Initiative for CO_2 Emission Reduction by Steam Turbine Retrofitting with High-efficiency Technologies

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Initiatives toward decarbonization are being undertaken worldwide. In the power generation market, the introduction of renewable energy is also in progress. Meanwhile, as a certain number of thermal power facilities are expected to remain in operation to ensure stable electricity supply, it is indispensable to implement CO_2 emission control in thermal power generation. The existing power facilities are no exception in this regard. Steam turbines, which have been incorporated as the main equipment of power facilities, inevitably degraded after long-term operation. Although the internal parts are often upgraded as a countermeasure, their simultaneous remodeling by applying the latest high-efficiency technologies can add more value: less fuel consumption due to higher efficiency, which in turn leads to the reduction of CO_2 emissions. This report presents some examples of the steam turbine retrofits with the latest high-efficiency technologies and the resulting effect of CO_2 emission reduction.

1. Introduction

The long-term use of steam turbines leads to degradation due to aging, increasing the susceptibility to damage. The risk of unexpected damage being caused becomes high, especially in the second half of the life of a power plant. In many cases, the major parts that have aged are replaced 25 to 35 years after the start of operation, eliminating the potential risk. Such upgrading can suppress repair costs that may otherwise be incurred in the future and prevent unexpected damage from being inflicted by unplanned events or shutdowns. As the efficiency of these aging steam turbines for upgrade is not so good, their simultaneous retrofitting with the latest high-efficiency technologies can add more value such as less fuel consumption and CO_2 emission reduction.

For the private power generation systems, the factors involved are not only degradation due to aging, but also others such as changes in the business environment, which result in alterations in the operational conditions (e.g., the output and the amount of steam supplied to a factory) planned at the time of construction. These may often lead to deviation from the optimal operation conditions. It is also possible to optimize the plant efficiency by retrofitting according to the most recent operational conditions.

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2. Examples of steam turbine retrofits for higher efficiency

In order to meet the need to improve the efficiency in steam turbines, Mitsubishi Heavy Industries, Ltd, (MHI) developed a state-of-the-art high-performance side exhaust steam turbine to which the latest high-efficiency technologies were applied. Its performance and reliability were verified at T-Point 2, the power generation demonstration facility of MHI[1]. The high-efficiency technologies employed therein are applicable to any steam turbines with a wide output range of small to large capacity, including for retrofitting of existing units. The number of applied units is increasing gradually.

2.1 Case of entire steam turbine retrofit

A 500 MW class steam turbine operating in an ultra-supercritical thermal power plant was retrofitted. It consists of a single high-intermediate pressure (HIP) turbine and two low pressure (LP) turbines. Starting its operation in 1995, the steam turbine had been in operation for more than 25 years before being retrofitted. With the purpose of extending the plant life, improving the efficiency and reducing the maintenance costs, the entire HIP turbine and the internal parts of the LP turbines were replaced as part of the plant renovation. **Figure 1** summarizes the turbine retrofit. The resultant improvement in the performance is expected to reduce CO_2 emissions by about 95,000 tonnes per year.

