Development of Electricity and Energy Technologies for Low-carbon Society

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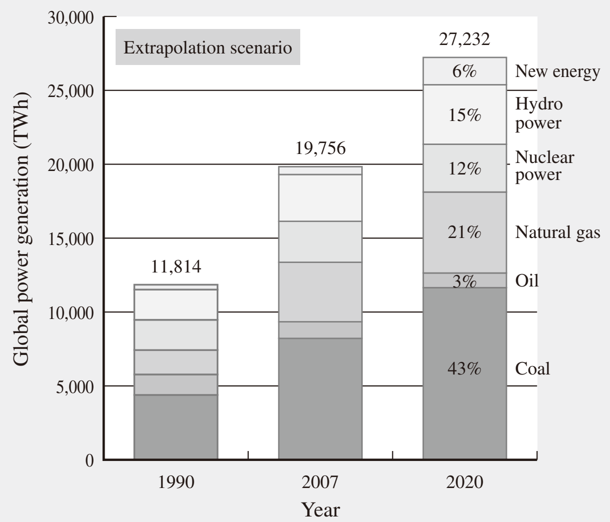
INTRODUCTION

THE population of the world already stands at about 6.8 billion and is expected to grow by 30% in the next 30 years. On the other hand, it is forecast that other factors including rising living standards will drive a 60% increase in energy consumption over this period, with an increase of 80% in electricity consumption which is a high-quality form of energy(1). Through its Power Systems Company in particular, Hitachi is involved in the field of power generation technology including thermal, nuclear, hydro, wind, photovoltaic, and other forms of power generation (see Fig. 1) and supplies power generation equipment to customers around the world through its own operations and in collaboration with its partners.

When the quantity of electric power generated is categorized by fuel source, approximately 70% of production is currently thermal-powered by using coal, oil, or natural gas. Based on an extrapolated scenario that assumes the current structure of energy supply and demand will continue, this proportion will remain unchanged over the next decade, and while renewable

Fig. 1—Hitachi Power Generation Technologies.
Hitachi is contributing to realizing a global low-carbon society by developing highly efficient power generation systems based on thermal, nuclear, hydro, wind, photovoltaic, and other forms of power generation.



Source: World Energy Outlook 2009 published by the International Energy Agency

Fig. 2—Trend in Global Electric Power Generation.
Although use of renewable energy will grow, thermal, nuclear, and hydro power will remain our primary sources of energy over the next decade.

energy sources such as wind and photovoltaic power will increase, thermal, nuclear, and hydro power will retain their roles as our primary sources of energy[1] (see Fig. 2).

Because they do not release any CO_2 (carbon dioxide) in the generation process, increasing the proportion of electricity produced from nuclear, hydro, wind, and photovoltaic power will contribute to preventing global warming. Thermal power in turn has a particularly important role in the overall power generation system because, in addition to providing base-load generation capacity, it is also used to regulate the power supply in response to fluctuations in load. Use of thermal power will remain essential in the future and the objective of reducing CO_2 emissions by half by 2050 will involve not only improving the efficiency of power generation but will also require the development of technologies for separating and capturing the CO_2 produced by thermal power generation[2] (see Fig. 3).

This article describes the features of the thermal, nuclear, hydro, wind, photovoltaic, and other forms of power generation technology handled by Hitachi, primarily through its Power Systems Company, and its involvement in the development of technologies for the future that will help achieve a low-carbon society.

