Achievement of World's Highest Thermal Efficiency and High Flexibility Joetsu Thermal Power Station Unit No. 1, Tohoku Electric Power Co., Inc.

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The Joetsu Thermal Power Station Unit No. 1 of Tohoku Electric Power Co., Inc., which started operation in December 2022, employs a 1,650°C class JAC gas turbine from Mitsubishi Heavy Industries, Ltd. (MHI) and has achieved the world's highest plant thermal efficiency of 63.62%. Even with regard to the operability, which generally has a trade-off relationship with the thermal efficiency, this plant attained about 25% shorter start-up time and about 3 times higher power output change rate (ramp rate) compared to conventional gas turbine combined cycle plants, and has a minimum output as low as 25% of the rated output. Thus, it is also expected to promote the introduction and expansion of renewable energy sources with large fluctuations. This report describes the features of the plant, which we believe will contribute to the development of the electric power industry toward further environmental load reduction and carbon neutrality due to its high efficiency and high operability.

1. Introduction

In recent years, as seen from the spread of the SDGs(Note 1), people have become more environmentally conscious, and thermal power plants are expected to reduce the environmental burden by reducing carbon dioxide emissions and to have the ability to adjust the power supply in response to the introduction of renewable energy, which fluctuates widely. MHI delivered the latest JAC-type gas turbine, heat recovery steam boiler, steam turbine, and other major auxiliaries for Joetsu Thermal Power Station Unit No. 1 of Tohoku Electric Power Co., Inc. (Joetsu Unit No. 1), realizing the world’s most thermally efficient gas turbine combined cycle (GTCC) plant. In addition, the plant has both high thermal efficiency and high operability, which generally have a trade-off relationship, and has received high evaluations from external parties, including Tohoku Electric Power Co., Inc.

Note 1: SDGs: Sustainable Development Goals

2. Overview of plant planning

2.1 Plant overview and main features

(1) Main equipment specifications

Table 1 shows the main plant equipment specifications and the schedule outline for the Joetsu Unit No. 1.

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Table 1 Power generation equipment specifications and schedule outline

Plant general	Generator end output	572,000 kW
	Unit configuration	572,000 kW x 1 (new)
Gas turbine	Model	M701JAC
	Turbine inlet temperature	1,650°C
	Pressure ratio	25
Steam turbine	Model	TC2F-40.5 Side exhaust
	Steam conditions	High pressure : 16.4 MPaG x 600°C Reheat : 3.35 MPaG x 600°C Low pressure : 0.41 MPaG x 325°C
Heat recovery steam boiler	Type	Horizontal reheat triple-pressure natural circulation type
	Maximum evaporation	High pressure : 403 t/h Medium pressure : 62 t/h Low pressure : 49 t/h
Generator	Type	Horizontal-shaft cylindrical rotary-field magnetic synchronous generator
	Cooling method	Indirect hydrogen cooling
Schedule	January 2018	Contract signed
	May 2021	Installation of main system
	March 2022	Burning
	March 2022	Connection to grid
	December 2022	Commencement of commercial operation (scheduled for June 2023 at the time the contract was signed)

(2) Main system configuration

The Joetsu Unit No. 1 employed a single-shaft CGS arrangement(Note 3) reheat combined-cycle power generation system in which MHI's latest large-capacity, high-efficiency 1,650°C class gas turbine (M701JAC), generator, and steam turbine (TC2F-40.5) were arranged on the same axis and an SSS clutch(Note 2) was installed between the generator and steam turbine. The CGS layout and the side-exhaust steam turbine instead of the conventional downward exhaust steam turbine minimized the amount of excavation needed and lowered the height of the power plant building, thereby reducing construction costs (**Figure 1**).

Note 2 : SSS clutch: Synchro self-shifting clutch

Note 3 : CGS arrangement: Axial configuration arranged in sequence of gas turbine (combustion turbine), generator, and steam turbine

Figure 1 Appearance of turbine floor

2.2 Plant performance and environmental performance

(1) Plant performance

The M701JAC gas turbine used in the Joetsu Unit No. 1 is based on a J-type gas turbine (turbine inlet temperature: 1,600°C class), which is highly regarded for its high thermal efficiency and has been operated in many countries, and has achieved even higher efficiency by increasing the turbine inlet temperature to the 1,650°C class through the use of a forced air-cooling system and other measures.

As a result, the plant achieved a thermal efficiency of 63.62% (based on the lower heating value), and was certified by Guinness World Records™ as the "Most efficient combined cycle power plant in the world" (January 24, 2023).

