

Renewal Work of Power Plant for High Efficiency GTCC Power Plant with 1,500°C-class Gas Turbine - Sakaiko Power Station of The Kansai Electric Power Co., Inc. -



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Environmental problems such as global warming have captured worldwide attention in recent years. Hence, the reduction of CO₂ emissions is an urgent and important issue, and high-efficiency measures for power plant construction are required. Mitsubishi Heavy Industries (MHI), Ltd., has been contracted to perform renewal work on an existing power plant, the Sakaiko Power Station (The Kansai Electric Power Co., Inc.), for conversion to a gas turbine combined-cycle (GTCC) power plant with state-of-the-art high-temperature large-capacity M501G gas turbines. New GTCC power plants have higher efficiency and lower CO₂ and NO_x emissions, and hence are more environmentally friendly. The first plant was put into commercial operation on April 1st 2009. The second and third plants have now also been completed. They are undergoing pre-operation tests and preparation until October 2010, when the remaining fourth and fifth plants are due to be completed.

1. Introduction

The Sakaiko Power Station (output: 2,000 MW) was put into operation in 1964. It has been the main power supply station in the central Kansai area ever since. However, due to aging of the plant, a plan to replace it with a state-of-art natural gas-fired high-efficiency combined-cycle power plant with a power output of 2,000 MW has been made. This will make more efficient use of natural resources and improve the environmental performance. The renewal plan adopted large-capacity high-efficiency M501G gas turbines, which were developed using technologies with good performance records, and heat recovery steam generators and steam turbines designed for high temperature and pressure conditions in the steam cycle.

Steps from the initial ignition of the first plant (December 2008) to the pre-operation of the third plant (October 2009) were smoothly completed, and the remaining fourth and fifth plants are undergoing pre-operation tests and preparation of installation. The plant efficiency has reached approximately 58% based on the low heating value (LHV), the highest value on record.

The conversion of existing water-intake and -discharge facilities, and the extra-high voltage switch gear station, in particular, were planned with the utmost regard for environmental impact. This paper gives a brief description of the combined plant.

2. Renewal Plan

2.1 Outline of the plant renewal

The Sakaiko Power Station, after renewal, will be an unfired heat recovery combined-cycle plant equipped with a large-capacity high-efficiency M501G gas turbine, operating at a combustor outlet temperature of 1,500 °C.

In the plant, one gas turbine, one steam turbine, and one generator were constructed with a single shaft, and five sets of single-shaft combined-cycle plants with 400 MW shaft horsepower were installed, giving a total output of 2,000 MW. The shaft configuration of the plant is shown in **Figure 1**.

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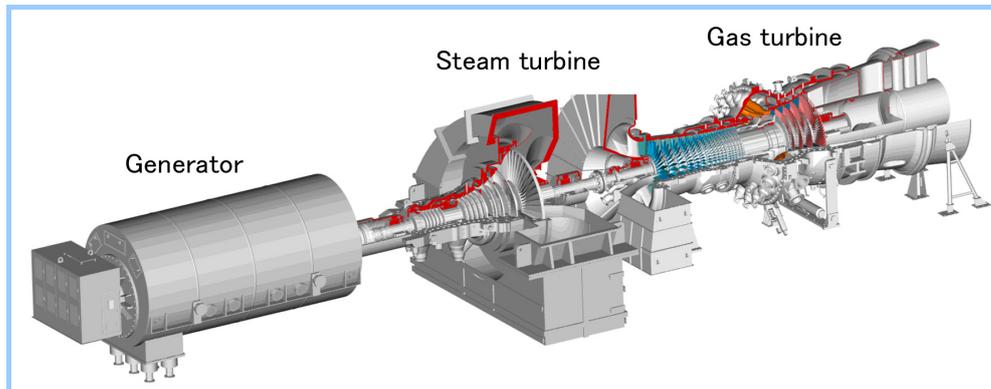


Figure 1 Shaft configuration of the plant

2.2 Key features

(1) High efficiency

The new plant uses 1,500°C-class M501G gas turbines, as well as three pressure reheating systems in the steam cycle. To achieve higher efficiency, a turbine cooling air (TCA) cooler and a fuel gas heater (FGH) were used to recover the exhaust heat of the gas turbine cooling air for the supply water and to increase the fuel temperature, respectively. This minimized the loss of heat from the plant cycle.

The actual heat efficiency of the plant was approximately 58% according to the LHV, surpassing that of state-of-the-art conventional plants by more than 20% (relative value).

(2) Environmental conservation

To curb the increase of NO_x emissions caused by raising the combustor outlet gas temperature to 1,500°C, a low NO_x combustor that cooled its combustor wall with steam was adopted, in addition to the conventional premixed system. Furthermore, the environmental regulatory criteria were satisfied by incorporating dry NO_x removal equipment into the heat recovery steam generator.

