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Energy conservation by optimizing operation of motive power facilities

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◎ **Keywords: Rationalization of fuel combustion**

◎ Outline of Theme

This establishment has 8 boilers, 6 steam turbine generators, and 2 gas turbine generators. There are differences in energy efficiencies of these facilities, but it was a very difficult work to manually adjust according to the ever-changing demands for electricity and steam. Therefore, we have developed an advanced control system that optimizes operation of all boilers and electricity generators in real-time to establish a mechanism for constantly generating required electricity and steam with minimum fuel.

◎ Implementation Period of the said Example

October, 2002 – March, 2005 (total of 30 months)

- Project Planning Period: October, 2002 – August, 2003 (total of 11 months)
- Measures Implementation Period: September 2003 – December, 2004 (total of 16 months)
- Measures Effect Verification Period: January, 2005 – March, 2005 (total of 3 months)

◎ Outline of the Business Establishment

- Produced items: General oil products including LPG, naphtha, gasoline, kerosene, diesel oil, heavy oil, lubricant oil
- Number of employees: 677（As of April 1st, 2005）
- Annual energy consumption （Actual record in 2004）

  Fuel gas (including heavy oil).:1,142,000 KL (Heavy oil equivalent)

  Electric power: 710,000 MWh

◎ Process Flow of Target Facility

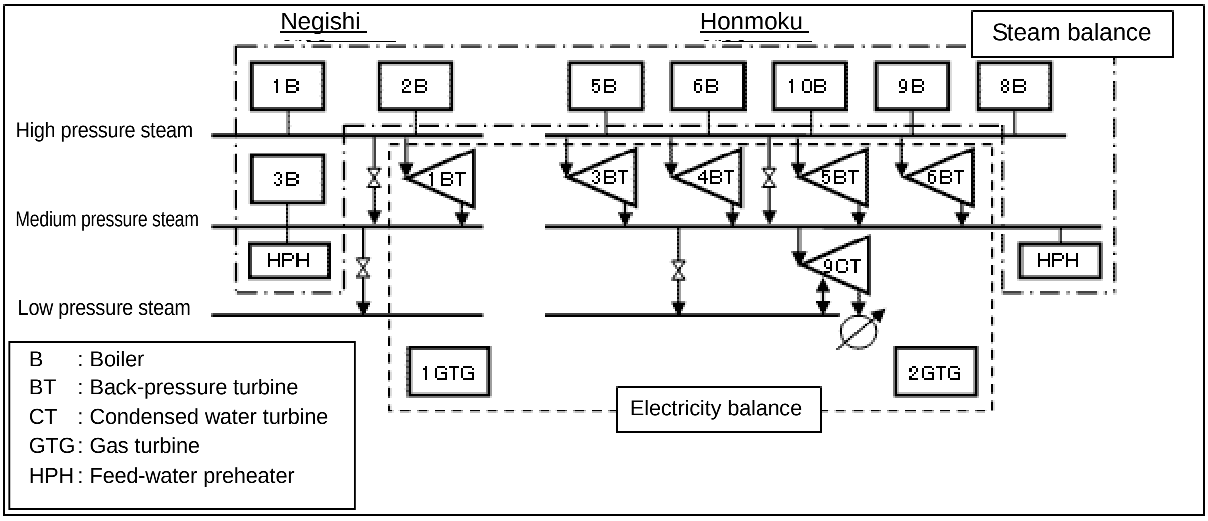

Fig. 1 Processes of the facility

1. Reasons for Theme Selection

Motive power facilities have large number of components and high degree of freedom of operation, so energy saving effect by optimization can be expected. In addition, fuel use of motive power facilities is 39% of the entire establishment, so only marginal improvement of operation can significantly contribute to energy saving. This is the reason for selecting this theme.