(2) Environmental performance

The forced air-cooling system can suppress the generation of nitrogen oxides because there is little introduction of cooling air into the combustion gas and the combustion temperature and turbine inlet temperature can be kept at the same level. **Table 2** shows the environmental performance of the Joetsu Unit No. 1.

In addition, carbon dioxide emissions can be greatly reduced due to the reduction in fuel consumption that accompanies the improved thermal efficiency.

Table 2 Joetsu Unit No. 1 environmental performance

Joetsu Unit No. 1 environmental performance (actual achievement)		
Nitrogen oxide	Emission concentration	3 ppm
	Emission amount	12 m^3N/h
Sulfur oxide	Emission concentration	- (Note 4)
	Emission amount	- (Note 4)
Dust	Concentration	- (Note 4)
	Emission amount	- (Note 4)

Note 4: Below measurable lower limit

2.3 Operability

The JAC-type gas turbine does not require the combustor cooling steam system used in the J-type. Furthermore, the application of gas turbine clearance control and improvements in the shape of the steam turbine rotor have resulted in a higher operability, such as shorter plant start-up time, higher power output change rate (Ramp rate), and lower minimum power output, compared to conventional combined cycle power generation plants. **Table 3** shows the operational performance of the Joetsu Unit No. 1.

Table 3 Joetsu Unit No. 1 operability

	Joetsu Unit No. 1 achievements	Targets for GTCC set by working group of Ministry of Economy, Trade and Industry (Note 5)	Current situation researched by working group of Ministry of Economy, Trade and Industry (Note 5)	Current situation of once-through coal-fired thermal power generation researched by working group of Ministry of Economy, Trade and Industry (Note 5)
Start-up time	41 minutes	30 minutes	60 minutes	4 hours
Power output change rate (Ramp rate)	15%/min	14%/min	1-5%/min	1-3%/min
Minimum power output	25%	25%	About 50%	30%

Note 5: Grid Working Group of Electricity and Gas Basic Policy Subcommittee, Electricity and Gas Business Sectional Meeting, New Energy Subcommittee, Energy Conservation and New Energy Sectional Meeting, #32 Advisory Committee on Natural Resources and Energy

3. Features of main equipment

3.1 Gas turbine

The M701JAC gas turbine is a state-of-the-art gas turbine that incorporates advanced technology into the proven J-type gas turbine to achieve a high turbine inlet gas temperature of 1,650°C in order to increase the plant efficiency.

Specific technologies incorporated therein are introduced below (**Figure 2**).

(1) Forced air-cooled combustor system

The forced air-cooled combustor system, jointly developed by Tohoku Electric Power Co., Inc. and MHI, increases the turbine inlet gas temperature from 1,600 to 1,650°C, compared to conventional steam-cooled combustors, and reduces the overall plant start-up time by eliminating the need for external steam for cooling during start-up.

(2) Thicker-film TBC(Note 6)

By applying ultra-thick-film TBC with even better heat shielding performance than before based on the technology obtained through the national project and joint research with Tohoku Electric Power Co., Inc., the reliability of the combustor and turbine blades is ensured while increasing the gas temperature.

Note 6: TBC: Thermal-Barrier-Coating

(3) Turbine clearance control

In general, due to the difference in thermal expansion between the turbine rotor and stator, the turbine clearance tends to narrow during power plant start-up and power output changes, and widen during rated power operation. By supplying the appropriate amount of forced cooling air, which cools the combustor, to the turbine blade rings located on the periphery of the turbine rotor blades according to the output, the clearance is expanded to increase the power output change rate during start-up and power output change, and is reduced during constant power operation to improve efficiency, thereby ensuring both high efficiency and high operability.

(4) High-pressure ratio compressor

While also taking into account the achievements of the MHI M501H type, the use of a high-pressure ratio compressor with a pressure ratio of 25 suppresses the rise in exhaust gas temperature and reduces the thermal effects on the exhaust heat recovery steam boiler and steam turbine.

In order to confirm the performance and reliability of these technologies, we conducted more than 1,500 large-scale special measurements at the Joetsu Thermal Power Plant and obtained detailed operational data of the aerodynamic stability of the compressor, metal temperature of the combustor/turbine blades, and chip clearance of the compressor/turbine from start-up to rated output over a period of about 4 months. By sharing the problems identified in the obtained data with Tohoku Electric Power Co., Inc. as needed, we were able to improve both performance and operability while ensuring reliability.