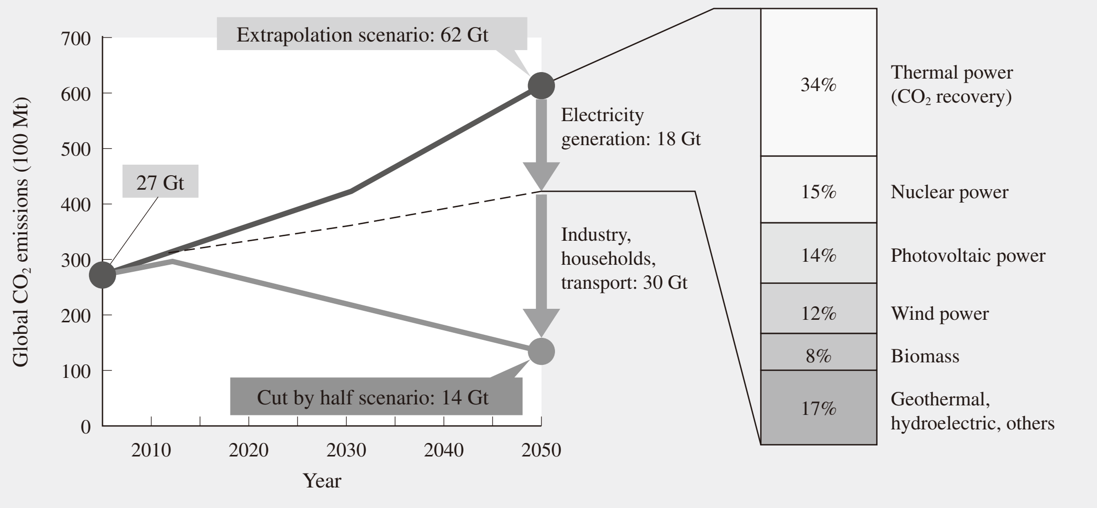
THERMAL POWER

Utilizing its global research and development capabilities, Hitachi undertakes research and development of technologies for the highly efficient generation of electricity using coal, oil, and natural gas.

Improvement in Efficiency of Coal-fired Thermal Power

The advantages of coal are that its price per unit of thermal output is only one-third to one-fifth that of oil and that extensive deposits of coal are widely distributed around the world. As shown in Fig. 2, it is used to generate approximately 40% of the world's electric power.

The efficiency of coal-fired thermal power can be improved by increasing the temperature or pressure of



Source: Energy Technology Perspectives 2008 published by the International Energy Agency

Fig. 3—Scenarios for Reducing Global CO_2 Emissions.
Power generation is anticipated to have a major role in preventing global warming.

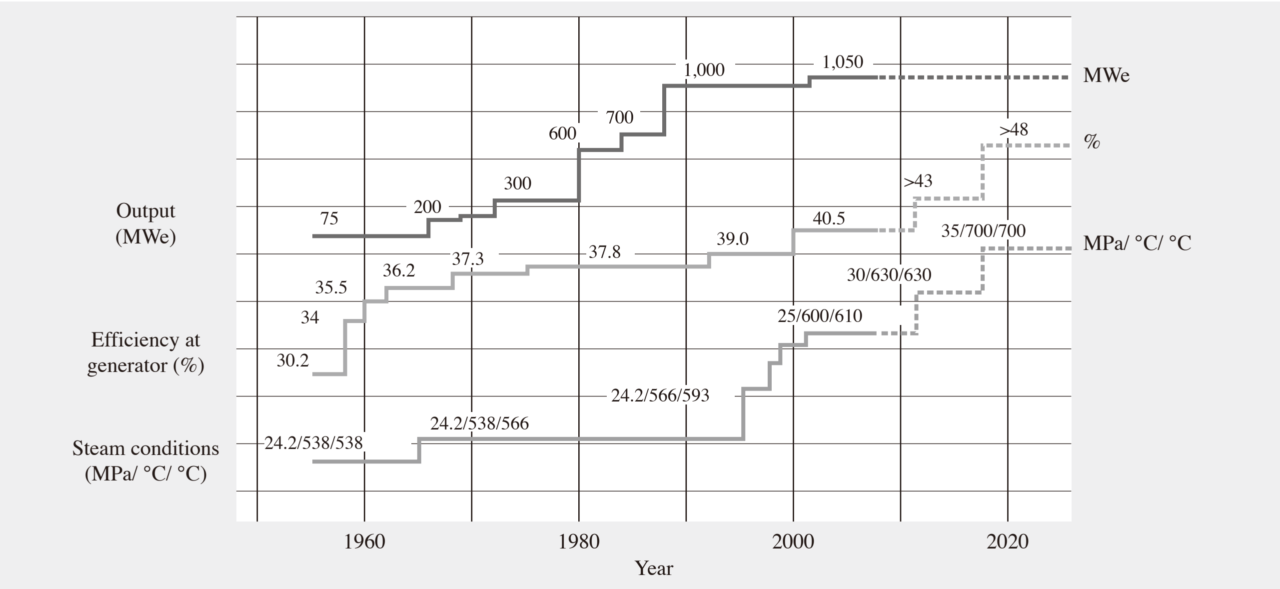


Fig. 4—Efficiency Improvement for Coal-fired Thermal Power.
The efficiency of power generation can be improved by improving the steam operating parameters.