2. Understanding and Analysis of Current Situation

(1) Understanding Current Situation

This establishment has 8 boilers, 6 steam turbine generators, and 2 gas turbine generators and we had adjusted loads during day and night considering the differences in energy efficiencies of these facilities. However, there was a limit to manually adjust according to the ever-changing demands for electricity and steam due to the large number of components.

(2) Analysis of Current Situation

As shown in Fig. 1, the motive power facilities adjust operation of each facility according to the demand for steam that can be grouped in three systems depending on the power and pressure.

To analyze optimal operation of each facility, we have made a table of impacts of boilers and turbines on electricity and steam balance.

① Table of impacts of boilers and turbines on electricity and steam balance

The following table indicates that, in the case of steam turbine generator as an example, when operation level is increased, high pressure steam is consumed(-), middle pressure steam is produced(+), and electricity is produced (+) (Table 1).
Moreover, power generation, steam generation, and restrictions of facilities, etc. must be considered.

	Fuel consumption	High pressure steam volume	Medium pressure steam volume	Low pressure steam volume	Generation of electricity
High pressure boiler	+	+			
Steam turbine generator		−	+		+
High pressure feed-water	−		−		
Gas turbine generator	+				+
Medium pressure boiler	+		+		
Condensed water turbine			−	±	+
Process turbine			−	+	
In-house electricity					−
Sold electricity					−
8M -> 2M decompression valve		−	+		
2M -> 0.2M decompression			−	+	

Table 1 Table of impacts on electricity and steam balance (+: increasing direction, -: decreasing direction,)

To optimize such a balance, usually linear programming (LP) is used. When there are many facilities that have strong non-linear factors, however, adapting other methods must also be considered. Therefore, we have reviewed if each facility has non-linear characteristics or not to decide the optimization method.

② Optimization methods and tools

Fig. 2 shows the result of plotting the fuel gas consumption and steam generation of boilers. The correlation between them can be virtually expressed linearly.
Similarly, we plotted the inlet steam flow rate and generation of electricity for turbines, we have found that it can be virtually expressed linearly although some facilities showed weak non-linearity.

Based on the above results, no strong non-linearity was observed in the facility characteristics and it was proved that most facility efficiencies can be expressed linearly within the range of facility operation.

Therefore, we have decided to adopt linear programming (LP) as the optimization method and multivariate prediction control.

In addition, the optimization calculation by simulation based on the table above showed that benefit of one hundred and some tens of million yen annually is expected.

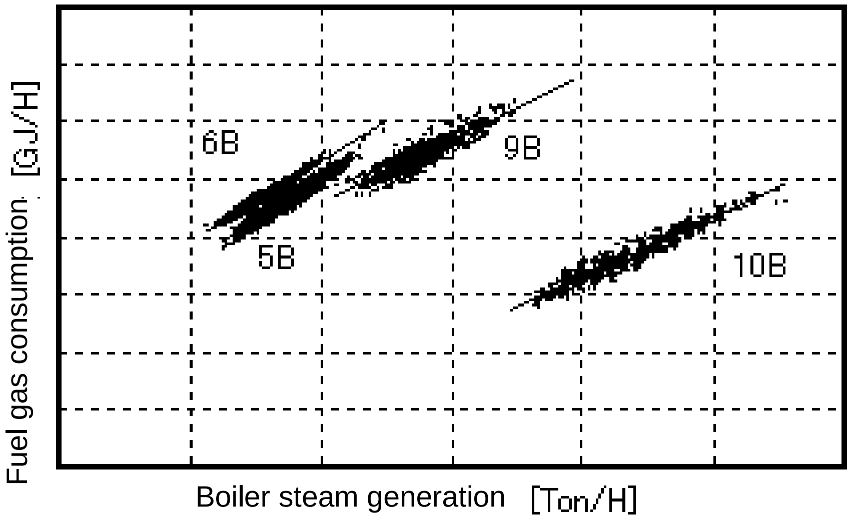

Fig. 2 boiler specific energy consumption

3. Progress of Activities

(1) Implementation Structure

Multivariate prediction control has scarcely been introduced to motive power facilities in Japan previously, and this is the first attempt in our oil refineries. Therefore, we took about one year to understand and analyze the current situation before introducing multivariate prediction control (Table 1).

