Anshan Iron & Steel Group Corporation, China, Construction and Operation Experience of 300 MW Blast Furnace Gas Firing Combined Cycle Power Plant

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In recent years in China, a chronic shortage of electric power and national necessity has required steel mills to secure electric power by themselves. The need for high efficiency power generation plants has been growing as well as concerns for environmental preservation. Meanwhile, having successfully developed the most advanced, high efficiency blast furnace gas firing M701S (F) gas turbine, Mitsubishi Heavy Industries, Ltd. (MHI) conducted a feasibility study of a gas turbine combined cycle plant together with China's Anshan Iron & Steel Group Corporation. As both parties confirmed its effectiveness as a result of the study, we signed an official contract in May 2004 to introduce the world's largest blast furnace gas firing combined cycle power plant (BFG Firing CCPP), the first in China. Ever since the power plant was taken over on May 10, 2007 it has continued successful commercial operation.

1. Introduction

A blast furnace gas firing gas turbine uses low calorie off gas generated in steel mills. MHI is the world's leading company in terms of technology for utilizing blast furnace gas and has received many orders and established a successful operating record. Although this is the first order for a full-scale, BFG firing CCPP in China, the design, procurement and construction proceeded successfully and the plant was officially taken over on May 10, 2007. Plant thermal efficiency reached 51% (LHV base) which is the world's highest level for a BFG firing CCPP, and it has been confirmed that this power plant contributes to environmental preservation and energy conservation. This paper introduces the construction and operation experience of this plant.

2. Features and outline of the project

2.1 Features of the project

The project has the following features.

(1) It is the world's largest class for a BFG firing CCPP and was the first order in China.

(2) The first design cooperation for power generation plant with the design and research institute of an iron & steel company in China.

(3) The first installation of a power generation plant in an extremely cold area (the minimum monthly average temperature is less than −15°C).

(4) Collaborative plant adopted Chinese-made products as related equipment for the bottoming cycle.

2.2 Scope of supply

MHI had the responsibility for the design and manufacture of the power train equipment consisting mainly of the gas turbine, generator, steam turbine and fuel-gas compressor, and FOB (free on board) delivery of the equipment supplied by MHI, and dispatching technical advisors for installation and supervisors for commissioning.

On the other hand, the customer had the responsibility for the design, manufacture and procurement of relevant equipment for the bottoming cycle including the surface condenser and heat recovery steam generator (HRSG), water supply and drainage system, utilities other than the power train, and took charge of all site work including civil, construction, and commissioning. **Figure 1** shows the scope of supply of this plant.

As for the customer supplied equipment, five design liaison meetings were held periodically and separate technical coordinations when necessary, these collaborations helped the power plant to be completed successfully.

2.3 Overall plan of power plant

As for the overall design, including the general arrangement, to ensure plant reliability and site work quality, previous designs were used as much as possible. However, the following design changes were inevitable.

(1) Since the project was constructed in an extremely cold area, all the plant auxiliaries such as pumps needed to be installed indoors and equipped with a complete heating system. The water piping, which had to be installed outdoors, was laid underground below the freezing depth.

(2) In a previous project, almost all the plant auxiliaries did not include any standbys. However, the plant auxiliaries for this project were all provided with standbys due to Chinese made pumps and other relevant equipment for the bottoming cycle being adopted.

