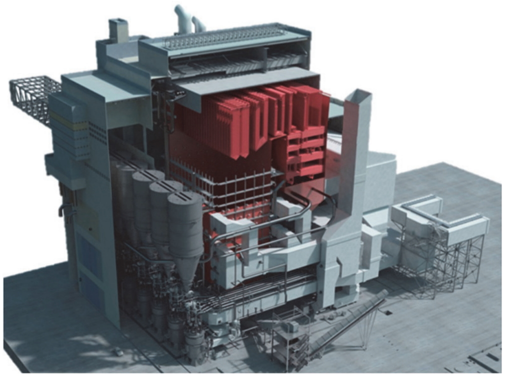
Expectations for Changing Steam Power Plants and Supporting Technologies



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Along with the increase in the amount of renewable energy being introduced, the stable supply of electric power according to demand and climatic conditions has become a very important issue for the Japanese power supply configuration, which is based on the best mix of energy. As a solution to this issue, coal-fired steam power plants are expected to contribute to the stable supply in the stable supply of electric power through the improvement of their load adjustment capability. This paper explains the latest coal-fired boiler load adjustment capability improvement menu produced by Mitsubishi Hitachi Power Systems, Ltd. (MHPS), and introduces the latest coal-fired steam power plants that enable the easier realization of versatile operation and their supporting technologies.

1. Our latest boiler load adjustment capability improvement menu

Along with the increase in the amount of renewable energy being introduced, steam power plants have begun to be operated in a manner where they generate power at the lowest level or stop during the daytime and increase the output during the evening hours when the output of solar power generation decreases and power demand increases. This paper introduces an improvement menu that draws out the potential of steam power plants and coal-fired boilers as much as possible and improves the load adjustment capability from the current status. **Figure 1** and **Table 1** show our "latest boiler load adjustment capability improvement menu."

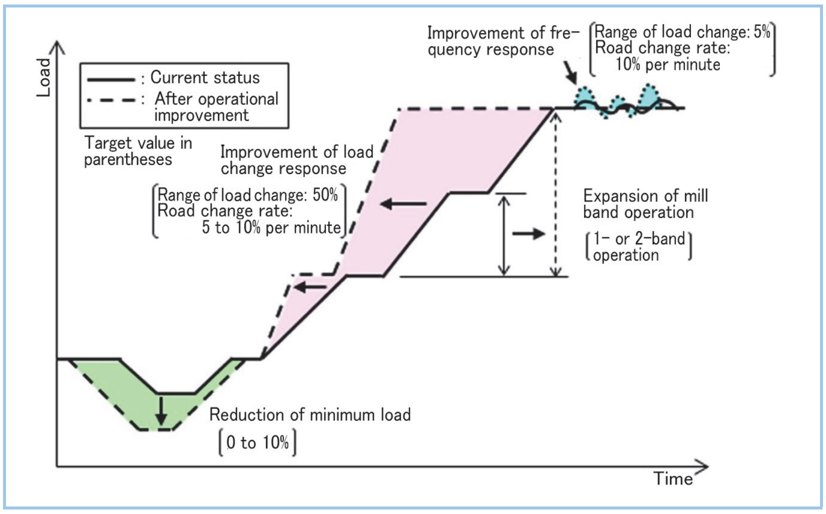

Figure 1 Latest boiler load adjustment capability improvement menu

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Table 1 Latest boiler load adjustment capability improvement menu table

■ Load change improvement menu

Operation menu			Current status	Target			Main improvement items	Reference
Frequency response	GF AFC	Rate of change	5% per minute	10% per minute			- Overload valve - Condensate throttling	Chapter 2
		Range of change	3%	5%				
				Target 1	Target 2	Target 3		
Load change response	DPC	Rate of change	3 to 5% per minute	5% per minute	7% per minute	10% per minute	Target 1 - Parameter adjustment Target 2 - Parameter adjustment - Logic modification (dedicated BIR logic) - T2 control logic (improvement of main steam temperature control) Target 3 - Parameter adjustment (Drive operation/setting value change rate) - Logic modification[*1] (dedicated BIR logic) - T2 control logic (improvement of main steam temperature control) - Load change initial response logic (use of condensate throttling function) - Utilization of heat storage system (currently under development)	Chapter 3.1 Chapter 3.2
		Range of change	20 to 25%	50%	50%	50%		

*1: Including reexamination of appropriate control deviation

■ Load range improvement/optimum operation menu

Operation menu		Current status	Target	Main improvement items	Reference
Multiple coal types	Multi-coal type control	Combustion test of 3 coal types	Combustion test of single coal type	New multi-coal type control	Chapter 4.2
	Compensation of calorific value fluctuation	Manual calorific value correction Water-fuel ratio correction	Automatic correction from operating conditions	Correction of calorific value fluctuation	Chapter 4.3
Minimum load reduction		20% to 15%	15 to 10%	Low NOx burner Adoption of inverter mill motor	Chapter 5.1
			up to 0%	Heat storage system (currently under development)	
Heat recovery at stop and start		Waste heat as start-up loss	Converted to electricity by waste heat recovery	Heat storage system (currently under development)	
Expansion of mill band operation		3 bands 3 mills: 30 to 50% 4 mills: 50 to 75% 5 mills: 75 to 100%	2 bands or 1 band 3 mills: 30 to 50% 4 or 5 mills: 50 to 100% or 30 to 100%	Low NOx burner Adoption of inverter mill motor	Chapter 5.2

2. Frequency response of steam power plants

Steam power plants have output control functions to respond to power system frequency fluctuations and power demand fluctuations. The control functions have variations such as GF (Governor Free), AFC (Automatic Frequency Control) and DPC (Dispatching Power Control) according to the load fluctuation cycle and the range of load change (**Figure 2**).

