Power Systems Research and Development

Hironobu Kobayashi, Dr. Eng.
Yuji Fukuda
Hideya Anzai
Kumiaki Moriya
Takashi Ikeguchi

ESTABLISHING, MAINTAINING, AND IMPROVING RELIABILITY

ESTABLISHING, maintaining, and improving reliability are the most important considerations for electric power business. To achieve these goals, Hitachi not only undertakes full-scale demonstration trials from specific research projects, it also utilizes the latest simulation techniques to identify and understand physical phenomena. In addition to equipment for large generation, transmission, and distribution systems, Hitachi is also working toward the adoption of distributed power sources and renewable energy and the development of control systems and systems for connecting these together over wide areas.

To this end, Hitachi is working by itself and with partners to extend its research and development globally, including in the field of monozukuri (manufacturing), taking active measures that are intended to build mutual trust through technology development.

Although Hitachi suffered some damage in the Ibaraki region as a result of the Great East Japan Earthquake, production at the power systems divisions is largely back to normal, and the company is now doing its upmost to help restore electric power infrastructure, including measures for dealing with the power shortage and security of supply (see Fig. 1).

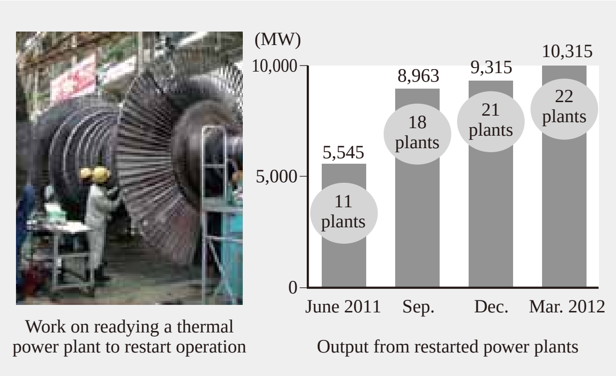


Fig. 1—Plan for Restoration of Electric Power Infrastructure.
Although buildings and production facilities in the Hitachi region of Ibaraki Prefecture suffered earthquake damage, they were back in operation by March 29. Hitachi has been helping to restart halted thermal power plants.

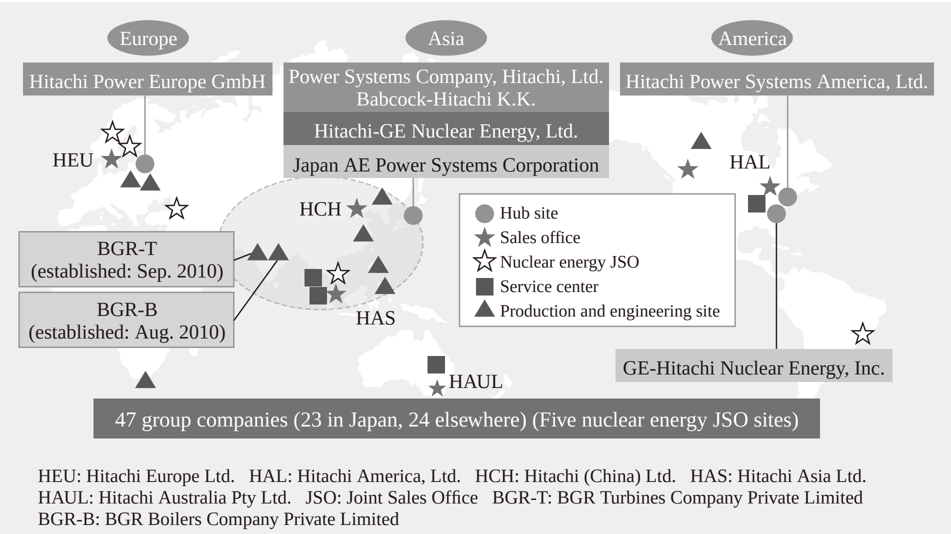
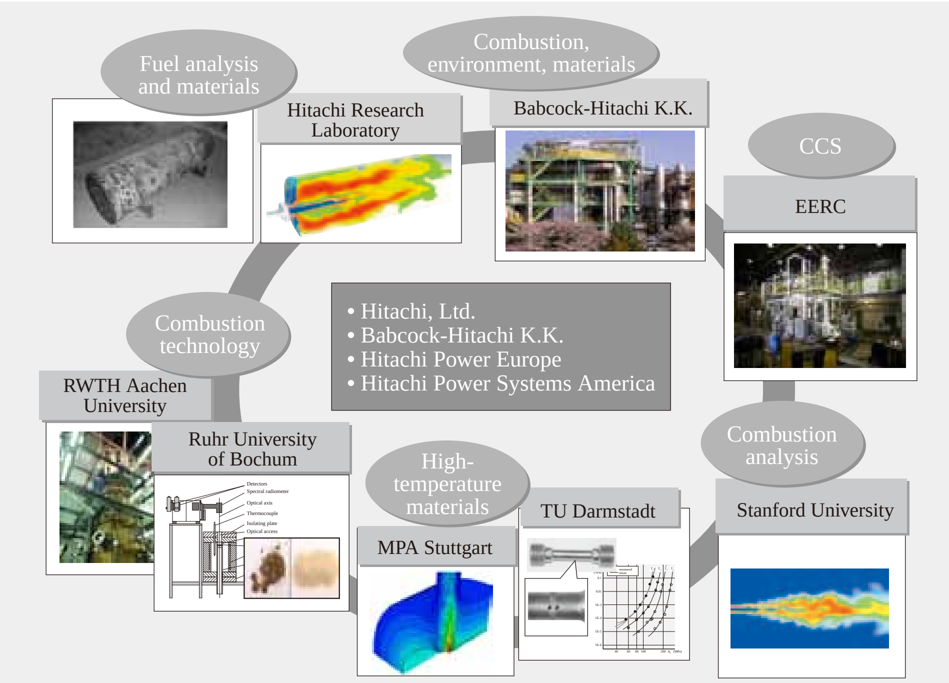
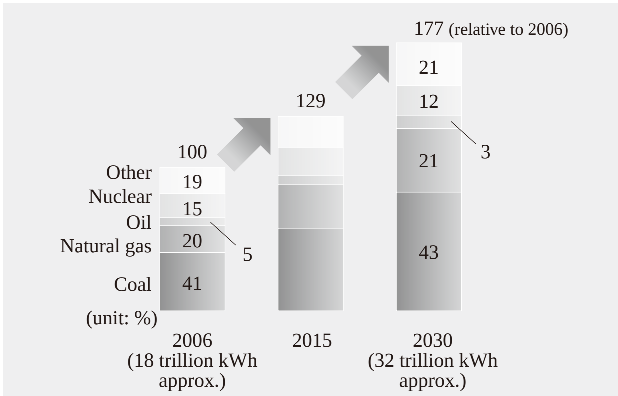