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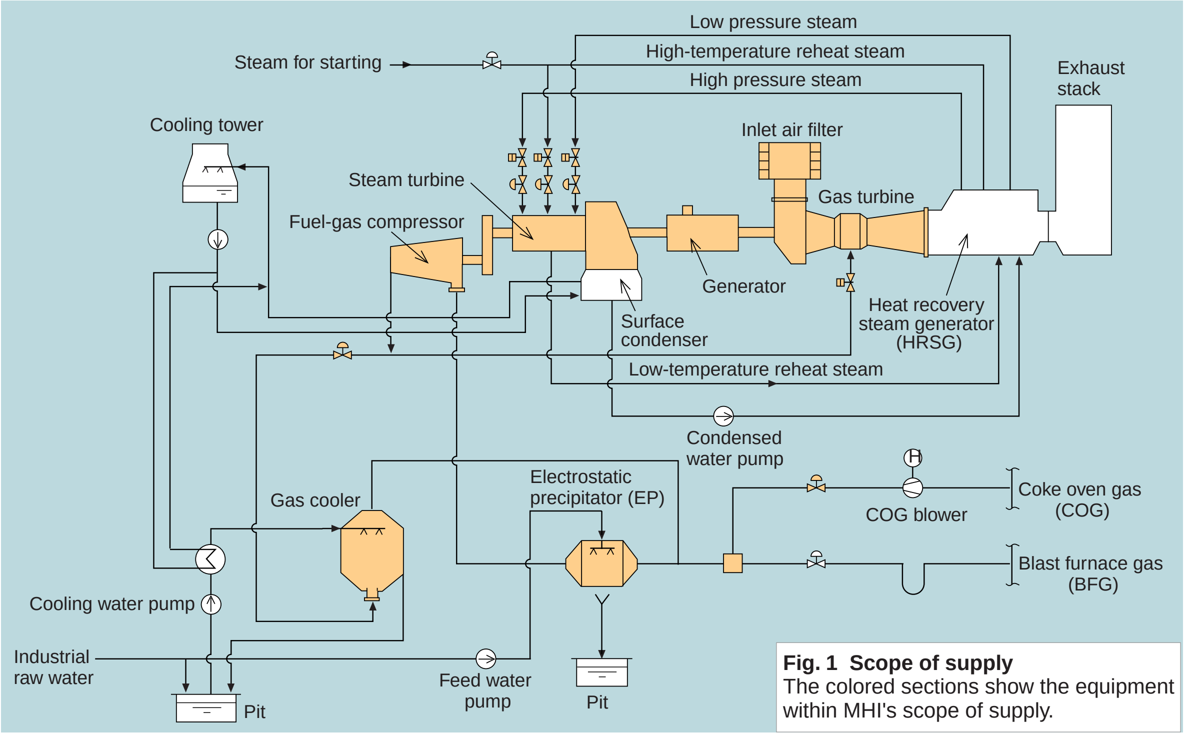

Fig. 1 Scope of supply
The colored sections show the equipment within MHI's scope of supply.

In principle, the basic arrangement inside the turbine generator building and the large piping route arrangement of the blast furnace gas installed outdoors, which greatly affected the overall design, basically adopted the design concept of the previous project. These correspondences caused little reworking at the site, helping the installation work to be completed more or less as scheduled. Providing the pumps and other equipment with standbys improved the total plant reliability.

3. Features and outline of the plant

3.1 Features of the plant

The features of the plant are as follows.

(1) Adoption of combined cycle power plant equipped with the most advanced, high efficiency blast furnace gas firing gas turbine model M701S (F).

(2) Adoption of a gas turbine inlet air heater, considering the start up and load operation during extremely low atmospheric temperatures.

(3) Realization of total integrated plant control including customer supplied equipment such as HRSG.

(4) Adoption of monitoring and control graphic screens written in Chinese for the plant control system.

3.2 Plant configuration

This plant is a single-shaft type combined cycle power plant which consists of a gas turbine, generator and steam turbine, and a fuel gas compressor through a step-up gear device located on the same axis. A steam turbine starting system was adopted to drive the single-shaft by the existing steam. **Figures 2** and **3** show the turbine floor layout and a longitudinal sectional drawing of the total assembly.

Fig. 2 Turbine floor layout
Viewed from front to rear, the gas turbine, generator, steam turbine and fuel-gas compressor are coupled with a single shaft.