Each control function can stably adjust the output of the boiler, turbine and generator mainly by controlling the turbine governor opening and increasing or decreasing the boiler feedwater, fuel and combustion air.

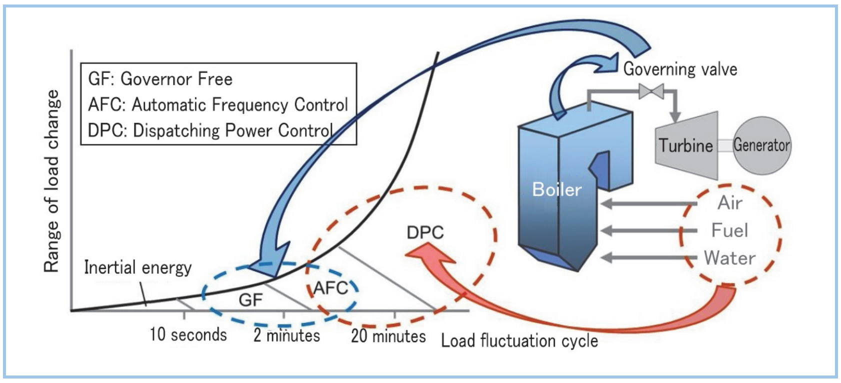


Figure 2 Control capability with regard to load fluctuation cycle and range of load change

However, in the case of a plant that emphasizes high-efficiency operation, the turbine governor always operates in a nearly full-open state, so it is necessary to secure a control margin in the turbine governor opening or to increase the steam flow rate to the turbine to increase the load from the current state. Effective methods thereof include OLV (Overload Valve) and condensate throttling. **Figure 3** presents the function of these methods. OLV is suitable for new units, and condensate throttling is suitable for new and existing units.

For both methods, it is necessary to supply a stable flow rate of steam from the boiler. In the case of a coal-fired unit, however, due to the delay in fuel input because of coal pulverization and the combustibility of coal, it is more difficult to do so compared with a unit that uses oil or gas fuel. The following chapters will mainly introduce the control technologies for coal-fired boilers.