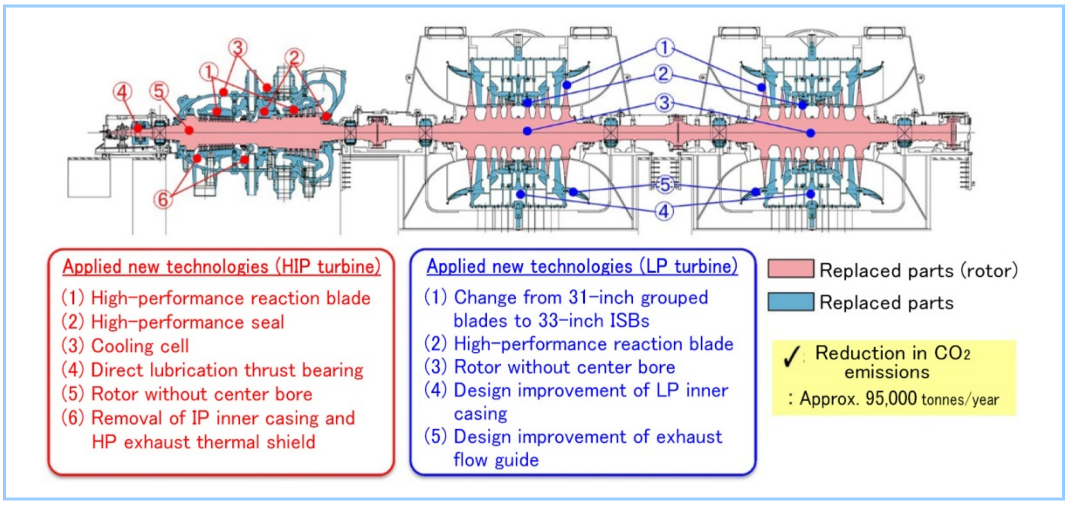

Figure 1 Summary of entire turbine retrofit

In the HIP turbine, the latest high-efficiency reaction blading design was applied to increase the blade-row efficiency. The original labyrinth seals were replaced with abradable ones to reduce the decline in the performance resulting from the leakage loss that will increase over time. The retrofit was carried out considering not only improved efficiency but also degradation prevention, enhanced reliability and better maintainability. The cooling cells, which are activated when the turbine is shut down, were additionally attached to the upper outer casing, thereby reducing the temperature difference between the upper and lower parts of the casing. In this way, the “cat-back” distortion of the casing, which may lead to the degradation of seals, can be prevented. The new rotor was manufactured without a center bore; the integral coupling was adopted instead of the original shrink-fit coupling to enhance the reliability. The HP exhaust thermal shield was also removed, making the maintenance simpler.

With regard to the LP turbines, the last stage blades were changed from 31-inch grouped blades to 33-inch integral shroud blades (ISBs), in addition to the application of high-performance reaction blading. Moreover, the shape of the exhaust flow guide was optimized to reduce the exhaust loss. The inner casing design was also modified in such a way that the deformation of the casing can be minimized.

2.2 Case of HIP turbine retrofit

A 100 MW class steam turbine operating in a steelworks was retrofitted. The start of its operation was in 1986. The customer’s request to retrofit the HIP turbine was based on the need to extend the life of the steam turbine by replacing the components with a very limited life span and to improve the economic efficiency (**Figure 2**). The resultant improvement in the performance is expected to reduce CO_2 emissions by about 46,000 tonnes per year.

The outer casing of the HIP turbine remained unchanged for continued use, whereas the internal parts of the turbine were replaced with the ones redesigned by applying high-performance technologies. A substantial improvement in the performance was achieved by changing the blade design from the original impulse blade to the high-efficiency reaction blade, by applying the high-performance seals to reduce the leakage loss, and by employing the direct lubrication thrust bearing to reduce the mechanical losses. The redesigned main steam inlet improved the flow of steam for cooling the casing, thereby realizing the structure by which the inner surface of the outer casing is prevented from being directly exposed to high-temperature steam. In this way, the reliability of the HIP turbine outer casing, which continued to be used, was enhanced.

