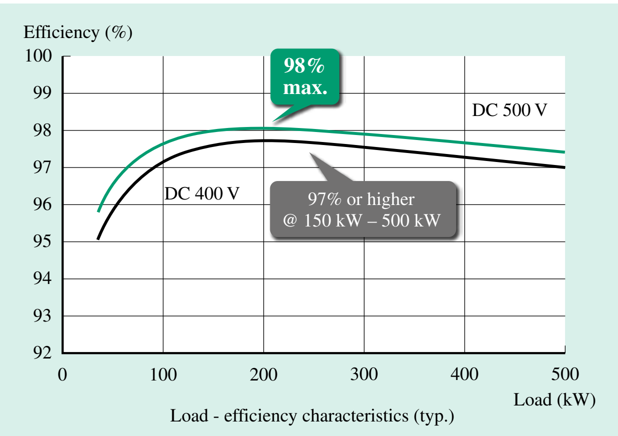



*Fig. 5—PCS Efficiency Curve.*
*The PCS features a high maximum efficiency of 98% and the ability to operate efficiently over a wide range of loads. The specifications listed here are typical measured values and are not guaranteed.*

## Monitoring System

Hitachi also installed a remote monitoring system and string monitors for power plant monitoring.

For the remote monitoring system, Hitachi built a system capable of monitoring power plant operation and reporting faults from the customer's headquarters or from Hitachi's monitoring center. 24-hour monitoring of the plant from the Hitachi monitoring center means that service staff can be dispatched quickly if needed to respond to a problem.

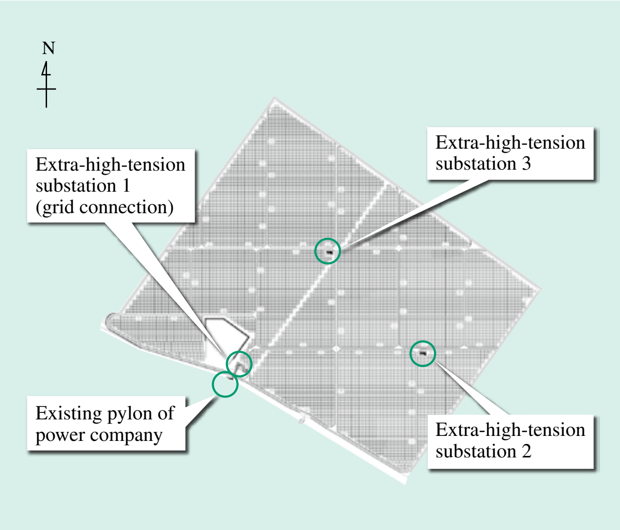



*Fig. 7—Locations of Extra-high-tension Substations at Power Plant.*
*The locations of the site's three extra-high-tension substations were chosen to minimize high-voltage cable lengths.*

*Fig. 8—Use of Slipforming to Lay Foundations.*
*The photograph shows the concrete array foundation being laid by the Huron concrete slipform paver, which pours and forms the foundation as it moves along. The Huron machine is on the right and the concrete mixer on the left supplies it with concrete.*

As mentioned above, in addition to the remote monitoring system, Hitachi also installed string monitors. These monitor the current from a string of PV modules connected in series to identify performance degradation or other faults in the PV modules in the string. Monitoring the strings individually rather than centrally at the PCS provides greater sensitivity and makes it easier to identify faulty components (see p.38 of this issue).

### Short Construction Time

Plant construction was completed in just 16 months, which is a very short time for a plant of this size.

To achieve this rapid construction schedule, Hitachi selected installation techniques that would make laying the 190 km of panel frame foundations more efficient, including the use of slipforming (which does not require a mold), as well as conventional mold-based techniques. Slipforming uses a concrete slipform paver supplied by Huron Manufacturing Corporation that pours and forms the foundations as it moves along. Use of this technique played a major role in shortening the construction time. Fig. 8 shows a photograph of the slipform paver being used to lay foundations.

Tasks such as equipment delivery management and work progress management were supported by the use of Hitachi's own delivery time management system, which ensured that the delivery of major items of equipment, such as the PCSs and step-up transformers, was timed to suit the site work schedule.

Hitachi sought to complete the job ahead of schedule, with more than 450 people working at the site each day during the peak period when the civil engineering and electrical installation work was at its busiest.

Through these measures, the work was completed more quickly than originally planned, allowing the commencement of operation to be brought forward by more than a month.

### Future Activity at Oita Solar Power

Following on from its EPC contract for the Oita Solar Power PV power generation system, Hitachi has also been awarded a 20-year contract for maintenance and operation.

Hitachi's responsibilities will include monitoring the operation of the generation system, providing operational support for managing power production, periodically inspecting and replacing parts, and responding promptly to faults or other problems.

## CONCLUSIONS

This article has described the Oita Solar Power PV power generation system.

In addition to PCSs and step-up transformers, which are the core products for its PV power generation systems, Hitachi is also striving to make further efficiency and quality improvements through measures such as fault diagnosis for PV modules. Hitachi also intends to utilize the experience and knowledge it has built up through this EPC contract to continue supplying highly efficient PV power generation systems.

## ABOUT THE AUTHORS


Yuichi Nagayama

*Natural Energy Generation Service Department, Hitachi Works, Power Systems Company, Hitachi, Ltd. He is currently engaged in systems design and maintenance work for megasolar power plants.*

Tetsuharu Ohya

*Photovoltaic Power Generation Systems Department, Hitachi Works, Power Systems Company, Hitachi, Ltd. He is currently engaged in design of photovoltaic power generation systems.*

Hiroaki Ota

*Photovoltaic Power Generation Systems Department, Hitachi Works, Power Systems Company, Hitachi, Ltd. He is currently engaged in design of photovoltaic power generation systems.*

Masayuki Sakai

*Photovoltaic Power Generation Systems Department, Hitachi Works, Power Systems Company, Hitachi, Ltd. He is currently engaged in managing and supervising construction as Director of the Hitachi Construction Office of the Oita Solar Power Plant.*

Katsumi Watanabe

*Electrical Quality Assurance Department, Quality Assurance Division, Power Systems Company, Hitachi, Ltd. He is currently engaged in coordinating on-site testing at the Oita Solar Power Plant.*

Yuki Kobayashi

*Photovoltaic Power Generation Business Department, New Energy Division Power & Industrial Systems Division, Power Systems Company, Hitachi, Ltd. He is currently engaged in coordinating photovoltaic power generation systems.*

Featured Articles

# O&M Service for Megasolar Power Plants and Precise Monitoring Techniques for PV Modules

Tohru Kohno
Tetsuharu Ohya
Tomoharu Nakamura

*OVERVIEW: The success or failure of large ("megasolar") PV power generation businesses depends on their ability to perform reliably over a period of 20 years. However, the short history of the megasolar power business itself means there is a lack of data and know-how relating to long-term reliability and maintenance. Hitachi is putting a lot of effort into long-term, turnkey services that handle plant O&M on the owner's behalf. In addition to its experience with the maintenance of electrical conversion and distribution equipment, Hitachi also supplies cloud-based remote monitoring services that utilize its IT infrastructure. PV modules are a key component of these power plants, and Hitachi also utilizes its own proprietary techniques for the precise detection of faults or degradation in these modules.*

## INTRODUCTION

THE construction of photovoltaic (PV) power plants has been growing dramatically since the introduction of a feed-in tariff scheme for renewable energy in July 2012. Whereas the total installed capacity prior to the scheme's introduction was approximately 5,600 MW, this had grown to approximately 11,260 MW by October 2013, more than doubling in a period of little more than a year. With further large-capacity plants still to commence production, this trend appears set to accelerate.

Whereas approximately 80% of PV power generation in the past was for household use, commercial plants have made up about 70% of the capacity since the introduction of the feed-in tariff scheme. The key considerations for commercial applications are the long-term reliability of the power plant and sustaining steady operation without ignoring faults or performance degradation.

In response, Hitachi is putting a lot of effort into operation and maintenance (O&M) services that help maintain consistent operation over the long term. PV modules are a key component of these power plants, and Hitachi has developed its own technology for monitoring these modules for faults or degradation through a cloud service.

This article describes these O&M services for megasolar power plants and precise monitoring techniques for PV modules.

## O&M SERVICE OVERVIEW AND SYSTEM

It is common practice with PV power generation for the plant to be managed by a specific-purpose company (SPC) set up by the company behind the project. When this structure is adopted, the SPC tends to be small and often finds it difficult to establish the resources needed for O&M. This is exacerbated by a lack of O&M know-how resulting from the fact that the industry is so young. For situations like this, Hitachi offers a turnkey service that can handle equipment O&M on the operator's behalf. In providing this turnkey service, Hitachi can draw on the monitoring techniques and know-how described below to achieve consistent operation over the long term.

### Causes of Faults on Megasolar Power Plants

Megasolar power plants include PV modules, power conditioning systems (PCSs), transformers, junction boxes, and distribution boards. Faults can arise at various points in these plants, such as in the electric power distribution equipment, power electronics, or PV modules. In particular, because the PV modules are situated outdoors where they are exposed to the sun, wind, and rain, they are likely to be subject to phenomena that can cause reductions in their output due to deterioration over time. External factors include the surface of the modules becoming dirty due to dust or other material carried in the air, the droppings of crows and other wildlife, or glass breakage due to

TABLE 1. O&M Services
*Hitachi offers extensive support for the operation and maintenance of megasolar power plants.*

| Service | Description |
|---|---|
| Operational support | • 24-hour remote monitoring<br>• Operating data management, analysis of operation (comparison with targets, etc.)<br>• Reporting (daily, monthly, and annual reports) |
| Routine operation support | • Routine inspections (weekly or monthly, etc.) |
| Maintenance inspections | • Maintenance planning<br>• Routine inspections, planned part replacements<br>• Faults, repair of worn parts |
| Emergency response | • Initial response<br>• Fault recovery |
| Ancillary services | • Online monitoring of PV module degradation or faults<br>• Web site design |

PV: photovoltaic O&M: operation and maintenance

falling rocks (which is also assumed to be the work of crows). Rather than a standard range of services, it is important that O&M offer services that are capable of handling potential problems like these.

### Available Services

#### Inspection and Maintenance Service

Table 1 lists the O&M services offered by Hitachi. Routine operation support (routine on-site inspection) is based primarily around visual inspections to check for things like broken or bent equipment, corrosion, staining, or rust. Inspection and maintenance consists of conducting periodic inspections and replacing parts as required to ensure that equipment functionality is maintained. The service ensures electrical integrity (insulation resistance measurement, and operation checks on PCSs, transformers, monitoring systems, and other equipment), as well as the replacement of consumables (fuses, space heaters, filters, packing, etc.).

#### Remote Monitoring Service

The operation of PV power plants is typically automated and unattended. Consequently, if a problem does occur, it may take a long time for it to be identified, resulting in a loss of long-term generation output and risking it developing into a more serious fault. To deal with this, Hitachi offers a remote monitoring service. The service performs 24-hour remote monitoring of the customer's generation plant operation from a control center so that it can respond promptly when a problem occurs, including notifying the customer by telephone or e-mail and dispatching a technician to the site if necessary. The remote monitoring system provides a way for relevant company departments, which may be based at different sites, to obtain detailed information about the power plant. Hitachi also supplies a range of services that reduce the workload of the power plant operator, including the management of operational data and analysis of plant operation.

This remote monitoring service utilizes Hitachi's information technology (IT) infrastructure to provide a highly reliable service that encompasses information security.

## MONITORING FOR PV MODULE DEGRADATION OR FAULTS

### Degradation and Fault Modes

PV cells are the main components in PV modules. However, these cells are not the only cause of degradation and faults in PV modules, with degradation of the cell connection wiring and filler material used in module construction also being major factors. The cells are connected together by metal wires (interconnectors) that are soldered to the cells. Also, the junction boxes are fitted with bypass diodes (see Fig. 1).

Because degradation or faults in these components are reflected in the equivalent circuit parameters of the PV cells, they can be identified quantitatively. Degradation or other component faults can be categorized into a number of different fault modes (solder peeling, cell degradation, broken wires, loss of optical transparency), each of which influences equivalent circuit parameters (series resistance, shunt resistance, bypass diode operation, and PV current) in different ways (see Fig. 2).

### Diagnostic Techniques

The power generation level is monitored to identify performance degradation or other faults in PV modules.

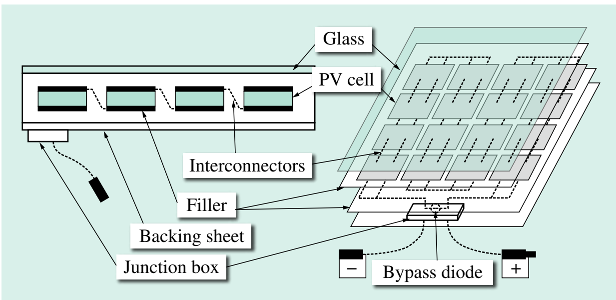



*Fig. 1—Cross-section of PV Module.*
*The PV cells are not the only source of PV module degradation and faults. Degradation of filler material and interconnectors are also common causes.*

| Fault mode | Cause | Effect on equivalent circuit |
|---|---|---|
| Solder peeling | • Increased resistance in interconnector wiring | Increase in series resistance (Rs) |
| Cell degradation | • Deterioration in performance of PV cell<br>• Development of ohmic characteristics | Drop in shunt resistance (Rsh) |
| Broken wire | • If the performance deterioration is large, the bypass diode will operate continuously | Bypass diode on |
| Deterioration in optical transparency | • Dirty glass<br>• Peeling of filler | Drop in photovoltaic current ($I_{sc0}$) |

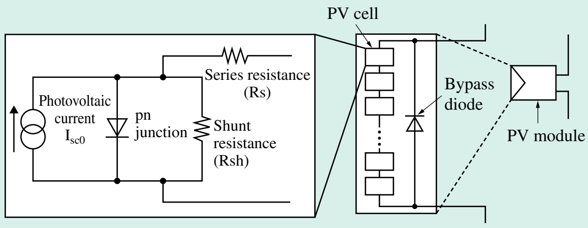
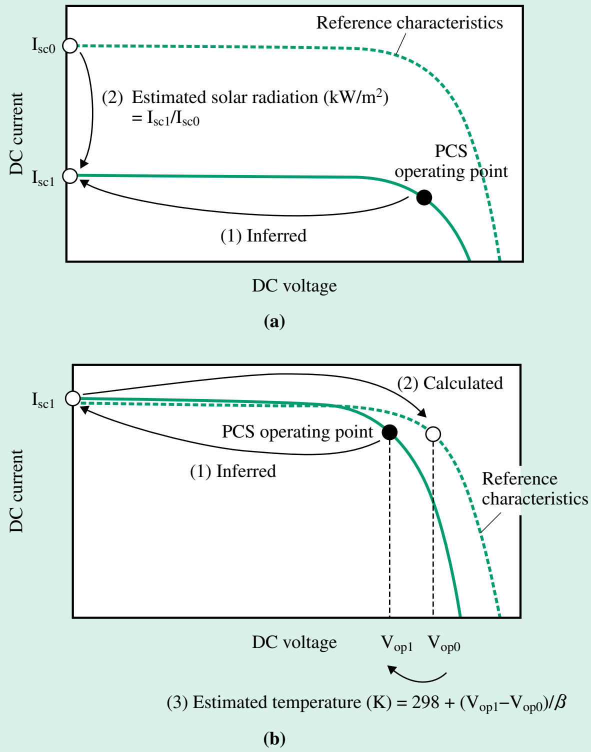



*Fig. 2—Fault Modes and Equivalent Circuit.*
*PV module faults can be classified into a number of different fault modes and characterized in terms of equivalent circuit parameters with high accuracy.*




DC: direct current PCS: power conditioning system

*Fig. 3—Calculation of Estimates for Solar Radiation (a) and Temperature (b).*
*The level of solar radiation at the PV cells (estimated solar radiation) and the PV cell operating temperature (estimated temperature) are calculated from the PCS operating point (DC voltage and current).*

While the conventional technique is to monitor the power output and compare it with solar radiation, because factors such as the air temperature and level of solar radiation fluctuate, and may vary across a large site, it is difficult to identify degradation or other faults until the fall in output reaches a certain level.

Hitachi has developed a monitoring method that assesses the state of the PV modules with a high degree of accuracy by obtaining more accurate values for the solar radiation (estimated solar radiation) and temperature (estimated temperature) from the actual operating point. Next, it calculates the theoretical power output based on these estimates and the equivalent circuit parameters, and then compares this result with the actual output[1][2].

The key technique in this method is that, instead of utilizing the raw measurements from pyrheliometers and thermometers, it uses theoretical values for solar radiation (estimated solar radiation) and module temperature (estimated temperature) calculated from the PV module characteristics and measured values (see Fig. 3). This eliminates both the need to rely on an uncertain measurement from a pyrheliometer positioned at a representative location and also the need to estimate the module temperature from the air temperature.

PV module diagnostics compares the measured current with the theoretical current calculated from the above estimated solar radiation and temperature and the measured operating voltage. A difference between these two current values indicates whether the PV module has a fault or suffers from performance degradation. The diagnostic procedure then performs an iterative calculation, recalculating the current for different numbers of PV module faults until the estimated and measured currents converge. This provides an estimate of the number of PV module faults. If string monitors are used, the monitoring function incorporates the fault mode into the calculation to determine which mode gives the best agreement with the actual string current (see Fig. 4).

The procedure was tested on a 50-kW system installed at Hitachi's Central Research Laboratory. Corrugated plastic was placed over the PV modules to simulate a fault (see Fig. 5). When 32 sheets of corrugated plastic were used, the procedure estimated the number of faults at 33, thus confirming that losses of around 2 to 3% can be detected (see Table 2). A similar result was obtained from another test using

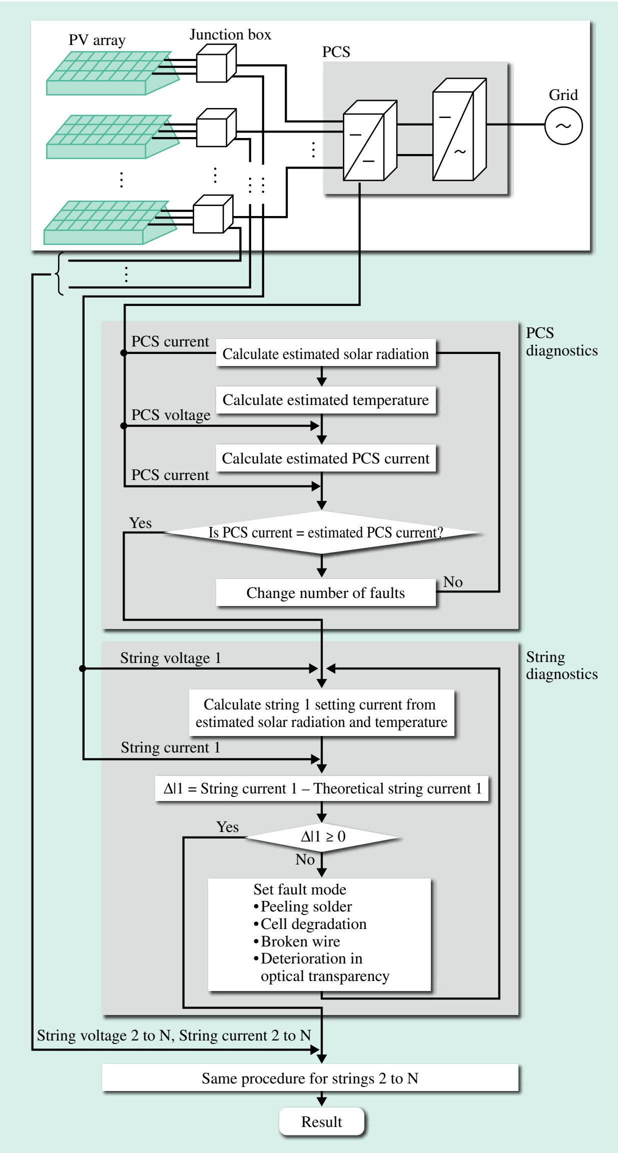



*Fig. 4—Diagnostic Flowchart.*
*This performs an iterative procedure that determines the fault mode by calculating the solar radiation and temperature from the PCS voltage and current until the theoretical estimated current and measured current converge.*

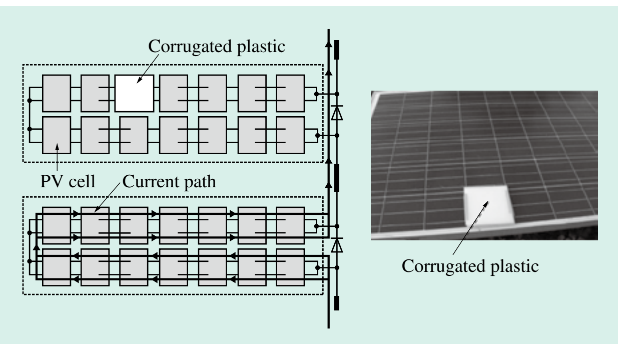



*Fig. 5—Use of Corrugated Plastic to Simulate Fault.*
*Corrugated plastic was placed over a PV module to simulate a broken wire fault by forcing the current to flow through the bypass diode.*

TABLE 2. Results of Testing on 50-kW System (PCS Diagnostics)
*When 32 faults were simulated (using corrugated plastic), the procedure estimated the number of module faults at 33 using only the DC voltage and current of the PCS.*

| Test | PCS diagnostics | | | | | |
|---|---|---|---|---|---|---|
| | Estimated power | Actual power | Estimated temperature | Estimated solar radiation | Degradation | No. of module faults |
| 32 sheets of corrugated plastic | 36.4 kW | 36.3 kW | 60.7°C | 0.83 kW/m² | 2.34% | 33 |

TABLE 3. Results of Testing on 50-kW System (String Diagnostics)
*Even for a loss of only 2 to 3%, the fault mode could be identified using the DC voltage and current from the string monitor.*

| Test | String diagnostics result | | | | Result |
|---|---|---|---|---|---|
| | Estimated power | Actual power | Estimated temperature | Estimated solar radiation | |
| Covered with corrugated plastic | 1.965 kW | 1.899 kW | 43.7°C | 0.67 kW/m² | Broken wire |
| Inserted 1.3Ω resistor | 2.511 kW | 2.468 kW | 53.7°C | 0.88 kW/m² | Solder peeling |

string diagnostics in which two different faults were simulated (respectively, insertion of a 1.3Ω resistor in the wiring and placement of corrugated plastic over the module) (see Table 3).