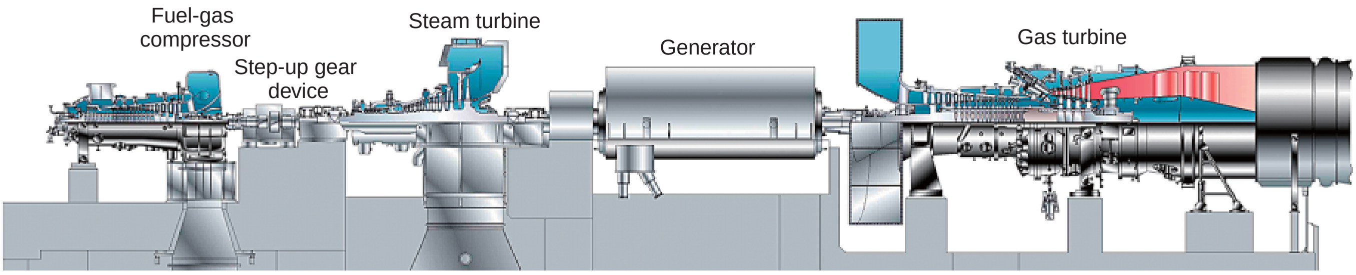

Fig. 3 Longitudinal sectional drawing of complete assembly

3.3 Main specifications of major equipment

Table 1 shows the main specifications of the major equipment including the customer supplied HRSG. See **Fig. 4** for the plant output characteristics which show that the power plant is able to generate a maximum output of 300 MW at an ambient temperature of 15°C or below.

3.4 Measures against low ambient temperatures

A gas turbine consumes a great deal of air as the driving source. While a lower ambient temperature helps increase the power output, too low a temperature causes the following problems.

(1) Decreasing the compressor surge margin due to increasing thrust force and pressure ratio limits the maximum power output.

(2) Combustion pressure fluctuations create an unstable combustion zone during start-up and acceleration.

To cope with these problems, an inlet air heater was installed to heat up the gas turbine inlet air in cold weather.

As the steam source for heating, auxiliary steam is used during start-up and acceleration while low pressure steam is extracted from the HRSG during load operations. The used steam is reclaimed by the surface condenser as a condensate to reduce the amount of waste water as an environmental measure.

Figure 5 is schematic of the inlet air heating system.

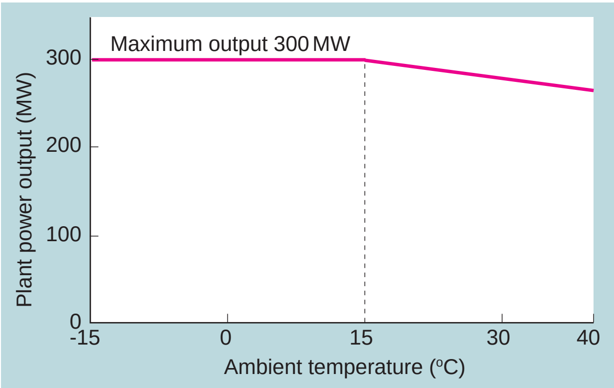

Fig. 4 Plant output characteristics

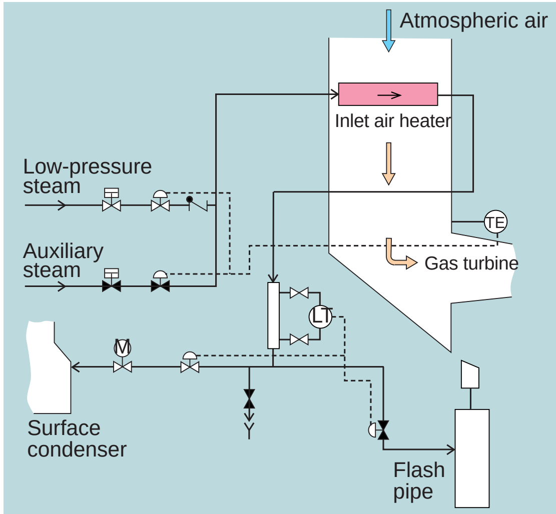

Fig. 5 Outline schematic of inlet air heating system

Table 1 Main specifications of major equipment

Major equipment	Particular	Specifications
Power generation facility	Model Output	Single-shaft type combined cycle power plant 300 MW
Gas turbine	Model Output Turbine inlet gas temperature Rotational speed	Open cycle single-shaft type M701S(F) (MHI) 183.0 MW 1 300°C class 3 000 rpm
Heat recovery steam generator (HRSG)	Model Steam flow rate	Triple-pressure natural-circulation reheat boiler (China Hangzhou Boiler) 568.4 tons/hr Details: High pressure 239.9 tons/hr Medium pressure 282.2 tons/hr Low pressure 46.3 tons/hr
Steam turbine	Model Output Steam pressure/temperature Rotational speed	Single-casing reheat mixed-pressure condensing type SRT-30.5" (MHI) 117.0 MW High pressure 10.2MPa (a)/538°C Medium pressure 2.95 MPa (a)/538°C Low pressure 0.49 MPa (a)/245°C 3 000 rpm
Generator	Model Capacity Cooling system Rotational speed	Horizontal-shaft tubular rotary field type (Mitsubishi Electric Corporation) 340 000 kVA Hydrogen gas cooled 3 000 rpm
Fuel-gas compressor	Model Rotational speed	Single-casing axial flow type (MHI) 5 025 rpm