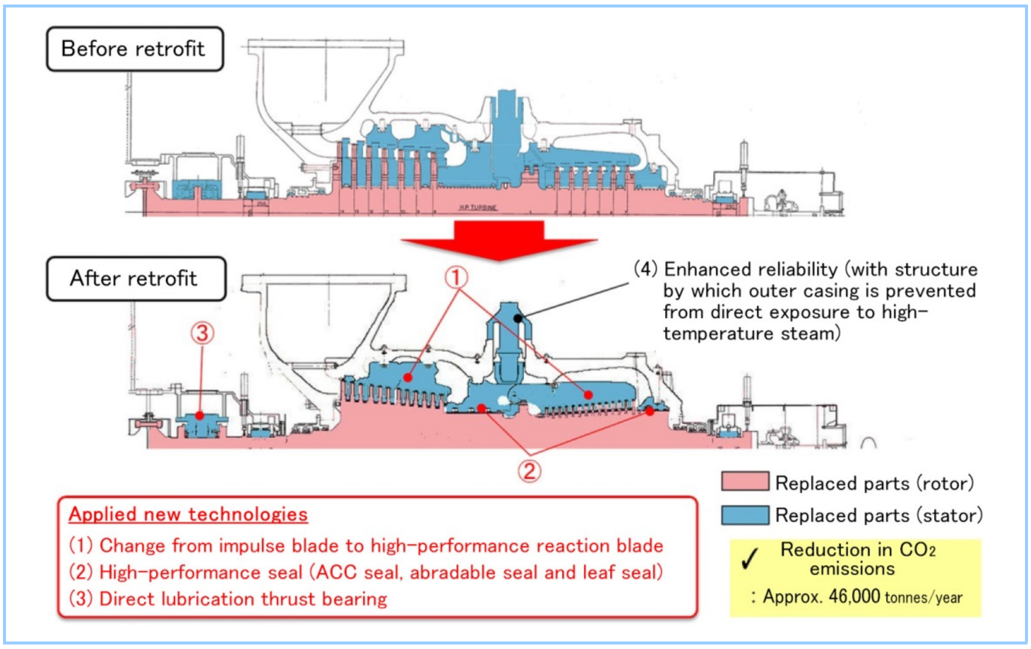

Figure 2 Summary of HIP turbine retrofit

2.3 Case of LP turbine retrofit

A 400 MW class steam turbine operating in a subcritical power plant was retrofitted. Since its operation commencement in 1984, the steam turbine had been in use for more than 30 years before being retrofitted. The reason to retrofit the LP turbine for higher efficiency was the need to switch the fuel from coal to gas because of the new policy implemented by the government in the country where the carbon tax is increased (**Figure 3**). The resultant improvement in the performance is expected to reduce CO_2 emissions by about 43,000 tonnes per year.

The outer casing of the LP turbine remained unchanged for continued use, whereas the internal parts of the turbine were replaced with the ones redesigned by applying high-performance technologies. With regard to the upstream side of the LP turbine, the high-efficiency reaction blading design was newly adopted (it had been originally impulse blading). The length of the last-stage blades was extended by employing 36-inch ISBs, instead of 33.5-inch grouped blades. This reduced the exhaust loss and improved the performance. The shape of the exhaust flow guide was also redesigned for the enhancement.

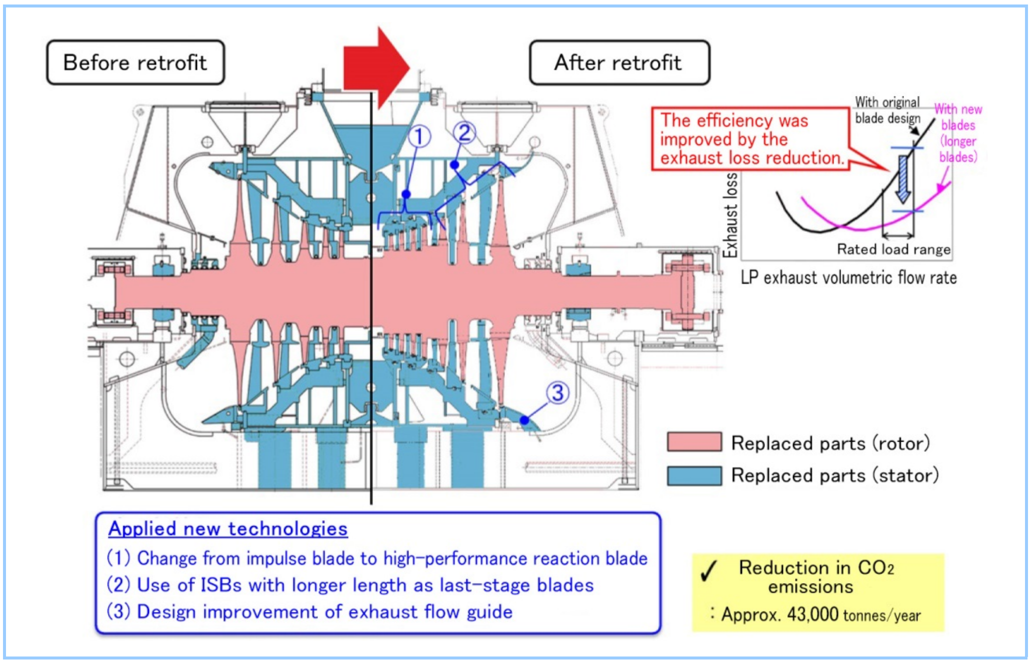

Figure 3　Summary of LP turbine retrofit

3. Examples of steam turbine retrofits according to altered operation conditions

The private power generation systems are often forced into operating under non-optimal conditions. This is because of the factors such as the changes in the business environment resulting in alterations in the operational conditions (such as the output, and the amount of steam supplied to a plant) planned at the time of construction. If this is the case, the performance of steam turbines can be improved by retrofitting according to the most recent operational conditions. Specifically, it may be a retrofit to increase/decrease the capacity, convert a condensing turbine into a back pressure turbine, or change the extraction pressure. **Table 1** lists some items on the retrofit menu[2].

