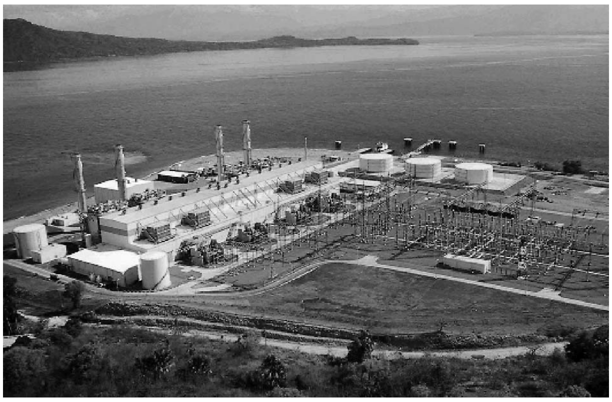

Description of the Latest Combined Cycle Power Plant with G type Gas Turbine Technology in the Philippines

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The Ilijan Plant is an advanced combined cycle power plant, the largest in the Philippines, with a rated capacity of 1,251 MW. The plant uses the latest G type gas turbines of Mitsubishi Heavy Industries, Ltd. (MHI), and the thermal efficiency of the plant is the highest in the world. In addition to the steam-cooled combustor system, unique to G type gas turbines, this plant introduced two more new features for the first time, namely dual firing on G type gas turbines and fuel gas heating system with boiler feed water. This article gives an outline of the Ilijan Plant and also describes the pioneering technology demonstrated and established at this plant.

1. Introduction

For a long time, the Gas Turbine Combined Cycle plants have been occupying a prominent place in the field of power generation because of their superior thermal efficiencies. Even now, the thermal efficiencies of such plants are improving further with the increase in operating temperatures, improvements in gas turbine performance and the advances in material sciences.

In response to the undeniable social need for improving the thermal efficiency of thermal power plants, MHI began work in 1993 on the development of G type gas turbines that operate at inlet temperature ranges of 1,500°C, drawing upon its vast experience in high-temperature gas turbine technology. As a result of this developmental effort, the first M501G gas turbine combined cycle power plant for the 60 Hz market began trial runs at the in-house power station for long term reliability verification at Takasago Machinery Works of MHI in February 1997. The plant has been running smoothly ever since, after passing a governmental acceptance inspection in June, the same year.

The Ilijan Plant in the Philippines is the first commercial plant exported by MHI that adopts the G type gas turbines. It can be certainly said that this plant is the world's latest combined cycle power plant to adopt the dual fuel firing system, in which both gas and oil fuels are used. Moreover, in addition to a steam-cooled combustor system that is unique to G type gas turbines, a fuel gas-heating system that utilizes the heat recovery boiler feed water as the heating medium has also been adopted for improving the thermal efficiency of the plant even further.

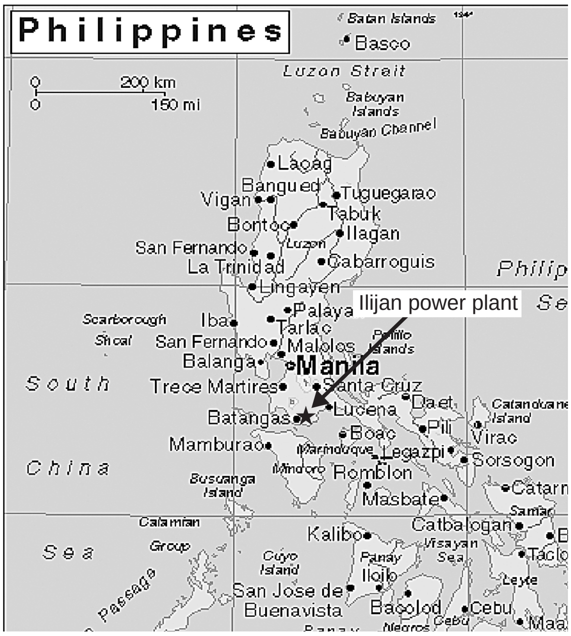

Fig. 1 Location of the Ilijan power plant
The plant is located on the sea coast about 100 km south of Manila city.