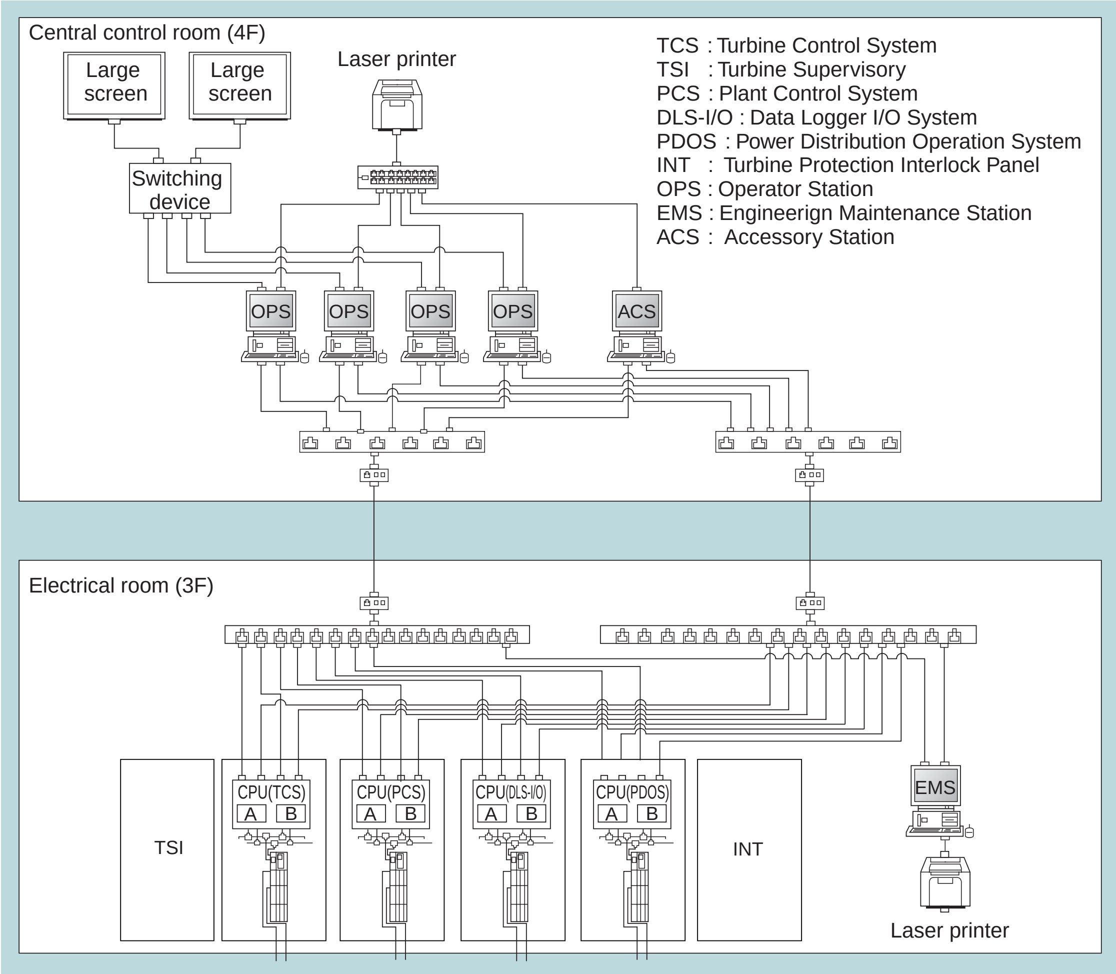

Fig. 6 Control system configuration

3.5 Automatic control system

Figure 6 shows the control system configuration. MHI supplied the total plant control system which has the functions of the automatic control, operation and monitoring of all the equipment directly related to power generation including the customer supplied equipment such as HRSG and boiler feed water pump.

