Efficient and Flexible AHAT Gas Turbine System

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OVERVIEW: Hitachi is developing an AHAT gas turbine system that features high efficiency and excellent operational characteristics. AHAT is a new type of gas turbine generation system in which the regenerative cycle has been enhanced. AHAT achieves higher efficiency without increasing the pressure ratio or combustion temperature, and does not require high-grade, high-temperature materials. Furthermore, because a boiler or steam turbine is not used in AHAT, it is expected to provide flexible operation and a high load change rate. The feasibility of the system has been verified through testing on a 3-MW-class pilot plant. A 40-MW-class pilot plant is currently under construction and is scheduled to commence operation in the latter half of the 2011 fiscal year. Subsequent plans include conducting tests at the demonstration plant and improving efficiency in preparation for commercialization, the aim being to enter the market with a power plant in the 100- to 200-MW output class.

INTRODUCTION

GAS turbines have been widely adopted as emergency power supplies since the late 1970s because of features including short construction and installation times and rapid load change rate. Combined cycle plants, which combine gas and steam turbines, have high efficiency and have come to be used as high-capacity base-load power plants. Nevertheless, high-capacity combined cycle plants suffer from a number of problems such as being unable to handle rapid load change rate. In addition, their high combustion temperatures and use of expensive materials result in high maintenance costs, and the steam turbine's condenser needs to be located by water. In response to these problems, Hitachi developed the AHAT (advanced humid air turbine) to be an efficient and flexible gas turbine system[(1), (2), (3)].

The AHAT system was proposed by Hitachi and the company was the first in the world to confirm its feasibility on a pilot plant. The Cool Earth-Innovative Energy Technology Program, adopted by the Japanese government to undertake specific measures for preventing global warming designated the technology as an "efficient gas turbine" and the development work needed to commercialize it is being carried out as a national project with funding from the Agency for Natural Resources and Energy.

This article describes the new AHAT gas turbine system.

AHAT

A combined cycle generation system combines a gas turbine and steam turbine. The gas turbine uses gas at high temperature and pressure to generate electric power. The remaining heat in the exhaust gas is then used to boil water, which is fed into a steam turbine to generate more electric power. In contrast, AHAT is a new type of gas turbine generation system that can achieve high efficiency without a steam turbine by using a recuperator to recover heat from the gas turbine exhaust and injecting moisture at a level comparable to the steam used in a steam turbine.

AHAT Features

Table 1 lists AHAT's features. Because it lacks a steam turbine, the operational characteristics of AHAT are expected to be more flexible than combined cycle plants. AHAT has a fast start-up speed and responds to load changes similarly to a standalone gas turbine, meaning that AHAT can operate at low load with a minimal output drop when the ambient temperature is high.

In terms of the environment, use of combustion with humid air achieves lower NO*x* (nitrogen oxides) emissions, and since the system uses a cooling tower it can be installed inland.

The economic benefits of AHAT include fewer components and a shorter construction time owing to the simple equipment configuration made possible by dispensing with the steam turbine. Moreover, AHAT does not require high-grade, high-temperature materials because a gas turbine has low combustion temperature. It is anticipated that piping, water quality management, and utility usage will be similar to a combined cycle plant.

TABLE 1. Comparison of AHAT and Combined Cycle

The equipment configuration of an AHAT is simpler than that of a combined cycle plant because AHAT does not have a steam turbine or waste heat recovery system. The advantages of AHATs are excellent operational characteristics, fewer restrictions on siting, and shorter construction time.

Comparison		AHAT		Combined cycle
Operation	Start-up speed	◎	Faster start-up speed due to not having an ST	ST and HRSG require warming-up
	Load responsiveness	◎	Equivalent to standalone GT system	Base
	Minimum load	◎	Combustion by humid air allows operation at low load.	Limited by need for stable combustion with low NO*x* emissions.
	Dependence on ambient temperature	○	Minimal loss of output when temperature high due to use of water atomization cooling	Loss of output occurs when temperature is high.
	Ease of control	○	Simple, equivalent to standalone GT system	Requires control of ST.
Environmental performance	NO*x* reduction	○	Combustion with humid air results in low NO*x*. NO*x* removal equipment may be required in some cases.	Low NO*x* can be achieved using a low-NO*x* combustor or by water or steam injection. NO*x* removal equipment is required.
	Restrictions on siting	◎	Can be sited inland because water is recovered at about 60°C which can be cooled using a cooling tower.	Must be located near water as ST output water temperature is 30°C and a condenser is required.
Economics	Construction lead time	◎	Short due to simple equipment configuration with no ST	Base
	Piping	–	Thin-wall piping as GT compressor outlet pressure is low. However, wide-diameter piping is required for regenerative cycle system.	Thick-wall piping required for high-pressure section of HRSG. Small-diameter pipes can be used for main steam piping.
	Water quality management	–	Requires water treatment system (such as ion exchange resin).	Requires addition of chemicals for pH control.
	Use of utilities	–	Demineralized water (for compressor water atomization cooling), ammonia (for NO*x* removal), cooling water (cooling tower replenishment)	Demineralized water (for HRSG blow replenishment), ammonia (for NO*x* removal), cooling water (replenishment)
	Maintenance costs	○	Simple equipment configuration (no waste heat recovery or water recovery system); low GT combustion temperature	Includes waste heat recovery, ST, and condenser systems; high GT combustion temperature.