2. Overview of the Ilijan Plant

The Ilijan Plant is located at Ilijan Village in the suburbs of the city of Batangas, about 100 km south of Manila, the largest city in the Philippines (**Fig. 1**). The plant is built facing the sea at a location reclaimed from an area of thick jungle, an undeveloped area where no one would have ever imagined that the most sophisticated combined cycle power generation plant of the world would be built.

The Independent Power Producers (IPP), who are the owners of the plant with investment interests from the Korea Electric Power Corporation, Mitsubishi Corpora-

Table 1 Plant Specifications

Type of plant	2 on1 X 2 Block
Fuel	Main fuel: Natural gas Back up fuel: Gas oil
Plant total output (MW)	1 251 (during gas firing) 1 200 (during oil firing)
Gas turbine	M501G gas turbine, DLN
Steam turbine	Tandem compound double flow exhaust type (TC2F-40) Steam condition HP 14.7 MPa/538°C I P 4.4 MPa/566°C LP 0.5 MPa/250°C
Heat recovery boiler	Horizontal triple pressure reheat system (Adoption of fuel gas heating system by boiler feed water)
Generator	Thyristor-excited type
Condenser	Sea water-cooled type

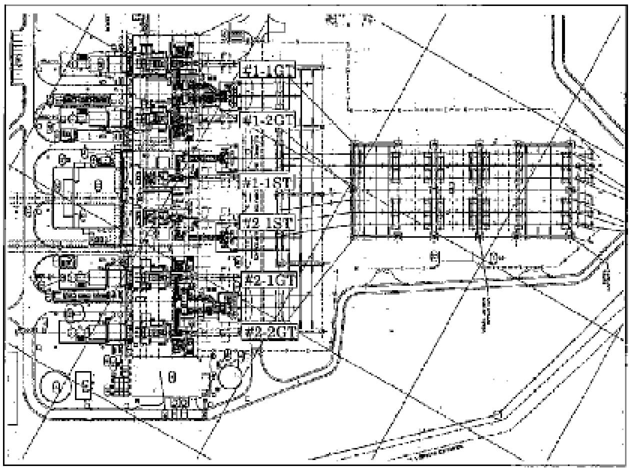

Fig. 2 Schematic layout of the Ilijan plant
The plant consists of two two-on-one units (see text).