## Cloud-based Services

Information on plant operation can be collected via a network from the PCSs. Hitachi has built a system that transmits the direct current (DC) voltages, DC currents, pyrheliometer measurements, and air temperature measurements from the PCSs to a monitoring server at a Hitachi data center, where diagnostics are performed and the results stored (see Fig. 6). This makes possible a variety of additional services.

For example, Hitachi has added a function for analyzing how the extent of degradation varies over time in order to determine when an on-site inspection is needed. Because Hitachi has a technique for accurately reproducing current-voltage characteristics in the presence of degradation or faults, it can provide comprehensive services that include using this technique to localize faulty modules.

By improving the flexibility of the diagnostic functions in the monitoring server, Hitachi can provide an accurate monitoring service that supports long-term operation. For example, while the replacement of modules over a long operating life will likely result

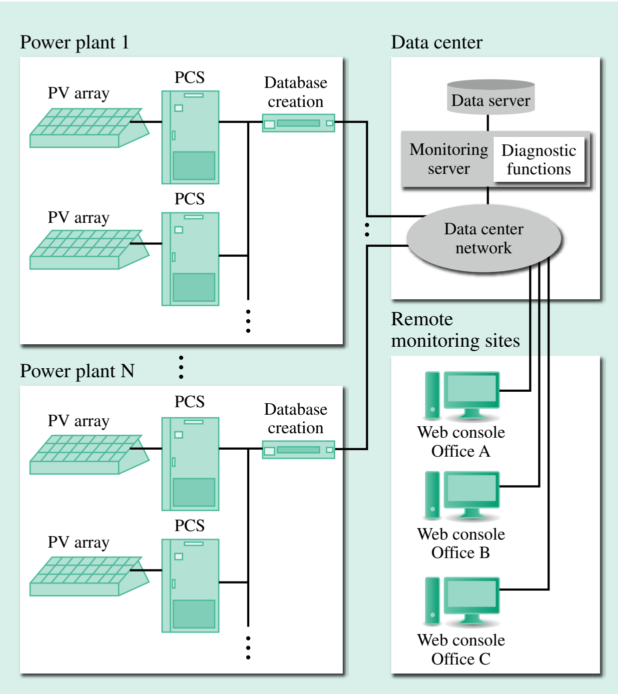



*Fig. 6—Cloud-based Implementation of Diagnostic Functions.*
*Additional services are provided by collecting diagnostic results obtained from diagnostic, time-series, and other data from a number of sites.*

in different types of PV modules coexisting, Hitachi's system can still provide accurate monitoring at such sites by updating the monitoring server with details of the added modules.

Hitachi is also developing a service that will determine the best time to replace modules based on the predicted losses in 15 or 20 years' time, which will be obtained by using the cloud to collate information such as the extent to which degradation has changed over time and the results of accelerated indoor testing conducted by Hitachi.

## CONCLUSIONS

Japan is entering a new era in which large amounts of PV power will be generated. However, the shortage of experience with full-scale power plants means there is a need to establish technologies for supporting reliable operation over the long term. The fault monitoring techniques described in this article are one example. Hitachi anticipates that combining these fault monitoring techniques with techniques for verifying long-term reliability will help establish PV power generation as a viable business.

### REFERENCES

(1) T. Kohno et al., "A Technique for Detecting Faults in a Photovoltaic Array," 27th EU-PVSEC, proc, pp. 3610–3615.
(2) T. Kohno et al., "Experimental Verification of Fault-diagnosis Architecture in a Large-scale Photovoltaic Power Plant," 28th EU-PVSEC, proc, pp. 3709–3713.

## ABOUT THE AUTHORS

Tohru Kohno
*Energy Conversion Electronics Research Development, Central Research Laboratory, Hitachi, Ltd. He is currently engaged in research and development of a large-scale photovoltaic power generation system.*

Tetsuharu Ohya
*Photovoltaic Power Generation Systems Department, Hitachi Works,Power Systems Company, Hitachi, Ltd. He is currently engaged in design of photovoltaic power generation systems.*

Tomoharu Nakamura
*New Energy Division, Power & Industrial Systems Division, Power Systems Company, Hitachi, Ltd. He is currently engaged in development of a large-scale photovoltaic power generation system. Mr. Nakamura is a member of the Institute of Electrical Engineers of Japan (IEEJ) and the IEEE.*

Featured Articles

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

Shigeru Kiyomiya
Takashi Yoshikawa
Hiroyuki Endo
Tomokazu Ukisu

*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).

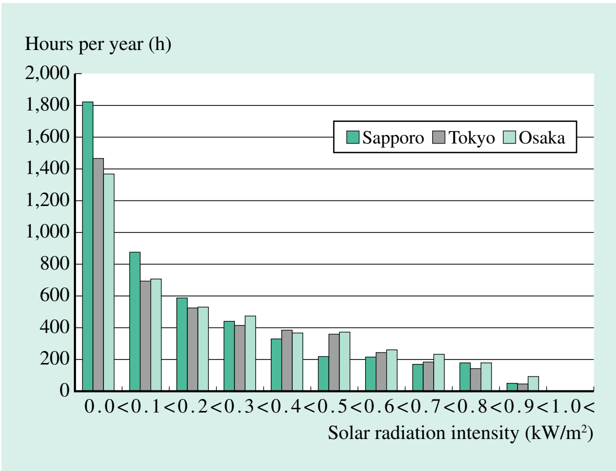



*Fig. 1—Time Distribution of Solar Radiation Intensity.*
*Distribution of hourly mean solar radiation intensities (kW/m²) measured by AMeDAS. The data was collected from January 1 to December 31, 2009. (Times with zero solar radiation were excluded).*

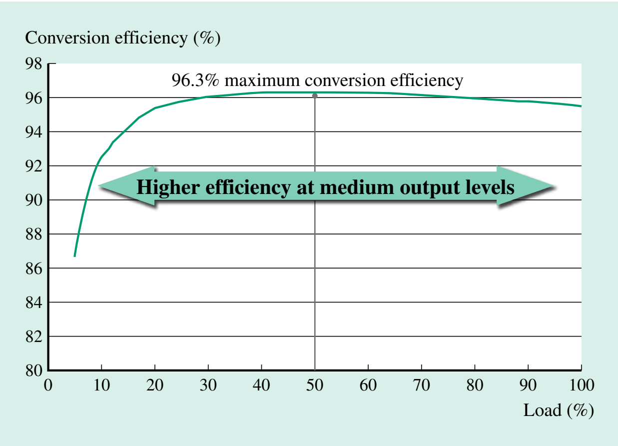



*Fig. 2—Conversion Efficiency.*
*The graph shows the conversion efficiency of the HSP900-1000LFH DC345 V. Hitachi designed the conversion efficiency curve to maximize overall power generation.*

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).

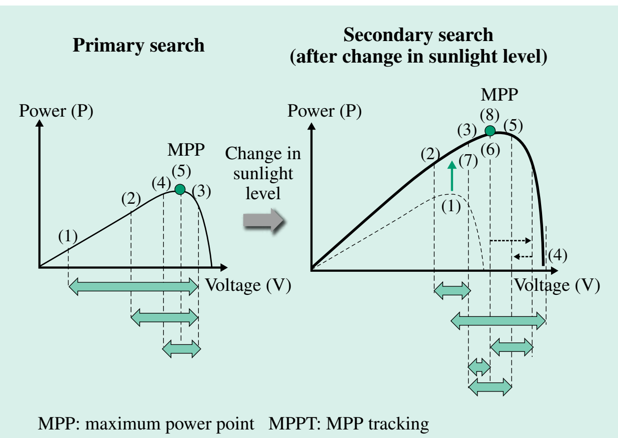



*Fig. 3—Binary Search Method.*
*Developed by Hitachi Industrial Equipment Systems Co., this method provides highly responsive MPPT that is good at dealing with partial shadows.*

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.

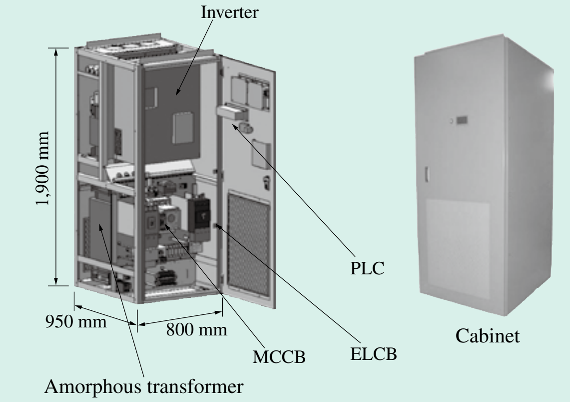
Fig. 4 lists the specifications and shows photographs of the newly developed HSP900-1000LFH.

## 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.

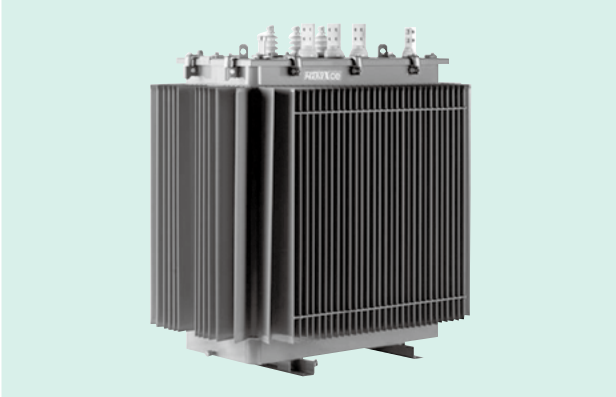


*Fig. 5—Super Amorphous X ce Series.*
*The transformer is designed specifically for photovoltaic power generation systems, using an amorphous transformer with low standby power consumption as a base.*

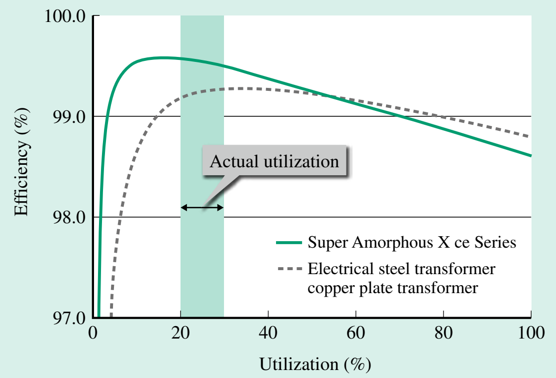



*Fig. 6—Comparison of Efficiency Curves.*
*Achieving high efficiency in the actual utilization range used in photovoltaic power generation helps maximize the amount of power generated.*


*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.

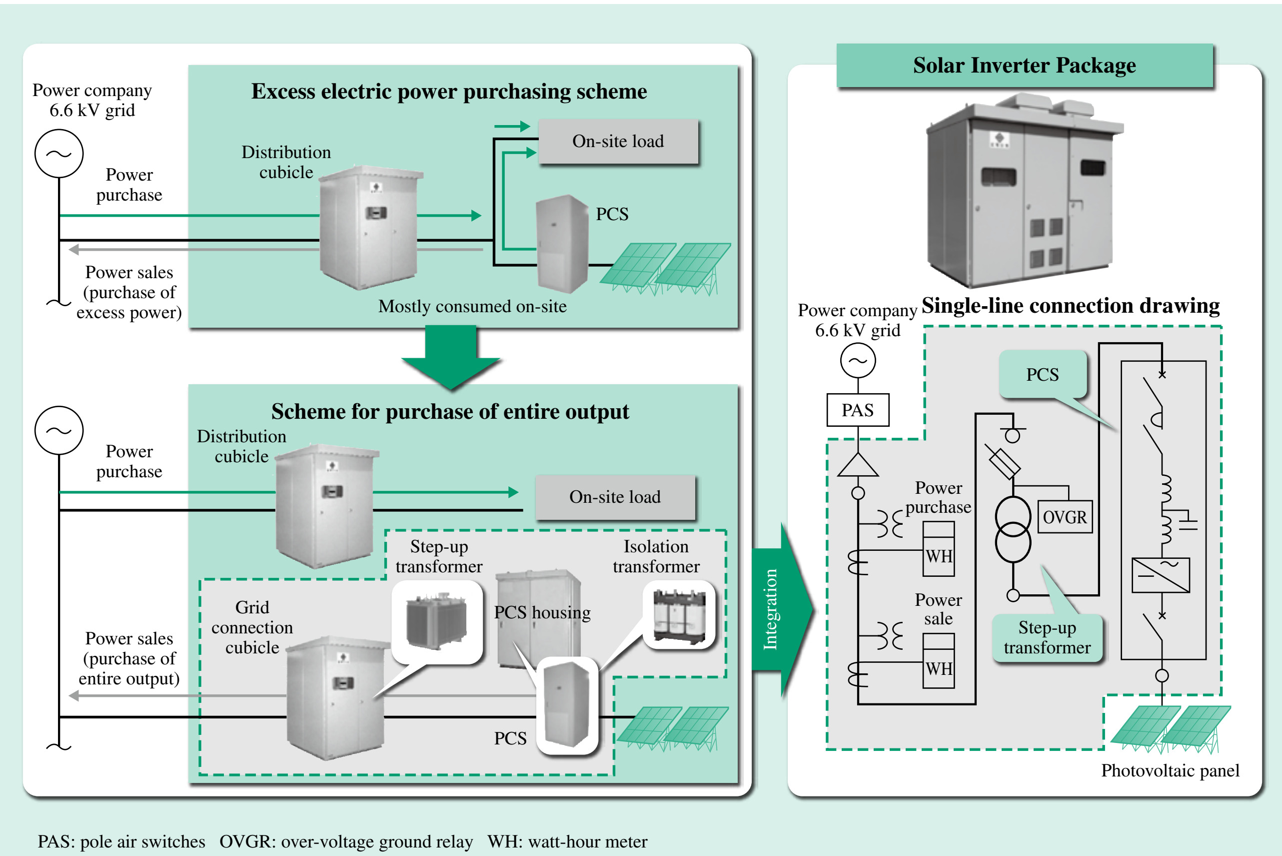



*Fig. 8—Grid Connection for Feed-in Tariff Scheme.*
*Under the feed-in tariff scheme, power generation equipment connects directly to the power company grid.*

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

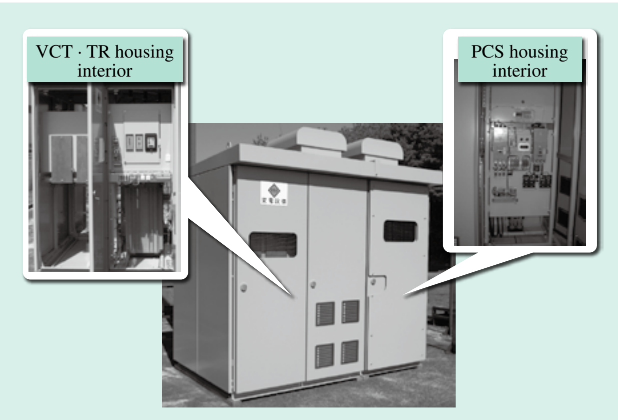
(a) Main circuit breaker: A study was conducted to compare a high-voltage load break air switch (LBS) and high voltage, current-limiting power fuse (PF) against a vacuum circuit breaker (VCB) and disconnecting switch (DS), resulting in the lower-cost LBS+PF combination being selected, with short-circuit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

(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).




VCT: instrument transformers for metering service TR: transformer

*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.*

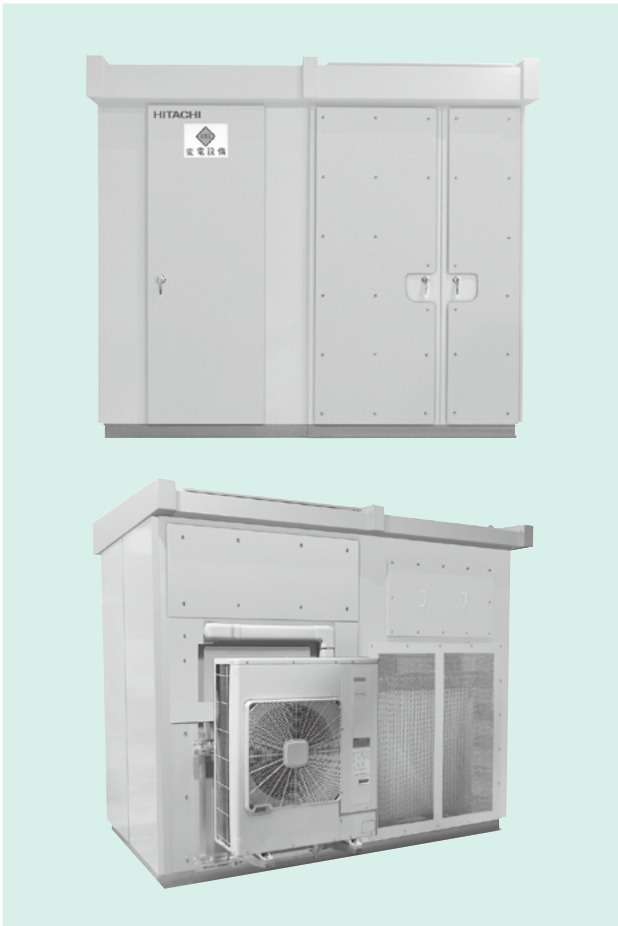



*Fig. 11—100-kW Solar Inverter Package (Salt-resistant Model).*
*To allow installation at sites prone to salt damage, air conditioning is used to segregate internal and external air.*

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


(1) News Release, Agency for Natural Resources and Energy (2014.1.10) in Japanese.

(2) Japan Meteorological Agency web site, http://www.jma.go.jp/jma/indexe.html


## ABOUT THE AUTHORS


Shigeru Kiyomiya

*Renewable Energy Business Development Department, Systems Development Division, Business Operations Group, Hitachi Industrial Equipment Systems Co.,Ltd. He is currently engaged in the business planning of renewable energy. Mr. Kiyomiya is a member of The Institute of Electrical Engineers of Japan.*

Takashi Yoshikawa

*Renewable Energy Business Development Department, Systems Development Division, Business Operations Group, Hitachi Industrial Equipment Systems Co.,Ltd. He is currently engaged in the business planning of renewable energy and power conditioning systems.*

Hiroyuki Endo

*Transformer Oil Immersed Type Design Group, Transformer Design Department, Power Distribution & Environmental Systems Division, Hitachi Industrial Equipment Systems Co., Ltd. He is currently engaged in development of the amorphous-transformer.*

Tomokazu Ukisu

*Distribution System & Components Design Group, Power Distribution Systems Management Department Power Distribution & Environmental Systems Division. Hitachi Industrial Equipment Systems Co., Ltd. He is currently engaged in design and development of the switchboard.*

Featured Articles

# Development of 5-MW Offshore Wind Turbine and 2-MW Floating Offshore Wind Turbine Technology

Mitsuru Saeki
Ikuo Tobinaga
Junichi Sugino
Takashi Shiraishi

*OVERVIEW: To date, Hitachi has received orders for a total of 137 of the 2-MW downwind turbines it developed for use in Japan's demanding conditions such as tyhoon gusts and wind turbulance in its mountainous regions. The first seven offshore wind turbines mounted on fixed seabed foundations to be built in Japan commenced operation in 2010, with an additional eight turbines added in 2013. Hitachi is now drawing on this experience to develop a 5-MW downwind turbine for offshore use. Hitachi has also, as a member of the Fukushima Offshore Wind Consortium, supplied a wind turbine to the Fukushima Floating Offshore Wind Farm Demonstration Project sponsored by the Ministry of Economy, Trade and Industry. Similarly, it has installed a 2-MW downwind turbine for the Floating Offshore Wind Turbine Demonstration Project led by the Ministry of the Environment, with Hitachi being part of the group contracted to undertake the project.*

## INTRODUCTION

VARIOUS forms of renewable energy are being developed and commercialized around the world in response to the increasing environmental demands that accompany progress. Of these, wind power generation, in particular, has reached a stage where its output and cost are close to traditional forms of power generation using fossil fuels and nuclear power. It is growing in both scale and sophistication, being installed at various places around the world, not only in Europe, which is the leading early adopter of the technology.

Hitachi began developing its HTW2.0-80 2-MW downwind turbine in 2003, using the SUBARU22/100 to conduct quantitative testing of the differences between upwind and downwind configurations(1). Subsequently, seven offshore wind turbines built on fixed seabed foundations, Japan's first, commenced operation in 2010(2), with an additional eight wind turbines entering service in 2013. Drawing on this experience, Hitachi is now developing the HTW5.0-126, a 5-MW downwind turbine for offshore installation.

As a maritime nation, Japan is surrounded by large areas of ocean that have much greater potential for wind power generation than on land. However, if wind turbines are to be situated offshore, they need to be capable of generating power reliably from floating platforms ("floaters") without fixed seabed foundations. Hitachi has supplied one HTW2.0-80 to the Fukushima Floating Offshore Wind Farm Demonstration Project sponsored by the Ministry of Economy, Trade and Industry, and another to the Floating Offshore Wind Turbine Demonstration Project led by the Ministry of the Environment. Through this testing, Hitachi aims to verify the viability of floating offshore wind power generation.