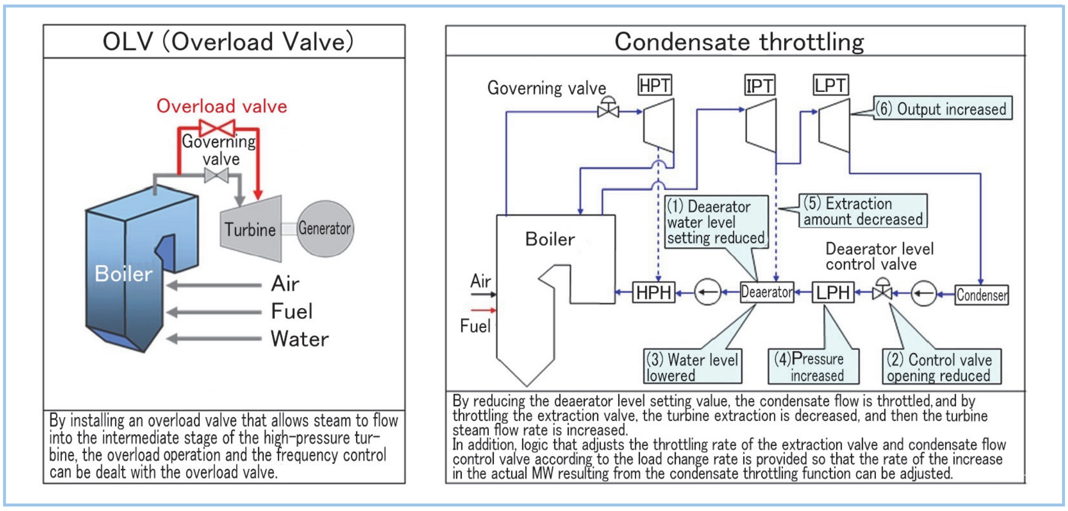


Figure 3 Load increasing method of high-efficiency boiler

3. Improvement of dynamic characteristics of coal-fired boilers

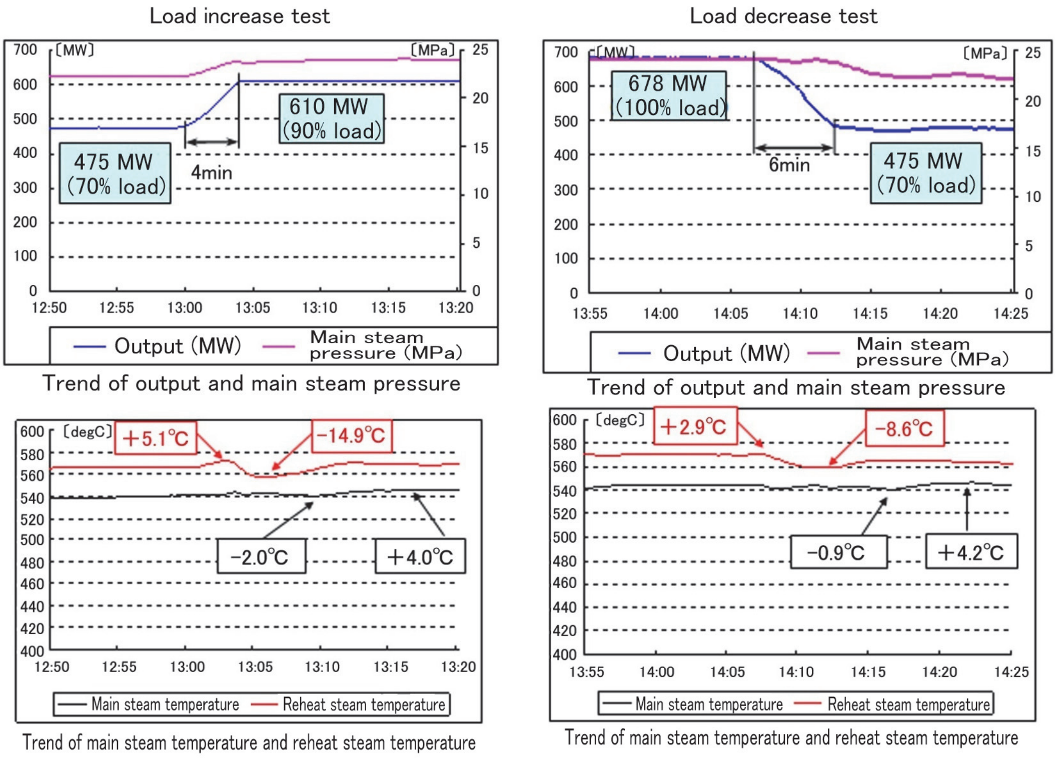
3.1 Dynamic characteristic test

After a combustion test (static characteristic test) is completed, a dynamic characteristic test is performed. In the case of a supercritical sliding pressure boiler, when the load is increased, extra amounts of water, fuel and air are added by the boiler input regulation signal (BIR) to the set values of the static characteristics corresponding to the rise in the saturation temperature accompanying the increase in pressure and superheater/reheater temperature, as well as also to increase the heat held by the boiler itself. In addition, each control parameter needs to have sufficient response and capacity with respect to load changes. If these additions are insufficient, the degree of superheating at the furnace outlet decreases, leading to a drop in the main steam pressure, bringing about risks such as control divergence. On the other hand, when the load is decreased, the amount of fuel input is controlled to be smaller through BIR, taking into account the heat stored in the boiler itself. Depending on the load change rate, in addition to the magnitude of BIR, it is important to adjust the change rate at which the BIR is switched on/off and to ensure the turn-down of the auxiliary equipment.

In addition, in the case of a coal-fired boiler, adjustment in consideration of the time until the pulverized coal is supplied to the furnace and the combustibility of the coal is required, because of the process of pulverizing coal with a coal mill. The following presents the results of our high load change test and further high load response technology.

3.2 Actual results of high load change test

Unit A, which was designed, manufactured, installed and commissioned by us, achieved 5% per minute (net) in a load increase test from 70% to 90% load and a load decrease test from 100% to 70% load. **Figure 4** depicts the operation trend. The deviation between the main steam temperature and the reheat steam temperature was within the criteria, and stable load change could be achieved. In the case of conventional units including Unit A, the steam temperature at the outlet of the final superheater (FSH) is controlled by the water-fuel ratio (fuel flow rate) and the secondary spray. However, due to the mutual interference of these two, the stabilization of the FSH outlet temperature took a significant amount of time in some cases. To solve this problem, we developed T2 control introduced in the next section and verified its effect in actual equipment.



	Rated temperature [degC]	Control deviation [degC]	
		In load increase	In load decrease
Final superheater outlet temperature	542	+4.0	−0.9
		−2.0	+4.2
Final reheater outlet temperature	568	+5.1	+2.9
		−14.9	−8.6

Figure 4 Results of response to high-speed load change

3.3 Improvement of high-speed load response technology (T2 control)

Figure 5 illustrates a conceptual control diagram of T2 control. T2 control uses the water-fuel ratio (fuel flow rate) to control the steam temperature at the outlet of the secondary superheater (2SH) placed at the top of the furnace and uses secondary spray to control the tertiary superheater (3SH) outlet steam temperature (3SH). The temperature control at the outlet of 3SH is left exclusively to the secondary spray. As a result, the ability to respond to the thermodynamic change of the furnace and 2SH is improved, and the interference of the fuel control and spray water flow control to control the 3SH outlet steam temperature is avoided. **Figure 6** gives the results of load change tests with conventional control and with T2 control. It was confirmed that the unit using T2 control also stabilized the FSH temperature faster in actual equipment. T2 control has a simple control system, so it has the advantage of being easier to adjust than before, and a dynamic characteristic test can be completed in a shorter amount of time.