Fig. 2—Global Operations of Power Systems Company.
The company is expanding its production and engineering sites and strengthening its marketing outside Japan.



CCS: carbon capture and storage EERC: Energy & Environmental Research Center

Fig. 3—Coordination of CCS Technology Development within Hitachi.
In addition to the development of CCS technology at facilities in Japan, America, and Europe, Hitachi is also collaborating on development with universities and research institutions in Europe and America.



Source: International Energy Outlook 2009, published by the U.S. Department of Energy

Fig. 4—Breakdown of World Electricity Demand.
Coal-fired thermal power plants are a key source of electric power, providing more than 40% of the world's electric power, a proportion that is unlikely to significantly change in the future.

PROMOTING GLOBALIZATION

Measures Covering the Entire Electric Power Business

Overseas sales average 40% of total sales by the electric power divisions of Hitachi, a figure that rises to 60% for thermal power. Accordingly, Hitachi has bases in various different parts of the world (see Fig. 2).

Rather than doing things on its own, Hitachi also undertakes joint research and joint development with universities, research institutes, manufacturers, and other organizations in Japan and elsewhere. As the example from the coal-fired thermal power plant sector in Fig. 3 shows, Hitachi has established global research and development capabilities to help with environmental protection and measures for dealing with global warming.

Thermal Power Business—Example Activities Relating to Coal-fired Thermal Power Plants

Because coal is widely distributed around the world with large reserves that are cheap to extract compared with other energy sources, coal-fired thermal power plants provide more than 40% of the world's electric power. Although measures such as the use of CCS[a] to reduce emissions of CO_2 (carbon dioxide) which have a greenhouse effect and adoption of A-USC[b] technology to improve efficiency are essential for coal-fired thermal power plants, it is also clear that coal will continue to be a key source of electric power in the future (see Fig. 4). Furthermore, Hitachi leads the world in development of technologies that remove

(a) CCS
Abbreviation of "carbon capture and storage." The technology for the separation and capture of CO_2 generated by thermal power plants, natural gas extraction, or other sources, and its storage in stable geological strata or by ocean sequestration. The main methods of CO_2 separation and capture include chemical absorption and oxy-fuel combustion.

(b) A-USC
Abbreviation of "advanced ultra-supercritical" power generation. Coal-fired thermal power plants use steam produced from a boiler by burning coal, and their efficiency increases the higher the temperature and pressure of this steam. The term "A-USC" is used for steam temperatures in the 700°C range.

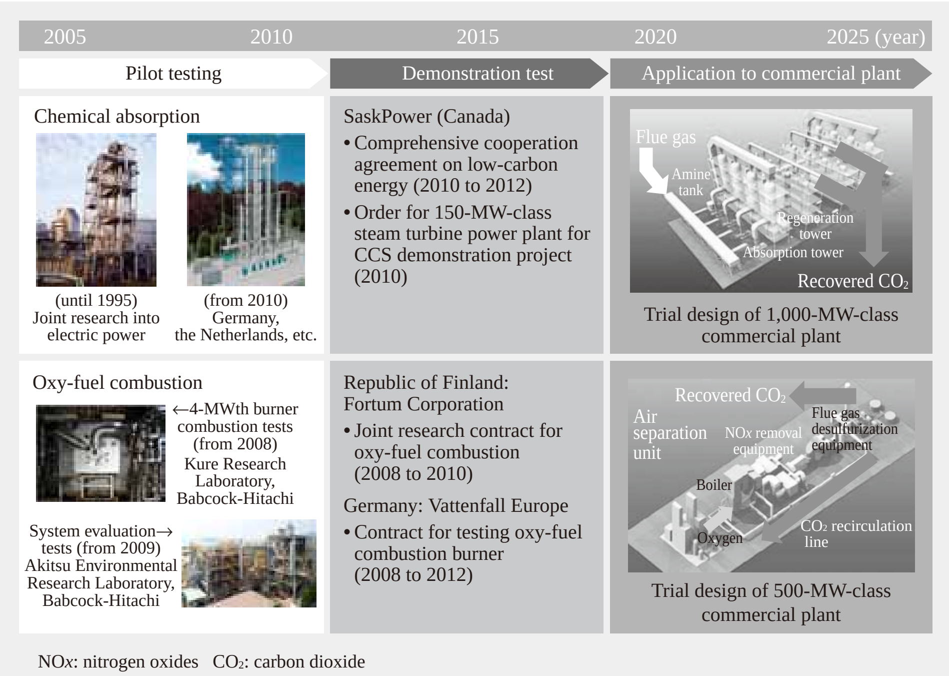


Fig. 5—Collaboration on CCS Technology Development with Power Companies in Europe and America.
Hitachi is working in collaboration with a Canadian power company on chemical absorption and with Finnish and German power companies on oxy-fuel combustion.