the steam used in the process and plants are currently being constructed to operate with a steam temperature of 600°C and an output in the 1,000 MW class (see Fig. 4). Japan has taken a lead in developing USC (ultra-supercritical) power plants[(a)] that operate in the 600°C range and coal-fired power plants in Japan have had the world's highest efficiency since 1990. The pressure of 25 MPa used in these plants is above the critical pressure which means that the steam is in a supercritical state.

Including plants currently under construction, Hitachi has constructed a total of eight USC power plants in Japan and 23 in other countries. A recent example is Hitachi's involvement in the Medupi Power Station of Eskom Holdings Ltd. in South Africa (which has a capacity of 800 MW) where installation of the boiler commenced in January 2010 and the first unit is planned to commence operation from 2012.

To achieve even greater efficiency in coal-fired power generation, Hitachi is developing a technology called A-USC (advanced ultra-supercritical) that operates in the 700°C range. In Europe, the Thermie Programme commenced in 1998 and Hitachi Power Europe GmbH based in Germany has joined this project with the aim of practical use of boilers. In Japan, development is also being conducted with support from the Ministry of Economy, Trade and Industry. Working through the Advanced Research and Development of Basic Technologies for Effective Energy Use program of the New Energy and Industrial Technology Development Organization (NEDO), Hitachi developed the NiFe-base superalloy rotor material suitable for use in A-USC turbines operating in the 700°C range[(3)]. Hitachi original NiFe-base superalloy is not subject to segregation and is one of the new materials likely to be adopted in practical applications. Hitachi will continue to work on the 700°C-range A-USC project to reduce CO_2 emissions by achieving even greater efficiency.

Reducing Environmental Impact of Coal-fired Thermal Power

Because coal-fired thermal power plants emit a higher concentration of pollutants such as NO*x* (nitrogen oxides), SO*x* (sulfur oxides), and CO_2 relative to their thermal output than do other forms of thermal power generation, they have a particularly strong need for technologies that can reduce these emissions.

NO*x* pollutants can be reduced by improving combustion and work is ongoing to reduce NO*x*

(a) Ultra-supercritical power plants
The efficiency of coal-fired power generation improves the higher the temperature and pressure of the steam produced in the boilers by burning coal. Power plants can be categorized by this temperature and pressure, with plants that operate at a temperature of 566°C and pressure of 24.1 MPa being called "supercritical" and those that operate at a temperature of 593°C and pressure of 24.1 MPa or more being called "ultra-supercritical" (USC). Compared to previous sub-critical power plants (538°C and 16.7 MPa), the reduction in CO_2 emissions is approximately 5% for supercritical operation and 7% for ultra-supercritical operation. Meanwhile, "advanced ultra-supercritical" (A-USC) systems that further increase the steam temperature up to the 700°C range are currently under development.

emissions by developing new burners, furnace combustion techniques, and similar technologies[(4)]. The remaining pollutants in the exhaust gas can then be eliminated using flue gas treatment systems that incorporate equipment for NO*x* removal, dust collection, sulfur removal, and other types of cleaning[(5)]. Hitachi's NO*x* removal medium is used in the form of sheets, is resistant to clogging, wear, and other damage caused by ash, and has demonstrated a high level of reliability at coal-fired thermal power plants in Japan and overseas. For sulfur removal equipment, Hitachi has developed new technology with a high gas flow rate, high-concentration slurry, and high-density spray, and the resulting equipment is compact with a high level of desulfurization performance and dust removal performance. To deal with the diverse nature of coal in different parts of the world, Hitachi is working on development using a test plant fitted with a range of different flue gas treatment systems (see Fig. 5).