Enforced item	2002	2003	2004	2005
Understanding and analyzing the current	←―――	―――→		
Modification of the DCS control method			↔	
Introducing multivariate prediction control		←―――	―――→	
Verification of the effect				↔

Table 1 Implementation Structure

(2) Target Settings

Our goal is to perform optimization control where facilities with higher energy efficiencies are operated preferentially.

(3) Problem Areas and their Investigations

The calculation of linear optimization by simulation indicated that significant energy saving effect can be achieved. However, we had to solve the following problems to utilize the effect of introducing multivariate prediction.

Sharing functions between DCS control and multivariate prediction control

The features of DCS control system and multivariate prediction control system are shown in Table 2. As indicated by this table, stabilization technology of multivariate prediction control system is inferior to DCS control system due to the issue of control cycle (slow control). Therefore, we have discussed appropriate sharing of functions between DCS control and multivariate prediction control.

Item	Control cycle	Stabilization technology	Optimization technology
DCS control system	0.5 sec. -	○(Good)	×(No-good)
Multivariate prediction control system	15 sec. -	△(Moderate)	○(Good)

Table 2 Comparison of features of control systems

Items and purposes of control of DCS control system discussed are as follows (Table 3):

	Item	Purpose of control
(1)	Boiler load control	To stabilize the pressure of high pressure steam (quick response to fluctuation of demand for steam)
(2)	Turbine load control	To stabilize the pressure of medium pressure steam (quick response to fluctuation of demand for steam
(3)	Electricity generation control	Follow-up of demand for electricity

Table 3 Purposes of DCS control system

4. Details of Measures

(1) Changing the Boiler Load Control Method

After modification of the control system

To appropriately share functions between DCS control and multivariate prediction control, we have newly created a mechanism to add bias from multivariate prediction control to output of the main pipe pressure control by DCS (Fig. 3). As a result, the main pipe pressure control that requires quick response and control of preferential operation of boilers based on their efficiencies can be coexist.

Sharing of functions between the controls is as follows:

➢DCS control: pressure control of high pressure steam

➢multivariate prediction control: control of preferential operation of high efficiency boilers

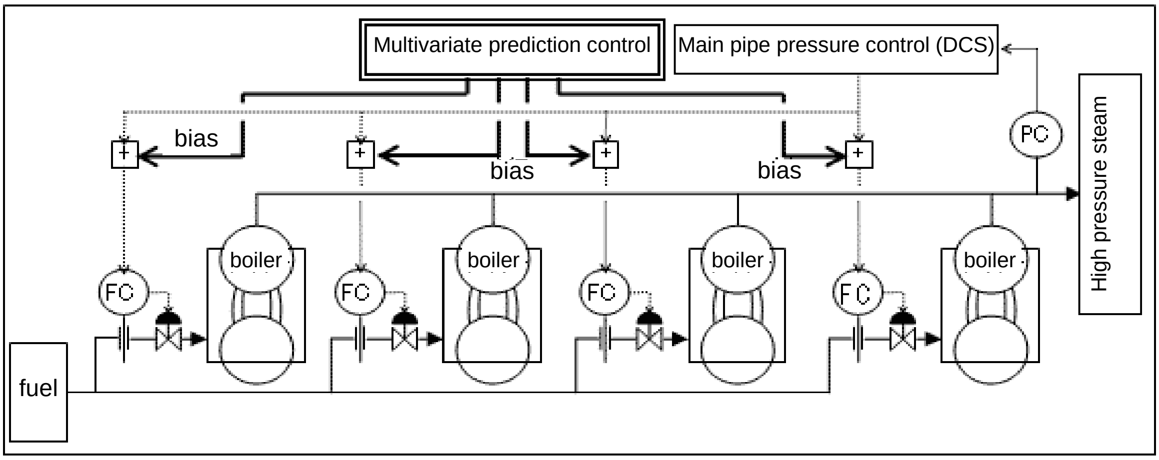

Fig. 3 boilers

(2) Changing the Turbine Load Control Method

Before modification of the control system

Because each turbine was controlling its outlet pressure, preferential control of turbines with higher efficiencies was not possible (Fig. 4).