The operating functions have the following features that help reduce the operators' load.

(1) The function of the ALR (automatic load regulator) control system requires the operators only to set the generator output (between 150 and 300 MW) to obtain the required output.

(2) The function of the APS (automatic plant start & stop system) enables all the functional control elements to be operated automatically, from the condenser vacuum up to reaching the ALR load operation while the plant is starting up, and from the ALR load operation to the condenser vacuum break when the plant is shut down.

DYASYS-Netmation which was developed by MHI based on the power generation plant know-how accumulated over many years was adopted as the plant control system of this project.

The important components within the control system, such as the CPU (central processing unit), have built-in redundancy to ensure high reliability.

The monitor and operation screens can display Chinese descriptions in addition to English, realizing a user-friendly operating system for the operators.

Figures 7 and **8** show the layout of the central operation room and sample system schematic screens in both Chinese and English.

Fig. 7 Central control room (4F)
The OPS desk panels are installed at the near side and two large screens are installed at the far end.

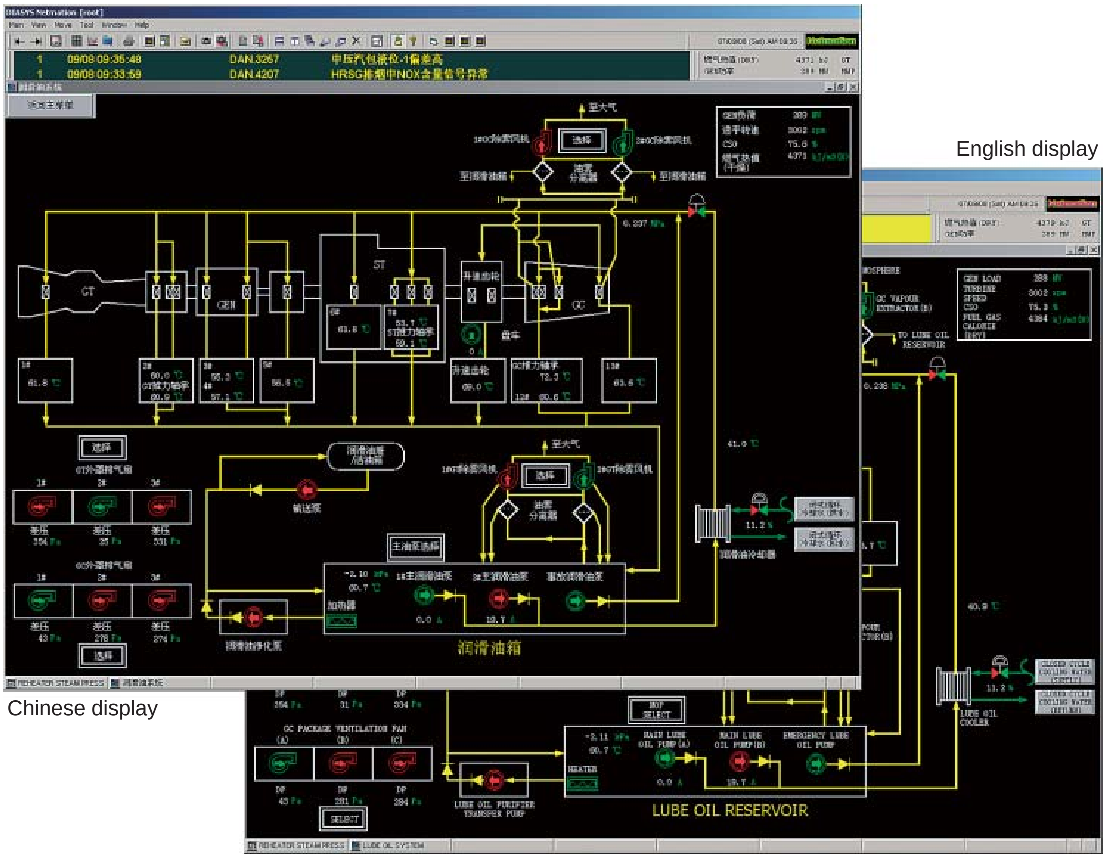

Fig. 8 Sample system schematic screens in both Chinese and English

4. Schedule for construction and commissioning

The project started construction in October 2004. Although experiencing two severe winters during the construction stage, the construction work proceeded satisfactorily and the installation of all the facilities and equipments was completed by the end of April 2006. Then, after testing and tuning each piece of auxiliary equipment separately, full-scale commissioning started in September, with the first synchronization in October. Then, full load operation at 300 MW was completed in November, and the results of almost all the commissioned items proved to be without problems by the end of 2006.

After a period of suspending commissioning due to restrictions in the fuel gas supply, they resumed in April 2007. The 300 MW performance test and 168 hours continuous operation test was completed successfully on April 10, 2007, then the plant was officially taken over on May 10, 2007.

5. Test operation results and operation records

5.1 Test operation results

(1) Startup characteristics

This power plant adopts a steam turbine starting system. After reaching the rated speed, it switches from the existing steam to HRSG steam once the conditions of the HRSG steam become acceptable for the steam turbine. The plant then increases its load automatically up to the minimum operational load of 150 MW. Once reaching 150 MW, the load can be changed between 150 and 300 MW depending on the power demand.

The power plant also shuts down automatically. During load down, the cooling down process is designed to make the mismatch between the steam and the steam turbine metal temperature small so that the time to the next hot start is shortened. The expected time for starting (from ignition up to full-load operation) is approximately 90 minutes for a hot start, 150 minutes for a warm start and 200 minutes for a cold start.