the NO*x* (nitrogen oxides) and SO*x* (sulfur oxides) contained in exhaust gases. In particular, Hitachi has the top share of the world market for de-NO*x* catalysts and it is actively involved in this field with initiatives including the opening of a production facility in China that complies with strengthened environmental regulations and the development of catalysts for biomass. With the aim of achieving zero emissions, Hitachi has also developed AQCS (air quality control system) with technology able to process all components of exhaust gas. This technology has been demonstrated in the USA and has earned a high reputation overseas(1).

Work is also in progress to demonstrate CCS at local power companies (see Fig. 5). Hitachi intends to help with global warming, environmental protection, and other challenges by using these projects to overcome the obstacles to commercialization and by making the technology developed by Hitachi into a global standard.

RESEARCH AND DEVELOPMENT AIMED AT RELIABLE SUPPLY OF ELECTRIC POWER

Coal-fired Thermal Power Plants

The objectives for coal-fired boilers are: (1) to cut emissions of environmentally harmful substances, such as NO*x* and CO (carbon monoxide), and (2) to increase the combustion efficiency of pulverized coal in order to reduce the quantity of CO_2 emitted per unit of coal burnt. The development of coal-fired boilers with this sort of performance requires advanced combustion analysis techniques. Because flow inside a boiler is influenced by complex nonequilibrium combustion reactions, Hitachi has developed an analysis technique that uses LES (large eddy simulation) and can predict the fluid dynamics with a high level of accuracy. Hitachi was the first in the world to apply an LES-based numerical simulation of pulverized coal combustion to a boiler furnace through the development of an actual plant.

Fig. 6 shows the LES combustion analysis results of a coal-fired boiler test unit with a thermal input of 20 MW. High gas temperature in the vicinity of the burner achieves reliable flame stabilization. In addition, OFA(c) is used to reduce CO emissions by ensuring that it is fully combusted. The calculation results show good agreement with experiment(2), indicating the practicality of adopting “design by analysis” in the future as an alternative to experiments.

The development of these combustion analysis techniques drew on numerical analysis techniques from Stanford University in the USA and combustion test results from the RWTH Aachen University in Germany.

To improve the efficiency of steam turbines, it is important to consider the thermodynamic properties of the steam and its supersonic flow characteristics.

(c) OFA
Abbreviation of “over fire air.” A type of secondary air supplied in the second stage in the case when air is supplied to the combustion chamber in a number of separate stages. Supplying additional air midway through the combustion process helps promote full combustion.

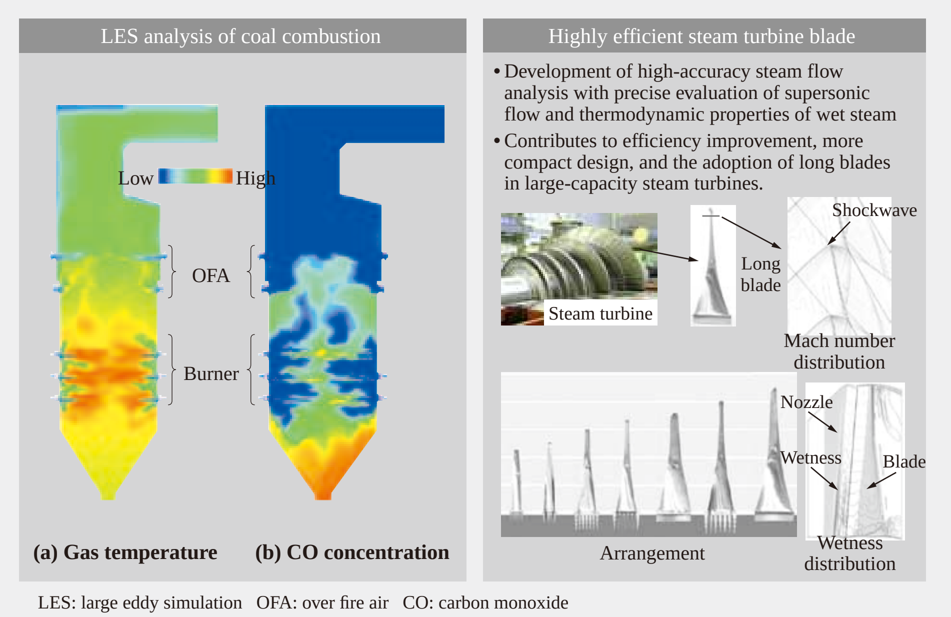


Fig. 6—Example Research and Development of Coal-fired Thermal Power Plants (Boilers and Steam Turbines).
Hitachi is using numerical simulation to develop products, such as low-NOx burners and highly efficient supercritical-pressure steam turbines.