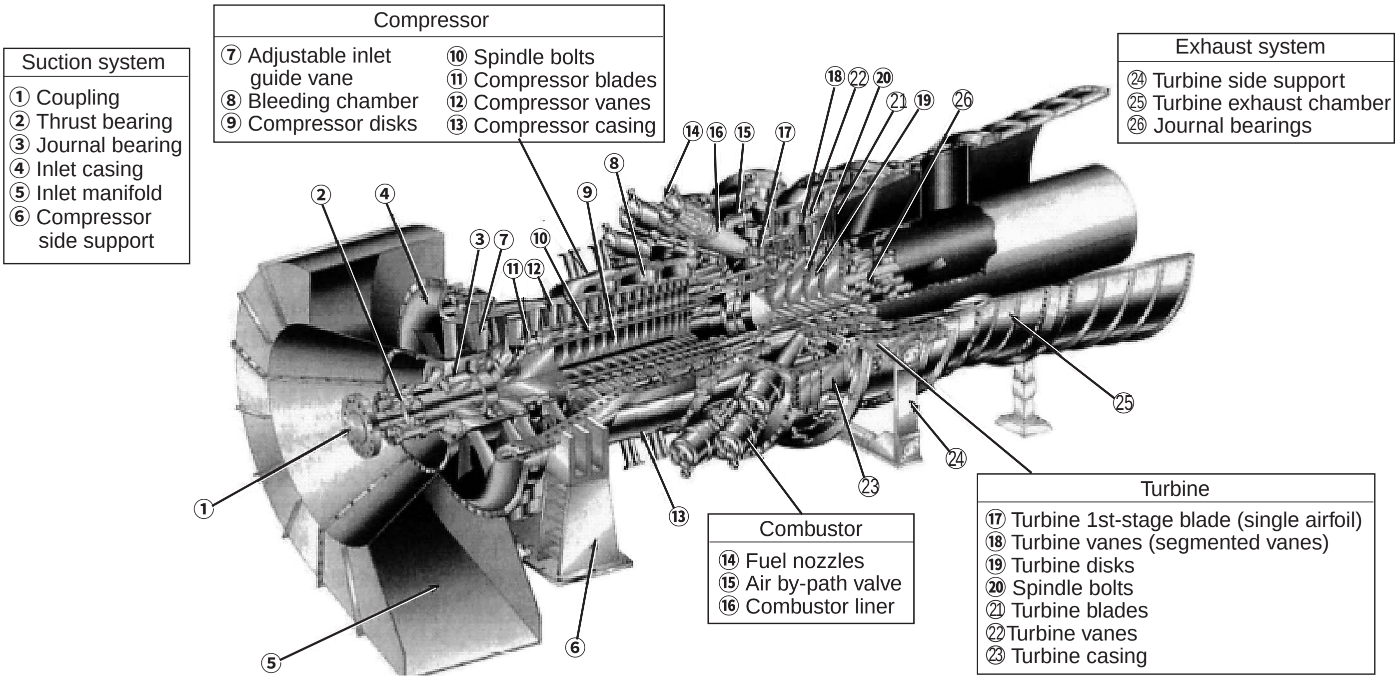

Fig. 3 Cross-sectional diagram of M501G gas turbine
The gas turbine consists of a seventeen stage compressor cascade, four stage turbine cascade, and sixteen combustors.

tion, Mirant Corporation, and Kyushu Electric Power Co., Inc., provide a stable supply of electric power to the city of Manila through 500 kV high-voltage power lines. Since the plant provides about 20% of the total power demand of Luzon in the Philippines, it is essential that the plant not only maintains high levels of efficiency but is also highly reliable.

The specifications of the plant are shown in **Table 1** and the layout of the plant is illustrated in **Fig. 2**. The plant consists of two blocks, each of which is composed of a combination of two gas turbines and one steam turbine, commonly referred to as a 2 on 1 configuration. The total rated output of the plant is 1 251 MW at its transmitting end. The two gas turbines adopted are MHI's M501G type gas turbines, whereas the steam turbine is a tandem compound double flow exhaust type turbine that is designed based on the latest MHI technologies. A horizontal triple pressure reheat system has been adopted for the heat recovery boiler that combines the fuel gas-heating system effectively through the use of boiler feed water. Thyristor starting systems have been applied for the generators for convenient starting and stopping.

A dual fuel firing system has been adopted so that gas oil can also be fired as a back-up fuel, for ensuring the stable supply of electricity even if the supply of the main fuel -natural gas is interrupted.

This plant achieved the assured levels of performance and was delivered in May 2002. A magnificent completion ceremony was held with the President of the Philippines in attendance in November 2002. The plant has been operating smoothly ever since.

3. Outline of M501G gas turbine

Fig. 3 shows a cross-sectional view of a 1 500°C class

M501G gas turbine. The M501G gas turbine was developed retaining the basic design and construction features of the 1 350°C class M501F and M701F gas turbines because of their proven operational records and high reliability, and supplementing it with the latest technologies related to high temperature operation fostered through a range of fundamental research efforts. The compressors adopted consist of 17-stage axial flow type compressors that use Multiple Circle Arc (MCA) blades and Controlled Diffusion Airfoils (CDA) instead of conventional NACA blades. In order to withstand a turbine inlet temperature of 1 500°C, the latest cooling technology (full coverage film cooling and angled turbulator), new heat-resistant alloys, directionally solidified airfoils, and thermal barrier coating (TBC) were adopted for the turbine blades. In addition, a fully three-dimensional design was applied in order to improve the aerodynamic performance of the blades. For the combustors, the multi-nozzle premix dry low NOx (DLN) method was applied because of the track record and experience gained with the F type, while the steam-cooled system was adopted for the first time for cooling the combustors.

