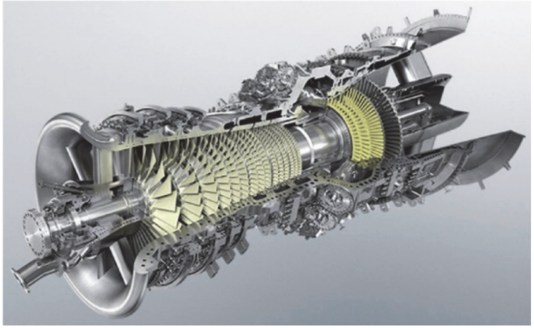
Approach and Experience of Gas Turbine Combined Cycle Power Plant Upgrade to Meet Social Needs



KOHEI HIDAKA*1 HIROFUMI OHARA*2
YASUOKI TOMITA*3 KEITA FUJII*1
MASATOSHI NOSAKU*4 SHOGO MIYOSHI*5

During its 20-30 years of operation, a gas turbine combined cycle (GTCC) power generation facility faces various changes in the business environment such as societal shifts (e.g. environmental regulations and decarbonization) and competition from new power source technologies. Maintaining the facility's competitiveness requires not only proper maintenance, but also continuous adoption of latest technologies to improve performance and operability. Such needs from the customer have increased year by year. As an OEM, Mitsubishi Heavy Industries, Ltd. (MHI) has developed state-of-the-art, advanced technologies for new constructions and implements upgrades which can be flowed down to existing power generation facilities. MHI has recently been developing service programs in response to the diverse and ever-changing needs of the market, by identifying effective menu contents through marketing analysis. As a result, a wide-range of upgrade programs, including those for higher thermal efficiency to achieve better performance (which contributes not only to economic efficiency but also to the realization of a carbon-neutral society), as well as improved start up time and operation flexibility (which allow power generation facilities to adapt to a renewable energy society). Here, cases of actual application are presented.

1. Introduction

Gas Turbine Combined Cycle (hereinafter referred to as GTCC) power generation facilities are required to accommodate a wide range of needs depending on operating environment factors such as regionality and customer characteristics. Specifically, these include: increase in power demand due to a growing economy and recent construction of more data centers, greater flexible operation for grid stability in response to the introduction of renewable energy, compliance with environmental regulations, and to achieve decarbonization.

Moreover, such needs constantly change as the environment changes. In order to handle such demand, marketing analyses to identify the required performance and functions are carried out, and new technologies developed for new construction power generation facilities are passed down to develop an effective upgrade menu.

This report presents how upgrade programs are developed by Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) and the achievements.

2. Development of upgrade programs

MHI's product lineup offers a wide range of gas turbines covering small to large units. This report mainly focuses on upgrading large frame gas turbines currently in use for power generation.

Efforts to achieve better performance, reliability and operation flexibility in gas turbines have been carried out by applying the latest technologies. The structure and parts dimensions of MHI gas turbines basically remain the same among products of the same series. Parts such as the turbine and

*1 Engineering Manager, Service Engineering Department, GTCC Business Division, Energy Systems
*2 Manager, Service Sales & Marketing Department, GTCC Business Division, Energy Systems
*3 Senior Manager, Service Engineering Department, GTCC Business Division, Energy Systems
*4 Manager, Service Engineering Department, GTCC Business Division, Energy Systems
*5 Engineering Manager, Service Sales & Marketing Department, GTCC Business Division, Energy Systems

combustor of the latest model can be installed in older models of the same series. In the upgrade program, therefore, old gas turbines in the existing power generation facilities can be retrofitted with the latest technology by installing parts from the most recent model. Having developed an upgrade menu for each series, retrofitting the gas turbines with the latest technologies can be offered to many customers.

The following sections present the actual upgrade applications of each series.

3. Upgrade application examples

In the following sections, upgrade programs developed in line with requests from the customer, and examples of application are introduced.

3.1 M701F-series gas turbines: retrofitting the turbine blades and vanes with a high-performance cooling system to improve the performance

By retrofitting existing gas turbine facilities with new technologies, efficiency can be improved as shown by the proven record of many successful upgrades. A conceptual diagram of performance improvement by upgrading the turbine blades and vanes is shown in **Figure 1**. Since it is necessary to withstand high-temperature combustion gas, gas-turbine hot parts such as the turbine blades and vanes have a complex internal air-cooled structure. As bleed air or discharge air from the compressor is used for cooling, some of the combustion air must be diverted for this purpose. Therefore, in order to achieve higher thermal efficiency of the gas turbine, reducing the amount of cooling air is desirable. Cooling technology and thermal barrier coating incorporated in new models significantly improve cooling performance. If existing models of the same series are retrofitted with such technologies, less cooling air would be required, thus improving gas turbine performance. This is the basic concept of an upgrade. The most effective method is the installation of the latest turbine blades and vanes with a proven record into existing units.