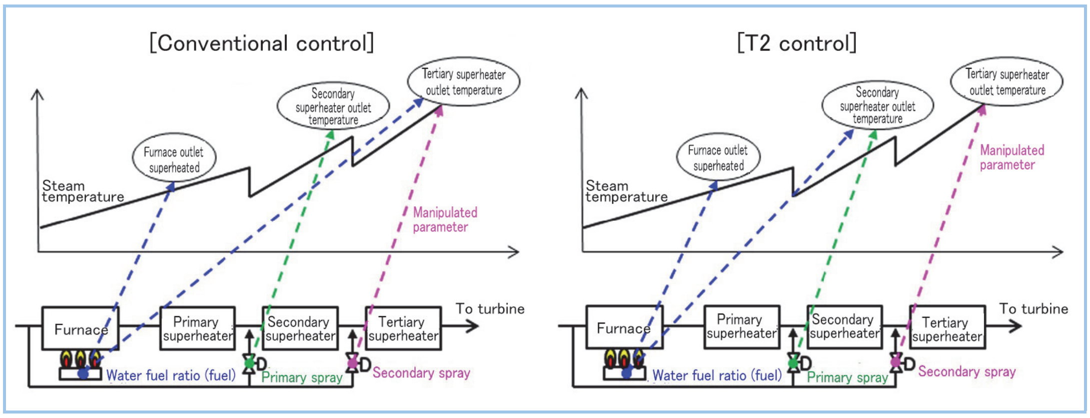


Figure 5　Comparison of conventional control and T2 control (manipulated parameters of each outlet temperature)

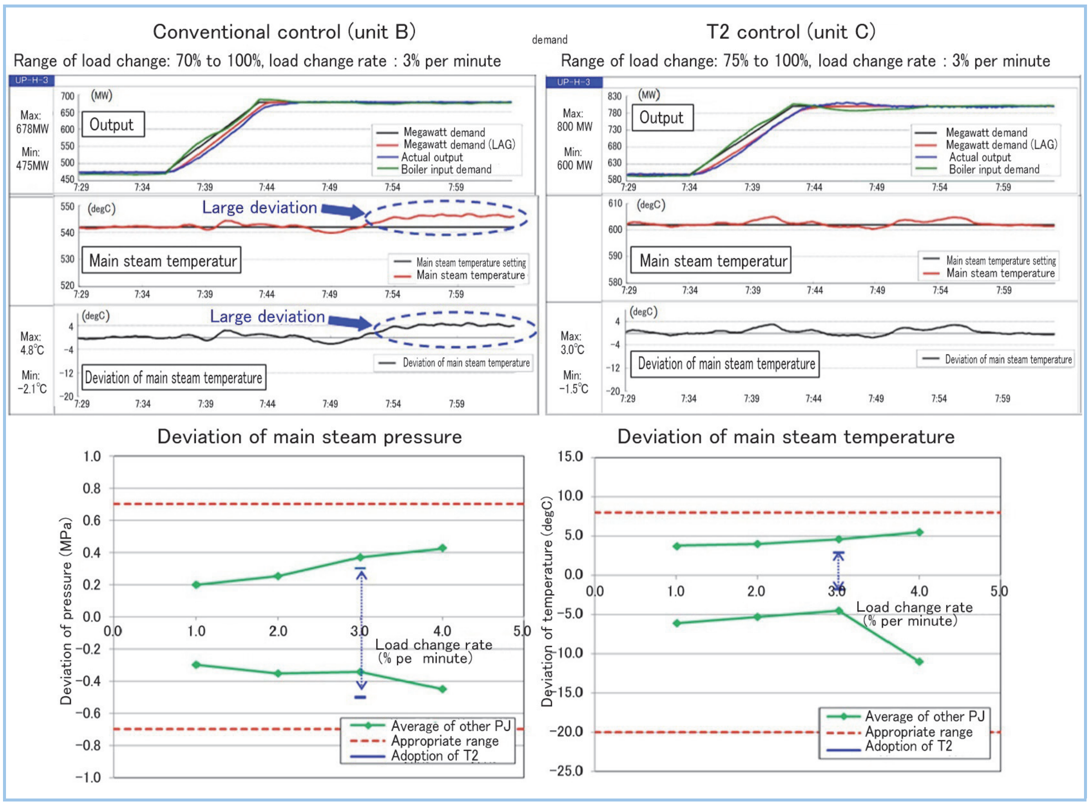


Figure 6　Comparison of actual operating data between conventional control and T2 control

3.4　Load change initial response logic (utilization of condensate throttling function)

In the case of a coal-fired boiler, the actual output (MW) is delayed with respect to the output command (MWD) at the initial stage of load change until the pulverized coal is supplied to the furnace due to its process of pulverizing coal with a coal mill. To improve the delay of the actual output at the initial stage of load change, the load response is improved by utilizing condensate throttling that has an excellent load response immediately after the start of load increase. **Figure 7** shows the effect of the utilization of the condensate throttling. At the initial stage of load change, mainly condensate throttling responds to the increase in generator output. When the output derived from condensate throttling decreases, the output of the coal-fired boiler increases. In the late stage of the load change, the coal-fired boiler responds to the increase in output. This function allows the target load to be reached faster than before.