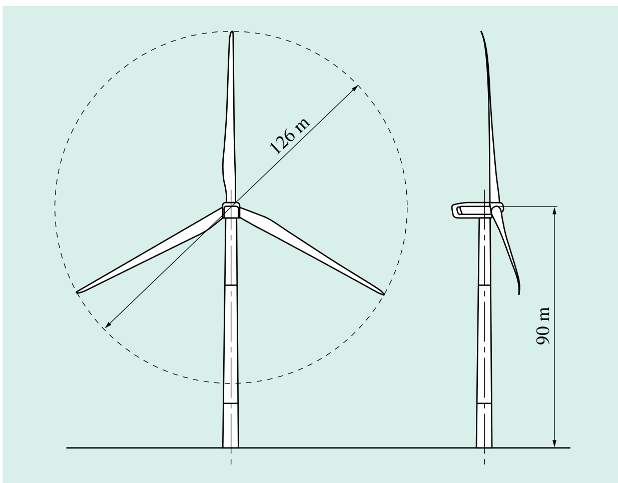



*Fig. 1—HTW5.0-126 Wind Turbine.*
*The HTW5.0-126 has a rotor diameter of 126 m and is designed to withstand gusts of 70 m/s or more.*

Table 1. HTW5.0-126 Specifications
*An output voltage of 33 kV was selected to improve the economics of the undersea cable used to connect to the onshore grid.*

| Parameter | Specification |
|---|---|
| Rated output | 5,000 kW |
| Rotor diameter | 126 m |
| Hub height | 90 m or more |
| Number of blades | 3 |
| Rotor orientation | Downwind |
| Tilt angle | −8° |
| Coning angle | 5° |
| Output control | Pitch, variable speed |
| Brake | Blade feathering (independent pitch) |
| Yaw control | Normal operation: Active yaw<br>When shutdown in high winds: Free yaw |
| Speed | 6.4 to 12.7 rpm ($min^{-1}$) |
| Gear ratio | 1:40 (approx.) |
| Generator | Permanent magnet synchronous generator |
| PCS | Full converter |
| Turbine output voltage | 33,000 V |
| Cut-in wind speed | 4 m/s |
| Cut-out wind speed | 25 m/s |

PCS: power conditioning system

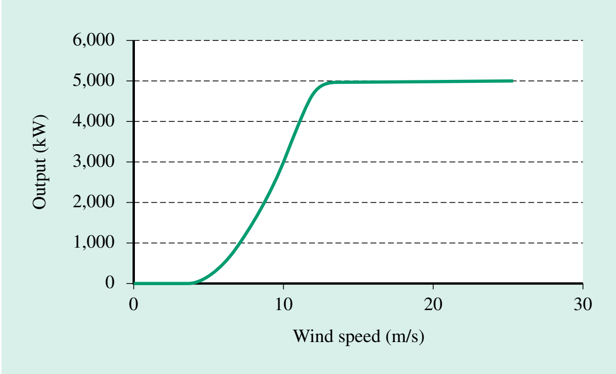



*Fig. 2—HTW5.0-126 Power Curve.*
*The wind turbine has a capacity of 5 MW and uses monopile foundations, which have the lowest cost.*

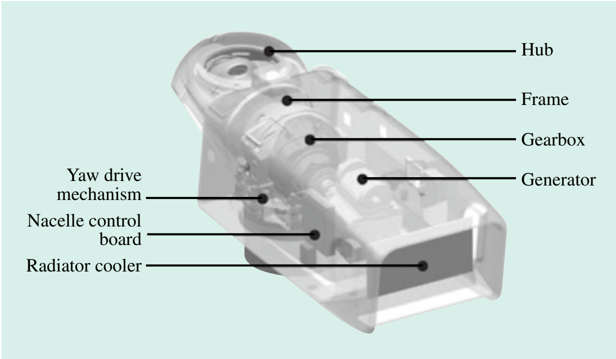



*Fig. 3—Nacelle Design.*
*The nacelle has a two-stage gearbox to reduce weight and improve reliability.*

This article describes the concept and features of the HTW5.0-126, the differences between mounting wind turbines on floaters and on fixed seabed foundations, an overview of two floating wind power generation systems, and the progress that has been made on testing these systems.

## HTW5.0-126 5-MW DOWNWIND OFFSHORE WIND POWER GENERATION SYSTEM

In response to demand for larger offshore wind power generation systems, Hitachi plans to build a prototype of its HTW5.0-126 5-MW downwind offshore wind power generation system off the coast of Kamisu City in Ibaraki Prefecture. Fig. 1 shows a drawing of the HTW5.0-126 prototype, Table 1 lists its specifications, and Fig. 2 shows its power curve.

Compared to locations such as Europe's North Sea, Japan and nearby parts of Asia have not only a low mean wind speed in the 6 to 8 m/s range, but also experience gusts of up to 70 m/s during typhoons.

The specifications of the HTW5.0-126 were chosen to achieve good economics, reliability, durability, and scope for future expansion under these conditions. The rated capacity for the wind turbine was set at 5 MW because this allows monopile foundations, which is the lowest cost option, to be used. Use of a two-stage gearbox is being considered to reduce the weight of the tower head. The target weight of the tower head is 350 t. Fig. 3 shows the nacelle design.

### Features of Downwind Turbines

A major feature of the HTW5.0-126 is that the rotor is located on the downwind side of the tower. This configuration ensures high reliability in environments such as Japan, where typhoons are frequent, even during power outages on the grid[3].

Because the large rotor required for higher wind turbine capacity means greater bending, locating the rotors on the downwind side eliminates the risk of bending causing the rotor to collide with the tower, facilitating the adoption of larger rotor diameters by minimizing the restrictions associated with longer rotor blades. Furthermore, the clearance between the blades and tower increases with increasing wind speed on a downwind turbine. Compared to an upwind configuration, where the opposite occurs, this improves safety by further reducing the potential for a collision between tower and blade[4].

The stability of the downwind configuration is also potentially valuable for floating offshore wind power generation, and it provides major benefits to the two floating offshore wind power generation systems described later in this article.

## Reliability Improvements

Because offshore wind turbines are more difficult to access than land-based installations, they need to achieve higher utilization than on land in order to improve the economics of offshore wind turbines over their entire lifetime(5). This means they require higher reliability.

Because it was designed specifically for offshore use, Hitachi has already incorporated, or is considering incorporating, a number of reliability improvements in the HTW5.0-126. The following sections describe the most important of these.

(1) Medium-speed gear drive

To reduce the potential for faults in the gearbox and generator, Hitachi is considering adopting a medium-speed gear drive consisting of a gearbox (with a gear ratio of approximately 1:40) in place of parallel gears, along with a 36-pole permanent magnet synchronous generator.

(2) Dual-bearing outer ring drive

Hitachi is considering the use of a dual-bearing outer ring drive system on the HTW5.0-126 in order to bear the higher loads associated with larger wind turbines (see Fig. 4). This system uses two shafts (fixed and rotating) to split the rotor load and transmit it to the rest of the structure. This design improves the reliability of the gearbox by transmitting a very pure torque load to it, with minimal loading other than the rotor torque component. Also, because the fixed shaft that bears loads other than torque does not itself rotate, it improves the reliability of structural components by reducing the fatigue load.

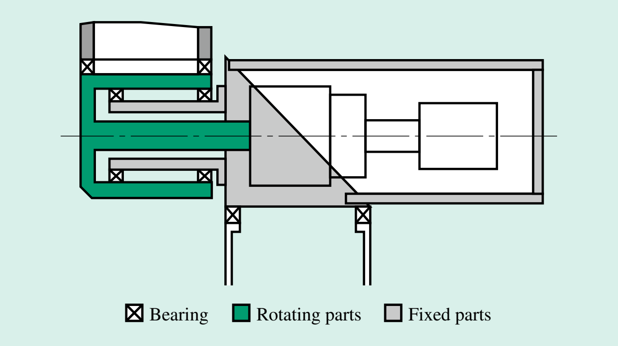



*Fig. 4—Dual-bearing Outer Ring Drive.*
*Use of separate fixed and rotating shafts splits the rotor load and transmits it to the rest of the structure.*

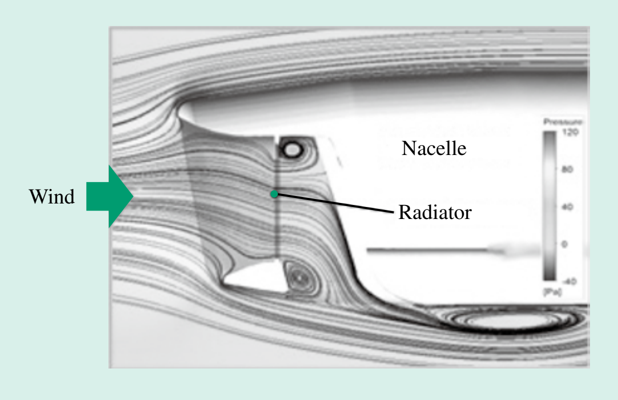



*Fig. 5—Fluid Dynamics Simulation around Nacelle.*
*The figure shows a simulation of air flow through the radiator used in the design of the nacelle shape.*

(3) Passive cooling

Because the HTW5.0-126 has a downwind configuration, the front side of the nacelle is the part that is furthest upwind. Hitachi has utilized this feature to incorporate a passive (fan-less) cooling system. Using computational fluid dynamics, it has designed the important parts of the nacelle shape to ensure the volume of air necessary for cooling (see Fig. 5).

## HTW5.0-126 Development Schedule

The HTW5.0-126 prototype is currently being fabricated and is expected to be ready for construction in the summer of 2014. The power train is undergoing full power testing at the factory prior to nacelle assembly.

Fig. 6 shows an overview of full power testing, which includes measuring the power train behavior

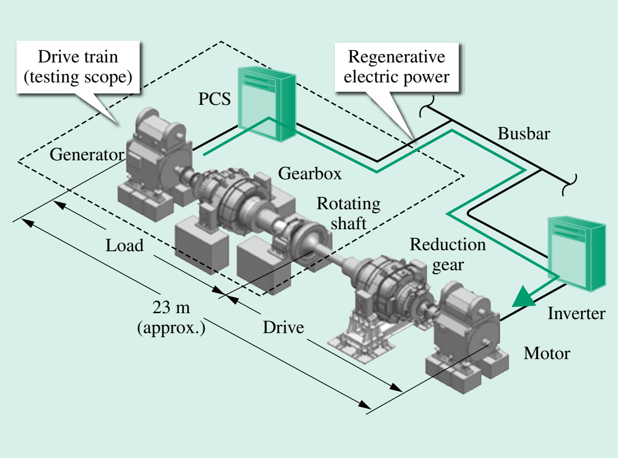



*Fig. 6—Full Power Testing of Drive Train.*
*Two power trains were installed and tested using electric power regeneration.*

*Fig. 7—Full Power Testing.*
*This equipment was used to measure the power train behavior under variable torque and with alignment deviations.*

under variable torque and with alignment deviations. Fig. 7 shows the test apparatus with which full power testing is conducted.

## FUKUSHIMA FLOATING OFFSHORE WIND FARM DEMONSTRATION PROJECT

### Overview of Fukushima Offshore Floater Project

The Fukushima Offshore Wind Consortium made up of Marubeni Corporation (as project integrator), ten companies (including Hitachi), and The University of Tokyo (as technical advisor) was contracted by the Ministry of Economy, Trade and Industry in March 2012 to undertake the Fukushima Floating Offshore Wind Farm Demonstration Project. The project involves the consortium building the world's first floating offshore wind farm off the coast of Fukushima Prefecture, and conducting testing to assess its safety, reliability, economics, and other characteristics, with each of the consortium members taking on a role that utilizes their respective technologies and other knowledge[6]. In addition to supplying the electrical conversion systems for the floating substation, Hitachi will also provide an HTW2.0-80 wind turbine modified to suit this purpose for the semi-sub floater supplied by Mitsui Engineering & Shipbuilding Co., Ltd. The wind turbine will be assembled on the semi-sub floater in a shipyard dry dock, which provides an environment similar to a land-based installation, and then towed all the way to the site. A feature of the semi-sub floater is its high level of stability (see Fig. 8).

*Fig. 8—Wind Turbine off Coast of Fukushima.*
*The 2-MW downwind turbine (HTW2.0-80) is mounted on the semi-sub floater (photograph courtesy of Fukushima Offshore Wind Consortium).*

### Strengthened Tower for Floating Wind Turbine

A coupled analysis of the wind turbine and floater was conducted during the design stage to ensure the tower design could cope with the higher static and fatigue loads caused by swaying. To align with the diameter of the center column on the floater and deal with the higher tower bending moment, the diameter at the bottom of the tower is 5 m, the largest to date for a HTW2.0-80. The tower needs to be made as narrow as possible because of its wind shadow, which is a consequence of the wind reaching the rotor of a downwind turbine after passing around the tower. One way of satisfying these requirements for (1) strength, (2) weight reduction, and (3) shape restrictions associated with the tower shadow, is to incorporate measures to improve the fatigue strength of the tower on the floater by machining weld toes. The wind turbine tower can be built by forming a welded structural steel plate into a cylindrical shape and then joining it with a full penetration weld. This can satisfy the above three requirements.

### Electrical Equipment Containers

Hitachi is considering mounting the power conditioning system (PCS) at the base of the tower. The PCS controls the frequency of the generated power to match the grid. This configuration requires the high-voltage panel, step-up transformer, special high-voltage panel, and other components to be located on the grid-side. The possibilities include


*Fig. 9—Containers on Deck of Floater.*
*The extra-high-voltage panel container is on the left, the high-voltage panel container is in the center, and the step-up transformer container is on the right (photograph courtesy of Fukushima Offshore Wind Consortium).*

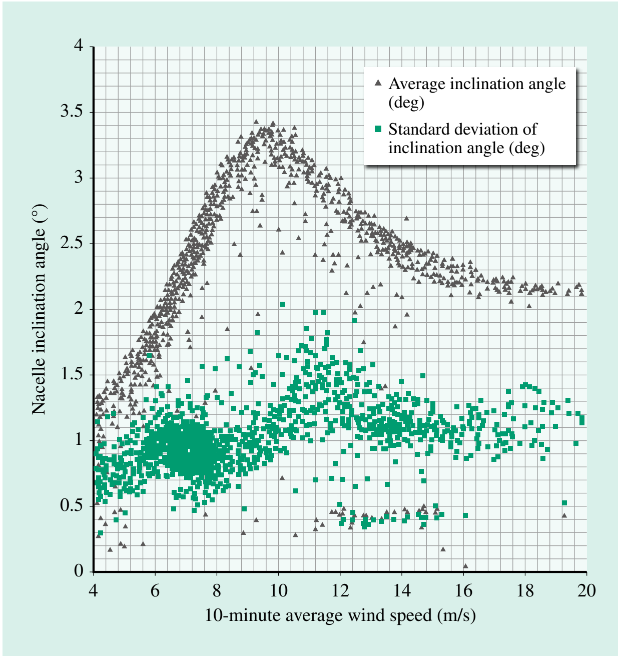



*Fig. 10—10-minute Average Wind Speed and Nacelle Tilt Angle.*
*A tilting sensor was attached to the nacelle to take measurements on the floater.*

locating the PCS inside the tower, inside the floater, or on the floater deck. Although the floating wind turbine is a prototype, its specifications have been designed with future commercial use in mind. Accordingly, Hitachi has mounted the equipment in three separate and independent containers in order to allow for replacement in the event of a fault (see Fig. 9). The two containers containing the special high-voltage panel and high-voltage panel are connected to the tower by a pipe, and there is a process for using a ventilation fan inside the tower to circulate air for cooling. For the step-up transformer, the possibilities include covering it with a coating to prevent salt damage and using a fan in the container ceiling to supply outdoor air and circulate internal air for cooling. One possibility is to attach the three containers to the deck of the floater by bolts, in which case it will be possible to detach and replace an entire container in the event of a fault.

### Testing

The wind turbine has been generating electric power reliably and producing test data since November 2013. The stability of the floater has been particularly good. Although there is some perceptible swaying, the testing has found no problems with performing the sort of routine maintenance carried out on land. Fig. 10 shows the inclining angle of the nacelle when generating power. The horizontal axis represents the 10-minute average wind speed and the vertical axis represents the measurement from an incline angle sensor located in the nacelle.

The average incline angle increases until it reaches the range in which the blade pitch is adjusted, and then subsequently decreases. Hitachi plans to utilize this data for future study of the details, considering influences such as ocean currents.

Testing is scheduled to continue until the end of FY2015. Data will be collected during this time and used as feedback for the design process so that it can be applied to the development of future floating wind turbines.

## MINISTRY OF THE ENVIRONMENT THE FLOATING OFFSHORE WIND TURBINE DEMONSTRATION PROJECT

In the Floating Offshore Wind Turbine Demonstration Project that began with a preliminary study in 2010[7), (8), (9] led by the Ministry of the Environment, a group of companies headed by Toda Corporation constructed a floating offshore wind turbine with a spar design off the Goto Islands in Nagasaki Prefecture. While a wide variety of designs have been proposed for floating offshore wind turbines, the project selected a spar design because of its excellent economics. They were able to improve its economics further by using a hybrid construction that combined prestressed concrete and steel components (see Fig. 11).

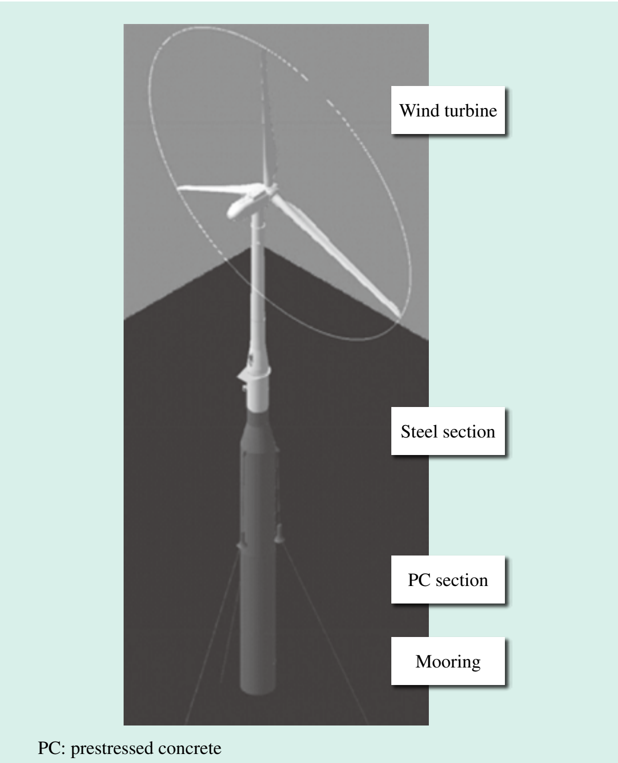



*Fig. 11—Hybrid Spar Design.*
*Instead of an all-steel spar, a hybrid spar design incorporating prestressed concrete was adopted.*

To take advantage of the characteristics of the floater, it is necessary to work on things like the overall transportability, ease of construction, and durability, factors that arise from having an elongated shape with a simple structural design.

Hitachi supplied two separate wind turbines for testing: a 100-kW base model and a 2-MW model.

*Fig. 12—Small 100-kW Prototype Wind Turbine.*
*This small prototype was built by modifying a 100-kW wind turbine designed for use on offshore islands and installing it on a floater.*

*Fig. 13—2-MW Demonstration Wind Turbine.*
*This demonstration model was built by modifying a 2-MW onshore wind turbine and installing it on a floater.*

The small 100-kW prototype wind turbine was a SUBARU22/100 base model designed for offshore islands that formerly belonged to Izena Island in Okinawa (see Fig. 12).

Although this wind turbine had been installed on land, its specifications were suitable for offshore use because it had been designed for use on islands. For example, it had been treated with a coating to prevent salt damage and had a cooling system that worked primarily by recirculating the internal air. Other possible ways of adapting it for floating use include changing the rotor to a downwind configuration and

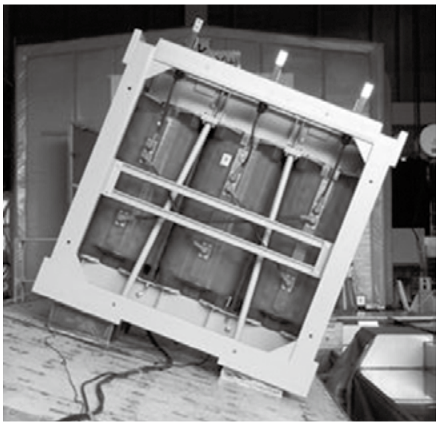


*Fig. 14—Inclination Test of Step-up Transformer.*
*Because the step-up transformer will be installed inside the floating wind turbine, inclination testing was performed in accordance with standards used for shipping.*

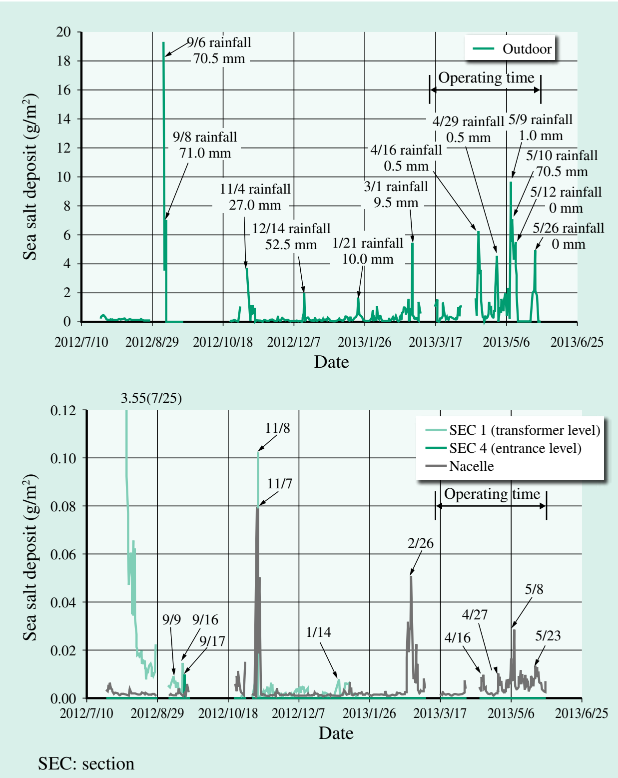



*Fig. 15—Salt Level Graphs (One-hundredth outdoor level of salt).*
*A practical technique for measuring the level of salt in the air has only become available recently. The graphs show examples of how the technique was used for quantitative assessment of measures to prevent salt from getting into electrical rooms.*

modifying the blade pitch control to dampen the swaying of the floater.