Steam in high-pressure sections of a steam turbine is in a supercritical state which combines the properties of a gas and liquid, whereas gas-liquid two-phase flow with non-equilibrium condensation occurs in the low-pressure sections. On the other hand, the flow becomes supersonic in aft stages of low-pressure turbines, and the key to efficiency improvement here lies in minimizing shock losses.

Hitachi has developed its own technique of fluid dynamical analysis that is able to evaluate supersonic flow with a high level of accuracy by considering the thermodynamic properties of the steam from a supercritical pressure to a gas-liquid two-phase flow[3]. This technique is used in the development of highly efficient blades. In particular, the last-stage long blades have a major impact on efficiency improvement, and although the flow in this section is a complex, supersonic gas-liquid two-phase flow, the technique of fluid dynamical analysis allows the development of highly efficient long blades (see Fig. 6).

Gas Turbines

There are two approaches to improving the efficiency of a gas turbine: one is to make separate efficiency improvements to the compressor, turbine, and other components, and the other is to improve the thermal cycle efficiency by operating at higher temperatures and pressure ratios. Based on the former approach, Hitachi is developing three-dimensional turbine blades using techniques such as those for optimum design or for analyzing the entire turbine. Similarly, developments aimed at improving thermal cycle efficiency include heat-tolerant alloys, heat-insulating coatings, and high-performance cooling techniques, and Hitachi is also using various types of experimental testing to verify performance and reliability (see Fig. 7).

For combustion, meanwhile, Hitachi is developing single-NO*x* multi-cluster burners designed to reduce the environmental burden (reduce NO*x* emissions) and burners able to work with a range of different fuels (gas/oil dual-fuel, hydrogen-rich gas, or blast furnace gas).

AHAT: a New Type of Thermal Power Generation System

Hitachi is working on the development of an AHAT[d] with the aim of creating a system consisting of a gas turbine only which can deliver operational flexibility combined with efficiency equal to or better than that of a combined cycle plant.

Development work sponsored by the Agency for Natural Resources and Energy has been ongoing since 2004 in cooperation with the Central Research Institute of Electric Power Industry and Sumitomo Precision Products Co., Ltd. Experimental results from a 3-MW-class pilot system have already demonstrated

(d) AHAT
Abbreviation of "advanced humid air turbine." A gas turbine generation system that humidifies the air from the compressor and uses a recuperator to recover and utilize waste heat. Efficiency improvements include the increased output due to higher humidity and the fuel savings resulting from the use of waste heat to preheat the combustion air. Despite consisting of a gas turbine only, a small- to medium-capacity unit in the 100-MW range can achieve better efficiency than a combined cycle plant.

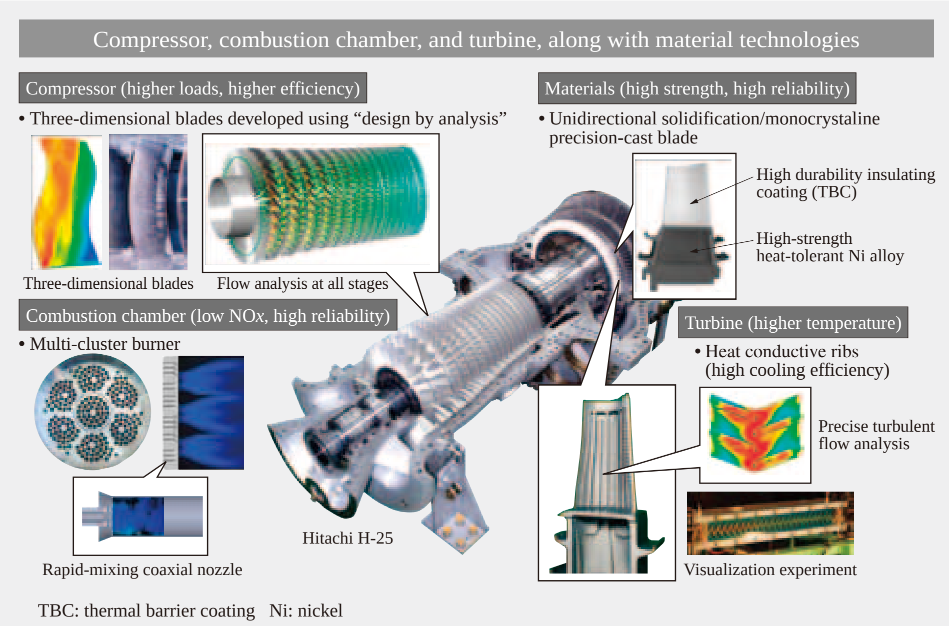


Fig. 7—Gas Turbine Research and Development Examples.
To improve efficiency and reduce the environmental burden, Hitachi is working on a broad range of research and development covering the compressor, combustion chamber, and various material technologies, as well as the turbine unit itself.

Fig. 8—Cutaway Photograph of 40-MW-class AHAT Gas Turbine.
Tests are scheduled to commence from the latter half of the 2011 fiscal year.

the excellent operational characteristics of the concept, including its power generation efficiency, ambient temperature effects, part-load characteristics, and start-up time[(4)]. A 40-MW plant for testing specific technologies required for commercialization is currently under construction, and is scheduled to commence operation in the latter half of the 2011 fiscal year. The aims for the future include conducting trials on a demonstration plant and improving its generation efficiency in preparation for commercialization, and entering the market with a plant with an output in the 100- to 200-MW range (see Figs. 8 and 9).