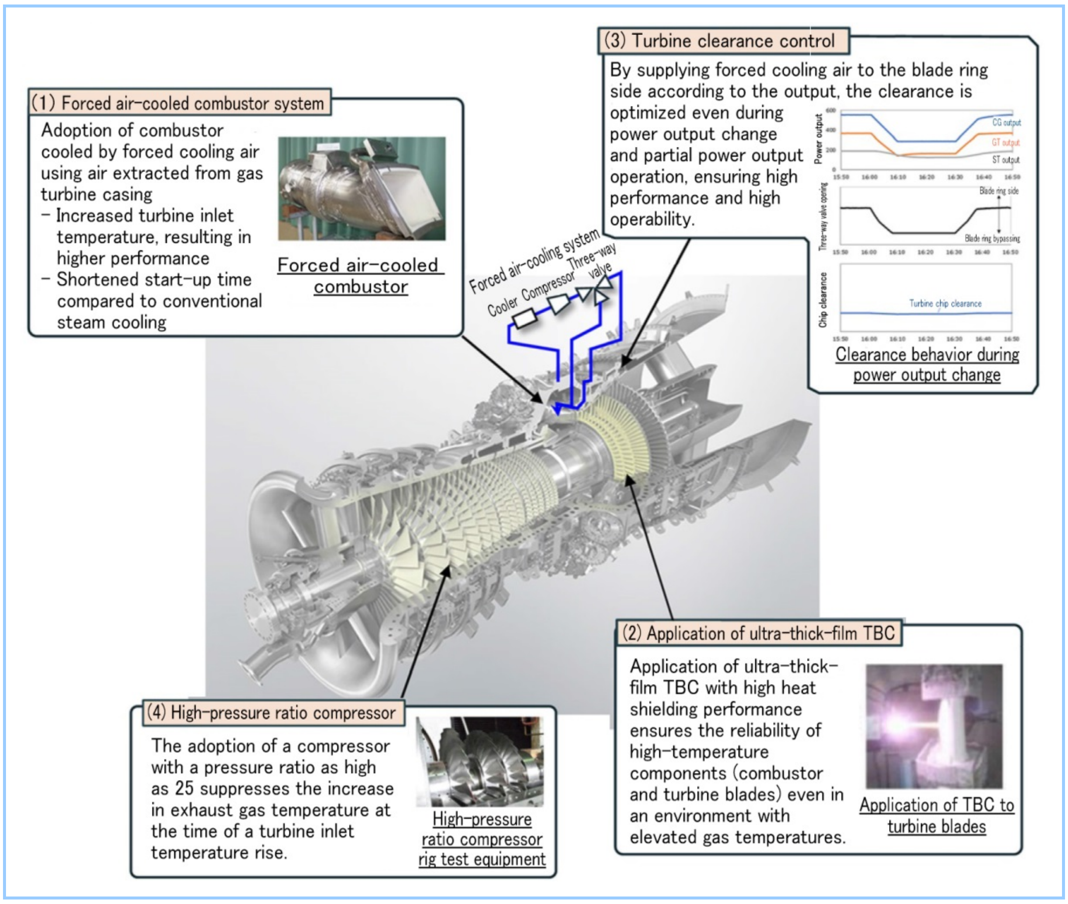

Figure 2 Features of JAC-type gas turbine

3.2 Steam turbine

The steam turbine adopted is a proven two-casing turbine suitable for the flow rate of steam generated by the heat recovery steam boiler and achieved high efficiency by adopting high-efficiency reaction blades designed by the latest three-dimensional flow analysis and a 40.5-inch ISB(Note 7) end-blade group.

Note 7: Integral shroud blade

Furthermore, the building height was reduced by adopting a side-exhaust low-pressure turbine with reduced exhaust loss, which was developed as next-generation equipment, and a compact layout was achieved by adopting a main valve unit that integrates a stop valve and a control valve. Also, the latest MHI technologies, such as a high contact pressure-type bearing that can withstand higher bearing contact pressure than conventional bearings and a new seal structure, were adopted. All these technologies have a high reliability tested and verified at MHI's demonstration test facilities, resulting in further improvement of the efficiency.

Figure 3 is a cross-sectional view of the steam turbine, and **Figure 4** shows the features of the side-exhaust steam turbine.

