

Energy-saving Solution by BTG Optimal Control

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In order to reduce operating costs, factories consuming large amounts of energy use boiler, turbine, and generator (BTG) systems to generate and distribute electricity and steam powered by commercial fuel and energy recovered in their premises. Because a BTG plant deals with huge amounts of energy, there is much room for improving energy-saving efficiency. This paper describes an application of optimal balance control for electric power and steam in BTG plants and its features. This control was achieved with Yokogawa's Exasmoc multivariable model predictive control package.

INTRODUCTION

The prevention of global warming is a critical challenge for the entire world and various efforts are being made to achieve a low-carbon society, such as

- reducing energy consumption,
- reducing CO₂ emissions due to the combustion of fossil fuels and other substances, and
- increasing CO₂ absorption by forests.

Recent rapid progress in computer technology has enabled the instrumentation to offer distributed control systems (DCS) with higher performance and reliability at lower cost. As a result, it has become relatively easy to achieve optimum operation control incorporating DCS, which was difficult a few years ago. These circumstances have made it possible to reduce CO₂ emitted from BTG facilities for private power plant, cutting energy costs, and efficiently operating the facilities.

Figure 1 shows the energy balance of a typical private thermal power plant. ⁽¹⁾ A private power generation facility supplies not only electricity but also thermal energy in the form of steam and hot water throughout the plant. In addition, the black liquor (wood-pulping by-product in paper plants), by-product gas (gas generated by blast furnaces, coke ovens, steel converters, etc. in steel plants), and residual oil (final residue after refining crude oil to produce petroleum products at refineries) are brought back from the manufacturing process to the facility for recovered energy. However, large amount of energy are still wasted, and so there is much room for improving the efficiency.

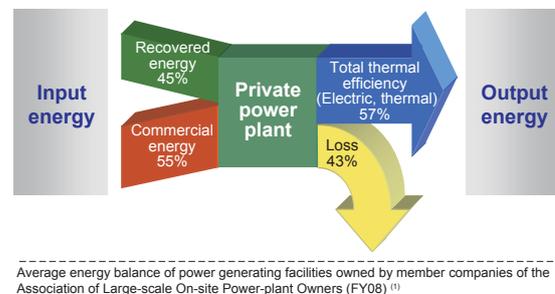


Figure 1 Energy Balance of a Typical Private Thermal Power Generation Facility

Multi-boiler and multi-turbine systems consisting of boilers, turbines, and generators (BTG) for private power generation consume much energy in the factory and so there is much room for improving its efficiency. This paper reports a solution for optimum operation control using a simulator and advanced control technologies, which calculate the optimum load balance of electricity and steam, and verify the effect of the system before the introduction.

APPLYING A OPTIMUM OPERATION CONTROL TO A BTG FACILITY FOR PRIVATE POWER GENERATION.

Figure 2 shows a typical configuration of a BTG facility for private power generation. The private power generation system must adjust the generation of electricity and steam based on continually changing demands from manufacturing processes. Moreover, it must make maximum use of the resources for recovered energy to offset the deficiencies of commercial energy such as coal and fuel oil while minimizing CO₂ emissions.

Unlike unit-based public-utility power generation systems, private power generation systems have complex steam piping, responses of the boilers vary by fuel, and various types of turbines are provided for condensation, back-

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pressure, and steam extraction. Therefore, the operating procedures are complex and operators must take great care to follow fluctuating demands due to changes in loads between day and night and adjustments in production processes.

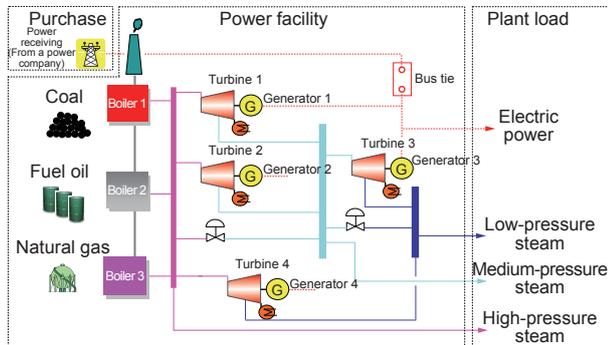


Figure 2 A Typical Configuration of a BTG Facility of a Private Power Generation System

Our effect-verification simulator can verify the effect of a BTG multi-boiler and multi-turbine facility before introducing it by calculating the optimum load balance of electricity and steam. The Exasmoc multivariable model predictive package can respond quickly to the above-mentioned processes with a large degree of freedom and achieve the ideal operation. This simulator is an engineering tool that embodies the know-how we have accumulated on the operation of BTG facilities. For advanced process control by Exasmoc, refer to “Energy-saving Solutions by Advanced Process Control (APC) Technology” in this issue.