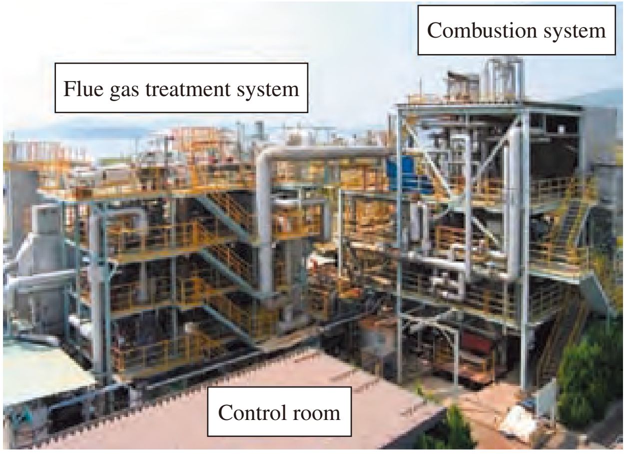


Fig. 5—Integrated Test Unit for Treating Combustion Flue Gas (2,000 Nm^3/h).
The flue gas treatment characteristics when coal from different parts of the world is burnt are measured and the information utilized in design.

To achieve major reductions in CO_2, it is necessary to put technologies for separating out and capturing the CO_2 into practical use. Technologies for CO_2 capture include amine-based CO_2 separation[(b)], which is easy to retrofit to existing power plants and can be used for partial CO_2 capture, and the oxyfuel combustion method[(c)] which is capable of efficiently capturing all of the CO_2. Hitachi started research and development of amine-based CO_2 separation in the early 1990s and is working on developing absorption fluids and equipment suitable for use with the flue gas from coal-fired boilers through basic experiments and by running trials on an actual gas pilot test facility. Hitachi is currently putting this technology into practical use in partnership with its overseas group subsidiaries and Hitachi Power Systems America, Ltd. is working in collaboration with an electricity generation company on the design of amine-based CO_2 separation equipment for coal-fired thermal power plants for which it has received funding from the Department of Energy in the USA.

The way the oxyfuel combustion method works is that, rather than using air for combustion, oxygen separated from the air is diluted with recirculated flue gas and this mixture is used instead. Hitachi has extensive experience in the development of coal-fired boilers and has world-class testing facilities and numerical analysis techniques that it uses for this development. Hitachi is also working with overseas electricity generation companies on developments that include scaling up this technology with the aim of bringing it into commercial use.

Hitachi is also involved in the development of IGCC (integrated coal gasification combined cycle) power generation systems that use steam-based coal gasification to turn coal into a fuel for gas turbines and recover the waste heat in a steam turbine. Hitachi is also participating in the EAGLE Project (Coal Energy Application for Gas, Liquid and Electricity) being run by the Electric Power Development Co., Ltd. and has achieved a high level of gasification and gas purification performance in a pilot plant with the capacity to process 150 t/d of coal. Because IGCC can remove the CO_2 from the high-pressure gas before it is supplied to the gas turbine, it is expected to demonstrate excellent overall efficiency and world-leading CO_2 capture pilot testing confirmed that the target performance could be achieved. Hitachi intends to build up its know-how with the aims of reducing the cost and improving the efficiency of commercial-scale CO_2 capture equipment.

In this issue, details about Hitachi's work on IGCC and CO_2 capture are described in the article "Progress

(b) Amine-based CO_2 separation
A technology for separating and capturing CO_2. The technology absorbs CO_2 by passing the flue gas produced by combustion in a thermal power plant or similar through an alkaline solvent (such as amine or potassium carbonate in aqueous solution) that selectively dissolves the CO_2. The resulting fluid is then heated to release the CO_2 so that it can be captured.

(c) Oxyfuel combustion method
A technology for separating and capturing CO_2. Using oxygen instead of air for combustion results in flue gas that contains a high concentration of CO_2 and which can then be cooled to recover the CO_2 with high efficiency.

toward Commercializing New Technologies for Coal Use," its work on CO_2 capture for coal-fired boilers is described in "Development of CCS (Carbon Capture and Storage) Technology to Combat Climate Change," and its involvement with CO_2 capture in Europe and America in particular is described in "Highly Efficient Power Stations with Carbon Capture."