As hot parts, turbine blades and vanes require periodic maintenance, and are regularly replaced according to the total operating time. Installing the latest turbine blades and vanes as an upgrade can be timed to coincide with this regular replacement. The resulting reduction in investment costs further supports this as the most effective method for performance improvement.

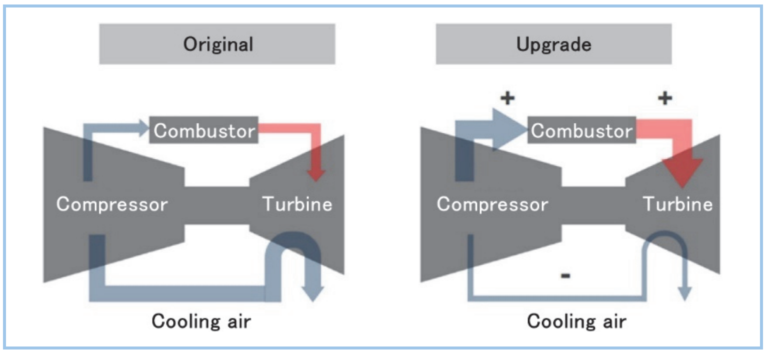


Figure 1 Conceptual diagram of an upgrade to reduce turbine blade cooling air leading to improved performance

As an example of this turbine upgrade application, a power plant in Singapore can be considered. Starting from 2001, MHI delivered a total of four M701F-series gas turbines to the power plant. Output of each combined cycle system is 360,000 kW. The highlighted parts in **Figure 2** were replaced by parts of the latest F-series model, improving thermal efficiency at both full load and partial load. As a result, the fuel costs and CO_2 emissions have been reduced without compromising energy supply from the power plant over a wide range of operating loads. Of the four gas turbine units, two were upgraded. These two combined-cycle systems can together reduce CO_2 emissions by about 16,900 tonnes per year. The remaining two units will also be successively upgraded.

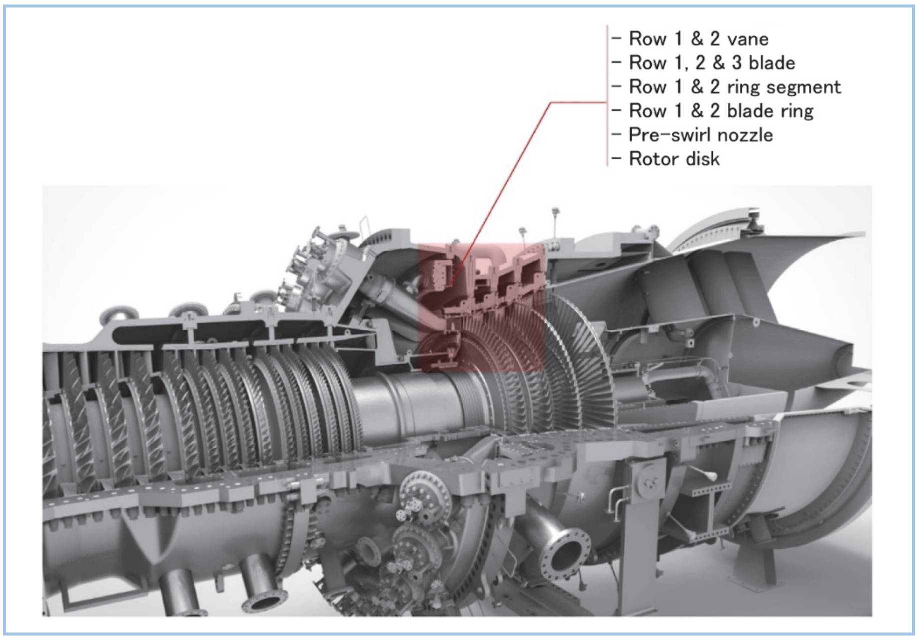


Figure 2 M701F-series gas turbine upgrade

3.2 M501G-series gas turbines: introduction of air cooling to improve operation flexibility and reduce emissions, and future application to hydrogen co-firing

In North America, as use of renewable energy increases, a more stable grid system is needed. GTCC power generation facilities have served as a balancing power source in the past, and their balancing capability can be enhanced by a shorter start-up time and an improved turndown. Turndown is the facility's capability to respond to a fluctuating power demand by staying on standby at minimum load and quickly increasing it as power demand increases. Further lowering the minimum load level is required to enhance the balancing capability.