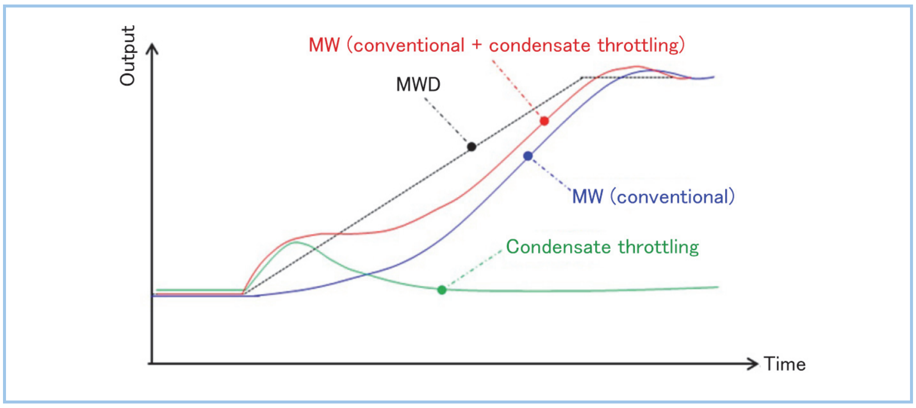


Figure 7 Effect of utilization of condensate throttling

4. Improvement of controllability of coal-fired boilers

4.1 Static characteristics of boiler

In the commissioning test of a steam power plant, the dynamic characteristics are adjusted after the static characteristics of the boiler are set at a constant unit output. For this reason, the controllability of coal-fired steam power plants depends on the static characteristics determined by the combustion test (static characteristic test) of the coal-fired boiler. In the combustion test, it is important to ensure not only the boiler efficiency and exhaust gas characteristics, but also the left/right side temperature balance of the boiler and the controllability margin of the steam temperature (i.e., opening of the spray valve and the damper). In particular, in the case of a coal-fired boiler, the performance of the boiler depends on the coal type (characteristics), the burner operation pattern, etc. We adopted a multi-coal firing control technology that enables stable operation even if the coal type changes.

4.2 Multi-coal firing control

Figure 8 depicts a conceptual diagram of multi-coal firing control. Multi-coal firing control is a function that calculates the HAI (Heat Absorption Index) signal based on the operating state of the boiler and automatically reproduces the optimum boiler static characteristics according to the HAI signal. It also automatically determines and adjusts the feedforward signal during load change and the setting value after load change based on the HAI signal. The HAI signal that was introduced for multi-coal type control was normalized using the heat absorption ratio (=2RH heat absorption amount/WW heat absorption amount) calculated by the heat transfer model provided in the control logic. However, this heat transfer model was complicated, and this complication is one of the reasons why it was difficult to adjust multi-coal firing control. In addition, the setting values of multi-coal firing control were determined based on the results of combustion tests for three coal types (high, medium and low fuel ratio) during the commissioning test. Therefore, it was problematic that about three times the adjustment time was required compared with that of a single coal type. To shorten the adjustment time, we are currently developing a new multi-coal firing control that theoretically creates set values based on the boiler performance calculation, confirms the deviation between the theoretical value and the actual measurement value of a standard single coal type in the commissioning test and reflects the results in the set values of other coal types. If this new multi-coal firing control can be established, it will be possible to easily incorporate multi-coal firing control into boilers to which it has not been introduced.