Gas Turbine Efficiency Improvement

Hitachi has received many orders for its 30-MW-class H-25 gas turbine from Japan and overseas due to its high reliability and its high efficiency for its class, with total orders exceeding 100 units. Also, these gas turbines have been used in a wide range of applications including electric power generation, general industry, and the oil and gas industry(6). Through improvements including to the compressor efficiency and turbine blade cooling efficiency, the gas turbine on its own achieves a thermal efficiency of 35% LHV (lower heating value) at the generator output and a combined-cycle efficiency when combined with a steam turbine of 50% LHV or better. This issue also contains an article entitled "Development of Highly Efficient H-80 Gas Turbine" describing example commercial applications of an 80-MW-class gas turbine developed using the H-25 as a base.

Hitachi is also working on developing the AHAT(d), a technology for improving the efficiency of electricity generation by enhancing the electricity generation cycle. This system involves a recovery cycle using humid air and achieves output and efficiency similar to a combined-cycle plant using only a gas turbine.

The feasibility of the system has already been demonstrated through work sponsored by the Agency for Natural Resources and Energy and Hitachi plans to continue testing the technology from a wide range of perspectives including performance, reliability, ease-of-operation, and economics(3).

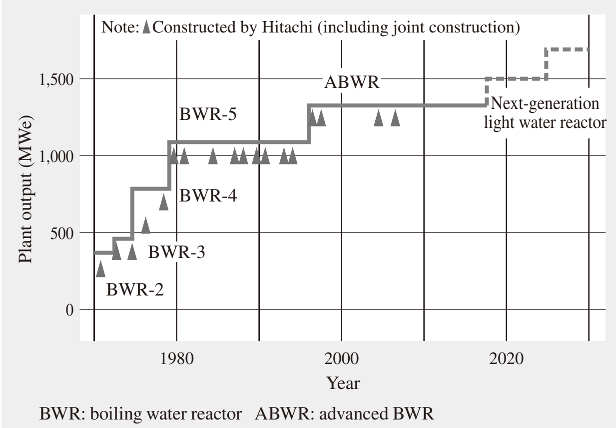


Fig. 6—History of BWR Development in Japan.
Hitachi has an ongoing track record of constructing nuclear power plants that stretches back 40 years.

NUCLEAR POWER

Hitachi is involved with BWRs(e) and more than 40 years have now passed since the first BWR was commercialized. Since then, plant outputs have been increased through many enhancements and other advances in technology, and 1350-MW-class ABWRs(f) featuring excellent safety, ease-of-operation, economics, and other characteristics have been put into practical use (see Fig. 6). In the global market, Hitachi has collaborated with its partner GE-Hitachi Nuclear Energy Americas LLC (GEH) to establish the infrastructure to supply ABWRs and other leading-edge BWR plants.

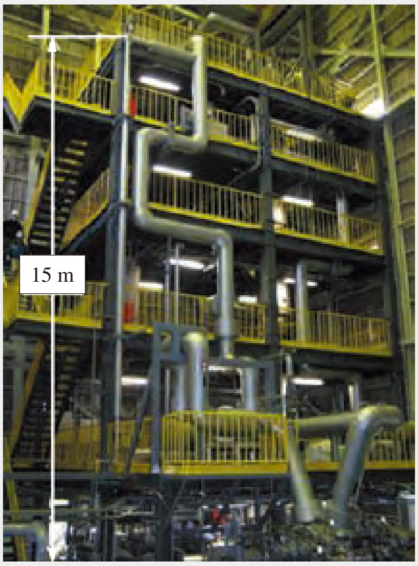
Development of Next-generation BWR

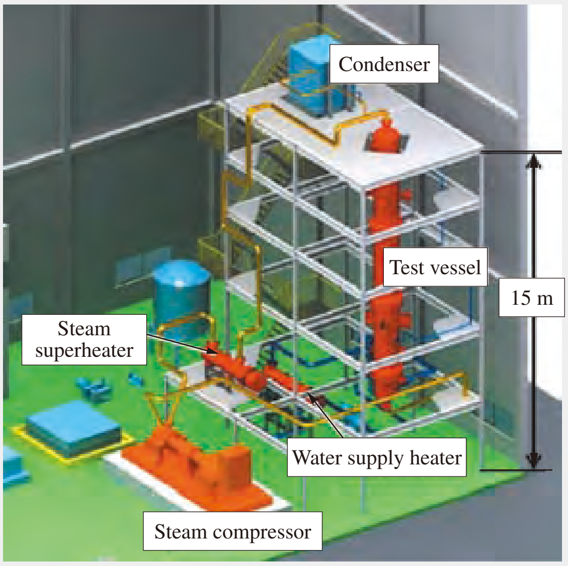
A large-scale national project to develop the next generation of light-water reactors started in 2008 to prepare for the coming period during which Japan will need to replace a significant number of nuclear power plants and to meet the world-wide expectations for nuclear power generation, with Japan taking the role of the leading nation in the field of nuclear energy. Taking guidance from electricity utilities, the government, and others, Hitachi will bring the nuclear power industry