Additional modifications made to the 2-MW demonstration model to suit floating use included measures for dealing with the inclination, water or oil leaks, and humidity (see Fig. 13).

One measure for dealing with the inclination is to conduct inclination testing of components such as step-up transformers in accordance with standards used for shipping (see Fig. 14). Possible countermeasures against water leaks, meanwhile, include double-skinned housings for electrical components and waterproofing them at three atmospheric pressures.

Waterproofing also serves to prevent salt from getting into the equipment (see Fig. 15). It would also be possible to extend measures for minimizing swaying on the 2-MW demonstration model by equipping it with independent pitch control.

## CONCLUSIONS

This article has described the development of technology for the 5-MW offshore wind turbine based on experience with the 2-MW wind turbine on a fixed seabed foundation, technology for wind turbines for the Fukushima Floating Offshore Wind Farm Demonstration Project, and a demonstration project for floating offshore wind power generation led by the Ministry of the Environment.

In addition to utilizing operational data from these two floating offshore wind turbines in future designs, Hitachi also aims to expand offshore wind power generation and help protect the global environment by utilizing testing of the HTW5.0-126 to make progress on commercializing offshore wind turbines.

## ACKNOWLEDGMENTS

Hitachi would like to express its gratitude to the New Energy and Industrial Technology Development Organization (NEDO) for the assistance received in the development of the HTW5.0-126 5-MW offshore wind power generation system.

Hitachi would also like to thank its consortium partners for their help in the Fukushima Floating Offshore Wind Farm Demonstration Project led by the Ministry of Economy, Trade and Industry, and its partners in the Floating Offshore Wind Turbine Demonstration Project led by the Ministry of the Environment.

## REFERENCES

(1) Yoshida, et al., “A Three-Dimensional Power Calculation Method which Improves Estimation Accuracy in Complex Terrains,” Vol. 29, No. 2, pp. 75–83, Japan Wind Energy Association (2005) (in Japanese).
(2) Sakamoto, et al., “Large Wind Turbine System and Smart Grid,” Hitachi Review **60**, pp. 394–398 (2011).
(3) Yoshida, et al., “Development of 2.0-MW Downwind Turbine Technologies,” JWES/JWEA Joint Conference (2011) in Japanese.
(4) Inoue, et al., “Power Generation, Distribution and Substation System for Development of Offshore Wind Farms,” Hitachi Hyoron **95**, 12, pp. 820–823 (Dec. 2013) in Japanese.
(5) T. Burton, et al., “Wind Energy Handbook,” Second Edition, p.663, John Wiley & Sons (2011).
(6) Ishihara, “Current Status and Future Prospects for Fukushima Floating Offshore Wind Farm Demonstration Project,” Journal of Japan Wind Energy Association, Vol.36, No.4, pp. 553–556 (2013) in Japanese.
(7) “FY2010 Progress Report on Floating Offshore Wind Turbine Demonstration Project,” Tokyo University (2011) in Japanese.
(8) “FY2011 Progress Report on Floating Offshore Wind Turbine Demonstration Project,” Toda Corporation (2012) in Japanese.
(9) “FY2012 Progress Report on Floating Offshore Wind Turbine Demonstration Project,” Toda Corporation (2013) in Japanese.

## ABOUT THE AUTHORS


Mitsuru Saeki

*Hitachi Works, Power Systems Company, Hitachi, Ltd. He is currently engaged in wind turbine development projects. Mr. Saeki is a registered electrics and electronics professional engineer and is a member of the IEEJ.*

Ikuo Tobinaga

*Wind Turbine Generator System Department, Hitachi Works, Power Systems Company, Hitachi, Ltd. He is currently engaged in the business of developing wind turbines. Mr. Tobinaga is a member of the Japan Wind Energy Association.*

Junichi Sugino

*Wind Turbine Generator System Department, Hitachi Works, Power Systems Company, Hitachi, Ltd. He is currently engaged in the business of developing wind turbines.*

Takashi Shiraishi

*Wind Turbine Generator System Department, Hitachi Works, Power Systems Company, Hitachi, Ltd. He is currently engaged in the business of developing wind turbines. Mr. Shiraishi is a member of the Japan Wind Energy Association.*

Featured Articles

# Core Technologies for Developing Wind Power Generation Systems

Shigehisa Funabashi
Kohei Tanaka, Dr. Eng.
Mamoru Kimura, Dr. Eng.
Masatoshi Watanabe, Dr. Eng.

*OVERVIEW: Wind power is a mainstay of renewable energy, with new wind farms being installed around the world in recent years. Use of offshore wind power, in particular, is expected to expand in the future. Even more so than onshore wind turbines, large offshore wind turbines require high reliability and easy maintenance. To meet this demand, Hitachi is utilizing technologies for reliability assessment and various types of analysis to improve the reliability of the drive train, generator, and other components in its HTW5.0-126 5-MW offshore downwind turbine, which is currently under development, and is developing a cooling system that takes advantage of its downwind configuration. Hitachi is also seeking to develop blade design techniques for improving the reliability and increasing the output of the next generation of wind turbine blades.*

## INTRODUCTION

INTEREST in renewable energy has been growing in recent years because of its role in overcoming environmental problems such as global warming. Along with photovaltaic power generation, this interest is focused on wind power generation in particular, with wind farms being installed throughout the world. Offshore wind power is expected to be developed further in the future, with offshore sites enjoying better wind conditions than those on land. Being located offshore also facilitates the adoption of larger wind turbines by alleviating problems such as noise and having to transport large components. On the other hand, offshore locations place greater demands than before on things like reliability and ease of maintenance.

This article describes the technologies used in the development of the drive train, permanent magnet generator, and cooling system for the HTW5.0-126, a large 5-MW offshore wind turbine that is currently being developed by Hitachi, the progress of that development, and the potential for using blade design techniques to increase power generation.

## TECHNOLOGIES FOR IMPROVING RELIABILITY OF DRIVE TRAIN

### Two Bearing – Outer Rotating System

Hitachi is considering the use of a "two bearing – outer rotating system" to improve the reliability of the drive train for large 5-MW wind turbines. This design ensures that only the torque from the wind energy delivered from the blades is transmitted through the hub, rotating main shaft, and gearbox to the generator, with the wind load and the weight of the blades being supported by the static main shaft. Also, a low-rigidity design is used for the rotating main shaft to absorb the effects of misalignment. Structural analysis was used during the structural design of component parts to check their strength, and the reliability of the components was subsequently verified by testing.

Fig. 1 shows a precise one-fifth scale model of the hub, rotating main shaft, static main shaft, and bearings that were manufactured and used for drive train testing. This included using a hydraulic cylinder to apply axial and radial loads, and adjusting the height of the rotating main shaft support structure to introduce misalignment. This allowed the deformation behavior of the shafts in particular to be assessed and verified.

### Back-to-Back Testing

For testing of the full-size drive train, two sets of generators, gearboxes, and power conditioning systems (PCSs) were operated back-to-back and measurements were taken of vibration, stress, and other parameters under a wide range of conditions in order to verify reliability (see Fig. 2). By shifting the position of the gearbox, this setup also allowed the characteristics to be determined for different levels of misalignment[(1)].

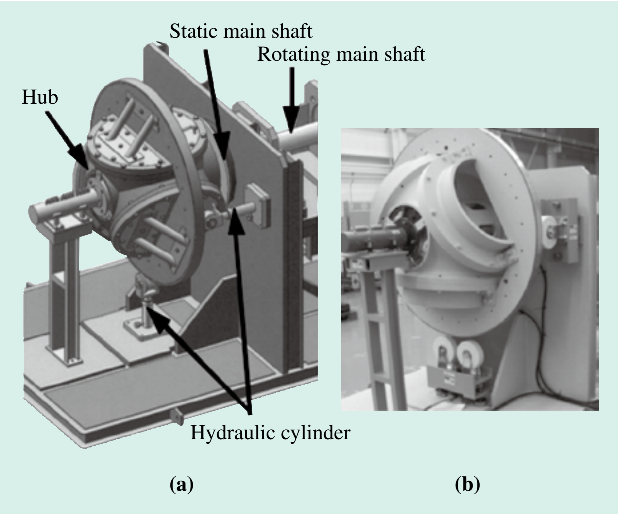



*Fig. 1—Testing on One-fifth Scale Model of Drive Train.*
*The figures show a schematic diagram of the test rig (a) and a photograph (b). The design consists of a rotating main shaft that transmits the torque used for generating electric power and a static main shaft that supports the wind load and the weight of the blades.*

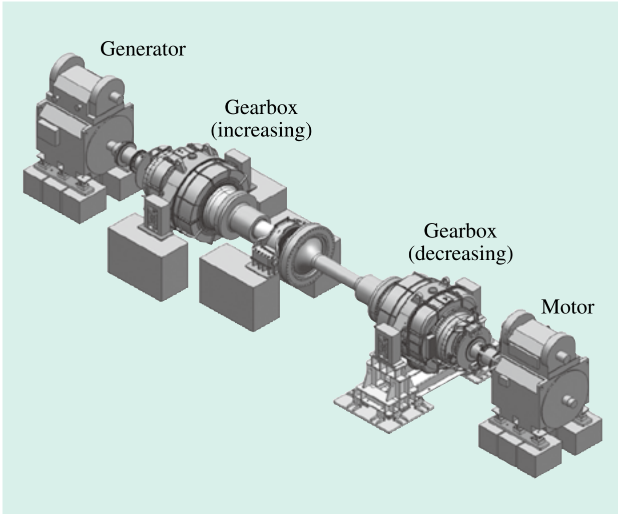



*Fig. 2—Back-to-back Testing Configuration.*
*The drive system on the right (in which the generator operates as a motor) turns the generator system on the left to perform reliability testing under a variety of different operating conditions.*

## TECHNOLOGIES FOR IMPROVING RELIABILITY OF LARGE PERMANENT MAGNET GENERATOR

### Clover Leaf Structure for Better Cooling

Generators for large wind turbines require a high output density to ensure small size and light weight. As a result, permanent magnet generators have increasingly been chosen for this purpose in recent years. However, because permanent magnets become demagnetized at high temperatures, temperature management (cooling) is required during operation.

Dysprosium, a rare earth element, is typically added to neodymium magnets to improve their thermostability. These magnets are located in the rotor, and Hitachi has designed a clover leaf structure that incorporates ventilation grooves into the rotor to improve cooling performance(2).

The clover leaf structure has a number of ventilation grooves located between the poles along the axis of the rotor, with improved cooling being provided by the air that passes through these grooves. Hitachi designed a 2-MW permanent magnet generator using computational fluid dynamics to perform an

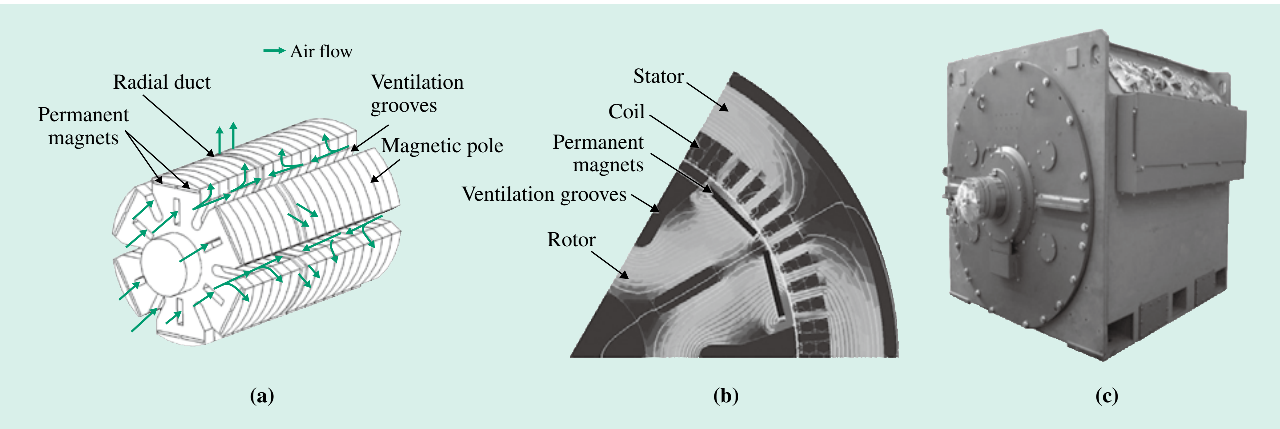



*Fig. 3—Permanent Magnet Generator with Clover Leaf Structure.*
*Fig. (a) shows the flow of air through the rotor and Fig. (b) shows the magnetic field line diagram obtained by electromagnetic field analysis. In addition to conventional radial ducts, the rotor design also includes ventilation grooves that run in the axial direction to improve cooling around the magnets. Fig. (c) shows the newly developed 5-MW generator in which these techniques were applied.*

analysis of air flow and associated losses, and an electromagnetic field analysis to predict the generation performance of the new structure. It also performed prototype testing. This succeeded in reducing the size of the generator by 30% compared to the previous doubly-fed induction generator [see Fig. 3 (a) and (b)].

### Permanent Magnet Generator for 5-MW Wind Turbine

Hitachi developed a large permanent magnet generator for use in the HTW5.0-126. The version for use with a medium-speed drive train has 36 poles, a rated speed of 440 rpm, and an output of 5,460 kW. Although it requires better rotor cooling performance because it runs at lower rpm than the existing 2-MW HTW2.0-80 wind turbine, this problem was solved by using the clover leaf rotor design.

The development included additional study of the number of poles and of how to position the magnets in order to accommodate the higher capacity, as well as measures for making the generator easier to assemble [see Fig. 3 (c)].

## PASSIVE COOLING TECHNIQUE UTILIZING NATURAL AIR FLOW

Because the HTW5.0-126 has a downwind configuration, its most upwind point is the tip of the nacelle. Hitachi has utilized this feature to incorporate a passive (fan-less) cooling system.

The radiator used to air-cool the cooling water from the generator and gearbox is located at the upwind end of the nacelle. This provides efficient cooling because it gets the full benefit of the natural air flow before the wind speed is reduced by the rotor blades [see Fig. 4 (a)].

Computational fluid dynamics was used to design the nacelle shape, which is important for ensuring sufficient air flow for cooling [see Fig. 4 (b)]. Locating the radiator inside the nacelle wind profile is also beneficial for reducing the wind load on the nacelle(1).

## BLADE DESIGN TECHNIQUES

### State of the Art for Wind Turbine Blades

Currently, in 2014, large wind turbines in the 7-MW class with blade diameters of about 160 m are being prepared for deployment in Europe. Furthermore, steady progress is being made in the development of larger wind turbines. The European Wind Energy Association (EWEA) predicted (in 2008) that wind turbines in the 10-MW class with blade diameters of about 180 m will enter service around 2015.

Among production wind turbines, meanwhile, improved models with long blades designed to be capable of generating power at low wind speeds have been released on the market. The trend toward larger blade sizes designed to increase the amount of power generated as much as possible is intended to maximize the return to the customer. This demonstrates the importance of customer-oriented product development in the wind power generation business.

### Wind Turbine Blade Design

Blades generate torque from the energy of the air flowing over them. Fig. 5 shows a diagram of blade bending moment and torque.

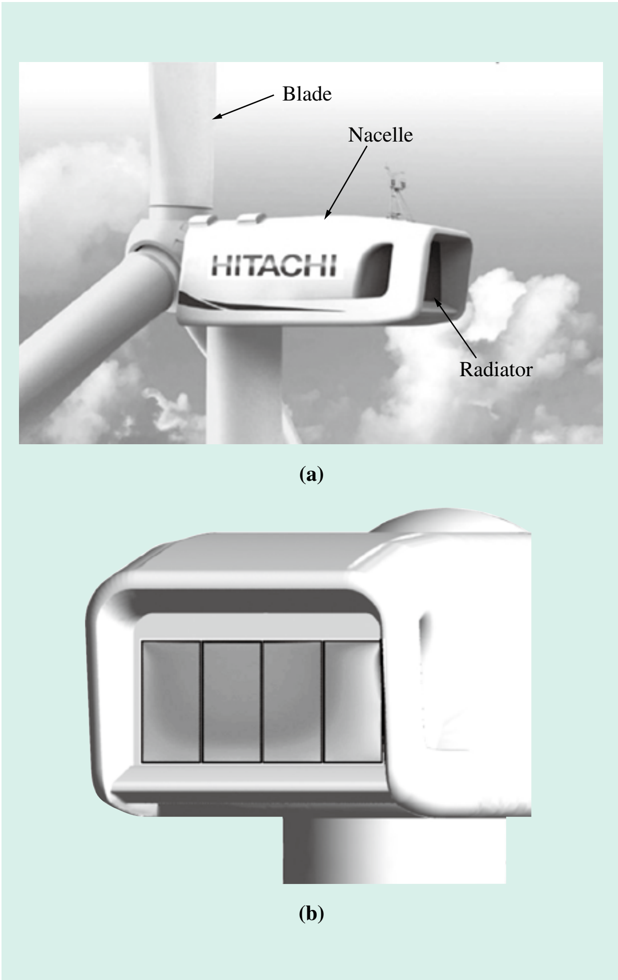



*Fig. 4—Passive Cooling System.*
*Fig. (a) shows the nacelle where the radiator is located, and Fig (b) shows the air speed distribution in the radiator obtained by computational fluid dynamics. The shape of the nacelle was designed to provide good and uniform airflow without the use of a fan.*

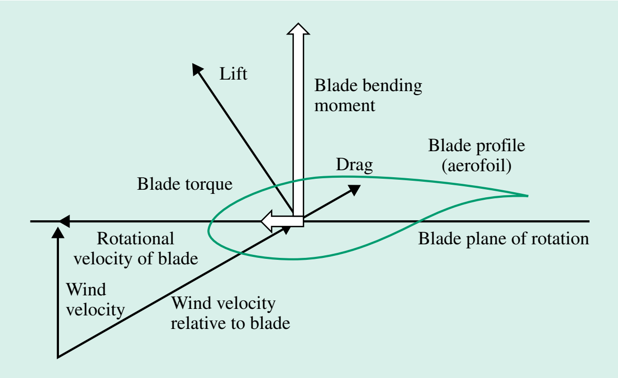



*Fig. 5—Relationship between Wind Velocity and Forces with Respect to Wind Turbine Blade Profile.*
*Since the blade profile acts as an aerofoil, its design should maximize lift and minimize drag. Since the rotational velocity of blade is high relative to the wind velocity on large wind turbines, most of the lift acts to bend the blade in the downwind direction.*

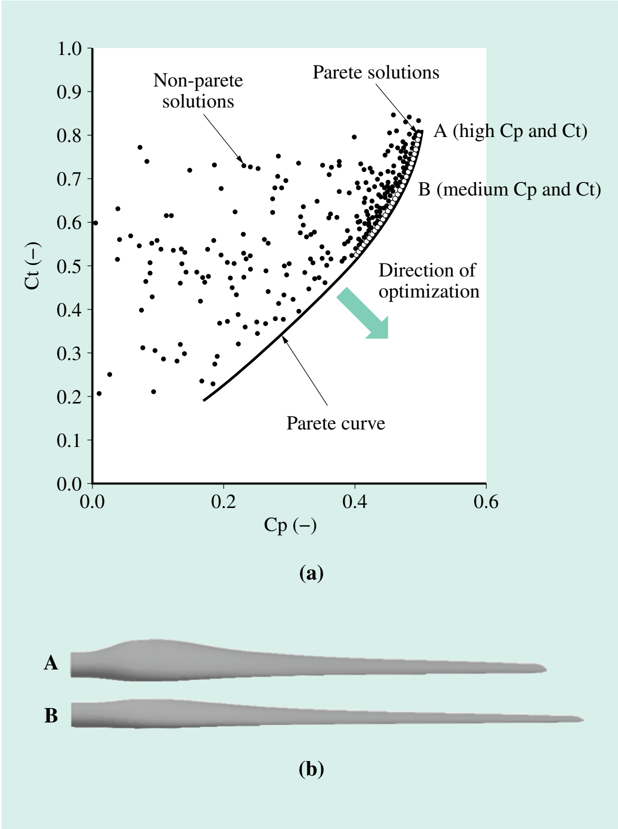



*Fig. 6—Results of Optimal Design Search for Wind Turbine Blade.*
*The graph plots the results of a two-objective design optimization (design search) with an objective function that seeks to minimize the thrust coefficient (Ct), which influences reliability, and to maximize the power coefficient (Cp), which influences output. In these results, profile B has a similar bending moment to profile A under the same wind speed conditions. Profile B has a slender blade profile for which the lower Cp allows the aerofoil chord length to be shorter and the lower Ct allows the blade length to be about 10% longer.*

Bending moment has a major influence on wind turbine reliability. It corresponds to the flexing of the blades in the downwind direction and is applied to the main shaft at the points where the blades are attached (the roots). Torque, on the other hand, is what causes the shaft to rotate. A higher torque produces a higher output. Because the return on investment is strongly influenced both by income from the sale of generated power and by savings on the cost of operation and maintenance (O&M), blades need to have both high reliability (through lower bending moment) and high output (through higher torque).