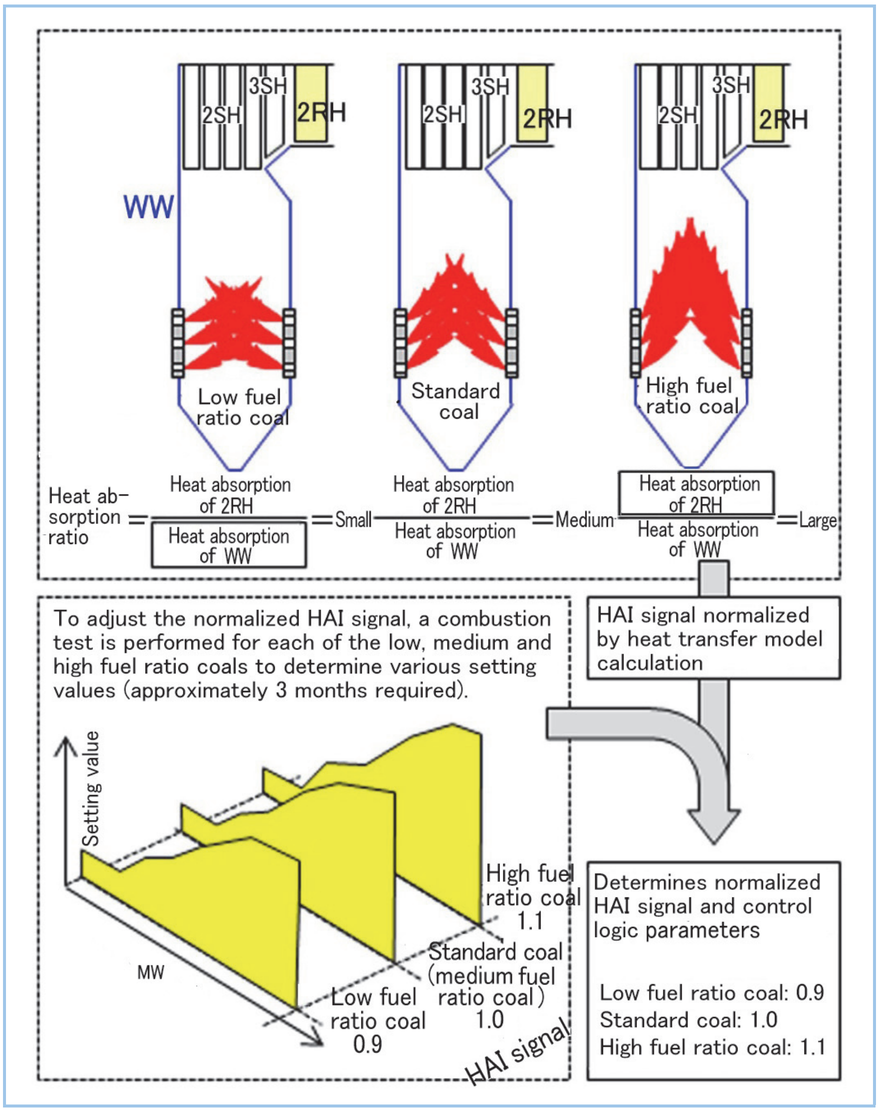


Figure 8 Concept of multi-coal type control

4.3 Correction of calorific value fluctuations

Since coal has various calorific values depending on the brand, coal-fired boilers cannot avoid fluctuations in the calorific value of coal. Conventionally, customers understood the calorific value of coal, handled the coal so that the property of the coal in all bunkers became uniform and manually carried out the calorific value correction. In addition, the fluctuation of the calorific value within the same coal brand was corrected according to the water-fuel ratio correction amount based on the idea that the calorific value setting at which the water-fuel ratio correction for steam temperature control is 0 (zero) is the true value of the calorific value at that time. A function to perform this automatically has been provided, but the process “steam temperature deviation => water-fuel ratio => calorific value correction” has the problem of slow response, and it was necessary to apply calorific value correction very slowly because if the control gain for calorific value correction is increased too much with the aim of increasing the response speed, the risk of hunting arises with the correction based on the water-fuel ratio.

To make the correction of calorific value fluctuations faster, the process was revised to a method that always calculates the calorific values based on the relationship in the boiler efficiency calculation formula and applies calorific value correction when there is a difference between the “calorific value in the control logic” and the “calculated calorific value.” As shown in **Figure 9**, the calorific value simulation results when the improved calorific value correction program is applied indicate that the calorific value is automatically corrected if it fluctuates. As can be seen in **Figure 10**, the boiler system simulation results when the improved calorific value correction program is applied indicated that by quickly correcting the calorific value, the operation can be continued while keeping the water-fuel ratio within the appropriate range (so as to not conflict with the upper and lower limits) and therefore the rise in the secondary superheater outlet temperature and the degree of superheating can be suppressed, resulting in the realization of safe and stable boiler operation.