(d) AHAT
Abbreviation of "advanced humid air turbine," a gas turbine system that uses humid air. Whereas in conventional combined cycle gas turbine plants the exhaust heat from the gas turbine is used to produce steam and drive a steam turbine, AHAT plants use a humidifier to increase the moisture content of the compressed air used in combustion to increase the output of the gas turbine. This provides high efficiency, low cost and excellent operating characteristics because it does not require an exhaust gas boiler or steam turbine and can effectively recover the exhaust heat downstream of combustion in the gas turbine and use it to generate electricity. Use of a high-humidity combustion unit also achieves a low level of NO_x without using NO_x scrubbers.

(e) BWR
Abbreviation of "boiling water reactor." Reactors that use light water as their moderator and coolant include BWRs and PWRs (pressurized water reactors). BWRs pass the steam produced by water boiling inside the reactor pressure vessel directly to a turbine to generate electricity.

(f) ABWR
Abbreviation of "advanced BWR." ABWRs have better thermal efficiency and higher maximum output due to use of the latest technology together with improvements derived from experience with the operation of BWRs. ABWR features include an internal-pump configuration in which the pump used to circulate the reactor coolant is located inside the reactor pressure vessel, an improved control rod drive mechanism that inserts and retracts the control rods used to control the reactor output, and a steel-reinforced concrete containment vessel that is integrated into the building with benefits that include reducing the volume of the reactor building, shortening the construction time, improving equipment utilization, and improving safety.





HUSTLE: Hitachi utility steam test leading facility

Fig. 7—HUSTLE Multi-purpose Steam Source Test Facility.
This test facility can supply steam and hot water at the actual operating pressure and temperature of a BWR and is used in the development of high-performance and high-reliability equipment.

together into a single body to push forward strongly the development of the next-generation BWR by working together with plant manufacturers, general contractors, and others with The Institute of Applied Energy taking a central role.

The specific technologies being promoted by Hitachi include: (1) ultra-high-burnup fuel, (2) SSR (spectral shift rod) fuel, (3) new construction techniques (SC structural methods), (4) earthquake-proof equipment, (5) advanced materials and water chemistry, and (6) use of digital technology to improve plant operation. In developing new systems and equipment, Hitachi has a "two-wheeled" approach of improving development efficiency and understanding of phenomena using advanced simulation technology and using large-scale trials and experiments to check performance and reliability.

The advanced simulation technologies include the development of techniques such as analysis of the thermal-hydraulic characteristics of the reactor core, dual-phase gas/liquid flow analysis, acoustic vibration analysis, and corrosion environment analysis(7). For large-scale demonstration experiments, Hitachi has equipment that allows it to conduct various types of thermal-hydraulic testing, material radiation exposure testing, testing to confirm robustness in the event of an earthquake, and testing to confirm maintenance techniques. Last year, Hitachi constructed HUSTLE (Hitachi utility steam test leading facility), one of the world's largest test facilities that is able to supply steam and hot water at the actual operating pressure and temperature of a BWR (see Fig. 7). Hitachi will use the facility to develop high-performance and high-reliability equipment for the next-generation BWR, equipment for improving the performance of existing BWRs, and other types of equipment.

This issue has an article describing the next-generation BWR entitled "Development of Next-generation Boiling Water Reactor for Era of Large-scale Plant Construction."

Advanced Inspection Technologies

Maintenance becomes increasingly important as nuclear power plants age and Hitachi is working on practical use of advanced inspection technologies with benefits that include helping reduce worker exposure to radiation while also sustaining stable long-term operation and improving plant utilization(8). Achieving stable long-term operation of aging plants requires checking on equipment health using inspection techniques appropriate to the importance of the equipment involved together with measures for preventing problems during plant operation such as improving water quality or upgrading equipment.