Blade design makes use of blade element momentum (BEM) theory(3). The design parameters include the blade aerofoil profile (cross section) from root to tip, and the associated performance tables, chord length, thickness, and lift. BEM theory is used to determine the aerofoil profile by identifying the design parameters that provide the required aerodynamic performance. Next, the forces to which the blades will be subjected are estimated for various different operating conditions, and the internal design that will provide the necessary static and fatigue strength is determined. Fig. 6 shows the results of a design search that sought to satisfy the requirement for both high reliability (low bending moment) and high output (high torque)(4). The design search was performed by coupling these calculations with an optimization system. Ct is a dimensionless thrust coefficient representing the bending moment, and Cp is a dimensionless power coefficient representing the output.

As shown in Fig. 6 (a), the design search found numerous solutions as the priority was shifted from output (high Cp) to reliability (low Ct). Fig. 6 (b), meanwhile, shows the blade profiles for point A, where the value of Cp is highest, and for point B, where the lower Ct means the bending moment remains roughly the same despite the blade being 10% longer. Because the benefit of longer blade length outweighs the reduction in Cp between points A and B, the total annual power generated by blade B over a year is about 7% higher than for blade A (assuming the same wind conditions and operation below the maximum output limit).

While this is just one example, Hitachi intends to establish a role for itself in the renewable energy sector by taking account of customer requirements when designing trade-offs between reliability and power generation.

## CONCLUSIONS

This article has described the development of the drive train, permanent magnet generator, and cooling system for a large offshore wind turbine currently being developed by Hitachi, the technologies used in that development, and the potential for using blade design techniques to increase power generation.

Hitachi is also developing other technologies, including those required for instrumentation and monitoring, and for the system control of wind turbines. Hitachi believes that the use of these technologies in the development of highly reliable and efficient wind power generation systems will lead to greater use of energy sources that are conscious of the global environment.

## REFERENCES


(1) M. Saeki, et al., "Concept of the HITACHI 5MW Offshore Downwind Turbine," EWEA2014 Annual Event, PO.ID15 (Mar. 2014).

(2) Kimura, et al., "Permanent Magnet Generator with Ventilation Flues between Poles in the Clover Leaf Structure Rotor for a Large Wind Turbine Generator System," IEEJ Transactions D, Vol.133, No.8, p. 821–827 (Aug. 2013) in Japanese.

(3) Tony Burton, et al., "Wind Energy Handbook," 2nd Edition, WILEY (Jun. 2011)

(4) Watanabe, et al., "Aerodynamic Design Optimization of Wind Turbine Rotor Blade," Proceeding of the 21st Ibaraki District Conference of The Japan Society of Mechanical Engineers (Sept. 2013) in Japanese.


## ABOUT THE AUTHORS


Shigehisa Funabashi

*Department of Applied Energy Systems Research, Energy and Environment Research Center, Hitachi Research Laboratory, Hitachi, Ltd. He is currently engaged in the research and development of a cooling system for large wind turbines. Mr. Funabashi is a member of The Japan Society of Mechanical Engineers (JSME).*

Kohei Tanaka, Dr. Eng.

*Wind Turbine Generator System Department, Hitachi Works, Power Systems Company, Hitachi, Ltd. He is currently engaged in the research and development of structural reliability for large wind turbines. Dr. Tanaka is a member of the JSME.*

Mamoru Kimura, Dr. Eng.

*Department of Applied Energy Systems Research, Energy and Environment Research Center, Hitachi Research Laboratory, Hitachi, Ltd. He is currently engaged in the research and development of a generator system for large wind turbines. Dr. Kimura is a member of The Institute of Electrical Engineers of Japan (IEEJ).*

Masatoshi Watanabe, Dr. Eng.

*Department of Applied Energy Systems Research, Energy and Environment Research Center, Hitachi Research Laboratory, Hitachi, Ltd. He is currently engaged in the research and development of blade design technology for large wind turbines. Dr. Watanabe is a member of the JSME.*

Featured Articles

# Electric Power Distribution and Utility Monitoring System for Better Energy Visualization

Hideki Hayakawa
Tetsunori Watanabe
Toshiko Kimura

*OVERVIEW: EMSs use IT functions such as visualization for the efficient management of energy use. They are also known as FEMSs when used in factories, BEMSs when used in buildings, and HEMSs when used in the home. In the market for remote monitoring systems, few small- to medium-sized sites with power supply contracts of less than 1,000 kW have installed EMSs in the past. Recently, however, this has changed, with the introduction of subsidy schemes leading increasing numbers of such sites installing EMSs. Hitachi Industrial Equipment Systems Co., Ltd. supports energy efficiency, the environment, preventive maintenance, and productivity management through its range of products, which include not only large systems, but also simple energy monitoring systems for small- or medium-sized sites that do not require an always-on PC.*

## INTRODUCTION

A survey of the Japanese market for commercial energy management systems (EMSs) found that it has continued to grow year by year. The market can be divided into the following categories, (1) Central monitoring systems - system integration, (2) Central monitoring systems - energy management services, (3) Supply of remote monitoring systems and energy management support services, and (4) Energy analysis and consulting. In addition to the replacement of existing large systems, the market is also being boosted by growth, from a low base, in the installation of EMSs by small- and medium-sized businesses (see Fig. 1).

There has been an increase in the installation of equipment for demand monitoring since the Great East Japan Earthquake in March 2011, and subsequently the beginning of a shift, since the latter half of FY2011, toward the use of EMSs for management based on recently acquired experience with power saving policies to help alleviate the summer peak in electric power demand.

Although the Japanese market for EMSs in FY2012 saw increases in the installation of EMSs at both large sites and small- or medium-sized sites, it is installation at small- or medium-sized sites that will drive the EMS market in the future.

Whereas products belonging to market categories (1) and (2) (central monitoring systems - system integration and central monitoring systems - energy management services) are primarily supplied to large factories or office buildings, the low initial and running costs of categories (3) and (4) (supply of remote monitoring systems and energy management support services, and energy analysis and consulting) mean they tend to be supplied to small- or medium-sized sites (see Fig. 2).

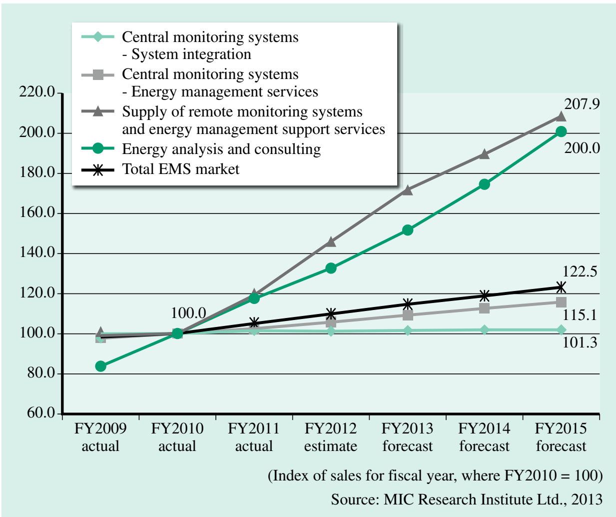
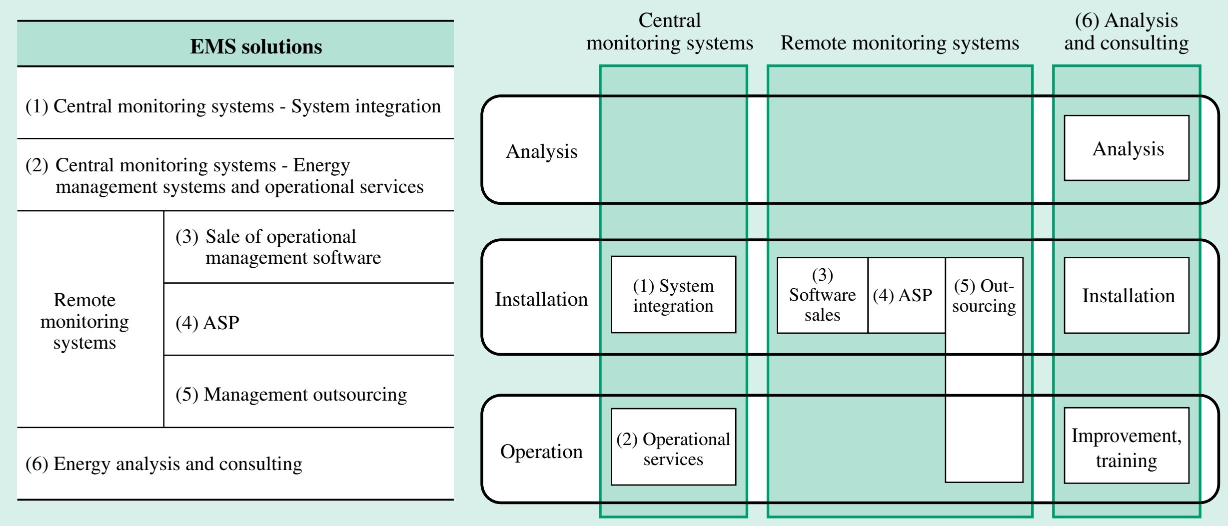



*Fig. 1—Sales Index (Relative to Actual Sales in 2010).*
*The EMS market continues to grow year after year. In addition to the replacement of existing large systems, the market is also being boosted by growth, from a low base, in the installation of EMSs by small- and medium-sized businesses.*




EMS: energy management system ASP: application service provider IT: information technology FEMS: factory energy management system
BEMS: building and energy management system HEMS: home energy management system

*Fig. 2—Definition of IT-based EMS Solutions.*
*EMSs use IT functions such as visualization for the efficient management of energy use. They are also known as FEMSs when used in factories, BEMSs when used in buildings, and HEMSs when used in the home.*

The following is a summary of the Bill to Partially Amend the Act on the Rational Use of Energy (Energy Conservation Act) of 2013.

(1) Introduction of a scheme for recognizing energy consumers who, in addition to conventional energy saving measures, also take steps to reduce their use of grid power during demand peaks using technologies such as batteries, on-site power generation, or energy management systems [factory energy management systems (FEMSs), building and energy management systems (BEMSs), or home energy management systems (HEMSs)].

(2) Specifically, the calculation for savings targets (a mean 1% annual improvement in unit energy consumption) was revised to make achieving the target easier by recognizing steps (energy savings) taken during periods of peak demand to reduce use of grid power.

Various subsidy schemes have also boosted the market for EMSs. These include the "FY2014 subsidies for supporting business operators that strive to rationalize their energy use," an energy efficiency subsidy to be offered by the Ministry of Economy, Trade and Industry (METI) in FY2014. This extended the subsidy to cover costs associated with the use of EMSs for energy saving measures or for managing peak demand.

Hitachi's product range already included the electric power distribution and utility monitoring system for large or medium-sized sites. It has now added simple energy monitoring systems for small- or medium-sized sites that do not require an always-on personal computer (PC).

This article describes the electric power distribution and utility monitoring system for large or medium-sized sites.

## ELECTRIC POWER DISTRIBUTION AND UTILITY MONITORING SYSTEM

The electric power distribution and utility monitoring system provides data collection software that runs on a PC together with multi-circuit units and clamp-on current sensors to allow those energy consumers who are designated as using energy management to collect environmental and energy efficiency data economically (see Fig. 3).

Up to 121 electric power distribution and utility monitoring system units can be connected to each system running the DE-SWA data collection software, and the communication lines between units can be up to 4.8 km in length.

A measurement data screen is provided to display realtime measurement data and status information from each electric power distribution and utility monitoring system unit. Similarly, the demand monitoring screen supports five channels of demand monitoring and provides 30-minute demand forecasts.

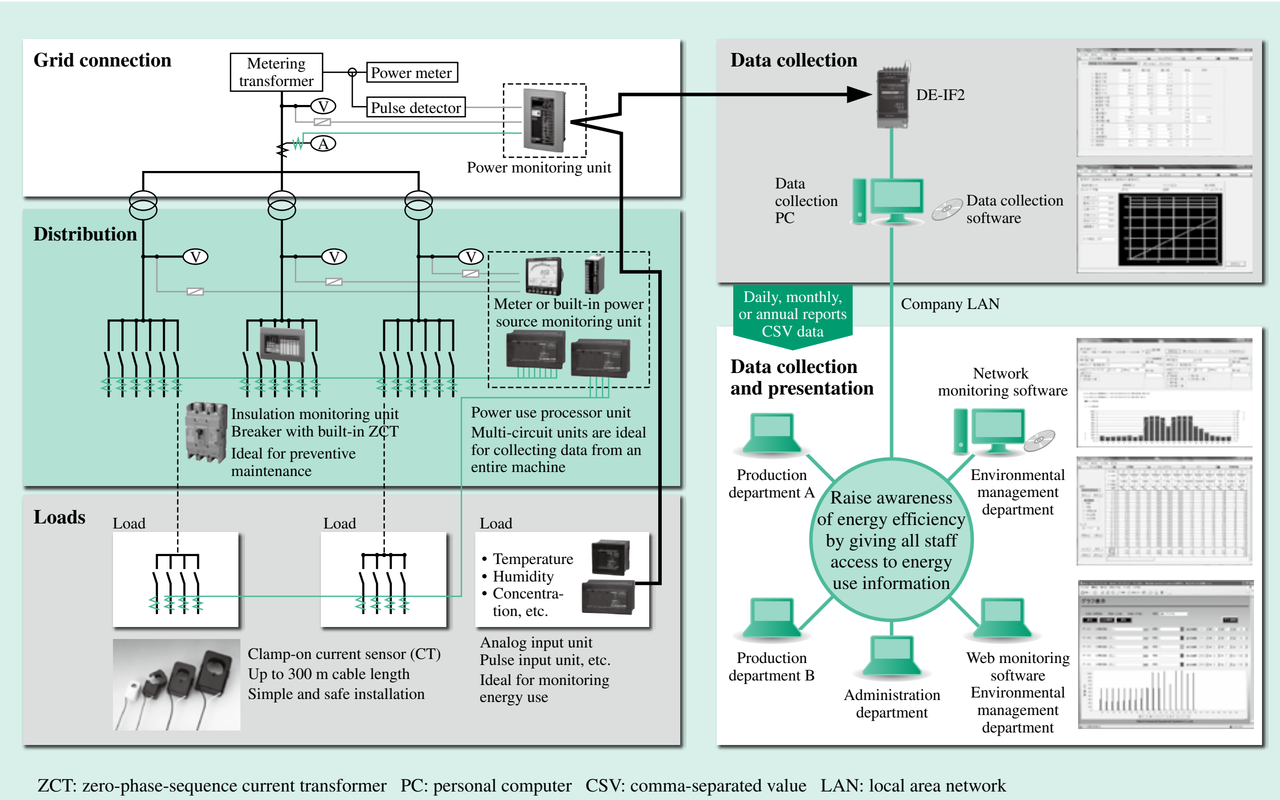



*Fig. 3—Example System Block Diagram.*
*Environmental and energy efficiency data can be collected economically using Hitachi's electric power distribution and utility monitoring system for large or medium-sized sites.*

An alarm is output if the predicted demand exceeds a preset level, and the alarm data is recorded. Trend screens display daily, monthly, and annual trends. They can also display multiple variables, allowing parameters to be compared with their past values or with different parameters from the same time period. The reporting screens, meanwhile, can be used to display, print, or edit daily reports dating back one

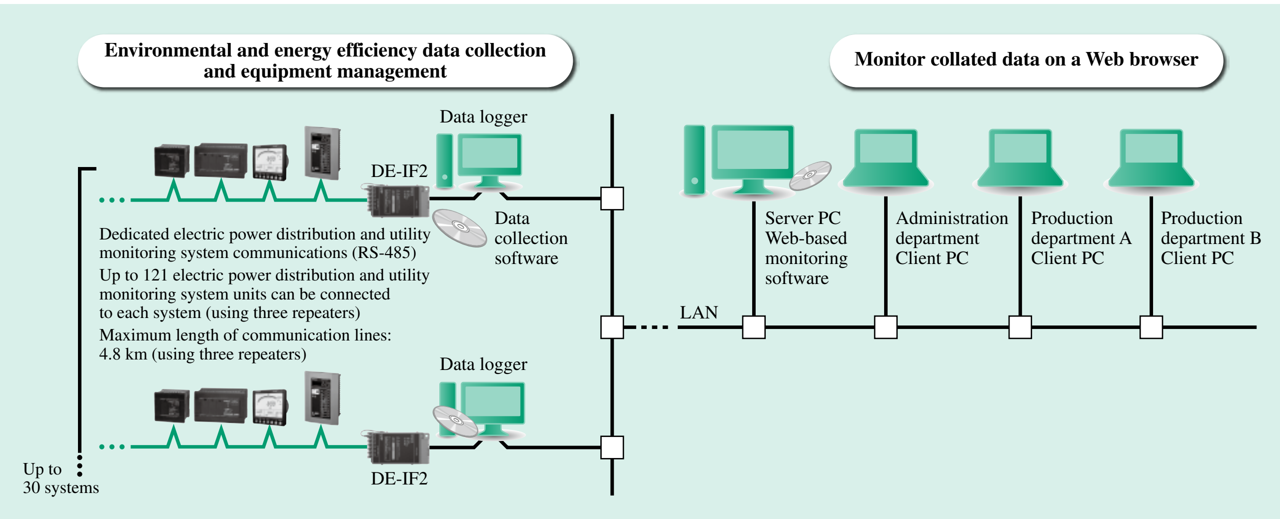



*Fig. 4—Example Block Diagram of System for Environmental and Energy Efficiency Data Collection and Collation of Data for Monitoring.*
*Up to 121 electric power distribution and utility monitoring system units can be connected to each system running the DE-SWA data collection software, and communication lines can be up to 4.8 km in length.*

month, monthly reports dating back two years, or annual reports dating back 10 years.

The daily, monthly, and annual reports can also be saved in comma-separated-value (CSV) file format to allow user editing in Microsoft Excel* or other spreadsheet software. Hitachi also offers the DE-WEB Web-based monitoring software for displaying measurement data graphs or reports, collated from CSV data, in a Web browser.

DE-WEB can collate daily reports of hourly data for up to 30 DE-SWA systems. These functions are described below (see Fig. 4).

(1) Trend graph display

Displays up to five graphs of the same variable (see Fig. 5).

(2) Report display

Stores up to 100 pages with 24 columns of daily (by hour), monthly (by day), and annual (by month) reports (see Fig. 6).

(3) Departmental classification function

Specifies up to four levels of unit measurements (cumulative values), collates (adds up) departmental categories, and presents the results in graph or tabular form.

(4) Virtual circuit function

Performs arithmetic operations on unit measurements to calculate virtual measurements for locations that have no sensor, and presents the results in graph or tabular form.

(5) Carbon dioxide ($CO_2$) emissions function

Uses cumulative energy data, such as use of electric power or gas, and predefined $CO_2$ emission coefficients to calculate $CO_2$ emissions, and presents the results in graph or tabular form.

(6) Unit consumption function

Uses cumulative energy data and predefined or measured unit consumption factors to calculate the (cumulative) amount of energy required to produce a unit quantity of product, and presents the results in graph or tabular form.

## EXAMPLE ELECTRIC POWER DISTRIBUTION AND UTILITY MONITORING SYSTEM INSTALLATION

Hitachi installed electric power distribution and utility monitoring system at the Nakajo and Narashino Administrative Division Hitachi Industrial Equipment Systems Co., Ltd. in 1993 and 2000, respectively in order to make energy data available for formulating and implementing energy saving measures. Both plants have since been recipients of METI Minister Awards for excellence in energy management in recognition of the energy efficiency benefits of electric power distribution and utility monitoring system. The plants have also been designated as "Super Eco-factories" by Hitachi, with visitors from all over Japan coming to learn from that know-how.

Both plants have had electric power distribution and utility monitoring system units installed throughout their operations, from the extra-high-tension substation that connects to the power company grid, to the machinery that consumes the power. A monitoring PC collects data from each unit at 10-minute intervals and presents daily reports in tabular or trend graph form in 10-minute, 30-minute, or one-hour increments. The system outputs an alarm if the contracted maximum of 3,300 kW is at risk of being exceeded, causing the

* Microsoft Excel is a registered trademark or trademark of Microsoft Corporation in the USA and other countries.

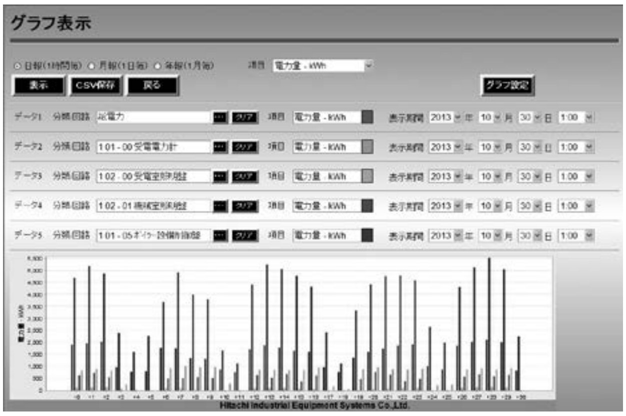



*Fig. 5—Trend Graph Screen.*
*The DE-WEB Web-based monitoring software can display collated measurements in graph or tabular form. Up to five graphs of the same variable can be display at the same time.*


*Fig. 6—Report Screen.*
*The reporting function can store up to 100 pages with 24 columns of daily (by hour), monthly (by day), and annual (by month) reports.*

plant air conditioning or other loads to shut down automatically. Because the system can also be used to check the operational status of machinery, it can assist with improvements by looking at workload balance or idle times.