- The effect-verification simulator can estimate the reduction in energy costs and CO₂ emissions by comparing the main steam flow calculated based on the actual demand for electricity and steam under various constraints with that of actual operating data.
- Exasmoc, which achieves an advanced process control, can be applied to control systems which cannot be stably controlled by conventional PID due to disturbances, dead time, inverse response, mutual interference, etc. Exasmoc improves the controllability and reduces fluctuations in the process values, so the target value of PID control can be brought closer to the operational limits (upper or lower limit values allowed during the operation), thus minimizing energy consumption. In this paper, such operation is referred to as a “limit operation.” Optimum operation control can reduce energy consumption while maintaining stable operations, reducing not only operating costs but also the workload for operators.

EFFECT-VERIFICATION SIMULATOR

The effect-verification simulator is outlined below. It simulates an optimum combination of boilers, turbines and generators, taking account of the capacity of each equipment and energy unit prices. Figure 3 shows a configuration of the simulator.

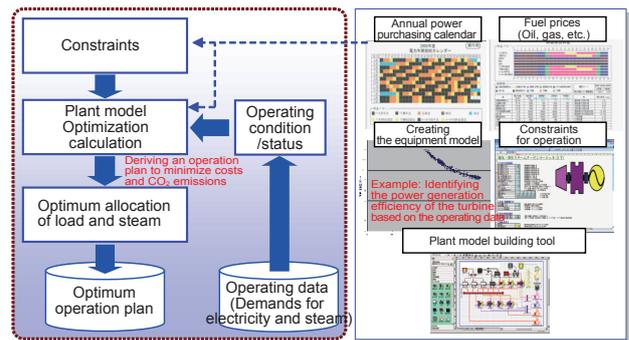


Figure 3 Effect-verification Simulator

Creating a plant model and deriving an optimum operating plan

The characteristics and operating restrictions of boilers, turbines and generators which make up the plant are represented as mathematical models using a model description language. Using these mathematical models and mathematical programming, the simulator can solve the optimization problem, identify optimum operating patterns, and derive an optimum operating plan (optimum load balancing).

Basic model equations for equipment, energy balancing, and objective function are shown below. Many these equations are combined to construct the accurate model for each plant.

- Basic model equations for equipment

The output energy from equipment is assumed to be proportional to the input energy (electricity, steams, etc.). For equipment having nonlinear output and input characteristics, an interval linear approximation is applied as shown below.

$$y_j = \sum a_i x_i + b_j \delta_j$$

$$x = \sum x_i \quad x_{\min} \cdot \delta_j \leq x \leq x_{\max} \cdot \delta_j$$

i : Interval number

j : Equipment number

x_i : Input energy

a_i, b_j : Characteristic parameter

x_{\min} : Lower limit of input energy

x_{\max} : Upper limit of input energy

y_j : Output energy

δ_j : Integer variable indicating Start (1) and Stop (0)

- Basic model equations for energy balancing

The supply-demand balance of energy (electricity, steam, heat, etc.) used in the process is as follows.

$$E_{\text{gen}} + E_{\text{buy}} = \sum E_i + E_{\text{demand}}$$

E_{gen} : Energy generated by the equipment

E_{buy} : Energy purchased from outside

(example: purchased power)

E_i : Energy consumed by the equipment

E_{demand} : Energy demand

- Basic model equations for objective function

The objective function in the case of the minimum operating cost mode is as follows.

$$\text{Minimize } J = J_{\text{en}} + J_{\text{op}} + J_{\text{pn}}$$

$$J_{en} = \sum J_{cost,j} : \text{Energy cost}$$

$$J_{op} = \sum (c_j \times | \delta_j(k-1) - \delta_j(k) |)$$

: Energy loss due to the start and stop of equipment

$$J_{pn} = \sum p \cdot E_{rest} : \text{Penalty for excessive supply over demand}$$

c_j, p : Parameter, k : Time

A support tool utilizing Visio is used for creating plant models. Constraints such as equipment capacity, upper and lower limit, etc. are entered into Excel worksheets.