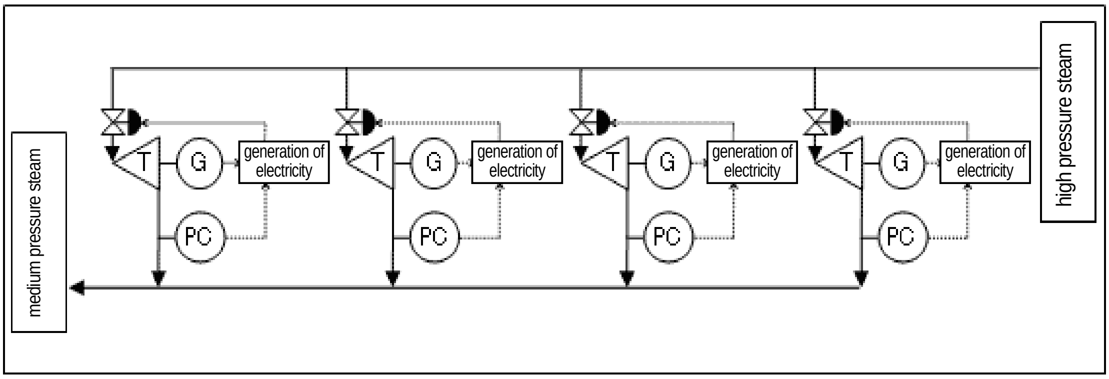

Fig. 4 steam turbine generator control (before modification)

After modification of the control system

From separate outlet pressure control, a method where all turbines control the common main pipe pressure was adopted. Then, we have created a mechanism to add bias from multivariate prediction control to the output of main pipe pressure control by DCS as in the case of boilers to realize control or preferential operation of turbines based on their efficiencies (Fig. 5).

There had been no previous cases of this turbine control system, so we conducted verification test of control performance for one week to ensure that there is no problem on following capacity of the pressure control. In addition, there is an added effect that pressure interference between adjacent turbines was eliminated and the main pipe pressure became more stable than before.

Sharing of functions between the controls is as follows:

➢DCS control: pressure control of middle pressure steam

➢multivariate prediction control: control of preferential operation of high efficiency boilers