Utilizing power data monitoring, the plants were able to significantly reduce the number of transformers on site by identifying the appropriate transformer capacities and consolidating on low-loss amorphous transformers. This reduced power losses to one-third of their previous levels, delivering annual savings of several million yen.

Similarly, an analysis of compressor power use found that they were consuming electric power at 65% of rated capacity, even when idle. Hitachi was able to minimize this idling by installing inverter-driven compressors that can adjust to changing loads. These operational improvements provided annual savings of several million yen.

## CONCLUSIONS

Through the centralized management and analysis of integrated energy data, including water and gas as well as electric power, utilities data such as temperatures and concentrations, and protection data such as data from low-voltage insulators, electric power distribution and utility monitoring system provides extensive support for energy savings, the environment, preventive maintenance, and productivity management. Hitachi hopes this article will prove useful to anyone installing an EMS.

## ABOUT THE AUTHORS

Hideki Hayakawa

*Planning Department, Power Distribution & Environmental Systems Division, Hitachi Industrial Equipment Systems Co., Ltd. He is currently engaged in the product planning of monitoring systems.*

Tetsunori Watanabe

*Production Administration & Sales Support Department, Hitachi Industrial Equipment Nakajo Engineering Co., Ltd. He is currently engaged in the development and sales support of monitoring systems.*

Toshiko Kimura

*Planning Department, Power Distribution & Environmental Systems Division, Hitachi Industrial Equipment Systems Co., Ltd. She is currently engaged in the development and sales support of monitoring systems.*

Featured Articles

# Container-type Energy Storage System with Grid Stabilization Capability

Atsushi Honzawa
Taichi Nomura
Yuki Myogadani
Moera Ohno
Akihiko Emori, Dr. Eng.
Kenji Takeda

*OVERVIEW: The installation of large amounts of renewable energy capacity, including photovoltaic and wind power generation, is anticipated. The concern with this is that connecting the fluctuating output of all this renewable energy to the grid will overwhelm its regulation capabilities, resulting in grid instability. In response, Hitachi has developed a grid stabilization system that uses a container-type energy storage system to maintain the stability of electric power use and also balance supply and demand. Hitachi aims to expand the adoption of clean energy sources by working to promote wider use of energy storage systems as one of its solutions businesses for the global market.*

## INTRODUCTION

THE installation of large amounts of renewable energy capacity, including photovoltaic and wind power generation, is seen as a means of meeting growing demand for electrical energy and of reducing carbon dioxide ($CO_2$) emissions. Various countries have been introducing national policies such as feed-in tariffs (FITs), subsidies, and preferential tax treatments to encourage the wider adoption of renewable energy. However, because of its fluctuating output, there are concerns that connecting large amounts of renewable energy capacity to the grid will overwhelm its regulation capabilities, resulting in grid instability. To overcome this problem, Hitachi has developed a grid stabilization system that uses a container-type energy storage system.

This article describes the background behind the development of this container-type energy storage system, which incorporates grid stabilization capabilities, along with its system configuration and features.

## HITACHI'S ENERGY STORAGE BUSINESS

Along with manufacturing materials for energy storage devices and batteries for consumer, industrial, and automotive applications, Hitachi's current activities also extend from research and development to system integration (see Fig. 1).

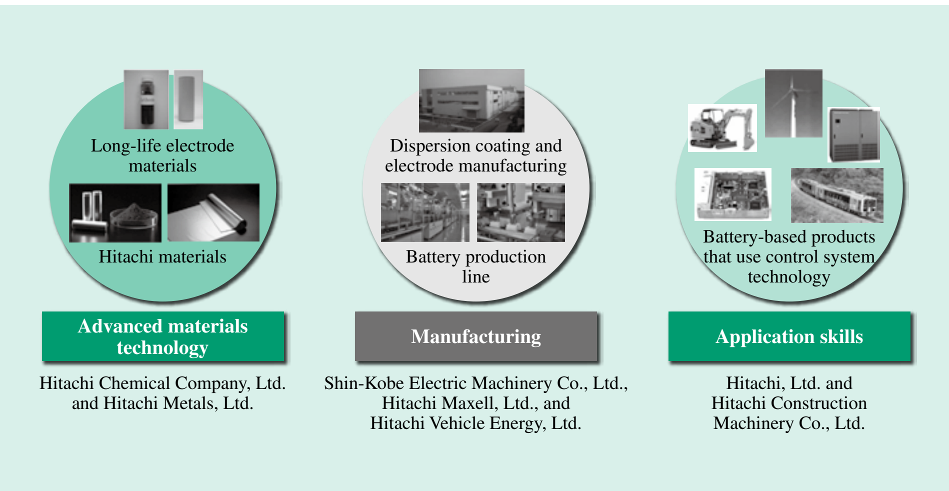



*Fig. 1—Hitachi's Battery Business.*
*Along with manufacturing materials for energy storage devices and batteries for a wide range of applications, Hitachi's activities also extend from research and development to system integration.*

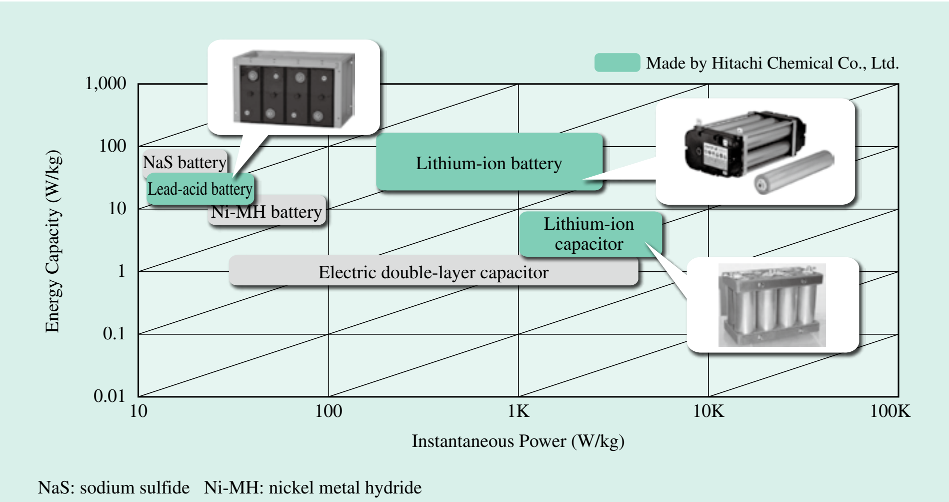



*Fig. 2—Comparison of Power System and Industrial Battery Characteristics.*
*Hitachi can configure economical systems for specific applications by selecting the best energy storage devices for the task. These include lead-acid batteries, lithium-ion batteries, and lithium-ion capacitors.*

Hitachi deals with a wide range of different systems, and can configure economical systems for specific applications by selecting the best energy storage devices for the task. These include devices capable of storing comparatively large amounts of energy, such as lead-acid batteries, and devices that can deliver a high level of output over a short period, such as lithium-ion batteries (see Fig. 2).

This article describes a system for electric power grids that uses lithium-ion batteries.

## DEVELOPMENT BACKGROUND

The frequency of an electric power grid is kept stable by balancing supply and demand. As shown in Fig. 3, the connection of large amounts of renewable energy with variable output, such as photovoltaic or wind power, results in a greater number of short-term power fluctuations ranging from a few seconds to ten or more minutes.

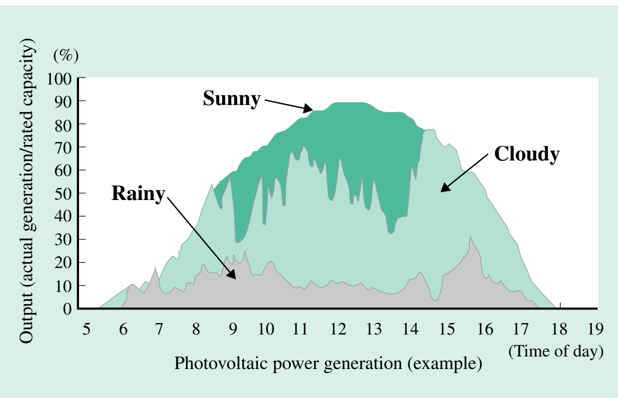



*Fig. 3—Example of Weather-related Variation in Output of Photovoltaic Power Generation.*
*The output of a photovoltaic power plant varies widely due to the weather. In particular, large short-term variations in output occur in cloudy conditions.*

There are also off-peak times when an oversupply of generation capacity means that the amount of power generated needs to be reduced. Power fluctuations can influence the frequency of the grid, resulting in grid instability. Energy storage systems can provide an effective way of mitigating fluctuations, both in the comparatively short-term governor-free (GF) range and the load frequency control (LFC) range. Currently, control of these operating ranges is performed using the GF functions of adjustable-speed pumped storage hydro power plants and thermal power plants with high-speed control capabilities, or by the LFC function of load dispatch offices. However, because of the time needed to construct additional pumped storage hydro or thermal power plants, and because of the difficulties involved with obtaining a construction site or upgrading transmission line capacity, it is possible that upgrades to power system regulation will fail to keep up with the rapid future growth in the installation of renewable energy capacity. In comparison, an advantage of energy storage systems is that they can be installed and brought on line quickly. With few site restrictions, they can also be installed at widely distributed locations.

Although the market for grid stabilization is fragmented by the different infrastructures and structural frameworks in different countries, moves to install energy storage systems for grid stabilization have begun on a commercial scale (see Table 1). However, because energy storage systems have smaller capacities than power plants, their requirements include installation at distributed locations and centralized control from a control center.

Table 1. Grid Stabilization Markets in Which Energy Storage Systems can Participate
*Energy storage systems are starting to be installed for grid stabilization on a commercial scale.*

| Item | Electric power/grid stabilization market | | |
|---|---|---|---|
| Market type | Europe and USA (where electricity market deregulation has taken place) | Japan (led by power companies) | Emerging economies Countries with low energy density (weak transmission infrastructure) |
| Mecha-nism | Ancillary service | | Microgrids incorporating wind and photovoltaic power |
| | ISOs purchase regulation capacity from market | Power companies use set-aside capacity | Trend is toward generators being required by grid code to also install wind or photovoltaic power |
| Size of battery system | 1-MW increments (approx.) | Centralized systems with capacities in the tens of MW | Additional installation of 1 to 20 MW |

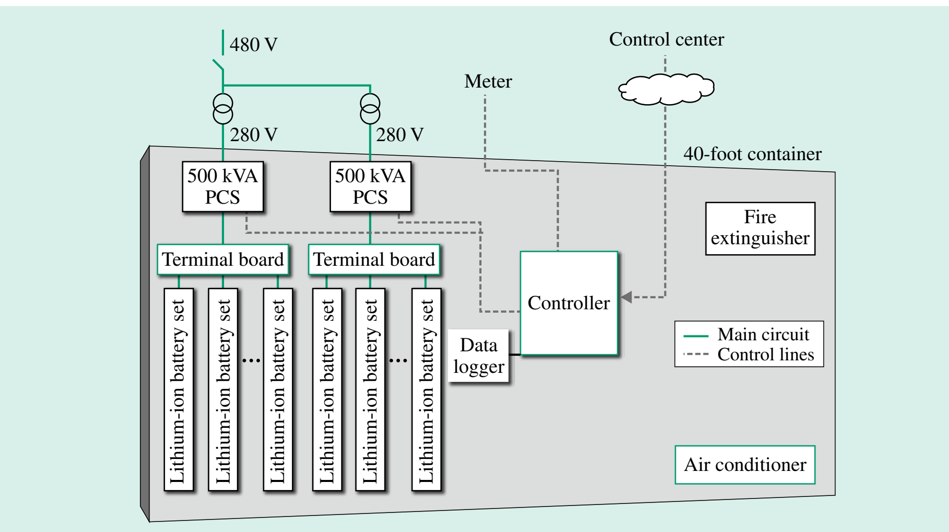
ISO: independent system operators, Ancillary service: a service whereby the grid operator maintains grid stability by using spare capacity or other adjustment methods to respond to variations in the level of power that a generator supplies to the grid, grid code: rules for transmission grid operation

The USA has already introduced a market for frequency regulation (FR) in which independent system operators (ISOs) and regional transmission organizations (RTOs) can provide ancillary services for reducing power fluctuations by purchasing (by MW and by hour) electric power to mitigate short-term fluctuations ranging from several seconds to several tens of minutes. The ISOs minimize fluctuations in grid frequency by issuing instructions at intervals of several seconds to the purchased power source. The value of transactions on the fast response market is particularly high. This market operates in such a way that responding accurately to instructions is valued more highly. Because the FR market requires batteries to charge and discharge repeatedly over short periods with comparatively high currents, it suits lithium-ion batteries, which can handle heavy currents and have high charging and discharging efficiency.

PJM Interconnection (PJM), a major RTO based in the eastern USA, is a notable participant in the FR market. This is a result of its being one of the first organizations to start operating systems in accordance with Federal Energy Regulatory Commission (FERC) Order 755 of October 1, 2012, which requires that a premium be paid for the supply of power from energy storage systems, such as batteries, which can respond accurately to ISO instructions, over power from thermal and other conventional generators.

Other than the region represented by PJM, another major region in the USA with impressive hopes for renewable energy is California, which has set a target of raising the proportion of electric power supplied from renewable energy to 33% by 2020. To achieve this, California passed assembly bill AB2514 in 2010 that requires the installation of energy storage systems on the grid. In accordance with AB2514, the California Public Utilities Commission (CPUC) in October 2013 instructed the state's three main utilities, Southern California Edison (SCE), Pacific Gas and Electric (PG&E), and San Diego Gas & Electric (SDG&E), to install a total energy storage system capacity of 1.3 GW by 2020.

A 1-MW container-type energy storage system fitted with lithium-ion batteries was developed to target these markets in particular. The system is installed at




PCS: power conditioning system

*Fig. 4—Block Diagram of 1-MW Container Package.*
*The 1-MW container-type energy storage system includes PCSs, lithium-ion battery sets, a controller, a data logger, and air conditioner.*

factories or other sites with the capacity to consume comparatively high levels of electric power, or at sites such as photovoltaic power plants, wind farms, or substations. In Japan, meanwhile, full-scale trials of the use of energy storage systems for grid stabilization have already commenced, primarily on offshore islands or in regions with poor transmission infrastructure, and Hitachi is looking at the potential for using this system.

## DEVELOPMENT CONCEPT FOR 1-MW CONTAINER-TYPE ENERGY STORAGE SYSTEM

The 1-MW container-type energy storage system includes two 500-kW power conditioning systems (PCSs) in parallel, lithium-ion battery sets with capacity equivalent to 450 kWh, a controller, a data logger, air conditioning, and an optional automatic fire extinguisher. Fig. 4 shows a block diagram.

Hitachi designed the 1-MW container-type energy storage system to incorporate all of the components, including the PCSs, batteries, and controller, into a 40-foot container as an all-in-one package. This minimizes the installation work, significantly reducing the time and cost of installation. Furthermore, along with a single-container system configuration, the package was also designed to facilitate the configuration of large-capacity systems made up of multiple containers. Table 2 lists the specifications and Fig. 5 shows a photograph.

## FEATURES OF 1-MW CONTAINER-TYPE ENERGY STORAGE SYSTEM

The features of the system are as follows:

(1) Improved availability

To improve availability, it is necessary not only to make maintenance inspections shorter and reduce failure rates, but also to shorten the duration of service outages needed to maintain battery conditions, including the performance of battery-specific cell voltage equalization, and the use of resets to determine the state of charge (SOC) (whereby charging and discharging of a battery is halted for a fixed time to determine its SOC). When SOC is measured by integrating the battery current over time, it is necessary to perform reset charging frequently in order to eliminate the cumulative measurement error that occurs in FR applications due to the high frequency of battery charging and discharging. In the case of the lithium-ion battery modules used in the container-type energy storage system, however, reset charging is not required because the battery management unit (BMU) uses continuous battery voltage and current measurements to calculate a realtime estimate of SOC. This has significantly improved availability. Also, cell voltage equalization is performed continuously by the built-in cell controller.

(2) Longer battery life and improved reliability

Because of the high cost of existing lithium-ion batteries, it is essential that batteries have a long and reliable operating life in order to earn a return on investment. The CH75 lithium-ion batteries used in the container-type energy storage system have a circularly wound design with a long life and high capacity (75 Ah). These batteries can be charged or discharged at three times capacity (3C: 75 A × 3) and have a life of 8,000 cycles or more when used with a 1C charge/discharge rate. When designing the module layout and air flow, Hitachi also conducted temperature analyses

Table 2. Specifications of 1-MW Container Package

*A 40-feet container houses 1 MW/450 kWh of batteries, a PCS, controller, and other equipment.*

| Item | Specification | Remarks |
|---|---|---|
| System capacity | ±1 MW | System level |
| PCSs | 2 × 500 kW in parallel | |
| PCS efficiency | 97% or higher (at 30% or higher load) | |
| Batteries | Lithium-ion 450 kWh | Battery modules: CH75-6 (75Ah-22.2V) |
| Standard | PCS: UL 1741 | |
| Expected life | System: 15 years or more Batteries: 10 years or more | When installed in an approved environment and maintained correctly |
| Cooling | Air cooled | |
| Container | 40-feet class | |


*Fig. 5—1-MW Container Package.*
*The photograph shows the 1-MW container package.*

of the battery set to ensure that all battery modules receive roughly equivalent cooling. The batteries have a predicted life of about 10 years under the anticipated operating conditions.

The use of high-capacity battery cells not only significantly reduces the number of batteries to be connected together, it also improves reliability by reducing the component count for auxiliary functions such as the BMU and battery controller unit (BCU). A large fan has been fitted to provide centralized cooling. Because fans require maintenance and periodic replacement, this improves reliability and reduces the replacement costs because the number of fans is much smaller than if separate fans were provided for each module.

(3) Improved system efficiency

Because the electrical losses in charging and discharging contribute to operating costs, improvements to system efficiency are reflected in higher income from FR services. Improving system efficiency requires not only more efficient charging and discharging of the lithium-ion batteries, it also requires improvements to PCS efficiency and a reduction in losses due to the cooling system. FR instructions vary randomly and at short intervals, and the system frequently operates at the lower end of its rated output capacity. The PCSs used in the container-type energy storage system have a conversion efficiency of 97% or higher at low load, with a high system-level charging and discharging efficiency of about 90% being achievable in practice.

(4) Compliance with standards

To satisfy the requirements of the US market, the PCS has been certified under the UL 1741 safety standard for distributed energy resources.

(5) Safety

If used incorrectly, lithium-ion batteries are a fire risk. The safety of the individual lithium-ion batteries used in the container-type energy storage system has been enhanced by the use of an electrode design that minimizes the risk of internal short circuits, and by packaging them in stainless steel for better durability. Multiple safety features are also provided at the system level, including the monitoring of voltage, current, temperature, and other battery parameters by the BMU and BCU so that a battery set can be disconnected if an abnormality is detected, and the provision of circuit breakers in both the direct current (DC) and alternating current (AC) circuits of the PCSs. Also available as an option is a fire control system that can detect smoke and extinguish a fire in the event of fire or smoke inside the container.

## FUTURE DEVELOPMENTS

The newly developed container-type energy storage system is scheduled to enter service in the US FR market during FY2014. Hitachi intends to analyze operational data with the aim of further extending the system life and making it more compact. Hitachi also intends to incorporate lead-acid batteries into the system to expand its applications, including its use as a countermeasure against oversupply of renewable energy, and as a peak shifting system for minimizing peak demand. Achieving wider use of energy storage systems will require more than just improvements in cost-performance and lower battery prices. Longer battery life and higher system efficiency will also be important factors in enhancing performance.

## CONCLUSIONS

By drawing on capabilities from across the group, Hitachi believes that use of clean energy can be expanded and $CO_2$ emissions reduced by the development of energy storage devices and systems that overcome a variety of challenges, and by promoting the wider adoption of these systems.

### REFERENCES

(1) T. Shibata, K. Sudo and Y. Kanazawa, “Energy Storage Solutions Utilizing Lithium-ion Batteries,” Hitachi Review **60**, pp.12–16 (2011).

(2) M. Toyota et al., “Energy Storage Technology and Batteries Required for Hitachi’s Vision for a Smart Society – Latest Materials Technology and Performance Evaluation of Next-generation Batteries,” Technical Information Institute Co., Ltd., p.802–807 (Dec. 2013) in Japanese.

## ABOUT THE AUTHORS

Atsushi Honzawa
*Power System Information & Controls Department, Power Systems Company, Hitachi, Ltd. He is currently engaged in commercializing power system stability solutions, especially energy storage systems. Mr. Honzawa is a Project Management Professional (PMP) and Convenor of IEC TC120 WG2 (Electrical Energy Storage System, Unit Parameters and Testing Methods).*

Taichi Nomura
*Energy Business Development & Management Center, Infrastructure Systems Company, Hitachi, Ltd. He is currently engaged in commercializing energy solutions centered on energy storage systems.*

Yuki Myogadani
*Power System Protection Automation & Solution Centter, Energy Systems Engineering Department, Hitachi, Ltd. He is currently engaged in work on designing and developing energy storage systems.*

Moera Ohno
*Industrial and Infrastructure Systems Division, Hitachi America, Ltd. He is currently engaged in promoting the power system stability solutions, especially the energy storage systems.*

Akihiko Emori, Dr. Eng.
*System Development Department, Energy Devices & System Development Center, Hitachi Chemical Company, Ltd. He is currently engaged in designing and developing energy storage systems. Dr. Emori is a member of The Institute of Electrical Engineers of Japan (IEEJ).*

Kenji Takeda
*Battery Research Department, Hitachi Research Laboratory, Hitachi, Ltd. He is currently engaged in researching and developing power systems utilizing power converters and various batteries.*

Featured Articles

# Home Photovoltaic Power Generation System

Kenji Shiraishi
Satoru Usui
Akihiko Kanouda

*OVERVIEW: In August of 2012, Hitachi Appliances, Inc. established a business that markets home photovoltaic power generation systems under the Hitachi brand. The systems have been subject to ongoing improvements, including not only the development of a power conditioner, peripheral equipment, installation fittings, and other structural components, but also the establishment of an in-house and external infrastructure that includes a product warranty scheme, training and accreditation schemes for sales and installation, and sales promotion tools.*

## INTRODUCTION

HITACHI'S home appliance and air conditioning products make extensive use of the highly efficient inverter technology it has built up over time. Hitachi embarked on a project in 2010 to develop a power conditioner that incorporates this superior technology and to create a Hitachi-brand home photovoltaic power generation system. The power conditioner is a key component of photovoltaic power generation systems because it converts the direct current (DC) power generated by the photovoltaic modules to the alternating current (AC) power used in the home. The objective was to commercialize a distinctive photovoltaic power generation system by bringing together technical capabilities from across Hitachi in order to develop a power conditioner that would be superior to its competitors.