◎: notably superior ○: superior –: equivalent
AHAT: advanced humid air turbine ST: steam turbine HRSG: heat recovery steam generator GT: gas turbine

System Configuration

Fig. 1 shows a schematic of the AHAT system. This AHAT system combines increased output (due to humidification) with higher thermal efficiency (due to the regenerative cycle of the recuperator).

A water atomization cooling system is located at the inlet of the gas turbine compressor. The increase in intake air quantity resulting from intake cooling and the transformation of atomized droplets into steam in the compressor act to reduce the compressor power requirement and minimize the output drop during summer. The air compressed by the compressor is humidified by hot water in the humidification tower. The compressed and humidified air passes through the recuperator where it is first heated by heat recovered from the exhaust gas and then supplied to the combustor. Use of humid air in combustion also significantly reduces the amount of NO*x*.

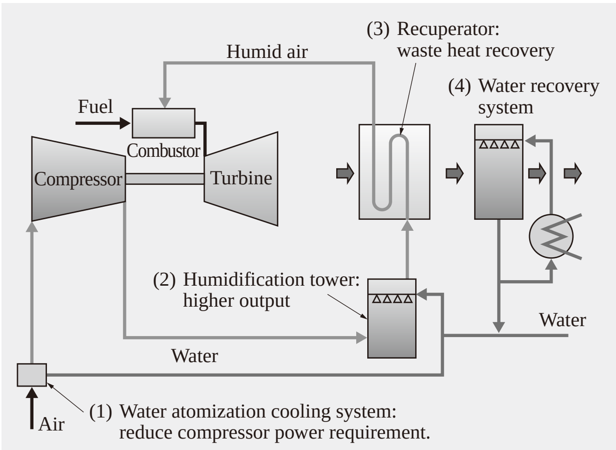
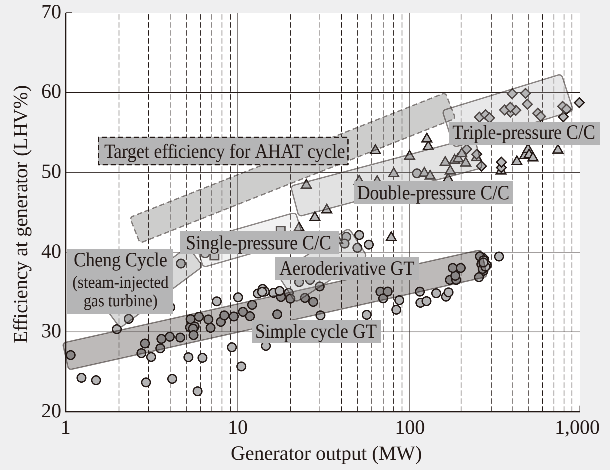


Fig. 1—AHAT System Configuration.
AHAT includes a water atomization cooling system, humidification tower, recuperator, and water recovery system. The design is simpler than that for a combined cycle plant.

Although demineralized water is used for humidification, the system includes a water recovery system in which most of the moisture content in the exhaust gas is recovered for reuse. The recovered water is supplied to the humidification tower and a proportion is also cooled and recirculated into the water recovery system.

Fig. 2 shows the outputs and efficiencies of different types of power generation systems. The



Source: Gas Turbine World (2010 GTW Handbook)

C/C: combined cycle LHV: lower heating value

Fig. 2—Output and Efficiency Relations for Different Electric Power Generation Systems.
The target for the AHAT is to have the best performance in the medium-capacity class.

target for AHAT is to have the best efficiency of all existing power generation systems in the medium-capacity class.

PROGRESS IN TECHNOLOGY DEVELOPMENT

Operational Assessment Using 3-MW-class Pilot Plant[4], [5]

Hitachi developed a 3-MW-class pilot plant and conducted testing of the entire AHAT system's feasibility, its dependence on ambient temperature, and its operational characteristics (see Fig. 3). Fig. 4 shows the dependence on ambient temperature. The test results indicate that both output and efficiency behave as predicted by calculation based on the heat balance.

Fig. 5 shows the test results for the turbine speed and generator output during a cold start (startup from a full shutdown). The rated output is reached after about 60 minutes, considerably faster than the approximately 180 minutes required to cold start a conventional combined cycle plant. The AHAT start-up time is equivalent to a hot start of a combined cycle plant.