Table 1　Example items on menu for steam turbine retrofits according to altered operation conditions

Steam condition	Electric power		Menu	Benefits
Steam demand is increased. Need to increase turbine swallow.	Larger large output .	⇨	Turbine Upsizing	**Amount of electrical power purchased down due to increasing output.** e.g.: 22% increased in output for 40 MW turbine.
Steam demand is not changed.	Power generation cost > power purchase price. Need to reduce the amount of power generation of the condensing turbine.	⇨	Turbine Back Pressurising from condensing.	**Fuel cost down due to improving plant efficiency, etc.** e.g.: 7% reduced in main steam flow for 25 MW turbine.
Steam demand is decreased.	Need to increase turbine efficiency at low loading.	⇨	Turbine Downsizing	**Output increased due to improving turbine efficiency, etc.** e.g.: 6% increased in output for 35 MW turbine
Steam supply pressure to the factory is changed.	Power demand is not changed. Need efficient operation.	⇨	Extraction Pressure Optimization	**Reduction in extraction pressure loss** e.g.: Extraction pressure is reduced by 30% and output is increased by 2.5% for 50 MW turbine

3.1 Retrofit to reduce capacity and change extraction pressure

Shown here is an example of retrofitting the extraction condensing turbine for private power generation, which started operation in 2001. Specifically, the retrofit includes: the introduction of GT cogeneration system to reduce CO_2 emissions, the optimization of the post-retrofit operation of the entire plant including the existing boiler and steam turbine, the capacity reduction of the existing steam turbine (from 86 MW to 47 MW), and the change of the extraction pressure (from 3.7 MPa to 2.8 MPa). **Figure 4** summarizes the retrofit.

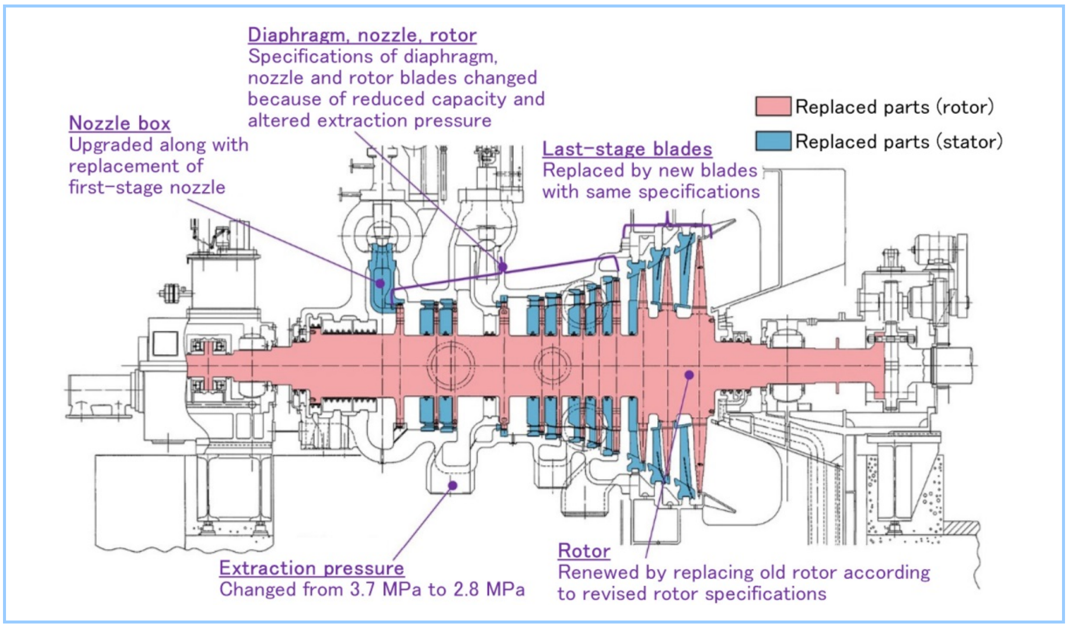

Figure 4 Summary of retrofit to reduce capacity and change extraction pressure

The nozzle box was upgraded along with the replacement of the first-stage nozzle. In order to adapt to the reduced capacity and the altered extraction pressure, the blade row specifications such as the blade height and the number of blades needed to be changed. The diaphragm, nozzle and rotor blades were therefore remodeled. The LP last-stage blades were renewed by replacing the old blades with the new ones with the same specifications. The outer casing remained unchanged for continued use. Given the structure in which the diaphragm is directly attached to the outer casing, we had to make the revised blade row specifications effective within the constraints.