New Types of Thermal Power Generation—Trigeneration System (Electric Power, Steam, and Water)

Trigeneration systems are a more advanced form of the cogeneration systems that combine a gas turbine and waste heat recovery system. In addition to electric power and steam, a trigeneration system also produces water (purified water, or drinking water).

This technology has attracted attention from CBM[(e)] mining sites in Australia, EOR systems[(f)] in South America.

Fig. 10 shows an example EOR system consisting of a cogeneration unit that produces electric power and steam, and an MED unit[(g)] that takes water from a lake and produces drinking water and water for the boiler. Oil production is boosted by injecting the steam produced by the system alongside oil wells that have suffered a decline in production after being in operation for many years. This warms the oil and thereby eases its extraction.

(e) CBM
Abbreviation of “coal bed methane.” Methane gas generated by the process of coal formation and retained in underground coal seams or in the coal itself. While CBM has been a cause of coal mine explosions in the past, it has started to be exploited as a resource in recent years.

(f) EOR
Abbreviation of “enhanced oil recovery.” A method for recovering crude oil that is left behind by primary recovery in which the oil comes up from the subsurface reservoir under its own pressure. EOR methods include the pressurized injection of water, natural gas, or CO_2, as well as thermal and chemical recovery methods.

(g) MED
Abbreviation of “multi-effect distillation.” A seawater desalination method, its features include high efficiency, low power consumption (approximately 40% that of the reverse osmosis membrane method), and steady performance that is not affected by water quality.

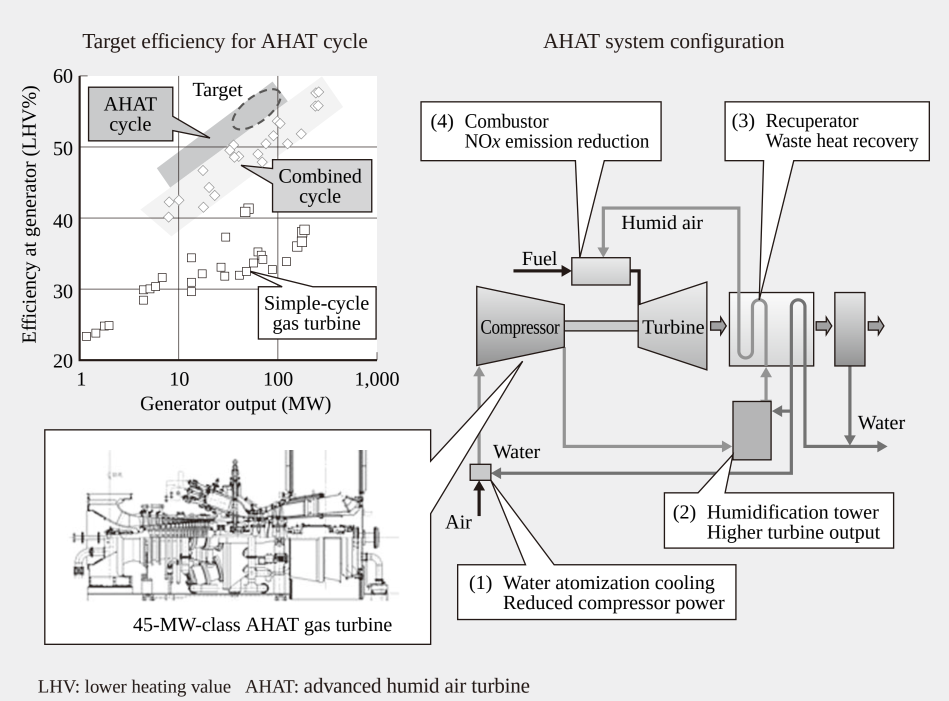


Fig. 9—AHAT System Configuration and Efficiency.
The aim for the AHAT system is to achieve an efficiency equal to or better than that of a combined cycle plant despite using only a gas turbine.

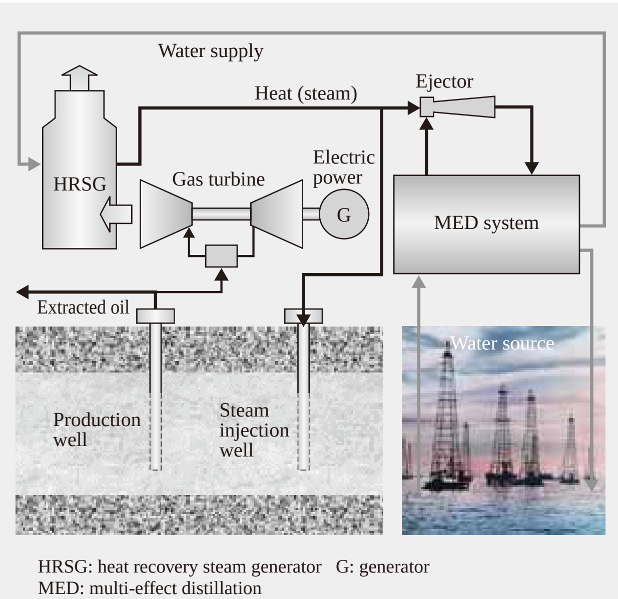


Fig. 10—Trigeneration System Producing Electric Power, Heat, and Water.
The waste heat from the gas turbine is recovered and used to produce purified water.