To establish a business to handle this Hitachi-brand home photovoltaic power generation system, Hitachi first developed a power conditioner, peripheral equipment, installation fittings, and a long-term product warranty scheme, and then set up its own training and accreditation schemes for sales and installation in order to provide in-house and external sales infrastructures.

Having undertaken these business preparations, Hitachi commenced sale of its branded home photovoltaic power generation system in August 2012. Since then, the business has made ongoing improvements to way of selling, extending the range of photovoltaic modules and installation fittings, and sale promotion infrastructure in response to customer wishes (see Fig.1).

This article describes the Hitachi home photovoltaic power generation system and the sales infrastructure that underpins the business.

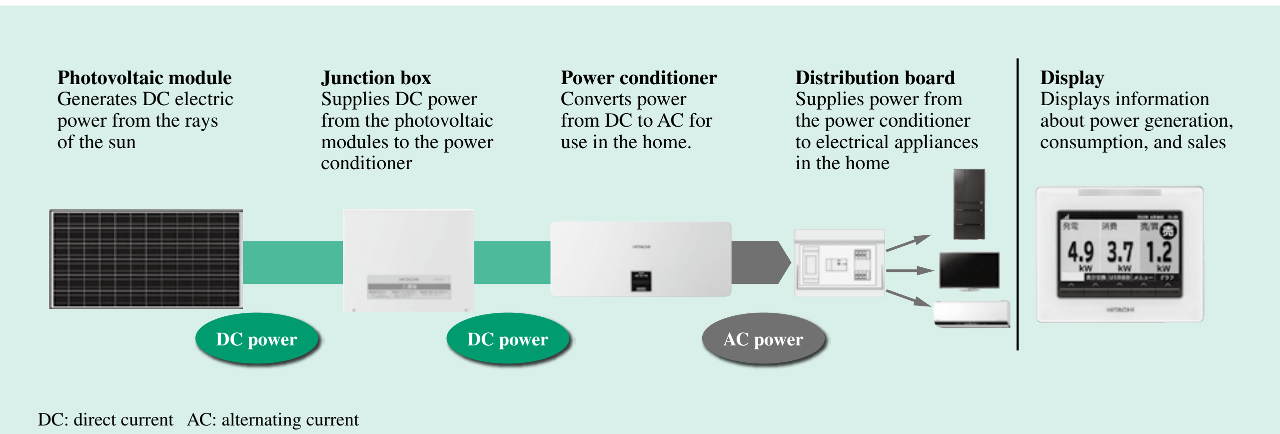



*Fig. 1—Equipment Included in Photovoltaic Power Generation System.*
*The system includes photovoltaic modules, a junction box, and a power conditioner. The electric power distribution board is not included.*

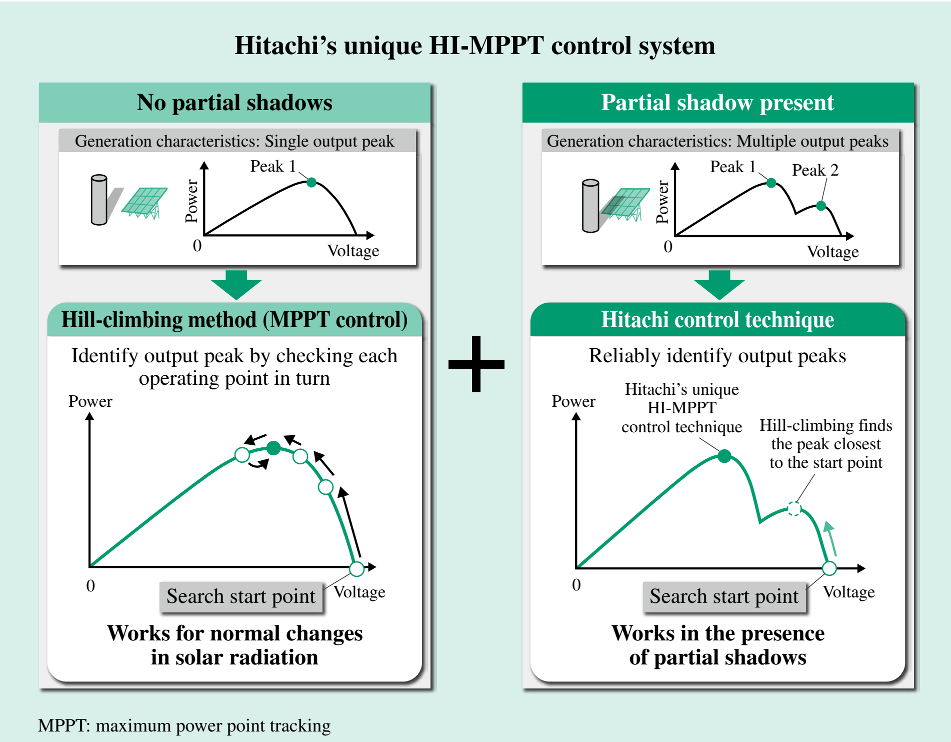



*Fig. 2—Features of HI-MPPT Control Based on Photovoltaic Module Generation Characteristics.*
*The presence of partial shadows on the modules results in multiple power output peaks. The amount of electric power generated can be increased by combining the previous hill-climbing MPPT method with HI-MPPT control, which reliably finds the highest output peak by searching for changes in the peak at appropriate times.*

## HITACHI HOME PHOTOVOLTAIC POWER GENERATION SYSTEM

### Development of Power Conditioner

The objective of product development was to maximize the amount of power produced by the photovoltaic power generation system.

The power conditioner has two functions: to extract more DC power from the photovoltaic modules and to convert that DC power to AC. Hitachi focused on these two functions in order to develop a product in which they would both contribute to maximizing power generation.

The factors that influence photovoltaic power generation include not only the variations in solar radiation because of weather conditions, but also partial shadows on the photovoltaic modules cast by objects such as trees or power poles. In response, Hitachi developed HI-MPPT, its own maximum power point tracking (MPPT) control system, in order to increase the amount of power produced even when partial shadows occur at different times of the day (see Fig. 2).

The conventional MPPT control method is to vary the voltage when searching for the peak power output of the photovoltaic modules. If only one peak exists, then this method will successfully locate the peak from the search starting point. When the photovoltaic modules are partially shaded, however, a number of peaks (local maximums) may exist, and this can prevent the search from finding the point of maximum output. Hitachi's HI-MPPT control system searches for changes in the peak at appropriate times in order to adjust the operating voltage to the value that generates the most power, even in the presence of more than one peak. This minimizes lost power generation and produces a greater amount of electric power.

The converter that steps up the voltage of the DC power from the photovoltaic modules uses a silicon carbide Schottky barrier diode (SiC-SBD) to significantly reduce the recovery losses in switching. This permits the use of a high switching frequency (40 kHz), allowing a smaller DC reactor and lower copper losses. For the inverter that converts the DC power to AC, meanwhile, Hitachi has developed a new pulse width modulation (PWM) control technology that minimizes distortion on the output current waveform despite having a switching frequency that is only one-quarter of that used previously. Through these features, Hitachi has created a power conditioner with a rated conversion efficiency of 96%, which is top-class in the industry (see Fig. 3).

Hitachi went on to release a new model in February 2014 that fulfills the requirements for multiple grid-interconnection systems defined by the Grid-interconnection Code(JEAC 9701-2012, Japan Electric Association). Along with pursuing even higher efficiency, Hitachi plans to continue developing its

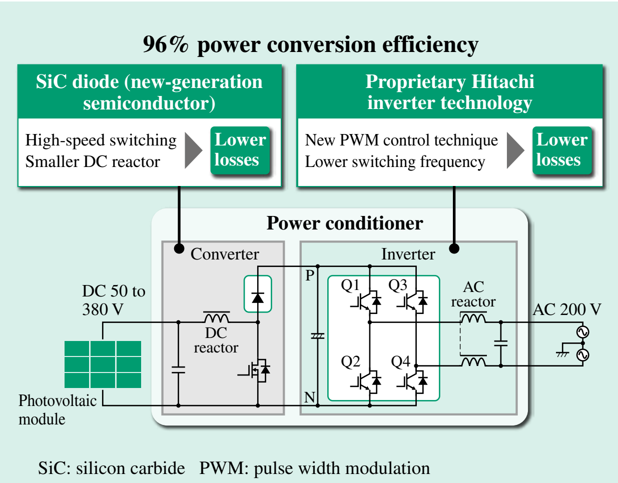



*Fig. 3—Improvements to Power Conversion Efficiency of Power Conditioner.*
*Use of a SiC diode in the converter and a newly developed PWM control technique in the inverter achieved a power conversion efficiency of 96%.*

product range, including the addition of models that are suitable for outdoor installation.

### Development of Installation Fittings to Suit Different Rooftops

Hitachi has developed its own rails and fasteners for mounting the photovoltaic modules.

Using its own unique horizontal rail design allows Hitachi to take account of considerations such as the ease of positioning the photovoltaic modules during installation, and their appearance once installed. To make installation more efficient, Hitachi has also chosen to use the same fasteners for attaching the rails and modules. It has also provided new fasteners that are designed to simplify minor adjustments to suit different roofing materials when fitting the rails to the roofing (see Fig. 4).

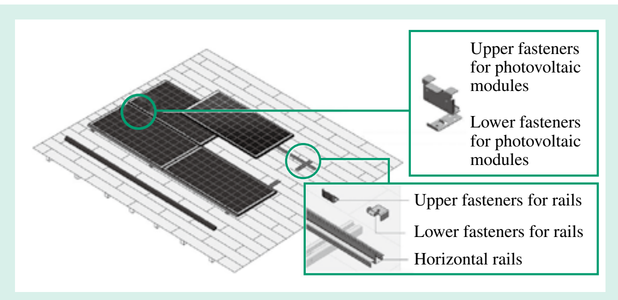



*Fig. 4—Horizontal Rails and Fasteners.*
*Hitachi developed and made available its own installation fittings to make the photovoltaic modules easier to install and improve their appearance once installed.*

Hitachi is working to expand the range of roofs on which the modules can be installed, with other additions to the product range including installation fittings for folded-plate roofs and clamps for metal roofs.

### Commercialization of Hitachi Photovoltaic Modules

When it first went on the market, the Hitachi photovoltaic power generation system used photovoltaic modules from other suppliers. Since November 2013, however, it has been selling its own modules, which are produced under an original equipment manufacturing (OEM) arrangement. The product range offers customers a choice of photovoltaic modules to suit their needs, with modules available in a 210-W monocrystalline model, a half-size 105-W model, and a 255-W polycrystalline model. They come with a 25-year linear output warranty*.

## SALES TOOLS AND SALES SUPPORT SYSTEMS

Along with providing product information by the usual means, including a catalog and website, Hitachi has also developed tools and introduced services to assist retailers and sales companies. The tools include a simple power generation simulator and the Hitachi Solar System (HSS) sales support system. The services include support for system design, utility cost simulation, summary quotations based on material selection, and subsidy application documents (see Fig. 5).

### Simple Power Generation Simulator

The website includes a simple power generation simulator available for public use. When the user selects the roof of the customer's home on a Google satellite image, the simulator estimates how many photovoltaic modules can be installed and how much power they can generate (see Fig. 6).

### Assistance Provided by HSS Sales Support System

Hitachi has developed the HSS sales support system to make the job of its home photovoltaic power

* The initial output of a photovoltaic module is within a tolerance of the nominal output. If the output falls by more than 3.5% from the bottom end of this tolerance range in the first year after the commencement of the warranty, by more than 0.68% annually in subsequent years, or by more than 19.82% over 25 years, the photovoltaic module will be repaired or replaced under warranty, or additional modules will be installed.

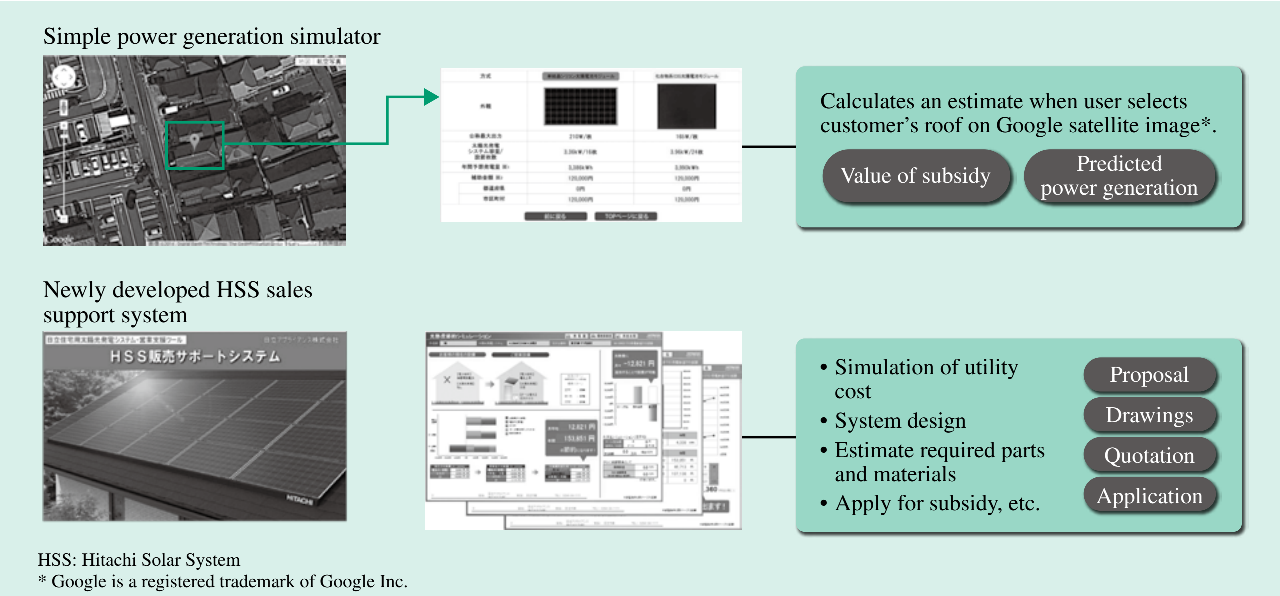



*Fig. 5—Sales Support Tool Functions.*
*Hitachi developed a tool for simulating how photovoltaic modules will perform when installed on the roof of a home, and a sales support tool for generating proposals, drawings, and quotations for photovoltaic power generation systems.*

generation system retailers easier. It includes selling system products required for installation, providing customers with system proposals or quotations, supplying application documents, and supplying drawings for installers.

Users who log in to the HSS sales support system on the website from a personal computer (PC) can access a service that, by entering the required information such as details of the roof and choice of photovoltaic modules to install, will not only automatically provide them with information such as photovoltaic module and mounting rail layout drawings while calculating the required quantities of installation fittings, it will also generate proposal, quotation, drawing, and application documents. This service can be accessed from a closed website exclusively for accredited retailers and other suppliers of Hitachi home photovoltaic power generation systems.

Because the support service manages customer details and equipment and other system configuration data centrally on a server, in addition to sales support, it also provides the infrastructure to ensure customers enjoy trouble-free use of their photovoltaic power generation system by linking to customer management and maintenance services such as periodic inspections (see Fig. 7).

## HSS Accreditation Scheme

To ensure the quality of its systems and that customers can feel confident about using them, Hitachi has

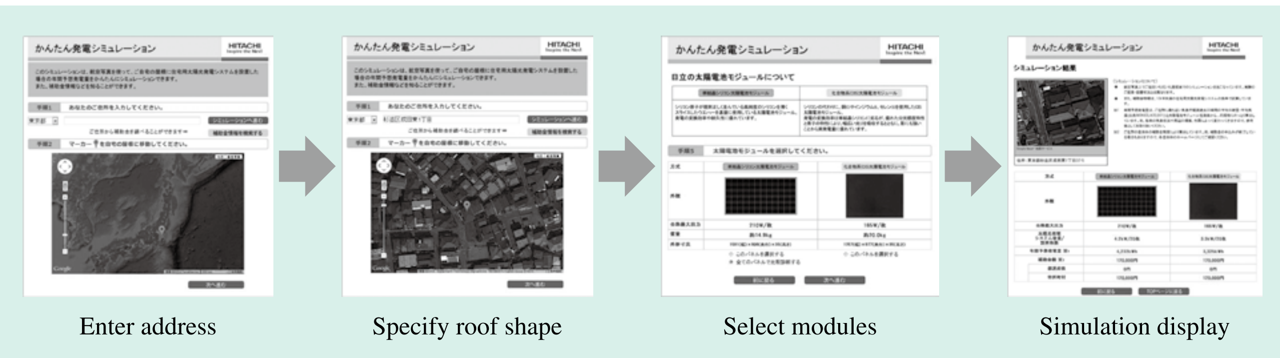



*Fig. 6—Simple Power Generation Simulator Screens.*
*The user specifies the home's address to find its roof, and selects which photovoltaic modules to install. The simulator then uses this information to calculate how much power the system will generate based on local weather data.*

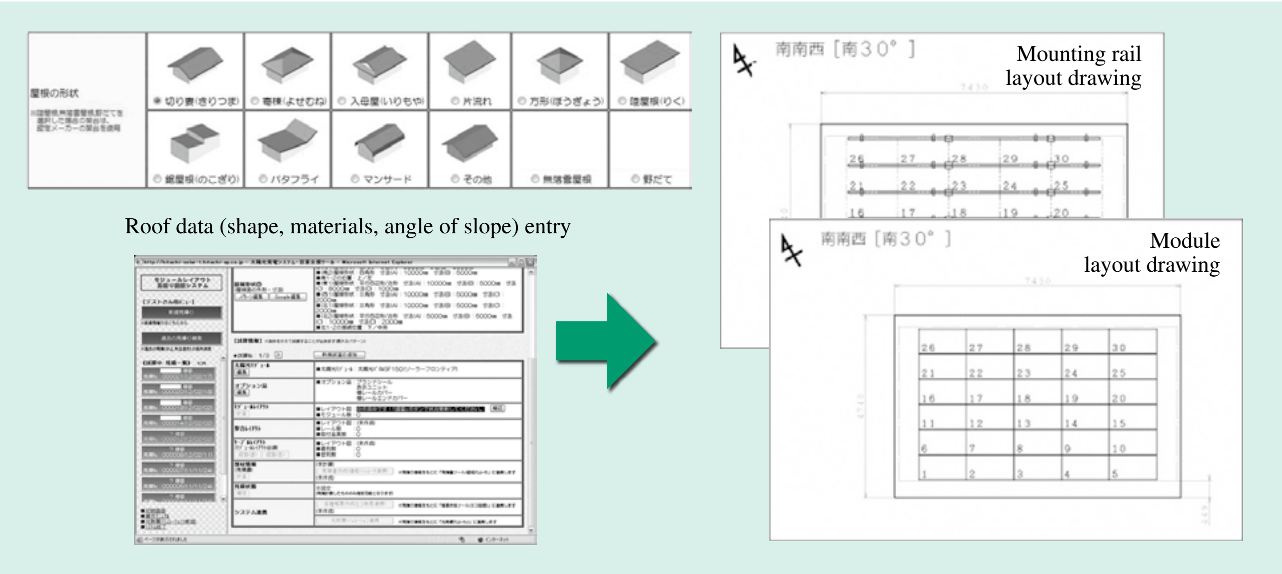



*Fig. 7—User Screens from HSS Sales Support System.*
*When the user enters roof data (shape, materials, etc.), customer details, and other required information, the system automatically generates documents such as photovoltaic module and mounting rail layout drawings.*

established three vocational qualifications for retailers and installers: HSS Master, HSS Advisor, and Accredited HSS Installer. Hitachi operates this accreditation scheme and trains accredited staff to ensure the quality of installation work, and that staff are able to provide customers with quotations and handle other sales activities. The accreditation identification (ID) awarded to people who complete the training also gives them access to the HSS sales support system (see Fig. 8).