Because of the efficiency increases, the CO₂ emissions were also reduced by approximately 30%.

	Existing power plant	After renewal
Plant capacity	2,000 MW	2,000 MW
Gross thermal efficiency (LHV basis)	Approx. 41%	Approx. 58%
CO ₂ emissions	0.51 CO ₂ -kg/kWh	0.36 CO ₂ -kg/kWh

(3) Superior operational characteristics

Because the combined plant has excellent starting characteristics compared to a conventional plant, daily start-up and shut-down (DSS) and/or weekly start-up or shut-down (WSS) operation was used. Although the combined plant has the world's largest power capacity per single shaft (400 MW), its starting time is equivalent to that of a conventional F gas turbine combined plant.

The load change of a conventional gas turbine is restricted based on comparisons with the rate of load change in the mid-load zone, to prevent the temperature exceeding that rated for combustion. This plant uses a control system to hold down the overshoot of combustion temperature by opening the gas turbine inlet guide vanes in advance, improving the follow-up of the load change.

(4) Environmental considerations by converting existing facilities

This renewal work was carried out based on our client's plan, in which extremely old power plants are to be replaced by state-of-the-art ones, without changes in capacity, to reduce the environmental load and decrease the cost of the power. By building a state-of-the-art power station while making maximum use of existing facilities (namely the water-intake and -discharge facilities, and extra-high voltage switch gear station), the ecological impact of the plant renewal project was minimized.

The scope of major facilities converted from existing facilities is shown in **Figure 2** (red portion).

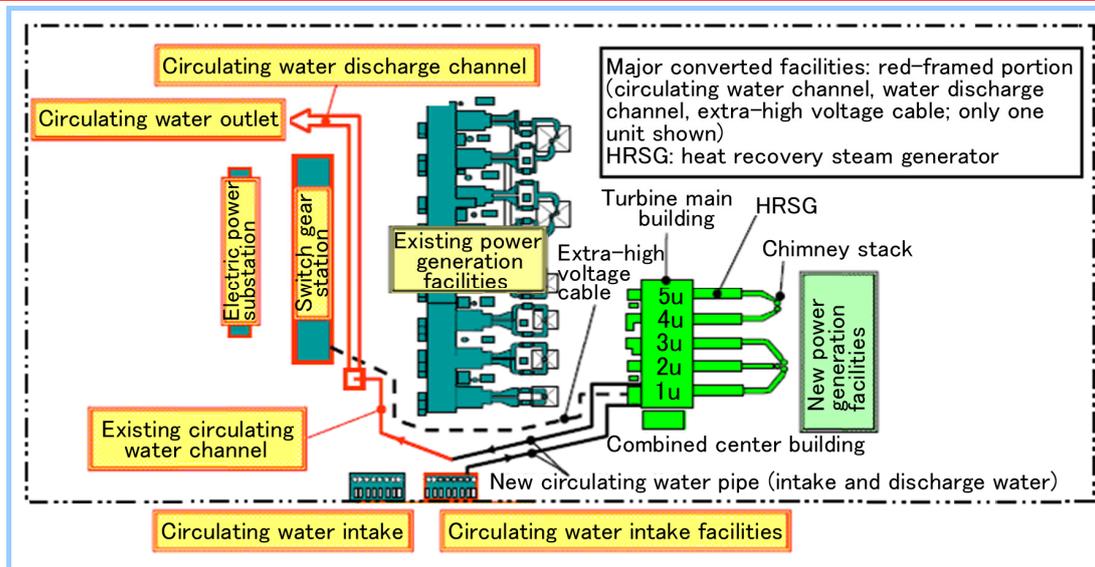


Figure 2 Schematic diagram of major existing facilities that were converted

2.3 Equipment specifications

The equipment specifications accounted for the output characteristics of the combined plant and its operational controllability. The essential parameters are compared with those of the existing plant in [Table 1](#).

Table 1 Comparison of essential specifications

	Equipment after renewal	Existing equipment
Plant system	Single-shaft gas turbine combined cycle	Conventional
Fuel	LNG vaporized gas	
Output of power station	2,000 MW	
Unit configuration	400 MW × 5 units	250 MW × 8 units
Gas turbine	Single-shaft open cycle	-
Steam turbine	Single-casing reheat mixed gas condenser (SRT-45)	Comb-shaped four-branch three-casing reheat condenser
Boiler	Vertical gas flow reheat natural circulation heat recovery steam generator	Single shell combustion boiler
Steam condenser cooling system	Seawater	
Steam condition		
Main steam / high-temperature reheat	12.2 MPa × 566°C / 566°C	17.2 MPa × 566°C / 538°C
Low pressure	0.4 MPa × 264°C	-
Condenser vacuum	-96.3 kPa	-96.3 kPa

3. Characteristics of the Major Equipment

3.1 Gas turbine

The M501G gas turbine, which was verified by long-term operation at the demonstration generator installed in our Takasago Machinery Works, has high performance and reliability. Forty-one units of this turbine have already been delivered worldwide.