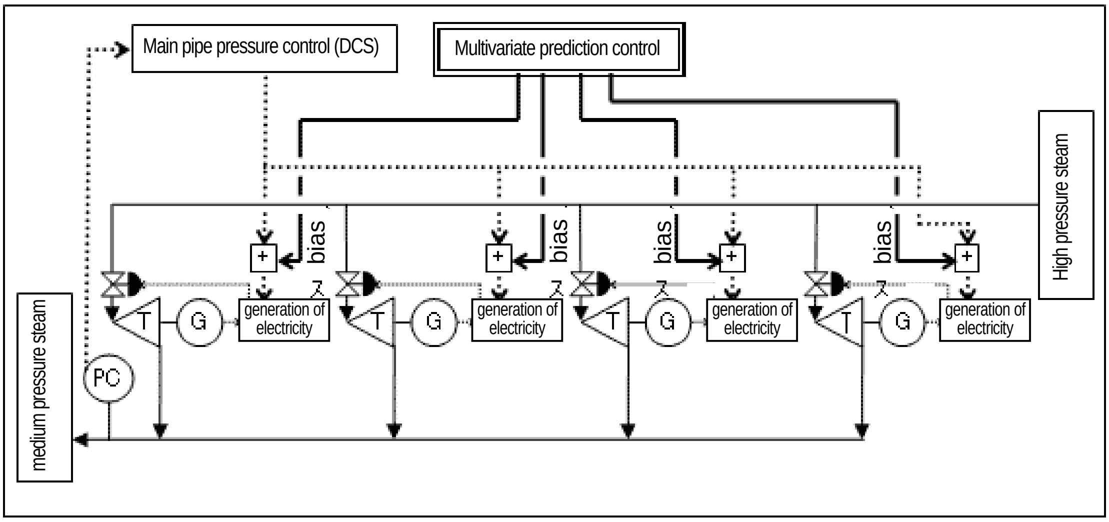

Fig. 5 steam turbine generator control (after modification)

(3) Changing Electricity Generation Control Method

Before modification of the control system

Electricity generation control is performed by gas turbines and condensed water turbines. Gas turbines control electricity generation with quick control while condensed water turbines control electricity generation with slower motion and, at the same time, keeps the output of gas turbines at a constant value (SP) (Fig. 6). As a result, to quickly respond to change of demand for electricity, gas turbines must operate with a margin to the maximum output

(High).

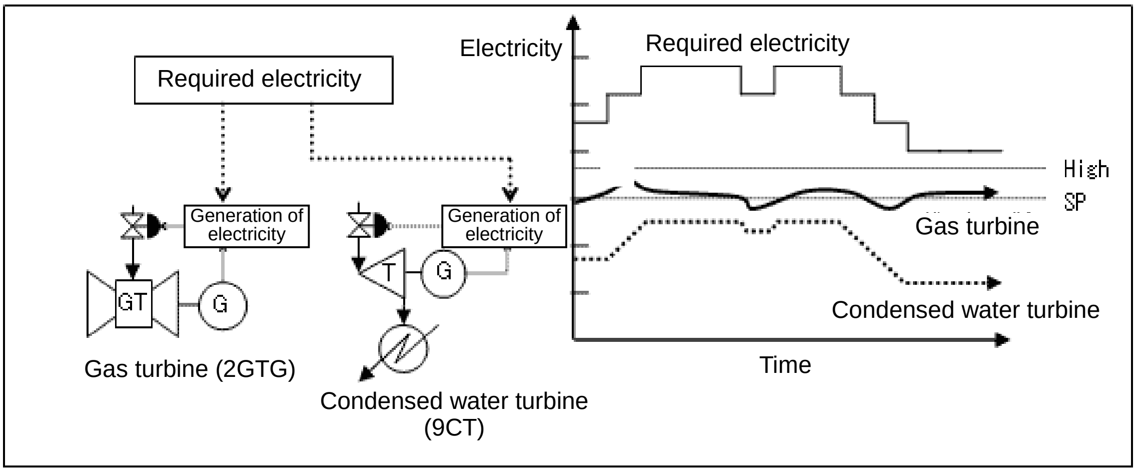

Fig. 6 Control of electricity generation at the same time and same amount control (before modification)

After modification of the control system

Because the condensed water turbines are operated at a slow rate to maintain gas turbine at a certain output value, we have assumed that they can be controlled by multivariate prediction control. Therefore, condensed water turbines were separated from the existing control and placed under control of multivariate prediction control (Fig. 7).

By this modification, electricity generation control by gas turbines is supplemented by both condensed water turbines and back-pressure turbines that are under control of multivariate prediction control, which enables keeping the condensed water turbines, whose efficiency is low, while operating the gas turbines, whose efficiency is higher, around the maximum output.