**HSS accreditations and type of work**

| Role | Type | For | Type of work |
|---|---|---|---|
| Management | HSS Master | Hitachi sales staff | • Advisor training<br>• Consultation of whether to install<br>• Management of installers |
| Sales | HSS Advisor | Retailer staff<br>Trade customers | • Site survey (simple)<br>• Commercial negotiation<br>• Quotation<br>• Ordering |
| Installation | Accredited HSS Installer | Installers<br>(electrical installation is performed by electricians with the Second Class Electric Work Specialist qualification) | • Project management<br>• Installation<br>• Application preparation<br>• Decision whether to install<br>• Site survey<br>• Preparation and submission of work completion report |

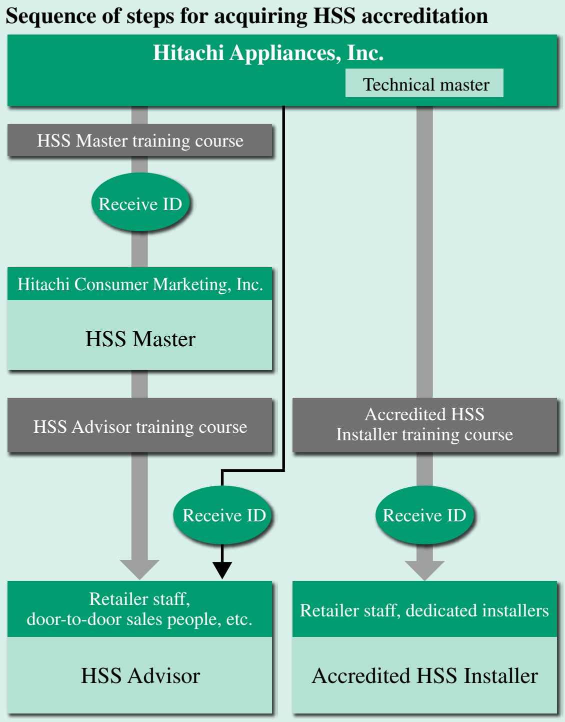



*Fig. 8—HSS Accreditation Scheme.*
*Hitachi has established three qualifications for its photovoltaic power generation systems: HSS Master, HSS Advisor, and Accredited HSS Installer.*

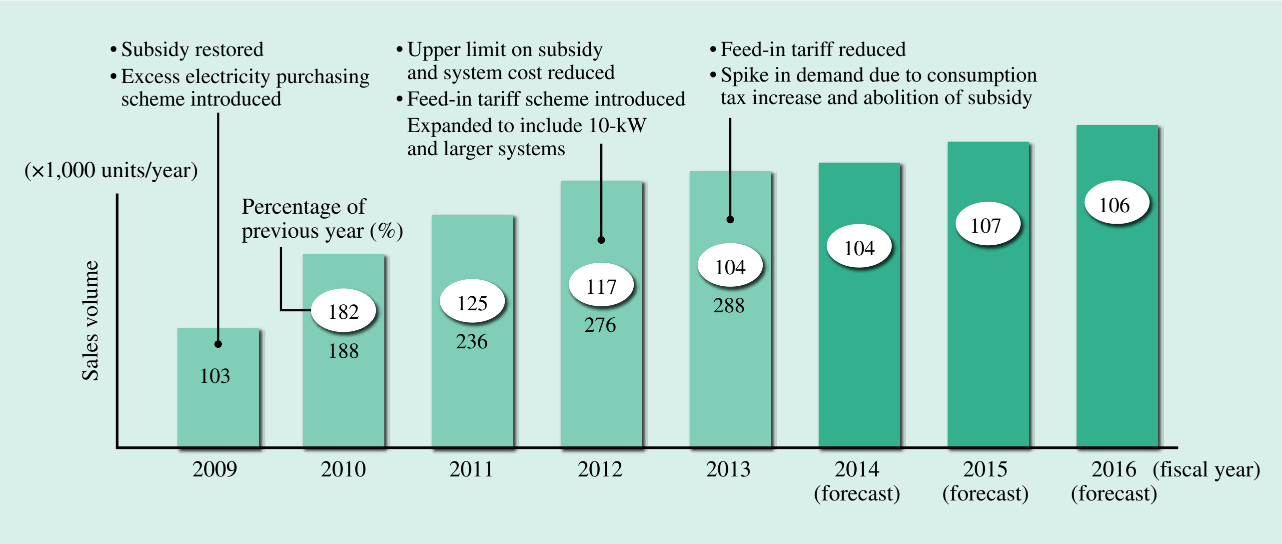



*Fig. 9—Trend in Demand for Home Photovoltaic Power Generation Systems.*
*The graph shows forecasts collated by the Japan Photovoltaic Energy Association and Hitachi Appliances, Inc.*

## DEMAND TRENDS AND FUTURE SALES INITIATIVES

### Trends in Demand for Home Photovoltaic Power Generation Systems

Since the 2009 restoration of subsidies for the installation of home photovoltaic power generation systems, the market for these systems has experienced steady growth underpinned by initiatives such as Japan's excess electricity purchasing scheme (since replaced). In addition to consideration of the environment and rising awareness of energy efficiency and the need to save electricity, it is anticipated that concerns about such things as the supply and demand of electric power and price increases will lead to ongoing growth in demand, with a steady rise in the number of customers installing photovoltaic power generation systems they can use in their homes (see Fig. 9).

### Future Plans for Home Photovoltaic Power Generation Business

Hitachi's home photovoltaic power generation system business was initially established to target home systems sold by Hitachi chain stores (distributors and retailers of Hitachi-brand products). Hitachi is now seeking to increase sales by expanding this to also include wholesalers, door-to-door sellers, and other vendors. To expand its photovoltaic power generation system business, Hitachi also intends to sell its power conditioner (a key component of its photovoltaic power generation system) as a standalone product, with a target of selling 30,000 units annually, which will give it 5% of the market by volume for power conditioners in 2015.

## CONCLUSIONS

This article has described the Hitachi home photovoltaic power generation system that first went on sale in 2012.

Hitachi Appliances, Inc. develops and manufactures home appliances and domestic and commercial air conditioners that feature excellent energy efficiency. Along with these energy-efficient products, the company's product range encompasses models for saving, storing, and generating energy in the home. These include energy-efficient water heaters with a hot water tank as thermal storage, and photovoltaic power generation systems that produce energy. In the future, Hitachi intends to continue working with its partners to develop products that contribute to the environment, including this range of appliances that provide highly efficient use of energy in the home.

## REFERENCE

(1) Japan Photovoltaic Energy Association (JPEA), http://www.jpea.gr.jp/

## ABOUT THE AUTHORS

Kenji Shiraishi

*New Energy System Planning Department, Business Management Division, Eco Appliances Business Group, Hitachi Appliances, Inc. He is currently engaged in the business planning for photovoltaic power generation.*

Satoru Usui

*New Energy System Planning Department, Business Management Division, Eco Appliances Business Group, Hitachi Appliances, Inc. He is currently engaged in the business planning for photovoltaic power generation.*

Akihiko Kanouda

*Information and Control Systems Research Center, Hitachi Research Laboratory, Hitachi, Ltd. He is currently engaged in the development of power supply circuits and control technologies. Mr. Kanouda is a member of The Institute of Electrical Engineers of Japan (IEEJ) and The Institute of Electronics, Information and Communication Engineers (IEICE).*

Topics

# Energy-efficient Products for Better use of Energy in the Home

*OVERVIEW: Recent years have seen growing interest in the idea of creating "zero energy homes" as a means of countering global warming. While photovoltaic and other power generation systems for producing energy, batteries, and other devices for storing energy all play important roles, so too does the energy saved by improvements in the efficiency of the appliances used in the home. This important aspect has attracted attention toward improving the energy efficiency of various products for the consumer-electric market. This article describes energy-efficient products that were awarded prizes in the product and business model category at the presentation of the 2013 Grand Prize for Excellence in Energy Efficiency and Conservation.*

## ECOCUTE HOME HEAT PUMP WATER HEATER WITH CARBON DIOXIDE AS NATURAL REFRIGERANT

### Development Background and Overview

SINCE water heating accounts for approximately 30% of energy use in the home, improvement of its energy efficiency has an important role to play. With EcoCute*[1] for the home having been added in March 2013 to the list of products covered by the standards of the Top Runner Program (target year: FY2017) established by Japan's Energy Conservation Law (Act on the Rational Use of Energy), further improvements in efficiency can be anticipated. Accordingly, by developing the most energy-efficient models on the market*[2] and utilizing the technologies they employ, Hitachi Appliances, Inc. was able to lead the market in achieving the FY2017 Top Runner standards, specified by the Energy Conservation Law, for the BHP-FV46ND and all other models in its new FY2013 product range (see Fig. 1).

### Energy-saving Technologies for Home EcoCute

To improve energy efficiency, Hitachi developed its own components for use in highly efficient heat pumps (evaporator, scroll compressor, and water/refrigerant heat exchanger) (see Fig. 2).

The following section describes the technologies used in models such as the BHP-FV46ND, a mains-pressure water heater that is fully automatic and features a standard type tank and high efficiency (the technologies used vary between models).

To improve the heat exchange performance of the evaporator, a high density of smaller refrigerant tubes has been used, and to minimize the loss of heat pump performance due to the increase of pressure drop resulting from the use of smaller tubes, Hitachi developed a multi-branch tube arrangement that improves performance by achieving equal refrigerant distribution by utilizing the characteristics of mist flow immediately downstream of the expansion valve.

For the scroll compressor, Hitachi shrunk the gap between scroll laps to reduce loss due to leakage, and also reduced heating re-expansion loss by developing a new lubrication design for the compression chamber. For the water / refrigerant heat exchanger, Hitachi also improved performence by using smaller refrigerant tubes to enhance heat transfer efficiency, and by extending the total length of the tubes to increase the area of heat transfer surfaces.

In recognition of these detailed and proprietary energy efficiency technologies, Hitachi's home EcoCute (55 models, including the BHP-FV46ND) received the Director-General's Prize, the Agency for Natural Resources and Energy at the presentation of the 2013 Grand Prize for Excellence in Energy Efficiency and Conservation (in the product and business model category).

*1 The name "EcoCute" is a generic term used by power companies and water heater manufacturers in Japan for electric water heater heat pumps that use natural refrigerants.

*2 As of February 26, 2014. In the category of home heat pump water heaters for normal environments, (1) The BHP-FV37ND has a annual water heating and heat-retention efficiency(JIS) of 3.6 in the category of storage capacity from 320 L to 460 L, and (2) The BHP-FV46ND has a annual water heating and heat-retention efficiency(JIS) of 3.5 in the category of storage capacity from 460 L to 550 L. The calculation method for annual water heating and heat-retention efficiency(JIS) is stipulated in JIS C 9220:2011. The value varies depending on factors such as the region, selected operation mode, and usage.

Fig. 1—BHP-FV46ND.
*This is the flagship model in Hitachi's range of mains-pressure water heaters. It is fully automatic and features a standard type tank and high efficiency.*

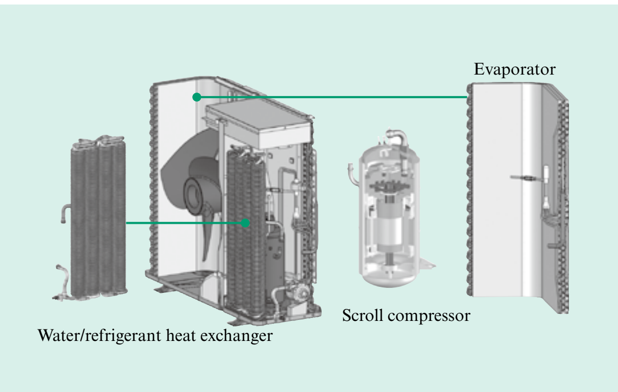



Fig. 2—Main Components in Highly Efficient Heat Pump.
*The figure shows the evaporator, scroll compressor, and water/refrigerant heat exchanger. The energy efficiency of these components has been improved through in-house development.*

## LED LIGHTING COMBINING HIGH LIGHT OUTPUT WITH ENERGY EFFICIENCY

### Development Background and Overview

With rising awareness of the need to save power, improving the energy efficiency of lighting, which makes up a significant proportion of power consumption by homes and other facilities, is an important task. In this context, the excellent energy efficiency of light-emitting diode (LED) ceiling lights has led to growing demand for their use as the main form of lighting in the home.

When Hitachi conducted a survey of what factors people consider when purchasing LED ceiling lights, many of the respondents expressed a desire for products that not only served their underlying purpose of providing good illumination, but were also energy efficient. Hitachi developed 22 models, including the highly efficient LEC-AHS1410B ceiling light, that have the intrinsic energy consumption efficiency of between 102.4 lm/W and 104.8 lm/W, while also providing maximum lighting for each room size, between eight and 14 tatami mats, defined in a standard*3 published by the Japan Lighting Manufacturers Association for specifying the floor area that can be illuminated by a light.

### Features and Energy Efficiency Technologies of LED Ceiling Lights

A characteristic of LED lights is that making them brighter typically causes them to produce more heat, and the resulting rise in the temperature of the LED module reduces their light emission efficiency. This makes it difficult to combine high light output with energy efficiency. These products incorporate proprietary technologies, including large

*3 "Residental catalog applicable room size standards"(Guide 121:2011) for specifying the floor area that can be illuminated by a light. Floor area is measured by number of tatami mats, where one mat is 910 mm × 1820 mm.

heat dissipating structures and dome LED units incorporating a lens function, to control the heat from the LEDs, and to combine high efficiency with a high level of illumination across the room (see Fig. 3).

And, seven of these models have a self-regulating function that uses a sensor to measure the level of external light and automatically turn down or extinguish the light. These functions and performance features achieve a high level of energy efficiency without sacrificing the level of illumination desired by users.

In recognition of the features of these products, which include their high efficiency and high output, 22 models of LED ceiling lights (released in FY2013) received Chairman's Prizes, the Energy Conservation Center, Japan at the presentation of the 2013 Grand Prize for Excellence in Energy Efficiency and Conservation (in the product and business model category).

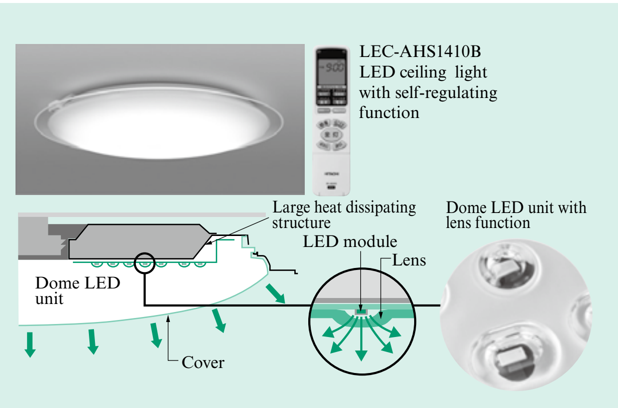



*Fig. 3—Appearance and Technical Features of LED Ceiling Light.*
*The figure shows a large heat dissipating structure and a dome LED unit with a lens function.*

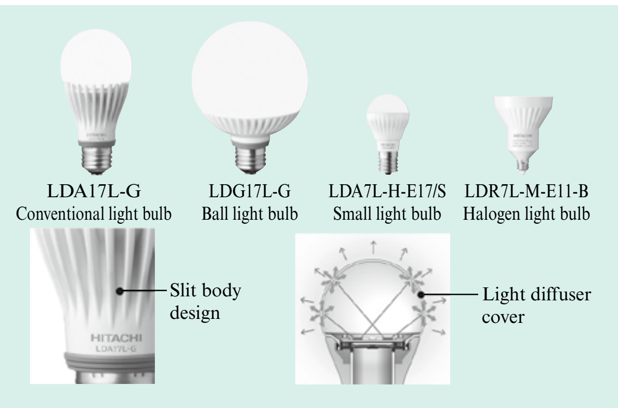



*Fig. 4—Technical Features of LED Light Bulb.*
*The figures show the slit body design and light diffuser cover.*

## Features and Energy Efficiency Technologies of LED Light Bulbs

Light bulbs have traditionally been used in a wide range of different lighting devices, such as downlights and pendants. Converting these to LED has the potential to save a large amount of electric power. However, problems such as the heat generated by LEDs make it difficult to house them in units of equivalent size to light bulbs.

By adopting a slit body design that can effectively dissipate the heat from LEDs and light diffuser covers that spread the light from the LED, Hitachi succeeded in producing an LED light with a standard light bulb fitting (E26 screw base) that combines a spread of light similar to a light bulb and equivalent illumination to a 100-W incandescent light bulb, while keeping the size similar to that of a traditional light bulb (see Fig. 4). The LED light has approximately one-fifth the power consumption of an incandescent light bulb*4.

Hitachi has also produced compact models in small light bulb, ball light bulb, and halogen light bulb sizes to facilitate their installation in a wide range of different light-bulb-containing devices in the home and other facilities.

Simply replacing conventional, ball, small-size, and halogen light bulbs with LED light bulbs can save significant amounts of energy.

In recognition of these technologies, 15 models of LED light bulbs (released in 2012 and 2013) received Chairman's Prizes, the Energy Conservation Center, Japan at the presentation of the 2013 Grand Prize for Excellence in Energy Efficiency and Conservation (in the product and business model category).

## REFRIGERATOR-FREEZERS COMBINING LARGE CAPACITY AND ENERGY EFFICIENCY

### Development Background and Overview

The trend in refrigerators is toward larger sizes in response to changes in consumers' lifestyles, including people taking advantage of services such as food delivery systems to buy food in bulk. This has intensified the need to improve the energy efficiency of large refrigerators that consume considerable amounts of energy. This has made it important to combine technologies in order to achieve the conflicting objectives of energy efficiency and larger refrigerator capacity.

Meanwhile, growing health awareness has reinforced the need for refrigerators to minimize the loss of freshness in the food they contain.

In response, Hitachi has continued to make advances in refrigeration by developing its own proprietary technologies, including dual-fan cooling and frost recycling cooling techniques for saving energy, and a vacuum*5 preservation technology for keeping food fresh. By incorporating these energy-saving technologies into its product series, Hitachi is able to supply appliances that offer excellent economics to a greater number of customers (see Fig. 5).

### Key Energy-saving Technologies for Large Refrigerators

**(1) New dual-fan cooling technique for refrigeration compartment**

In place of the conventional method for cooling the refrigeration compartment, which is to locate a cooling fan above the evaporator, Hitachi has developed a new concept for saving energy that uses a dedicated refrigeration compartment cooling fan


*Fig. 5—Refrigerator-freezer Equipped with Vacuum Compartment[R-G6700D(XT)]*
*Food is kept even fresher and more nutritious in the vacuum compartment*

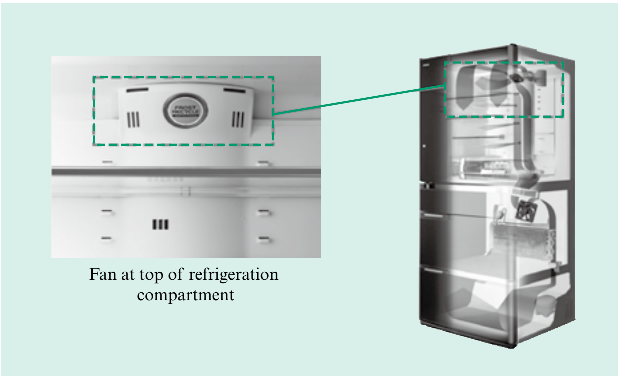



*Fig. 6—Dual-fan Cooling.*
*A dedicated fan at the top of the refrigeration compartment works in tandem with the cooling fan to cool the refrigeration compartment quickly.*

*4 Comparison between an LED light bulb (LDA17L-G, rated power consumption: 16.7 W) and a 100-W Hitachi incandescent light bulb (LW100V 90 W, rated power consumption: 90 W).
*5 Vacuum means a state of having air pressure smaller than the atmospheric pressure.

located at the top of the compartment to minimize over-cooling in the refrigerator.

Specifically, the dedicated fan is positioned at the top of the refrigeration compartment, which is more prone to warm air entering when the door is opened. This minimizes wasteful energy consumption by working in tandem with the conventional cooling fan to shorten cooling times by rapidly circulating cool air to all areas of the refrigeration compartment (see Fig. 6).

**(2) Frost recycling cooling**

This energy-saving technology, which utilizes the frost on the evaporator, was first introduced in FY2009 models. Because frost deteriorates cooling performance, the practice generally had been merely to remove this by defrosting. In contrast, the new technique uses the cooling power of the frost to cool the refrigeration compartment and vegetable compartment while the compressor is not running. The moisture from the frost also acts to keep food from drying out.

**(3) Improved insulation**

The insulation used in refrigerators consists of vacuum insulation panel and urethane foam insulation. Hitachi introduced its own vacuum insulation panel made of double packing bags and glass wool in its FY2004 models. Now, Hitachi has increased the covered area of vacuum insulation panel and improved insulation performance by utilizing its own composition of urethane, with excellent fluidity, in the glass door.

**(4) Energy-saving modes**

Hitachi has introduced two energy-saving modes. The energy-saving modes cut power consumption by reducing cooling to the compartments within tolerable level and by operating the compressor at a lower speed. The second mode, designed for when the user is away from home, operates on even lower power by further reducing the compressor speed.

In recognition of these proprietary energy efficiency technologies, 11 models (including the R-G6700D) in the Vacuum-chilled FS Series of refrigerator-freezers received Reviewer's Prize at the presentation of the 2013 Grand Prize for Excellence in Energy Efficiency and Conservation (in the product and business model category).

## CONCLUSIONS

This article has described EcoCute for the home, LED lighting, and large capacity refrigerator products, all of which were awarded prizes in the product and business model category at the presentation of the 2013 Grand Prize for Excellence in Energy Efficiency and Conservation. By developing products with even better energy efficiency and encouraging their wider adoption, Hitachi Appliances, Inc. believes it can contribute to the creation of a low-carbon society.

## ABOUT THE AUTHORS


Yutaka Enokizu

*Hot Water Supply Systems Design Department, Tochigi Home Appliance Works, Home Appliance Group, Hitachi Appliances, Inc. He is currently engaged in the development and design of heat pump water heaters.*

Takashi Okada

*Design Department V, Home Appliance Group, Taga Home Appliance Works, Hitachi Appliances, Inc. He is currently engaged in the development and design of LED lighting products.*

Toshihiko Nagamori

*Refrigerator Design Department, Tochigi Home Appliance Works, Home Appliance Group, Hitachi Appliances, Inc. He is currently engaged in the development and design of household refrigerators.*