The turbine uses steam-cooling technology in the combustor. Because the cooling steam is introduced into the steam passage of the turbine blade ring, clearance control of the turbine is possible. This steam warms the turbine blade ring side to widen the clearance during start-up. It cools the turbine blade ring side to optimize the clearance during load operation, which improves the turbine performance. The aerodynamic and cooling performance of the turbine primary blade and vane was also improved, increasing the overall turbine efficiency.

To further minimize the environmental impact, the NO_x combustor vibration characteristics were improved. In actual operation, it was confirmed that the combustor vibration characteristics were excellent, and that the NO_x levels were sufficiently low.

The gas turbine is shown in [Figure 3](#).

3.2 Steam turbine

This plant achieves performance improvements as a total combined plant by using a high steam temperature (566°C). This matches the high-pressure main and reheat steam conditions

corresponding to M501G exhaust gases. For the final-stage blade, a 45-inch titanium blade and single-casing turbine integrated with high and middle pressure portions were adopted, reducing the shaft length. Furthermore, a welded rotor was adopted to reduce the temperature difference between the high-middle- and low-pressure portions. For the high-middle pressure turbine, a fully three-dimensional-designed reaction blade was used.

Other improvements, such as a hollow vane to reduce the wet steam of the low-pressure turbine exhaust, were adopted by introducing state-of-the-art technologies, which improved the efficiency and reliability. The steam turbine is shown in **Figure 4**.

3.3 Heat recovery steam generator

The exhaust gas system chosen was a three-pressure reheat natural circulation boiler and high-temperature gas turbine. Due to the rise in exhaust gas temperature, a high temperature of 566°C (at the steam turbine inlet) was selected for both the high-pressure main and reheat steam. In addition, because a high-efficiency system using feedwater and an optimum heat exchanger tube arrangement was adopted, the cooling steam necessary for the gas turbine combustor was taken from the medium-pressure generated steam. The heat recovery steam generator is shown in **Figure 5**.

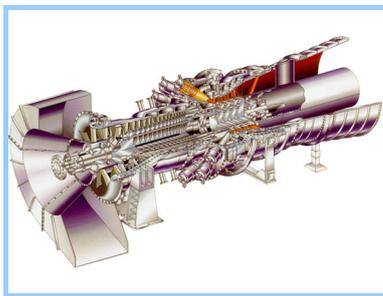


Figure 3 Sectional view of the gas turbine

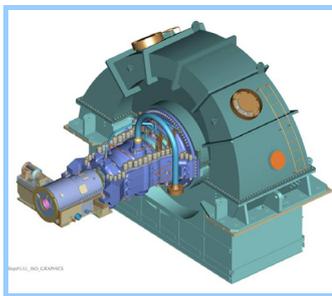


Figure 4 Sectional view of the steam turbine

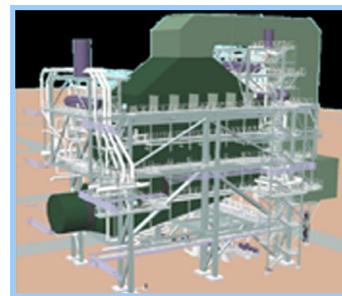


Figure 5 Integral module of the heat recovery steam generator

4. Pre-operation Results

The plant performance and environmental and operational characteristics were confirmed throughout the pre-operation to satisfy the planned constraints.

4.1 Plant performance

The rated output of 400 MW was achieved for atmospheric temperatures of even more than 4°C.

4.2 Environmental characteristics

The NO_x control technology, which used a steam-cooling low-NO_x combustor and dry NO_x removal equipment, resulted in stable low concentrations of NO_x. NO_x concentrations from the stack were below the regulatory criterion of 4 ppm (NO_x corrected at 16% O₂).

4.3 Operational characteristics

Many tests of the operational characteristics, including various kinds of starts and stops, and load dispatching operation tests, were successfully conducted during the pre-operation period.

5. Conclusion

The renewal work at the Sakaiko Power Station of the Kansai Electric Power Co., Inc., was carried out to remodel the existing power plant into a combined plant incorporating state-of-the-art technologies. The desired results have been demonstrated. While all of the extensive improvements in the plant performance and environmental adaptation by technological innovation are worth mentioning, the technological development of the gas turbine is particularly striking. The development of a plant system that includes a steam cycle has also been progressing according to current needs. The valuable benefits obtained from this plant will be useful for the next generation of plants with larger capacities and higher efficiencies. We believe the state-of-the-art combined plant that was delivered to the Sakaiko Power Station can contribute towards securing reliable stabilized electric power for the local area in an environmentally friendly manner.