40-MW-class System Test Facility

Fig. 6 shows the block diagram of a 40-MW-class pilot plant. This system configuration is used to test the interaction between the axial-flow compressor, recuperator, multi-can combustor, and cooling blades (all of which are designed to operate with humid air) under conditions of high pressure and humidity. The

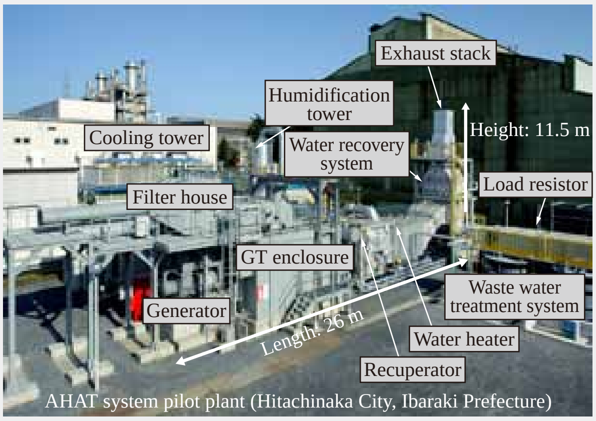


Fig. 3—3-MW-class Pilot Plant.
Trials were conducted to assess the feasibility, dependence on ambient temperature, and operational characteristics of the entire system.

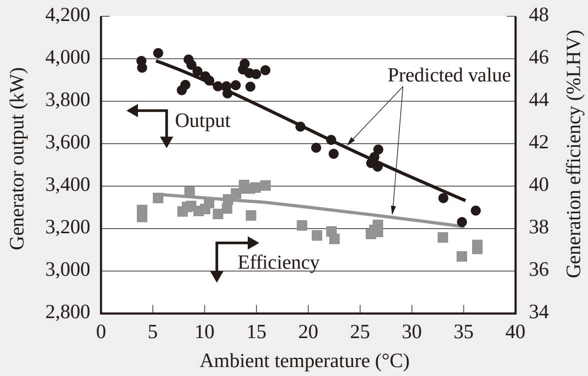


Fig. 4—Dependence on Ambient Temperature.
The measured and calculated values for output and efficiency both show similar behavior.

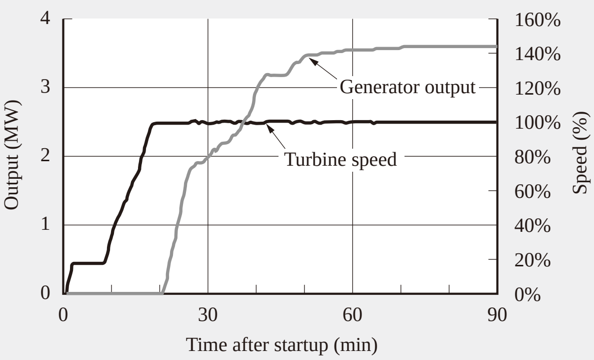


Fig. 5—Turbine Speed and Generator Output during Cold Start.
The system reaches its rated output about 60 minutes after a cold start, similar to a hot start on a combined cycle plant.

plant design has been completed, and construction of this plant is underway. Load testing is planned for the latter half of the 2011 fiscal year.

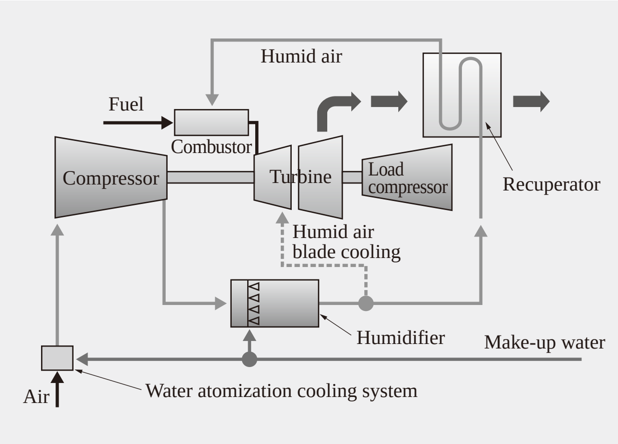


Fig. 6—System Block Diagram of 40-MW-class System Test Facility.
The pilot plant is used to determine the interaction between its different components under conditions of high pressure and humidity.

FUTURE DEVELOPMENTS

Spin-offs of Specific Technologies

Humid air blade cooling (which was developed as a separate technology) and technologies that have emerged from the technical development process for humid air combustion have been applied to Hitachi's range of gas turbines. These technologies are helping to reduce the environmental burden by decreasing the volume of cooling air and thus improving efficiency and cutting emissions of CO_2 (carbon dioxide) and NO*x*.