When a gas turbine uses steam to cool the combustor, (1) time to start up the auxiliary boiler for cooling steam supply and warm the steam cooling pipes, and then (2) time to gradually switch from using steam from the auxiliary boiler to steam of the heat recovery steam generator (HRSG), are needed. However, when the combustor is retrofitted from a steam-cooled to an air-cooled system, time required for warming processes and switching the steam in use can be considerably reduced. The consequent reduction in the time between start-up and rated load is significant and can lead to greater startup performance.

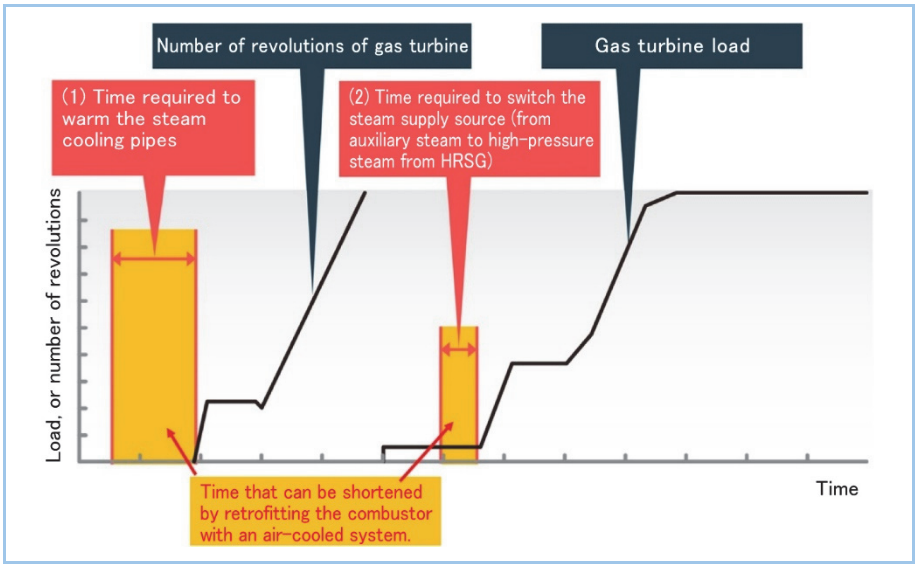


Figure 3 Retrofitting of the combustor with an air-cooled system to reduce the start-up time

Meanwhile, gas turbine combustion temperature decreases at a lower load and generation of CO (carbon monoxide) tends to increase. The level of minimum load is limited due to CO. As a countermeasure, a regulating valve is installed in the turbine cooling system. The valve is open at a partial load to intentionally increase the amount of cooling air, so that the combustion temperature under the same load conditions is higher than when the valve is closed, resulting in a reduction in the formation of CO.

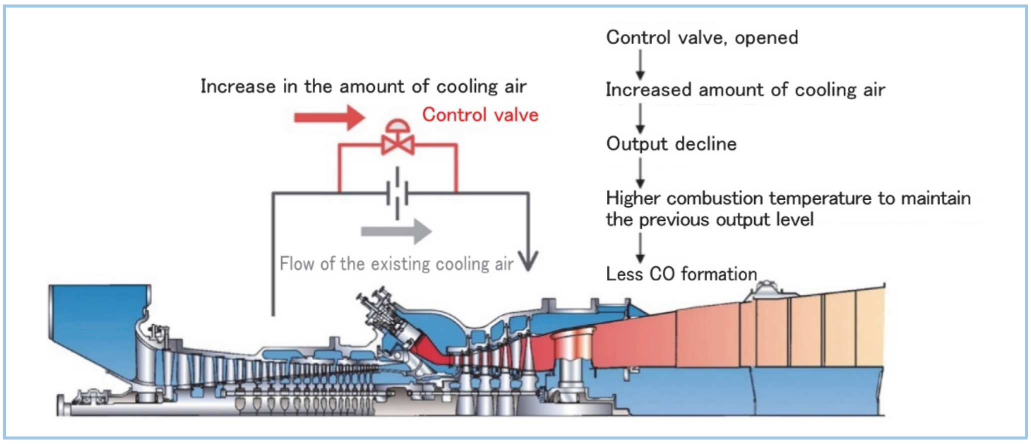


Figure 4 Conceptual diagram of the control valve installed in the turbine cooling system

At a power plant in North America, the steam-cooled combustor was replaced by the air-cooled combustor of the latest model from the same gas turbine series with a proven record for improved start up time. By installing a regulating valve in the turbine cooling system, the allowable minimum load level was improved, and the operation flexibility was greatly improved. Adoption of the latest air-cooled combustor also led to a reduction in NOx emissions at a rated load. Since this air-cooled combustor can also burn hydrogen-blended fuel, a hydrogen co-firing test is also planned in the future.