4. Steam cooled combustor system

(1) Application of steam-cooled combustor

The application of steam-cooled combustors is one of the main characteristics of the M501G type gas turbine (**Fig. 4**). Since the combustion temperature reaches as high as 1 500°C, additional combustion air is necessary in order to keep NOx emission levels equivalent to those of conventional gas turbines, which operate at combustion temperatures of around 1 400°C. However, since the total amount of usable air is constant, the amount of air left for cooling the combustors is limited. Accordingly, steam-cooled combustors, as shown in **Fig. 5**, that use steam instead of air as the coolant were engineered, for the first time. Before actually adopting the steam-cooled combustors, the performance and reliability of the system were verified through both atmospheric combustion tests and pressurized combustion tests. In addition, verification tests were carried out on a M701F gas turbine that was tentatively fitted with steam-cooled combustors. The results of the high pressure combustion tests confirmed that NOx emission levels can be reduced to a level comparable to the 25 ppm level of M501F and M701F systems, for the steam cooled combustor.

(2) System for steam cooling of Combustor

Fig. 6 shows the schematic of the system for cooling the combustor using steam. The combustor is cooled by intermediate pressure (IP) steam drawn from the Heat Recovery Steam Generator (HRSG). The IP steam heated through the combustor joins the stream of the reheat steam, after which it is fed to the IP turbine where the effective recovery of output from heat is achieved. The optimum cycle was evolved, balancing the thermal cycle efficiency of the plant and the cooling requirements of the combustor, at the same time taking into consideration the easy operability, reliability, and the overall economic viability of the plant.

Fig. 4 M501G steam-cooled combustor
Steam-cooled piping is shown above the combustor.

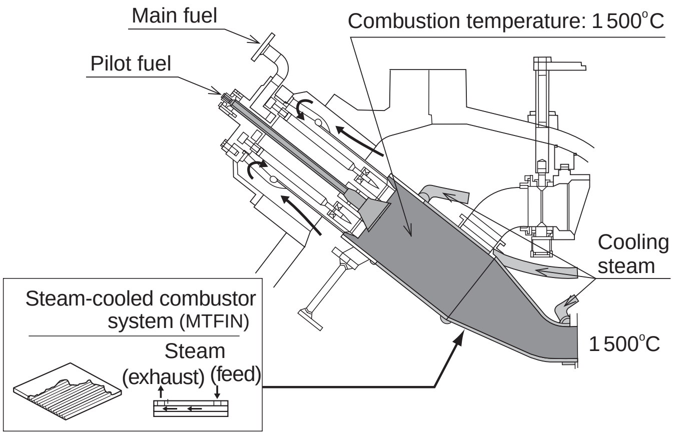

Fig. 5 Structure of steam-cooled combustor
The figure shows a schematic of the DNL combustor combined with a premixing nozzle.

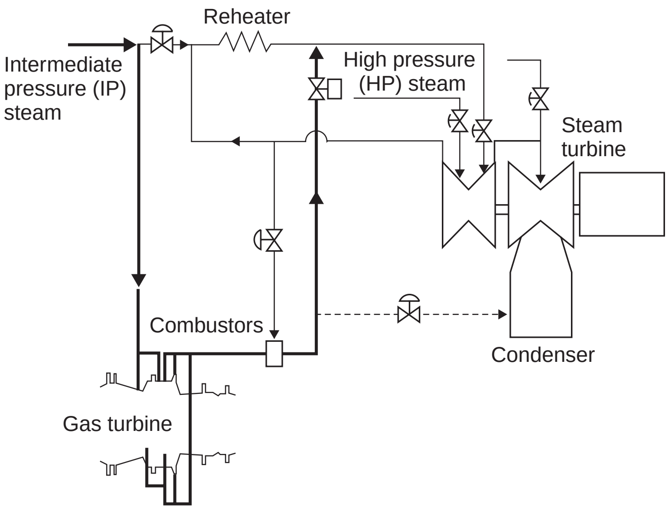

Fig. 6 Steam-cooled combustor system flow diagram
Generated intermediate pressure (IP) steam is used to cool the combustors.