Example of creating a model equation for equipment

A model equation for equipment can be created by the approximation using the equipment operating data. Creating a model for a turbine is explained here. Figure 4 shows the turbine model, and Figure 5 shows the approximation using the operating data for creating the model equation.

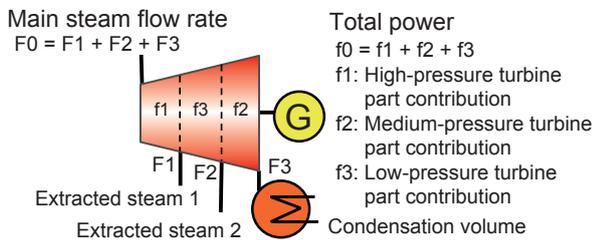


Figure 4 Turbine Model

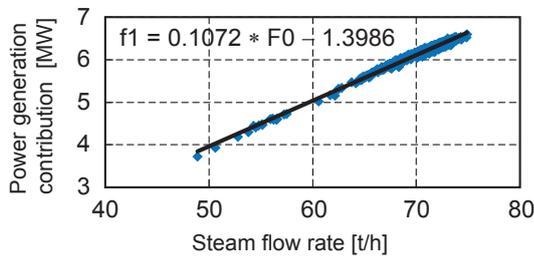


Figure 5 Approximation for Creating the Model Equation

Contribution f1 of the high-pressure turbine part to the total amount can be expressed as a function of the main steam flow rate F0. In the same way, the model equation of f2 can be expressed using F0–F1 and f3 using F0–F1–F2. The calculation is based on the assumption that the steam energy consumed at each turbine part contributes to f1, f2 and f3 respectively.

Example of assessment using the effect-verification simulator

The simulator proved that the main steam flow could be reduced by about 1% as shown in Figure 6 by optimizing the steam extraction balance while satisfying the demands for electricity and steam. Although the amount reduced may fluctuate depending on the equipment and fuel prices, it is estimated that for a 500-ton/hour boiler, about 100 million yen can be saved annually.

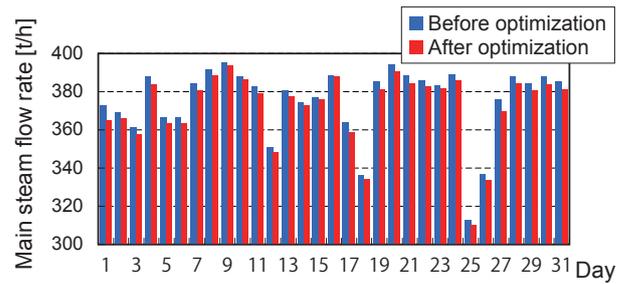


Figure 6 Reducing the Main Steam Flow

OPTIMUM OPERATION CONTROL BY EXASMOC

The Exasmoc controller performs the following control functions while keeping various constraints. Figure 7 shows how the Exasmoc controller performs the various controls functions.

- Calculating the optimum ratio of purchased power and private power generation, taking account of the difference of power prices and CO₂ emissions conversion factors
- Performing the limit operation applying the calculated optimum amount of private power generation as the operational limit
- Performing the limit operation applying the main steam at the allowed upper limit temperature to improve the turbine efficiency
- Performing the limit operation applying the required steam pressure as the operational limit

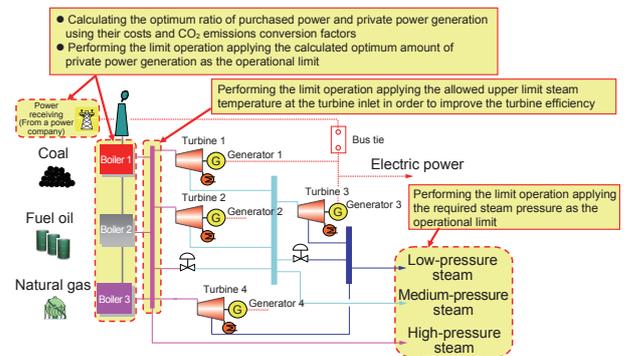


Figure 7 Applying the Optimum Operating Control by Exasmoc to BTG Facilities

Building and adjusting the Exasmoc controller

The standard procedure for building and adjusting the Exasmoc controller is described below. This can easily be done by any engineer who has knowledge of advanced process control at a certain level.