3.3 M501J-series gas turbines: performance improvement

Following the F and G-series, MHI is also working on upgrading the J-series, which is the most advanced among available series. The electricity market in North America, a region where major J-series customers of MHI are located, is booming due to increased demand from data centers and e-mobility such as electric vehicles (EVs). According to the U.S. National Electrical Manufacturers Association (NEMA), electricity demand is expected to increase by 50% by 2050. Given such circumstances, incentive to invest in increasing output is strong. In order to meet this demand, MHI has developed an upgrade menu for the J-series.

In the J-series, the original 1600°C-class model has evolved into the 1650°C-class JAC-series by incorporating state-of-the-art technologies. Such latest technologies for cooling, low NOx and others were included in the development of an upgrade menu for the J-series. In this development, a 4% increase in output (as a relative value) was targeted largely based on the economic efficiency estimates from the market situation in the U.S., electricity sale price, and fuel unit cost.

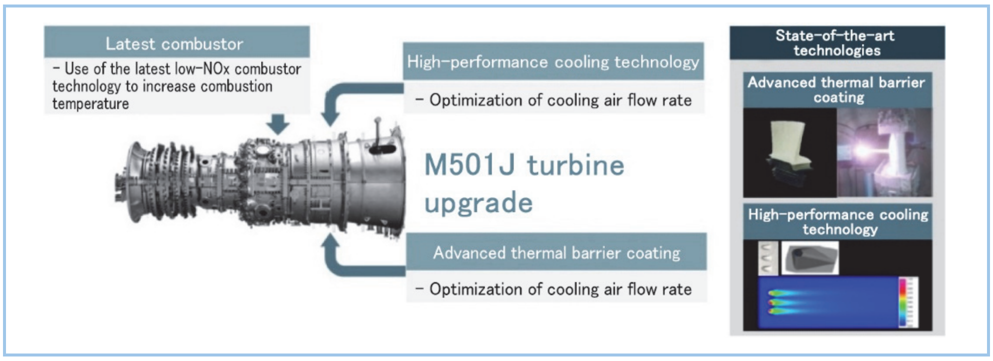


Figure 5 Conceptual diagram of M501J-series gas turbine upgrade

As shown by the cross-sectional diagram in **Figure 6**, the highlighted parts of an existing J-series gas turbine are replaced to achieve the following three objectives: (1) flow-down of the latest turbine cooling technology, (2) increase in combustion temperature, and (3) optimization of the inlet guide vane (IGV) to maximize the inlet air flow rate.

Working on the conceptual design began in 2021, and the performance test of the first upgraded unit was completed in the spring of 2025. Achieving the target value mentioned above could be confirmed.

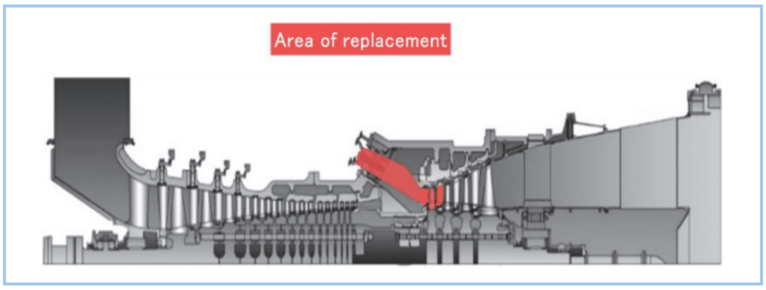


Figure 6 Parts replacement for the upgrade of M501J-series gas turbine

Efforts to establish and operate the "Pay For Performance" scheme (described below), which is a win-win business model between the customer and the manufacturer, is considered to be another contributing element to smooth retrofitting, i.e. planning, order reception and execution.

In this scheme, the amount the customer is charged for the upgrade is proportional to the amount of increase in output that is achieved by the upgrade. This is a win-win proposition. From the customer's point of view, the investment is made in line with the effect of the scale of the upgrade. At the same time, the developer is motivated to make an upgrade program with the greatest possible increase in output.

This scheme, which is a successful business model, has already worked well for a large number of F- and G-series upgrade projects in the U.S., prior to its introduction for the J-series. Currently, the upgrade will be offered to approximately 40 units of the 1600°C-class J-series which are in operation around the world.

4. Conclusion

MHI has continued to develop upgrade programs for each series, by considering the properties of the region and analyzing the needs of each customer. Various upgrade programs have been successfully created to improve not only output and efficiency, but also start up time, turndown, emissions reduction, application to hydrogen co-firing, etc. While maintaining a win-win relationship with its customers, MHI will continue to meet the needs of more customers by combining these upgrade programs.