Figure 3 Cross-sectional view of steam turbine

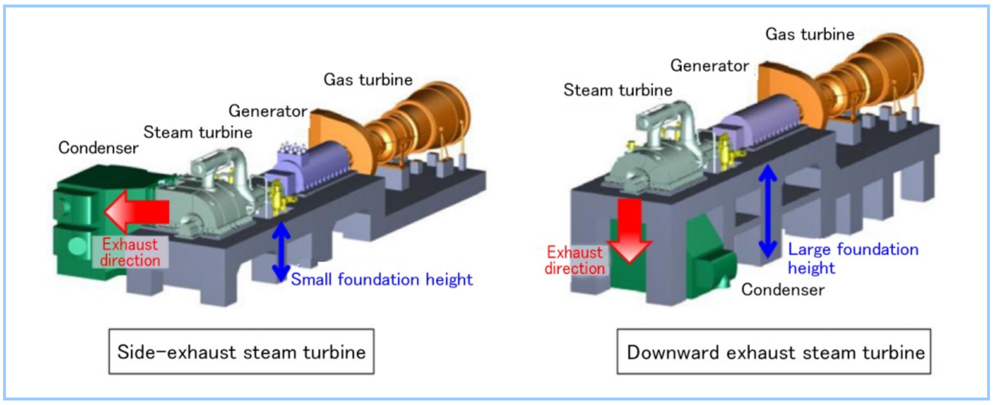

Figure 4 Features of side-exhaust steam turbine

3.3 Heat recovery steam boiler

The heat recovery steam boiler adopted for Joetsu Unit No. 1 is a horizontal reheat triple-pressure natural circulation type. The high-temperature steam conditions of 600°C for high-pressure main steam and 600°C for reheat steam (at the steam turbine inlet) due to the higher exhaust gas temperature resulting from the adoption of a high-temperature gas turbine improves the thermal efficiency. The adoption of a triple-pressure reheat method, which consists of high-pressure, reheat, medium-pressure, and low-pressure systems, allows for an efficient heat-absorbing tube arrangement for the exhaust heat from the gas turbine in consideration of the fluid temperature characteristics (**Figure 5**).

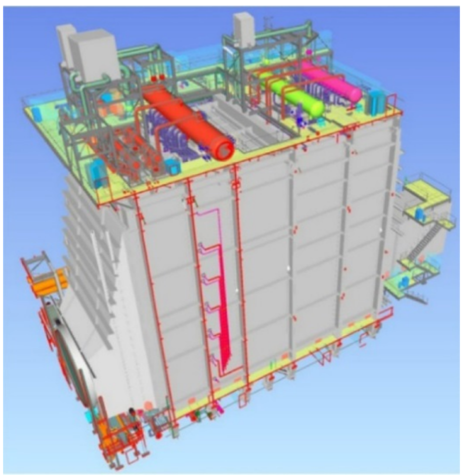

Figure 5 Heat recovery steam boiler

To further improve the thermal efficiency, a TCA cooler(Note 8) and FGH(Note 9) are incorporated into the boiler feed water system to minimize the heat loss due to heat discharge from the plant cycle. Exchanging heat between the gas turbine cooling air and boiler feed water in the TCA cooler contributes to steam generation in the heat recovery steam boiler. In addition, the boiler feed water heated by the heat recovery steam boiler is used to heat the fuel gas in the FGH in order to increase the fuel gas temperature at the inlet of the gas turbine. This contributes to the improvement of the gas turbine thermal efficiency.

As an environmental measure, the denitration device installed inside the heat recovery steam boiler decomposes nitrogen oxides (NOx) contained in the exhaust gas into nitrogen and water through a reduction reaction. This device employs technology MHI has cultivated over the years to reduce nitrogen oxides in the exhaust gas released into the atmosphere, resulting in a high denitration rate.

Note 8: Turbine cooling air cooler

Note 9: Fuel gas heater

4. Conclusion

The Joetsu Thermal Power Station Unit No. 1 of Tohoku Electric Power Co., Inc., which is a gas turbine combined cycle plant with the latest technology, achieved the world's highest thermal efficiency and has demonstrated high economic efficiency and reduction of environmental impact, thereby contributing to the local electric power supply. We believe that with its high operability achieved at the same time, this plant will not only stabilize the power grid, but also contribute to the development of the electric power industry and even industrial development, which are on the way to achieving carbon neutrality, by further reducing environmental impact through the promotion of the introduction and expansion of renewable energy and by reducing operating costs by lowering the supply-demand imbalance.

In recognition of these achievements, Joetsu Unit 1 has received the following awards from external parties.

- Minister of Economy, Trade and Industry Award, Excellent Energy-saving Equipment and System Award, FY 2008 (JAC-type gas turbine)
- Certified by Guinness World Records as the world record for highest power generation efficiency ("Most efficient combined cycle power plant in the world", January 24, 2023) (Joetsu Unit No. 1)
- Special prize of judging committee, 52nd Japan Industrial Technology Awards, 2023 (Joetsu Unit No. 1)