- 1) Determining the variables of the Exasmoc controller
For optimum operation, manipulated variables (MV) and control variables (CV) for the controller, and disturbance

variables (DV) uncontrollable for the controller are determined. Table 1 shows examples of manipulated variables and control variables in this application.

Table 1 Examples of Manipulated Variables and Control Variables

| Manipulated variables (MV) | Control variables (CV) |
|---|--|
| Boiler load, Turbine load, Exhaust steam pressure, Mixing steam for turbine, Extracted steam volume, Amount of power generated, Opening of pressure reducing valve, Opening of atmospheric release valve | Boiler constraints (Feed water volume, fuel volume, gas burner differential pressure, etc.), Turbine constraints (Amount of power to be generated, steam temperature, steam volume, etc.), Power constraints (Amount of power to be sold, amount of power to be purchased, etc.), Condensation flow rate, Boiler exhaust gas properties, Steam pressure |

2) PID Retuning

PID parameters, which are the basis of feedback control, are adjusted. The purpose of this retuning is to improve the response of the controller when the values calculated by the controller are set as the set values of the PID function block. This operation requires an optional dedicated tool for evaluating the controllability.

3) Process response test

The controller is equipped with process response models, which are created by performing process response test. To identify the correlation among the manipulated variables (MV), disturbance variables (DV) and control variables (CV), variables are changed stepwise according to the plan.

4) Creating a process response model

A process response model is created by identifying the dead time, gain, time constant, etc. of the response based on the data obtained in the test. As shown in Figure 8, parameters are adjusted by comparing the values simulated by this model with those of the actual operation to improve the quality of the model.

5) Setting constraints and parameters

Control target values and constraints such as upper and lower limits of various variables are set. Also, input-output correspondence for the interface with DCS are specified.

6) Off-line simulation

Off-line simulation is executed to confirm the optimization performances of the controller and parameters (priority, weighting, etc.) are adjusted.

7) DCS integration test, commissioning and adjustment

Commissioning is executed operating the controller online and connecting with the DCS, and necessary adjustments are performed.

8) Evaluating performance and verifying effects

The effects of this control system are confirmed by comparing optimization control items, amount of energy saving and others before and after introducing optimum operation control



Figure 8 Simulation Using a Process Response Model

Examples of effects of optimum operation control

Figure 9 shows the effects of using the Exasmoc for low-pressure steam control. The fluctuations clearly became smaller, showing that there is bigger allowance against the operational limit and the system can be operated at lower target values of steam pressure by introducing optimum operation control.

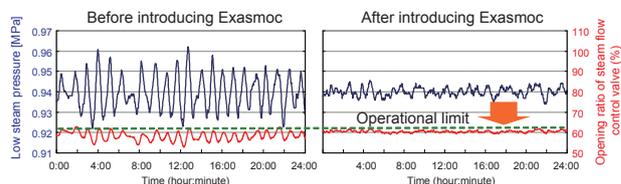


Figure 9 Effects of Introducing Exasmoc

CONCLUSION

The optimum operation control technology described in this paper has significant energy-saving effects. There are many other benefits of optimizing BTG facilities in addition to those mentioned in this paper. We believe that by combining other energy-saving control technologies, it is possible to reduce energy, costs and CO₂ emissions by more than 5%.

We will advance the introduction of our optimum operation control technology to the oil, chemicals, pulp and paper, and steel industries having large BTG facilities. BTG optimum operation control can significantly conserve energy and reduce costs and CO₂ emissions without requiring large capital investments. However, we will improve this technology to enable it to be introduced more easily and at lower cost, thus helping achieve a low-carbon society and a brighter future.

REFERENCES

(1) Association of Large-scale On-site Power-Plant Owners (JIKACON), <http://www.jikacon.com/>

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