5. Dual fuel firing system

Both gas turbines use gas oil as an auxiliary fuel in addition to natural gas as the main fuel. Hence, they are the first gas turbines in the world in which gas oil is applied at the high inlet temperatures of the G type gas turbines. In other words, this G type gas turbine has achieved the world's highest turbine inlet temperature, as a liquid fuel firing gas turbine.

The fuel supply system used to transfer natural gas and gas oil to the gas turbine combustion nozzles is based on design concepts that were drawn from the actual operating experiences with F type gas turbines. Consequently, the operating procedures followed from ignition to the rated loads for each type of fuel as well as the control procedure for switching fuels come from the procedures developed from actual practical experience.

In oil firing, the water injection method, whose effectiveness has also been demonstrated with F type gas turbines, was applied in order to reduce NOx emissions. As a result, the requirements of the local regulatory authorities of the Philippines Government (DENR: Department of Environment and Natural Resources), World Bank Guidelines, and US Exim Guidelines for both gas firing and oil firing were fully satisfied.

The fuel nozzles for the G type combustors are about 1.5 times longer than those used in F type combustors. Each combustor consists of a pilot nozzle that provides diffusion combustion for holding the flame and main nozzles that provide premixed combustion. Fuel oil flows in the core path while gas fuel flows in the peripheral path of each of the pilot and main nozzles. When oil firing is performed alone, the compressor discharge air is supplied to the peripheral path in order to prevent the backflow of hot gases from the combustor, since the fuel gas does not flow in the peripheral path at the time. As a result, a temperature difference is produced in the nozzle between the fuel oil (which has a temperature of about 20°C) in the core and the peripheral compressed air (which has a temperature of about 470°C), so that it is necessary to address the thermal stresses that result from the large difference in temperature. This problem in the nozzle design was overcome by making the core path into a double tube. The air in the annular path of the double tube acts as an insulating layer to reduce the heat transfer coefficient, so that fuel oil in the core path is kept from carbonizing due to the high temperature. In order to cope with the increase in radiant heat due to the red flames generated from oil firing, the steam cooled combustors require an amount of cooling steam that is about 1.3 times that used in gas firing. The system is designed so that a stable operation is maintained even under these conditions.

6. Fuel gas-heating system based on heat recovery boiler feed water

(1) Conventional fuel gas-heating systems

Turbine Cooling Air (TCA) System is a standard feature of MHI's gas Turbines. The turbine cooling air system provides the direct cooling of components exposed to hot gas path temperatures. Cooling air is provided at various critical points to ensure that the design environment is maintained throughout the turbine. In conventional systems, the compressor discharge air passes through an air-to-air cooler (called TCA cooler) for turbine cooling. In those conventional systems, a fuel gas-heating radiator is installed on the same radiator cooler unit for cooling the compressor discharge air. As a result, both cooling of rotor-cooling air and heating of fuel gas are performed at the same time by air fed from the bottom of the radiator cooler. In this method, the heat recovery is not so effective due to the inherent limitations of "air to air" and "air to gas" heat transfer mechanisms.

(2) Fuel gas-heating system based on heat recovery boiler feed water

In Ilijan plant, the conventional TCA plus Fuel gas heating system was replaced with a more effective system. **Fig. 7** shows the fuel gas-heating system newly adopted for the Ilijan plant, while a comparison of