Some of the water produced is supplied as drinking water to the surrounding area. This plan is being undertaken with subsidies from the "Subsidies for Cost of Refining Technology and Other Measures for Oil-producing Nations (Industrial Cooperation and Other Activities with Oil-producing Nations)" provided by the Ministry of Economy, Trade and Industry.

Nuclear Power

In the field of nuclear power, Hitachi is using highly accurate simulation technology to improve the safety and reliability of BWRs[h].

Ensuring the thermal integrity of fuel in the reactor core is an important part of nuclear reactor development, and one of the challenges is to develop a way to predict the thermal power distribution accurately. Hitachi has developed a new method of its own for conducting detailed analyses of the thermal power distribution in each nuclear fuel pin using a Monte Carlo neutron transport calculation method to model the nuclear fission reaction precisely (see Fig. 11)[5]. Hitachi is also working on three-dimensional methods for analyzing gas-liquid two-phase flow for use in detailed assessments of the water in the core and the steam produced by boiling of this water. The HUSTLE (Hitachi utility steam test leading facility) is one of the world's leading demonstration test facilities and can reproduce the pressure and temperature conditions to which steam and hot water are subjected in an actual reactor. Uses for this facility include validation of simulation techniques and the development of equipment with

(h) BWR
Abbreviation of "boiling water reactor." Light water reactors that use light water as a moderator and coolant include BWRs and PWRs (pressurized water reactors). A BWR generates electric power from a turbine fed directly with steam given off by the water boiling in the pressure vessel of the nuclear reactor.

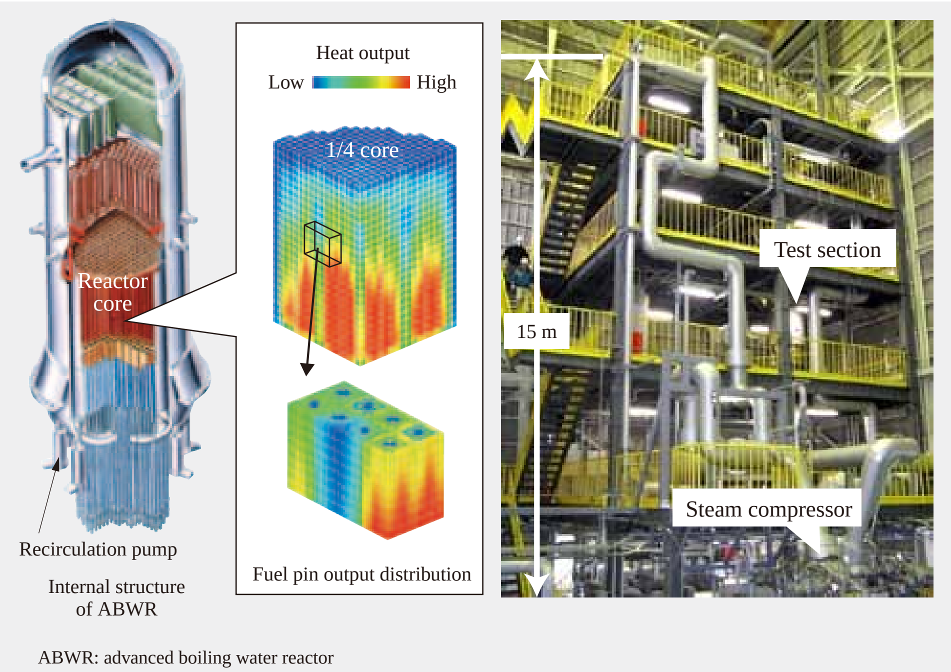


Fig. 11—Advanced Nuclear Reactor Simulation Techniques and a Demonstration Test Facility.
Hitachi is utilizing methods, such as three-dimensional simulation of the core, to determine detailed thermal power distributions and conducting steam-water thermal-hydraulic testing at temperatures and pressures that occur in actual reactors to develop equipment with high performance and reliability.