The "Advanced Inspection Technologies for Energy Infrastructure" article in this issue describes the features of the advanced inspection technologies that Hitachi has developed for power plant maintenance.

Nuclear Fuel Cycle Technologies

If nuclear power is to provide a reliable supply of electrical energy over the long term, it will be necessary to establish a fuel cycle that includes the use of fast breeder reactors[(g)] in order to improve by an order of magnitude the utilization of uranium resources which, like oil, are finite. Hitachi is actively involved in technology development and business operations in fields that include medium-term storage, fuel reprocessing, fast breeder reactors, and treatment and disposal of waste material. In the field of fast breeder reactors, for example, Hitachi is taking advantage of its experience in the development, manufacture, and maintenance of equipment for the Monju reactor, particularly the primary systems, to undertake work including the establishment of system concepts and the development of equipment, thermal hydraulics, and material and structural technologies with the aim of starting operation of a demonstration reactor around 2025 and an operational reactor around 2050.

Details of Hitachi's work in this field are described in the "Nuclear Fuel Cycle Technologies for Future Low-carbon Society" article in this issue.

HYDRO POWER

Since about 1960 when Japan changed from having an electricity generation system based on hydro power and supplemented by thermal generation to one in which these roles were reversed, developments in the field of hydro power have focused mainly on pumped-storage power[(h)]. Pumped-storage power has progressively shifted toward plants with larger capacities in order to obtain economies of scale. Greater capacity can be achieved either through a higher head (difference in water level) or higher flow rate, but since a higher head allows smaller civil engineering equipment and machinery, it is development at sites that offer a high head that has been encouraged. The largest such system that Hitachi has supplied in Japan is the pump-turbine at the Kazunogawa Power Plant of The Tokyo Electric Power Company which has a pump head of 700 m and an output in the 400 MW range[(9)].

The technologies underpinning this trend toward greater capacity include: (1) improved techniques for analyzing the flow past the runners that form the heart of the turbine and for measuring the flow past the runners and at the inlet and outlet, (2) improvements in cavitation performance and understanding of unstable phenomena achieved through use of the above techniques, and (3) improvements in structural design techniques obtained by using the finite element method for stress analysis, strain calculations, vibration analysis, and similar.

While balancing electricity supply and demand will become an major issue as increased use is made of renewable energy sources such as wind and photovoltaic power, adjustable-speed pumped-storage power systems can make rapid adjustments to the supply-demand balance even during the night time when operating in pumping mode, and society's need for such grid stabilization techniques is becoming very strong. Hitachi's adjustable-speed pumped-storage power system is described in the "Hitachi's Adjustable-speed Pumped-storage System Contributing to Prevention of Global Warming" article in this issue.

ACTIVITIES IN FIELD OF RENEWABLE ENERGY

Increasing use is being made of renewable energy sources such as wind and photovoltaic power around the world as measures to prevent global warming. The two forms of renewable energy that are anticipated to grow strongly in the period up to around 2020 are wind power and photovoltaic power (see Fig. 8).

Wind Power System

In cooperation with Fuji Heavy Industries Ltd., Hitachi has developed a 2-MW downwind turbine[(i)] that can achieve improvements in output of approximately 8% when used in the hilly or mountainous terrain that is

(g) Fast breeder reactor
The fast-breeder reactor is a type of reactor that utilizes the uranium 238 isotope that makes up the bulk of natural uranium but cannot be used as fuel in a light water reactor to produce ("breed") plutonium which is also used as reactor fuel. The reactor utilizes that fact that when uranium 238 absorbs neutrons generated by the fission reaction it is transformed into plutonium, thereby producing more plutonium fuel at the same time as energy is extracted from the fission of uranium to generate electricity.

(h) Pumped-storage power
A form of hydro power in which the power plant has upper and lower reservoirs with a large difference in elevation so that excess power available at times when electricity demand is low, such as during the night, can be used to pump water from the lower to the upper reservoir, and this water can then flow back from the upper to the lower reservoir to generate power when electricity demand is high during the day. Pumped-storage power can act as an adjustable power source that can respond to sudden changes in electricity demand. Pumped-storage power also includes adjustable-speed pumped-storage power plants that can adjust the pump speed during pumping to provide detailed control of the power consumed and thereby contribute to the stability of the electricity grid, particularly during the night.