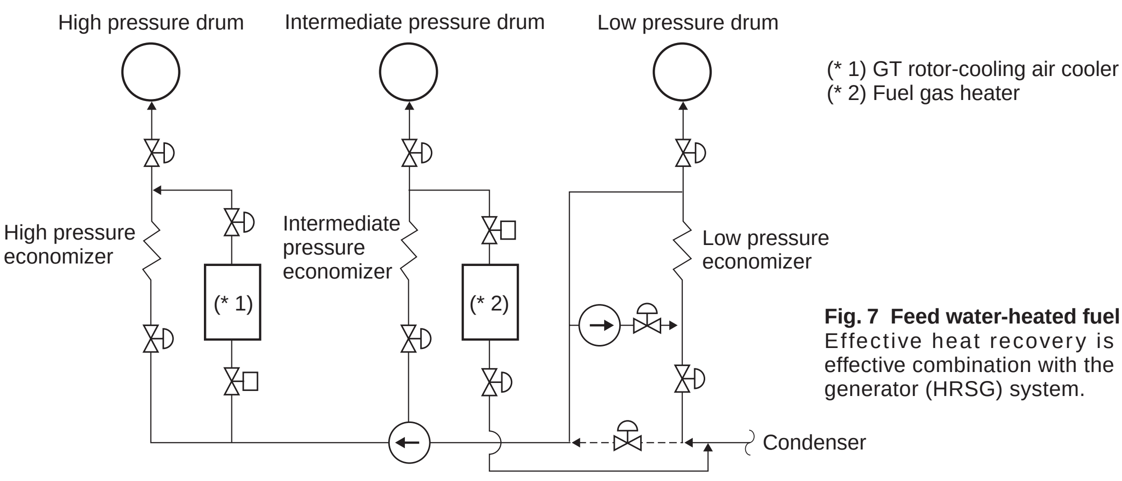

Fig. 7 Feed water-heated fuel gas-heating system
Effective heat recovery is achieved through effective combination with the heat recovery steam generator (HRSG) system.

Table 2 Comparison of Fuel Gas Heating Systems

	Radiator type (Conventional type)	Boiler feed water-heated system
Fuel gas-heating source	Hot exhaust of GT rotor cooling air	Boiler feed water taken from outlet of intermediate pressure economizer
GT rotor-cooling medium	Air	Boiler feed water taken from inlet of high pressure economizer
Characteristics	The effective heat recovery is not sufficient because heated air is emitted into the atmosphere.	Plant efficiency is increased by 0.6 % compared with conventional systems. The plant is also environmentally friendly because it is free from any discharges of hot air, noise, and vibration.

this system with a conventional system is summarized in **Table 2**. In the newly adopted system, fuel gas is heated by the IP feed water discharged from the IP economizer of the heat recovery boiler, and the cooled IP feed water is recirculated to the inlet of the LP economizer. In addition, the HP feed water drawn from HP economizer inlet is used as the cooling medium for cooling the gas turbine rotor-cooling air, while the heated HP water flows to the outlet of the HP economizer and is fed to the HP boiler drum, thereby achieving effective heat recovery. As a result of adopting this new system, plant efficiency increased by about 0.6% (in relative terms), in comparison with a conventional plant.

Furthermore, the ability to utilize the heat recovered from the rotor-cooling air in the feed water system, which has no relation to the fuel gas system makes it possible to beneficially recover heat from the rotor-cooling air, even during oil firing. Accordingly, the performance during oil firing is also improved.

The heat exchangers used in this system are designed to prevent water droplets from entering the gas turbines in case of any water leak from the tubes. Further, this system is also provided with an additional protection system that is capable of detecting moisture downstream of the heat exchangers. Besides the performance benefits, the noise and vibration normally encountered in conventional systems are eliminated in this system. From this perspective, this system is also environmentally friendly.

7. Conclusion

In the field of thermal power plants, combined cycle plants are highly regarded because of high plant thermal efficiency and low levels of NOx and CO_2 emissions. Among these plants, the Ilijan plant introduced in this paper has achieved the highest level of performance through adoption of the latest technology, which includes the M501G type gas turbines produced by MHI. In short, the establishment and demonstration of a wide variety of technologies through this plant has proved to be the most notable accomplishment. Based on this experience, MHI aspires to contribute significantly to global social benefits through the realization of power plants that achieve the highest levels of efficiency and lower levels of environmentally adverse emissions, in the days ahead.

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