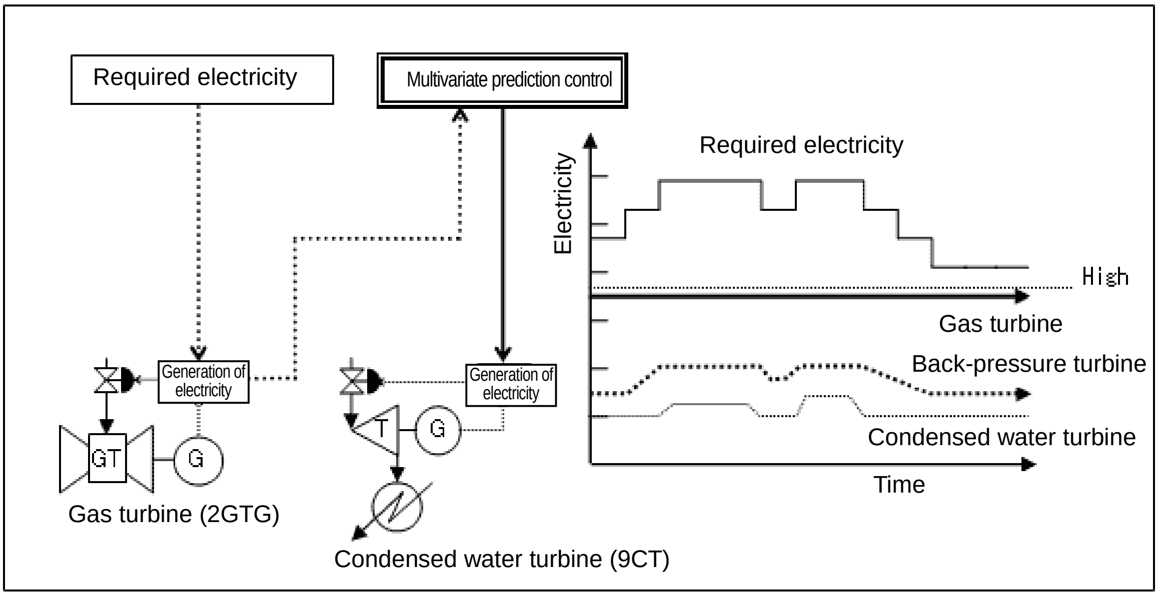

Fig. 7 Control of electricity generation at the same time and same amount control (after modification)

(4) Operation Before and After Introducing Multivariate Prediction Control

① Boilers

According to the priority (10B>9B>6B>5B), 10B with the highest efficiency is always maintained at high load and operation of other boilers is decreased in the order of lower efficiency facilities first when the load goes down, and operation of those with higher efficiencies is increased first when the load goes up, showing good control performance (Fig. 8).

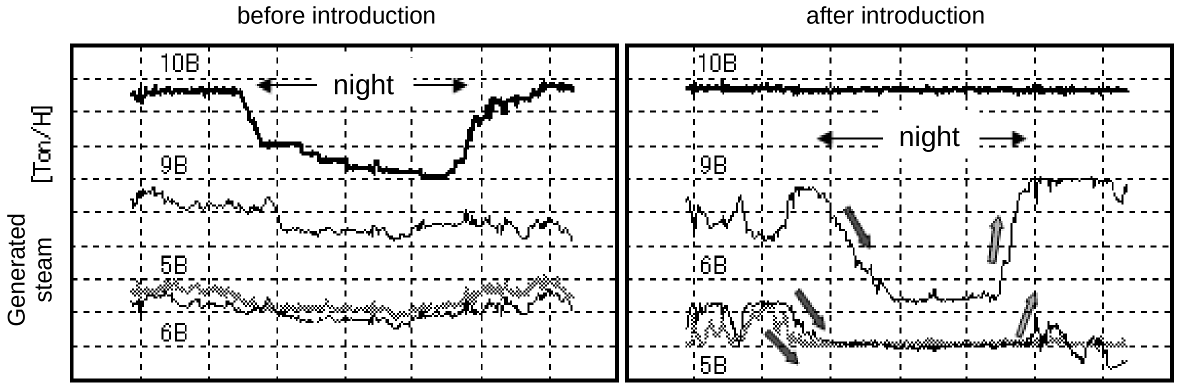

Fig. 8 Operation of boilers

② Turbine

Before introduction, loads of all facilities fluctuated in a similar way, but after introduction, loads are increased/decreased according to the priority (6BT>3BT>5BT>4BT), enabling to maintain high operation level of 6BT, whose efficiency is high (Fig. 9).