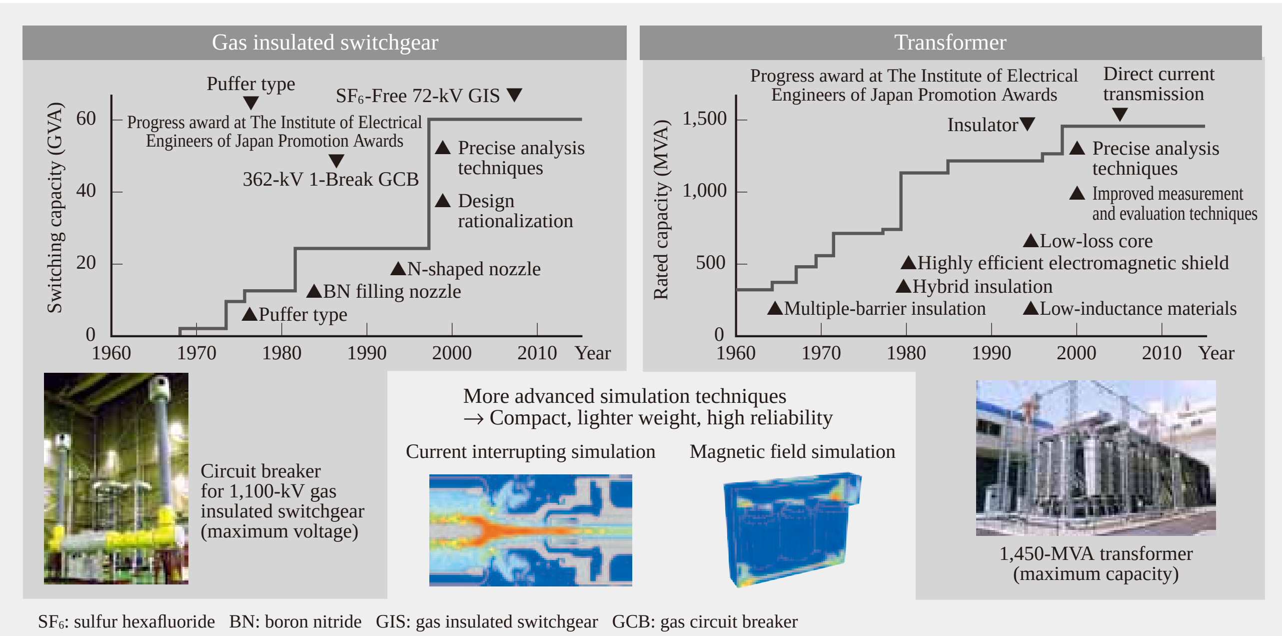


Fig. 12—Development of Electrical Substation Equipment.
Hitachi is achieving better efficiency, smaller size, and higher capacity through the use of numerical simulation for optimization and to elucidate the phenomena involved.

high performance and reliability that can be used in the latest ABWRs[(i)].

RESEARCH AND DEVELOPMENT FOR ELECTRIC POWER SYSTEM

Electrical Substation Equipment

In conjunction with power system controls, this equipment ensures a reliable supply of electric power by providing high-capacity transmission of electric

(i) ABWR
Abbreviation of "advanced BWR." An ABWR achieves higher thermal efficiency and maximum output owing to improvements derived from experience with BWR operation and the adoption of the latest technology. Developments such as the use of internal pumps located inside the reactor pressure vessel to circulate the coolant inside the nuclear reactor, an improved control rod drive mechanism that inserts and withdraws the control rods to control the reactor output, and a steel-reinforced concrete containment vessel that is built into the structure of the building have been adopted to deliver improvements such as a smaller reactor building, shorter construction time, better plant utilization, and greater safety.

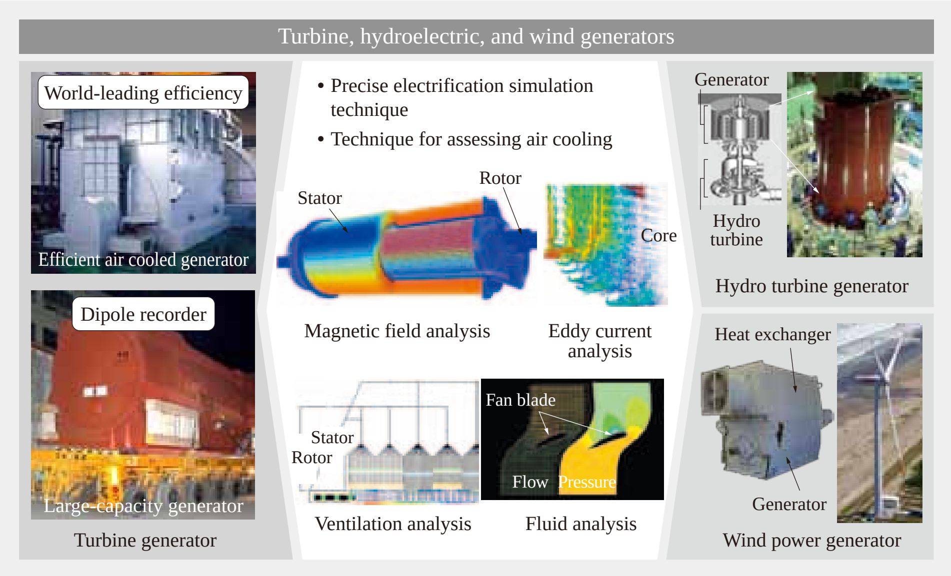


Fig. 13—Generator Development.
Hitachi is taking active steps to adopt simulation techniques as a way of ensuring the reliability of various types of generator, improving generation efficiency, and meeting the customer's requirement.

power to meet the demand from industry and general consumers. Hitachi is contributing to the development of efficient and compact equipment with high capacity by using simulations to elucidate the phenomena at work and to optimize this static high-voltage equipment. Such equipment is characterized by high temperatures and pressure, supersonic gas flows, arc discharge plasmas, and strong magnetic fields (see Fig. 12)[6].

Generators

Generators have an essential role as the source of electric power and cover a wide range, with large-capacity models able to cope with growing electric power demand being particularly important. Examples include air-cooled generators, which offer convenient operation and maintenance, and hydro and wind power generators, which have attracted attention as a form of renewable energy. Hitachi is taking active steps to adopt simulation techniques such that it can respond quickly to demand for generators that are smaller and more efficient, as well as to ensure the reliability of its products (see Fig. 13).

Renewable Energy Use and Maintenance of Grid Stability

In addition to supplying generation systems for renewable energy, Hitachi is working on developing a wide range of next-generation technologies that are likely to be needed in the future as use of renewable energy becomes more widespread, including technologies for minimizing fluctuations in generation output, handling interconnection, and balancing supply and demand (see Fig. 14)[7].