(i) Downwind turbine
A type of wind turbine in which the blades are positioned downwind of the tower that supports the turbine. In contrast, a wind turbine in which the blades are positioned upwind of the tower is called an "upwind turbine." Downwind turbines have superior stability and can generate electricity reliably and with high efficiency in mountainous and hilly terrain in particular.

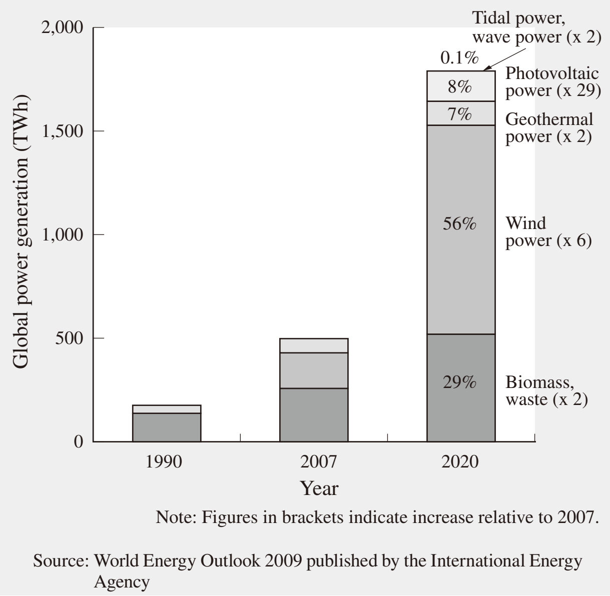


Fig. 8—Trend in Electricity Generated from Renewable Energy.
The amount of electricity generated from wind and photovoltaic power is expected to increase between now and 2020.

common at wind turbine sites in Japan[10]. Compared to wind turbines built to international standards, features of the design of the downwind turbine include the ability to withstand stronger winds and greater resistance to positive lightening than is specified in the standards. The control system uses the same active power priority control that is used in adjustable-speed pumped-storage power plant systems. Because this technique controls the active power directly, it can provide a stable power supply with minimal variation in the power output even when the wind speed varies.

The generator is a four-pole air-cooled type that incorporates windings in both the rotating and stationary elements and the power converter controls the magnetic field of the rotating element to allow operation to track across a wide range of rotor speeds.

IGBTs (insulated gate bipolar transistors) with a rated output of 1,400 V are used to allow the generator terminal voltage to be increased to roughly twice the standard 690 V used in most wind turbine generators to minimize the transmission power loss between the generator located in the nacelle and the converter at the base of the tower.

Hitachi is working to have this wind turbine adopted more widely, primarily at sites considered difficult for wind turbine installation due to restrictions such as terrain, typhoons, or lightning.

Photovoltaic Power System

As part of a NEDO demonstration study, Hitachi has developed a high-capacity PCS (power conditioning system) with a grid stabilization function for large-scale photovoltaic power systems in response to a repeat order from NTT Facilities, Inc.[11]. The features of this new 400-kW-class PCS include FRT (fault ride-through) and a function to suppress fluctuations in the grid voltage by using an interconnection inverter to output an appropriate level of reactive power based on the state of the power grid along with the generated active power. In addition to PCSs, Hitachi offers a wide range of other equipment and systems including monitoring and control systems, transformers, and circuit breakers. Based on these technologies, Hitachi will continue to offer large-scale photovoltaic power systems that help stabilize the electricity grid.

The article in this issue entitled "Power Stabilization Technologies for Next-generation Transmission and Distribution Networks" looks at the issues raised by the era of large-scale introduction of renewable energy and the technologies that can resolve these issues.

CONCLUSIONS

This article has described the features of the thermal, nuclear, hydro, wind, photovoltaic, and other forms of power generation technology handled by Hitachi, primarily through its Power Systems Company, along with Hitachi's future plans for these fields.

In its Environmental Vision 2025, Hitachi has announced its intention to "help reduce annual CO_2 emissions by 100 Mt by 2025 through Hitachi products and services." The power generation technologies described in this article are expected to make a significant contribution to reducing CO_2 emissions and to contribute to achieving a global low-carbon society through ongoing development of new technology.

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