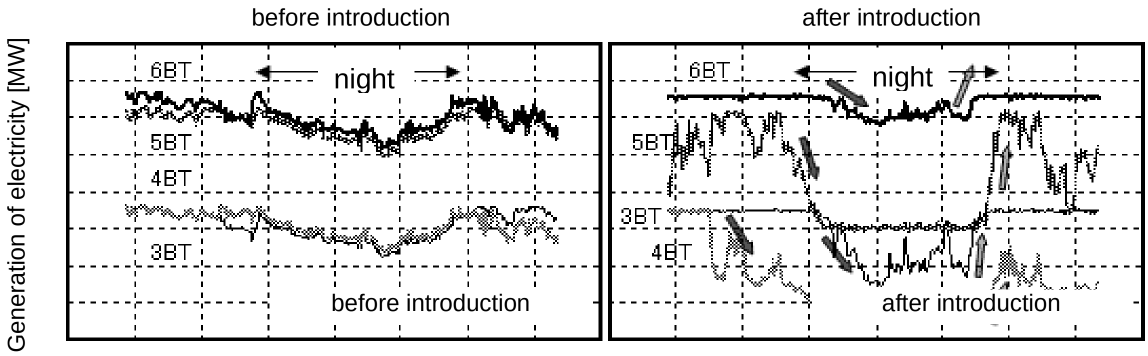

Fig. 9 operation of turbines

③ Generation of electricity

After introduction, operation of 9CT is kept as low as possible. For 2GTG, operation is almost kept at a high level except during the night when demand for electricity is low (Fig.

10).

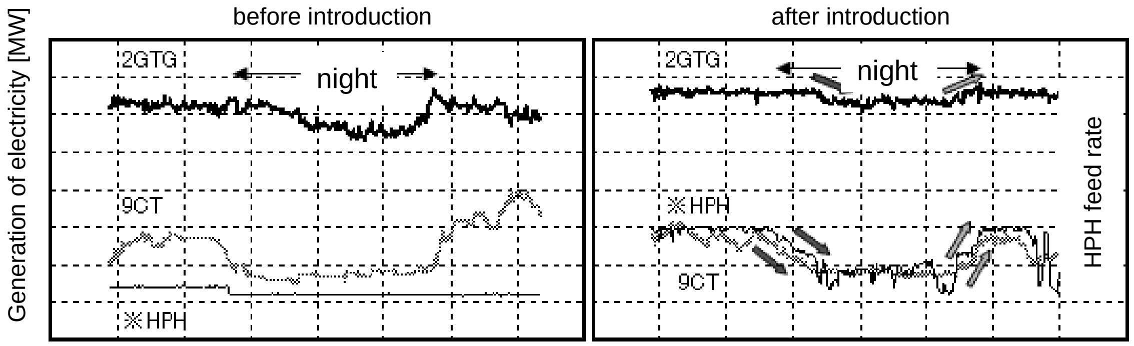

Fig. 10 Operation of facilities related to electricity generation

* HPH = high pressure feed-water preheater = a facility that collects excess middle pressure steam as heat. After introduction, it plays a part in minimizing operation of 9CT while supporting pressure control of middle pressure steam.

5. Effects Achieved after Implementing Measures

By optimizing operation of boilers and turbines in real-time, reduction of fuel use and reduction of CO2 is realized (Fig. 11).