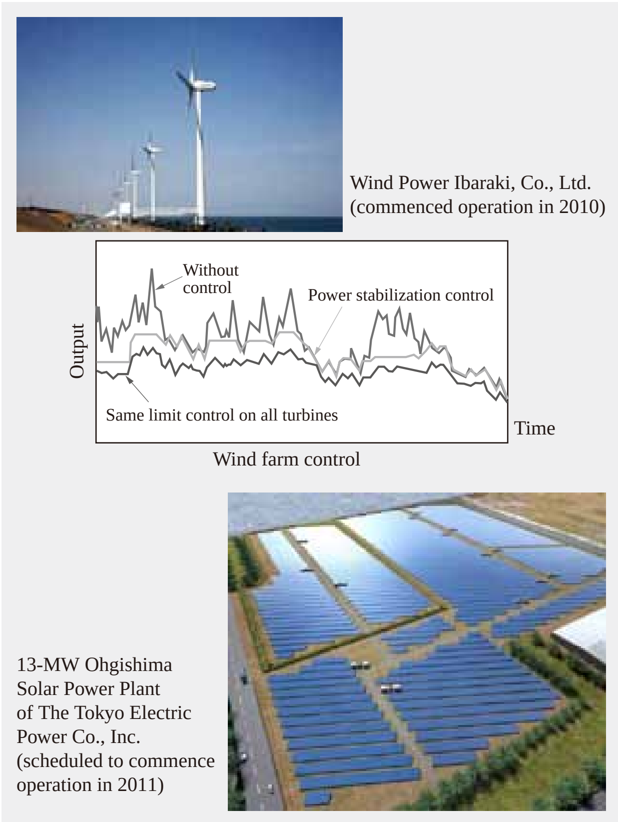


Fig. 14—Renewable Energy Generation System and Interconnection Technology.
Hitachi supplies interconnection technology that helps with electric power system stabilization.

CONTRIBUTING TO GLOBAL SOCIETY THROUGH AN INTERNATIONAL RESEARCH AND DEVELOPMENT ORGANIZATION

This article has described the research and development being undertaken at the Power Systems

Company, Hitachi, Ltd. Each of these projects involves more than just paper designs and includes the use of full-scale demonstration testing to improve reliability.

Hitachi intends to continue to operate its research and development activities on a global basis in order to contribute to measures for preventing global warming and protecting the environment, as well as to enhance the electric power infrastructure.

REFERENCES

(1) T. Kawasaki et al., “Development of CCS (Carbon Capture and Storage) Technology to Combat Climate Change—Advancement of Environmentally Conscious Clean Coal Power Plant Technologies,” Hitachi Review **59**, pp. 83–88 (Aug. 2010).

(2) K. Yamamoto et al., “LES of Pulverized Coal Combustion Furnaces,” Proceedings of the ASME 2011 Power Conference (POWER 2011) and the International Conference on Power Engineering 2011 (ICOPE-11), July 12–14, Colorado, USA, POWER2011-55367 (Dec. 2011).

(3) S. Senoo et al., “Computations for Unsteady Compressible Flows in a Multi-Stage Steam Turbine with Steam Properties at Low Load Operations,” ASME POWER2010-27096 (Jun. 2010).

(4) H. Araki et al., “Experimental and Analytical Study on the Operation Characteristics of the AHAT System,” ASME Turbo Expo 2011, GT2011-45168 (2011).

(5) T. Hino et al., “BWR Core Simulator Using Three-Dimensional Direct Response Matrix and Analysis of Cold Critical Experiments,” Journal of Nuclear Science and Technology **47**, No. 5, pp. 482–491 (2010).

(6) R. Hemmi et al., “Development of 1,100 kV/50 kA Double-break Gas Circuit Breaker,” AE Power Systems Review **1**, pp. 25–28 (2008).

(7) N. Uchiyama et al., “Reactive Power Control Method for Reducing Voltage Fluctuation in Large-scale Photovoltaic Systems,” IEEJ Transactions on Power and Energy, pp. 297–304 (Mar. 2010).

ABOUT THE AUTHORS

Hironobu Kobayashi, Dr. Eng.

Joined Hitachi, Ltd. in 1982, and now works at the Energy and Environment Research Center, Hitachi Research Laboratory. He is currently engaged in the development of power systems. Dr. Kobayashi is a member of The Japan Society of Mechanical Engineers (JSME) and the Combustion Society of Japan.

Yuji Fukuda

Joined Babcock-Hitachi K.K. in 1979, and now works at the Kure Research Laboratory. He is currently engaged in the development of boiler and air quality control systems. Mr. Fukuda is a member of The Japan Institute of Metals and the JSME.

Hideya Anzai

Joined Hitachi, Ltd. in 1983, and now works at the Department of Materials Research for Power Plants, Hitachi Research Laboratory. He is currently engaged in the management of materials research for power plants. Mr. Anzai is a member of The Iron and Steel Institute of Japan and Japan Society of Corrosion Engineering (JSCE).

Kumiaki Moriya

Joined Hitachi, Ltd. in 1980, and now works as Corporate Chief Engineer at Hitachi-GE Nuclear Energy, Ltd. He is currently engaged in the design and development of nuclear power plants. Mr. Moriya is a member of the Atomic Energy Society of Japan (AESJ) and The Physical Society of Japan.

Takashi Ikeguchi

Joined Hitachi, Ltd. in 1972, and now works as CTO and Chief Engineer at the Power Systems Company. He is currently engaged in guidance of research and development, mainly at the Power Systems Company. Mr. Ikeguchi is a member of the JSME and American Society of Mechanical Engineers (ASME).