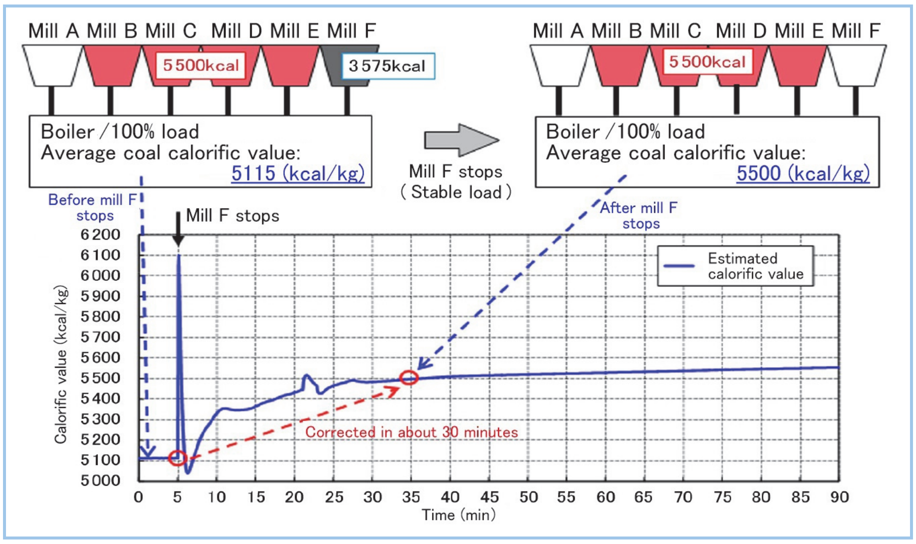


Figure 9 Improvement of calorific value fluctuation correction method

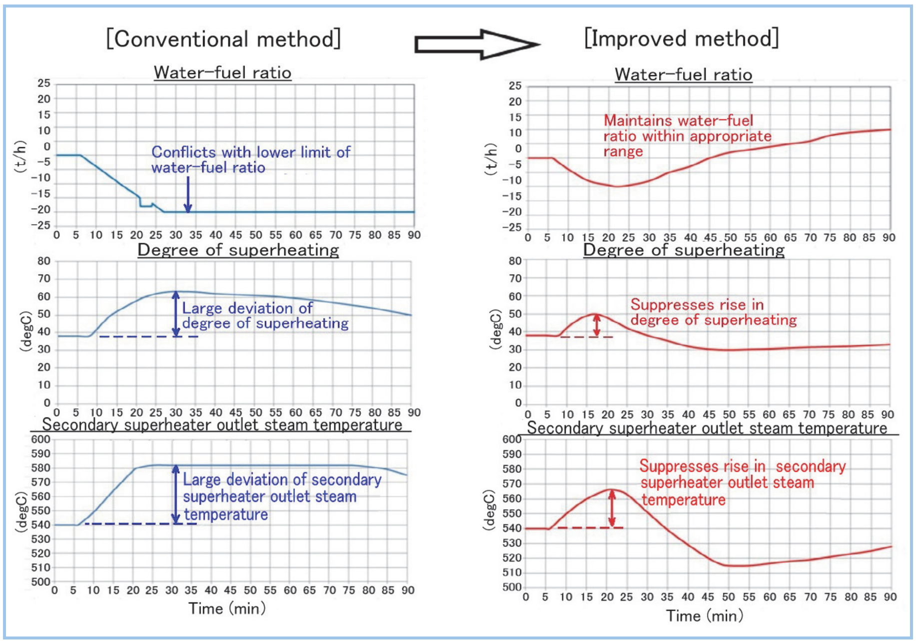


Figure 10 Steam temperature control using calorific value fluctuation correction

5. Improvement of load change range of coal-fired boilers

In the case of a coal-fired power plant with a large output per unit, the expansion of the load change range and the load change in a long range further improve the load adjustment capability of the unit. This chapter introduces technologies for the reduction of minimum load and the reexamination of mill band operations as technologies for improving the load change range of coal-fired boilers.

5.1 Reduction of minimum load

The main issues with the reduction of minimum load include dealing with the ignition and combustion stability of the burner, lowering of the turn-down of the mill, and exhaust gas environmental values. With regard to burners, an M-PM burner for corner firing and an NR3 burner for opposed firing have been developed. **Figure 11** gives conceptual diagrams of the M-PM burner and the NR-3 burner. **Figure 12** presents the results of the minimum load test of the M-PM burner conducted in our combustion test furnace. Stable ignition with a burner load of 20% was confirmed. With regard to mills, one of the effective means is to adopt an inverter for the mill motor to reduce the minimum operational load of the mill and widen the mill operational range.

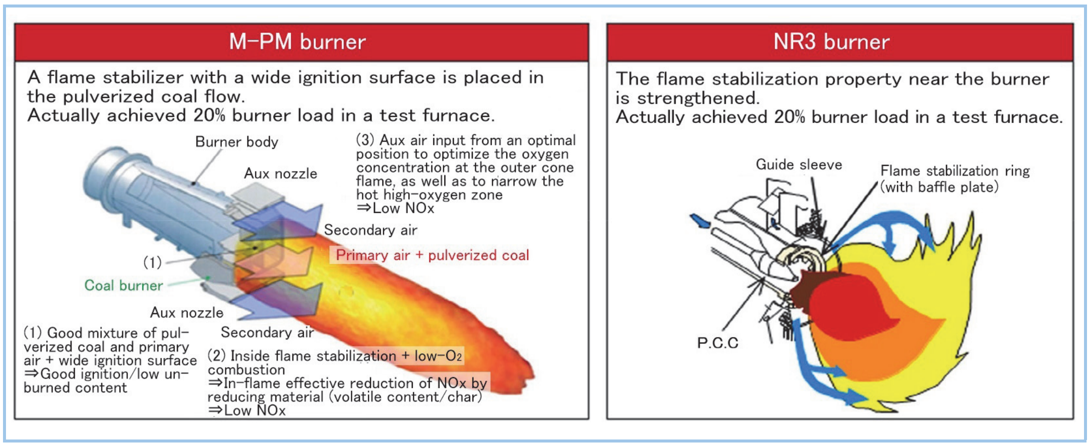


Figure 11 Our latest coal-fired burners

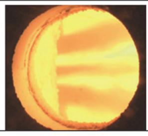
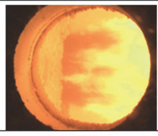
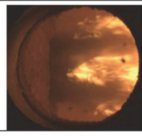
Burner ignition state (in test furnace)			
Burner load	100%	50%	20%
Boiler load	100%	30%	8%

Figure 12 Results of M-PM burner minimum load test in test furnace

By utilizing a heat storage system, excess heat resulting from the difference between the boiler minimum load and the turbine heat requirement can be converted into electric power at the time when generator output is required. We consider that one measure is to provide such a pumping-like function to lower the minimum load (currently under development). By expanding the operational range of this heat storage system to stopping and starting states, it is possible to convert the amount of waste heat (mainly start-up loss) that was discarded in the condenser without going through the turbine for electric power generation. About 1% to 3% of the fuel heat input can be saved in terms of relative value, depending on the conditions. In addition, further fuel cost savings can be expected with the price of heavy oil and coal for start-up fuel factored in (**Figure 13**).