- reduction of fuel use: 6,600 KL/year (fuel oil equivalent)

  (Reduction of CO2: 18,000 ton/year)

- money amount of energy saving: 160 million yen/year

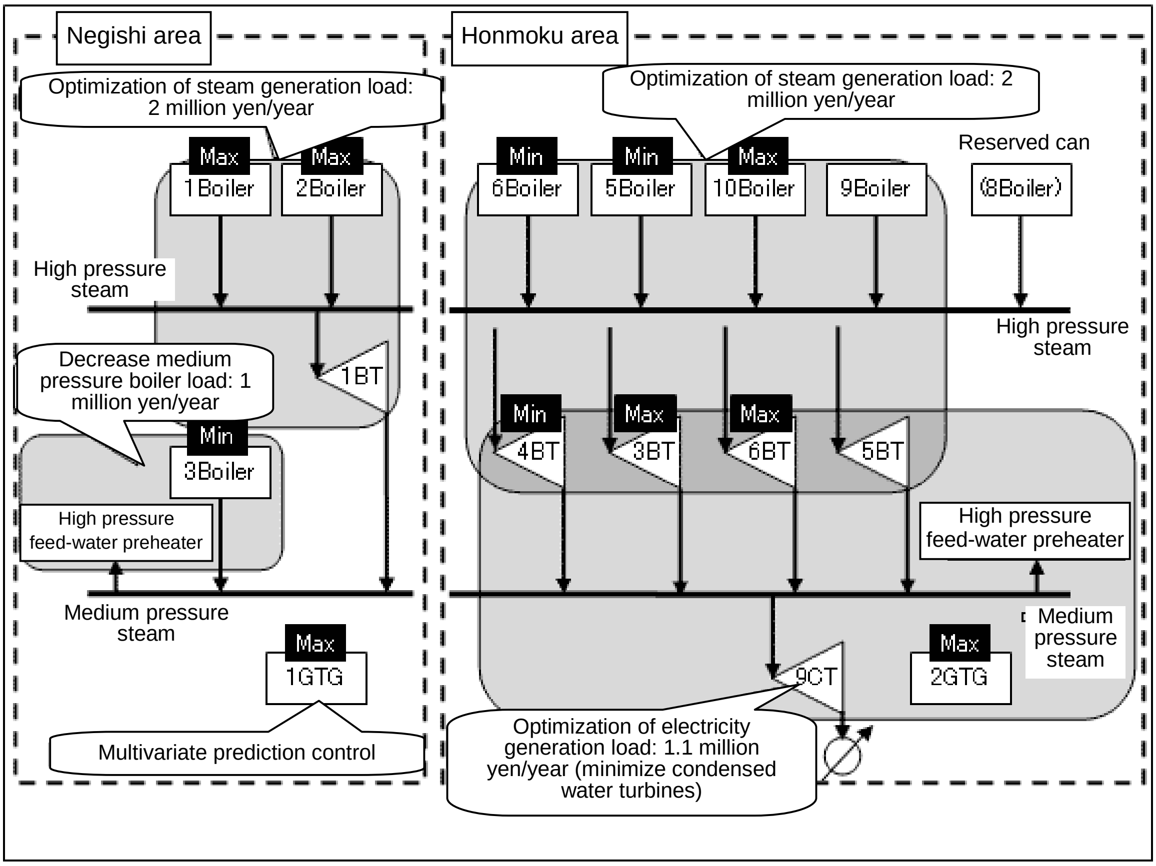

Fig. 11 Effect of measures (Max, Min shows typical operation status and facilities with no description perform load adjustment)

6. Summary

By realizing control to faithfully reflect the result of linear optimization calculation in real-time according to the ever-changing demands for electricity and steam, significant energy saving and reduction of CO2 have been achieved and we could contribute to prevention of global warming.

7. Future Plans

Advanced control has scarcely been introduced to motive power facilities in Japan previously, and this was the first attempt in our oil refineries. In the future, we would like to spread horizontally to other oil refineries to contribute to energy saving and environment protection.