(2) Plant performance

Table 2 shows the actually measured performance. The plant output and plant thermal efficiency after compensation to the standard conditions (ambient temperature at 15ºC and LHV base) sufficiently satisfy the planned values. The plant thermal efficiency reaches 51.2% compared to the planned 48.5%, and achieves the highest level in the world for BFG firing CCPPs.

Table 2 Actually measured performance

Guarantee item	Planned value	Measurement
Plant output	300 MW	313.9 MW
Plant thermal efficiency	48.5 %	51.2 %

(3) Environmental characteristics

By effectively transducing the low calorific blast furnace gas to electric power, this power plant contributes greatly to environmental preservation as follows.

First, this is a combined cycle power plant that effectively utilizes the blast furnace gas instead of the coal fired thermal power plants popular in China. It is estimated that the plant emits approximately 1,900,000 tons less CO_2 a year (assumed operation of 7,000 hours per year) than that emitted by burning coal in a coal fired thermal power plant of the same output.

Second, although the environmental characteristics depend significantly on the composition of the blast furnace gas, as it contains nitride and sulfur compounds, its combustion produces less thermal NOx than burning natural gas because of its low calorific value. Thus, this plant indicates the significantly low NOx value of 15 ppm (15% O_2 base, without a de-NOx system).

5.2 Operation records

Table 3 shows the availability of the plant for about five months from May 2007, when the plant was taken over, to the end of September. While the plant availability depended on the scheduled shut down due to maintenance of the blast furnace shortly after taking over the plant we experienced the degradation of plant availability because of initial failures and other incidents. After that, the plant reliability improved gradually, finally reaching 100% in September 2007.

Table 3 Plant availability

Month and year	Availability (%)
May 2007	82.3
June 2007	93.0
July 2007	91.9
August 2007	95.2
September 2007	100.0

6. Conclusion

As the first full-scale, BFG firing CCPP with the highest capacity and thermal efficiency in China, this project has attracted much Chinese public attention. The favorable transition to commercial operation has realized the effective use of surplus blast furnace gas and self-sustaining electric power while contributing significantly to environmental preservation and energy conservation.

Prompted by the acceptance of this project, many blast furnace gas firing power plants are now under commercial operation and/or construction in various regions of China. As the second stage of the project for Anshan Iron and Steel Group Corporation, the construction of a 150 MW, M701S (DA) combined cycle power plant has also started in Yingkou, Liaoning Province. In line with the China National Energy Saving and Recycling Economic Policy led by the National Development Reform Commission, it is sure that these projects will play an important role in accomplishing stable electric power supply and economic growth in China.


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