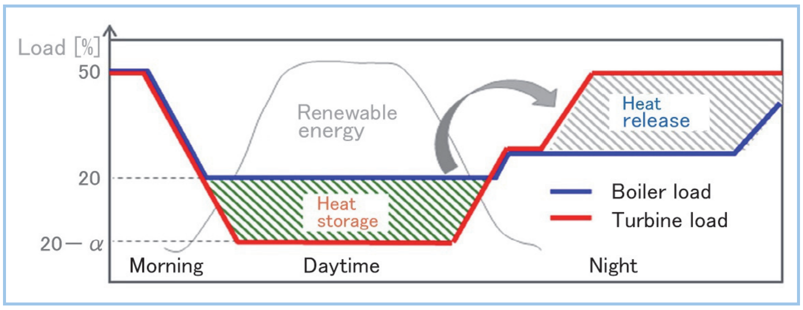


Figure 13 Heat storage resulting from difference between boiler load and turbine load and converting it into power

5.2 Reexamination of mill band operation

By utilizing a heat storage system, excess heat resulting from the difference between the boiler minimum load and the turbine heat requirement can be converted into electric power at the time when generator output is required. We consider that one measure is to provide such a pumping-like function to lower the minimum load (currently under development). By expanding the operational range of this heat storage system to stopping and starting states, it is possible to convert the amount of waste heat (mainly start-up loss) that was discarded in the condenser without going through the turbine for electric power generation. About 1% to 3% of the fuel heat input can be saved in terms of relative value, depending on the conditions. In addition, further fuel cost savings can be expected with the price of heavy oil and coal for start-up fuel factored in **Figure 14** describes the relationship between mill band operation and boiler load/mill load.

One effective means to deal with this issue is to expand the mill operational range by increasing the mill motor capacity and applying an inverter as shown in Figure 15 to eliminate the stabilization time associated with turning on/off of the mill. In this case, it is necessary to reduce the minimum load of the burner. For that purpose, one of the effective means is to apply M-PM burners or NR3 burners.

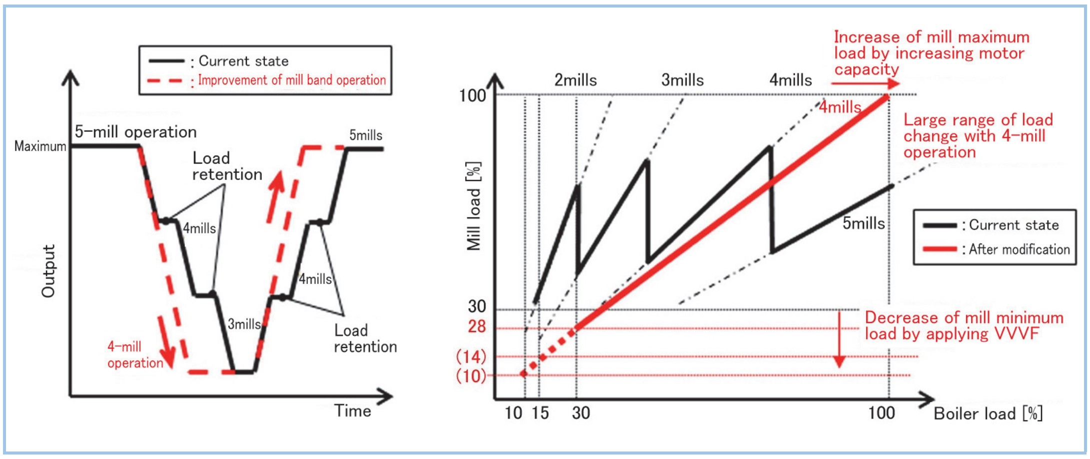


Figure 14 Improvement of operability by reexamination of mill band operation

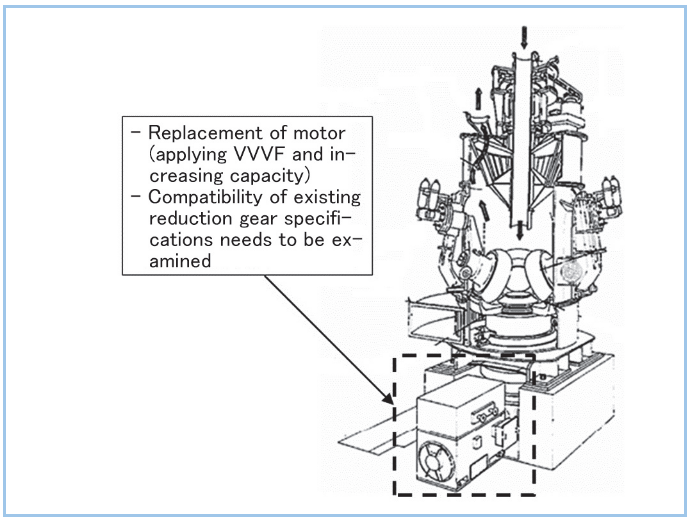


Figure 15 Major mill modifications accompanying reexamination of mill band operation (*Range of modification varies depending on existing mill specifications)

6. Conclusion

This paper introduced the load adjustment capability of steam power plants and technologies for operability improvement that is still being promoted. As the introduction of renewable energy increases, the operation of its output control has actually begun. By further increasing the load adjustment capability of steam power plants, the needs of the best mix of energy, such as providing a stable power source that balances power supply and demand and improving economic efficiency through efficient operation, can be met. We will continue to develop technologies that can respond to the various needs and problems of our customers.

References

(1) H Aiki, et.al., Boiler Digital Twin Applying Machine Learning, Mitsubishi Heavy Industries Technical Review Vol. 55 No. 4 (2018)

(2) H Ishigaki, et.al., MHPS-TOMONI: Thermal Power Generation Digitalization Platform Cloud/Edge Service and System Architecture, Mitsubishi Heavy Industries Technical Review Vol. 55 No. 4 (2018)