3.2 Retrofit to convert into back pressure turbine

Shown below is an example of retrofitting the double extraction condensing turbine for private power generation, whose operation started in 1995. In the country where the turbine was installed, the sale price of electricity to the power company did not rise as initially expected, despite the soaring coal price. Thus, power generation by the steam turbine turned out to cost more than the purchase of electricity. At the request of the customer who needed to further improve the plant efficiency for reduced coal consumption and CO_2 emissions, we assessed by balancing the amount of steam supplied to the factory against the amount of electricity generated and, based on the results, converted the existing condensing turbine into a back pressure turbine.

With this conversion, the amount of electricity generated is reduced, but the plant efficiency can be improved because of reduction heat loss in condenser and less power used for the auxiliary equipment in the condensate system. There is also the issue of a plume (white smoke) coming out of the cooling tower. The back pressure turbine has an advantage of negating the need to use the cooling tower completely or partially. **Figure 5** summarizes the retrofit.

In converting into a back pressure turbine, all the stages until the steam extraction remained unchanged, whereas the last four stages on the steam outlet side were removed. For continued use of the outer casing, a partition plate was attached to the exhaust outlet, allowing the exhaust to escape from where steam used to be extracted.

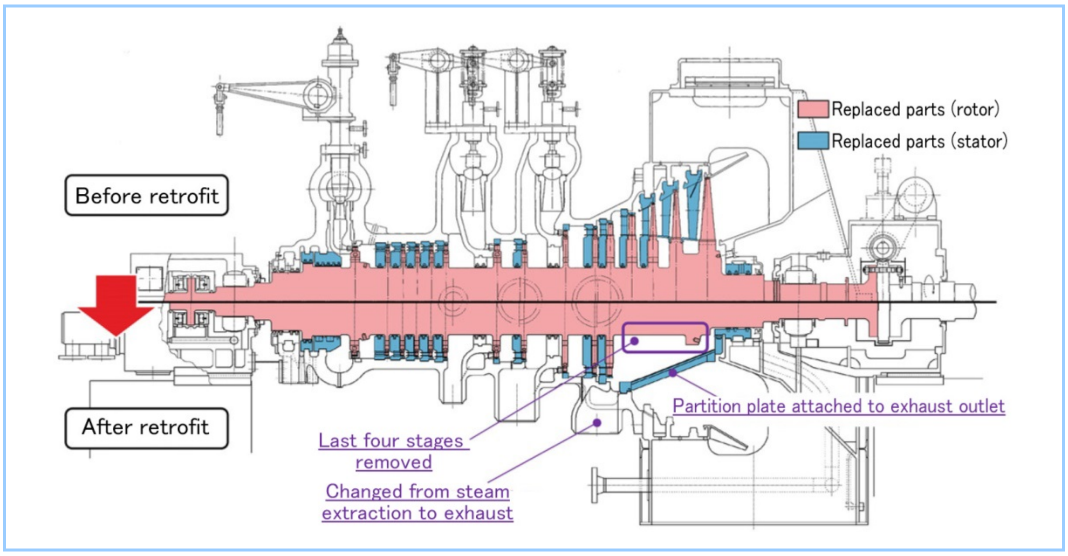

Figure 5 Summary of retrofit to convert into back pressure turbine

4. Conclusion

For the existing steam turbines, the renewal of the parts that have aged because of the long-term operation is effective in negating repair costs that may otherwise be incurred in the future and eliminating the risk of unplanned shutdown due to unexpected damage. In addition, the simultaneous retrofitting with the latest high-efficiency technologies can add more value such as less fuel consumption and reduced CO_2 emissions. Moreover, turbine remodeling according to the altered operational conditions can optimize the efficiency of the entire plant.

MHI will continue with the development to realize higher efficiency and provide steam turbines that can contribute to further reduction of environmental impact.

References

(1) Takashi Nakano et. al, Development of Latest High Efficiency Side Exhaust Steam Turbine, Mitsubishi Heavy Industries Technical Review Vol.58 No.3 (2021)

(2) K. Ikushima, et al., “Strategic Renovation for Existing Steam Turbine in the Electricity Market Changing”, ICOPE-2021-0106