Distributed Power Sources

Small to medium-sized power generation systems with high efficiency can help to supply electric power in areas where the grid transmission infrastructure is inadequate, particularly those areas experiencing rapid growth in energy demand. They can also be used to build cogeneration (electricity and heat) systems.

Fuel Flexibility

Against a background of rapidly rising fuel prices, energy security considerations are driving the demand for fuel flexibility. With fuel being an important factor when selecting a power generation system, the ability to operate using a range of different fuels is expected to open up the system to a wider range of users. One example is the anticipated increase in the use of liquid biofuels, which have, in effect, zero emissions of CO_2. Since obtaining the required amount of fuel is comparatively easy for the medium-sized power plants to which AHAT is particularly suited, the adoption of AHAT is likely to encourage the use of liquid biofuels.

Electric Power System Stabilization Measures Required for Adoption of Photovoltaic Power

Japan intends to reduce emissions of greenhouse gases by 25% relative to 1990 levels by 2020 and, to this end, has set a target of installing 28 GW of solar power by 2020 (20 times the 2005 capacity). The Study Group on Low Carbon Power Supply System at the Ministry of Economy, Trade and Industry has reported on the need for solar power generation to be backed up by thermal power[6].

This group identified the following performance requirements for thermal power generation used as a backup for solar power:
(1) Short start-up time prior to starting generation
(2) High rate of change in output (kW/min) in response to sudden changes in demand
(3) Low minimum load level (known as having a large "depowering margin")
(4) Adequate capacity for governor-free operation and LFC (load frequency control)
(5) Minimal reduction in efficiency when operating at low load
(6) Ability to operate on a range of different fuels.

Table 2 lists how different power generation systems compare in terms of these performance requirements for handling the fluctuations in solar power output, assuming a 100-MW-class gas-fired

TABLE 2. Performance Requirements for Handling Fluctuation in Solar Power Output
Compared with combined cycle and conventional steam power, AHAT exhibits good performance in response to fluctuating loads.

Required performance characteristic	Power generation system (comparison of 100-MW-class gas-fired plants)		
	AHAT (targets)	**GT combined cycle**	**Conventional steam**
Short start-up time prior to starting generation	◎ 30 min (hot start) 60 min (cold start)	○ 60 min (hot start) 180 min (cold start)	△ 180 min or longer
High rate of change in output (kW/min) in response to sudden changes in demand	◎ 8.3–10%/min	○ 5%/min	△ 3–5%/min
Low minimum load level	◎ 25% load	△ 50% load	◎ 20% load
Adequate capacity for governor-free operation and LFC	○ LFC use possible	○ LFC use possible	◎ Governor-free operation and LFC use possible
Minimal reduction in efficiency when operating at low load (efficiency between 50–100% load, HHV)	◎ 43–51%	○ 40–50%	△ 38–40%

LFC: load frequency control HHV: higher heating value △: base level power plant. Although the values for AHAT are still targets at this stage, the excellent start-up speed, load change rate, and operating load range of this technology indicate that it should help in maintaining power system stability.

CONCLUSIONS

This article has described the new AHAT gas turbine system.

The AHAT system has improved cooling and an enhanced regeneration cycle, and is expected to achieve high efficiency, excellent operational characteristics, and good economics, without increasing pressures or combustion temperatures. This new technology for increasing efficiency has been recognized by a total of seven awards over the past five years from industry bodies in both Japan and overseas, including the J. P. Davis Award[(4)] from the American Society of Mechanical Engineers (ASME).

A 40-MW-class pilot plant is currently under construction and due to commence operation in the latter half of the 2011 fiscal year. Subsequent plans include conducting tests at the demonstration plant and improving efficiency in preparation for commercialization, the aim being to enter the market with a power plant in the 100- to 200-MW output class.

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REFERENCES

(1) S. Hatamiya, “Gas Turbine Generation Technology Using Humid Air,” Journal of the Thermal and Nuclear Power Engineering Society **552**, pp. 47–54 (Sep. 2002) in Japanese.

(2) S. Marushima et al., “Development of Advanced Humid Air Turbine,” 2007 Conference on Thermal and Nuclear Power (2007) in Japanese.

(3) T. Takahashi, “Research and Development of the Advanced Humid Air Gas Turbine (AHAT)—Development of 3MW Verification Plant and Demonstration of the System,” CRIEPI Research Report (Sep. 2008) in Japanese.

(4) S. Higuchi et al., “Test Results from the Advanced Humid Air Turbine System Pilot Plant - Part 1,” ASME Turbo EXPO 2008, ASME Paper GT2008-51072 (2008).

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

(6) Documents for Study Group on Low Carbon Power Supply System, Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (2008) in Japanese.

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