

# Energy Optimization System for Cogeneration Plant of Paper Factory

TATTA Naoto \* KANEHIRA Yoshiji ‡

## ABSTRACT

A cogeneration plant provides steam and electric power required for paper factories. Fuji Electric has developed and delivered an energy optimization system for the cogeneration plant of a paper factory. The system is capable of monitoring the state of various facilities, including power/steam loads and the amount of steam produced by an exhaust-heat recovery boiler, which fluctuate greatly in the factory. The system can thus optimize the operation in real time according to the supply-demand balance of power and steam. Since the system automatically optimizes loads so that contracted electricity limits are never exceeded at times of excessive steam loads, while also ensuring that there is no inverse power flow during times of steam shortages, the cost of installing the system can be confirmed to be recovered in one year.

## 1 Introduction

Cogeneration facilities first went on the market in the 1980s. With growing electric demand, cogeneration facilities are introduced at the time of renewing equipment such as boilers or converting energy sources from heavy oil to natural gas, intending to attain energy-saving and cost-saving. They are in wide use at plants, industrial facilities, etc. Although the introduction of cogeneration facilities slowed down because of the recent steep rise in the price of crude oil, the number of utility customers introducing cogeneration facilities has been on the increase since the Great East Japan Earthquake as they think it important to ensure electric power for themselves.

We proposed a cogeneration system for a paper-making factory, and accepted an order to develop and deliver the system. This paper provides an overview of the system that optimizes energy-saving operation of the cogeneration facility.

## 2. Cogeneration Facility

### 2.1 Overview of the cogeneration facility

An overview of the cogeneration facility of the paper-making factory to which our energy optimization system was delivered is shown in Fig. 1. This facility consists of a gas turbine, generators, an exhaust gas boiler, a steam turbine, a waste heat recovery boiler, and an auxiliary boiler, etc. The exhaust gas boiler is designed to enable reheating.

The electric power required for the factory (electric load of the factory) is provided by the electric power

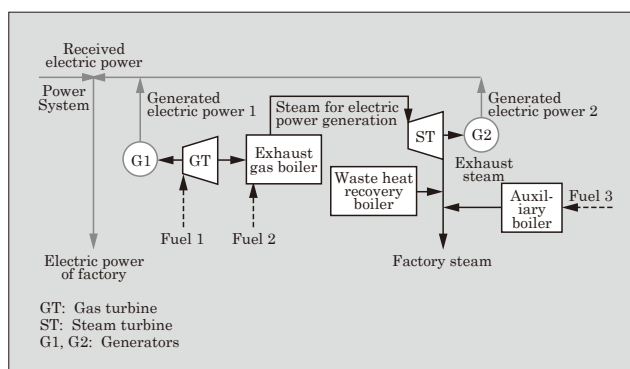


Fig.1 Overview of the cogeneration facility

received from the electric power company and the electric power generated by the combination of the gas turbine generator and steam turbine generator which are installed inside the factory. The steam consumed in the factory (steam load of the factory) is provided by exhaust steam from the steam turbine and steam from the waste heat recovery boiler and the auxiliary boiler.

### 2.2 Operation of the cogeneration facility

The electric and steam loads of the factory significantly vary depending on the operating state of the factory or the season, and the volume of steam generated by the waste heat recovery boiler varies as well. What is most required for the cogeneration facility is the ability to supply the proper volumes of electric power and steam in response to greatly varying electric power and steam needs of the factory just enough without delay.

The cogeneration facility is operated in the following three patterns depending on the steam load of the factory and the supplying state of steam:

(1) During normal operation

\* Industrial Infrastructure Business Group, Fuji Electric Co., Ltd.

‡ Sales Group, Fuji Electric Co., Ltd.

When the operation of the factory is at normal state, each of electric power supply and the volume of generated steam are in balance with the factory's electric load and steam load respectively, and steam supply is automatically regulated by operating the gas turbine with maximum load and bringing the steam turbine into backpressure mode.

As the electric load of the factory slightly decreases, received electric power is monitored to avoid unnecessary electric power generation so as to minimize reverse power flow.

(2) When steam is excessive

The steam load of the factory is decreased if the operation level of the factory is relatively low, and steam becomes excessive when the waste heat recovery boiler is in operation. In these situations, excessive steam will be inevitably released. To reduce the volume of steam to be released, the steam turbine will be placed in output operation mode, which keeps the volume of exhaust steam from the steam turbine constant, and operated with pressure controlled by a steam release valve. The factory will be monitored to prevent demand over\*1 because the amount of electric power generated decreases.

(3) When steam is insufficient

Even though the operation of the factory is at a normal level, the waste heat recovery boiler may stop operation and the factory may fall short of steam, just for a short period. In this case, the auxiliary boiler will be operated to make up for insufficient steam. The steam turbine will be operated in backpressure operation mode. The factory will be monitored to prevent a reverse power flow because the amount of electric power generated increases.

### 3. Energy Optimization System

#### 3.1 Configuration of the energy optimization system

The configuration of the energy optimization system introduced this time is shown in Fig. 2, and its functions are described in Table 1.

This system collects data about the operating state of the cogeneration facility through an existing PLC for data collection. The manufacturing and energy analysis assisting package of Fuji Electric Co., Ltd., "MainGATE"<sup>(1)</sup>, is introduced and used to accumulate and analyze data.

On the operation console for the energy optimization system, three optimum operation mode switches (optimization during normal operation, optimization when steam is excessive, and optimization when steam is insufficient) are provided, and they can be turned on and off any time. The screen of the operation console displays the state of the cogeneration facility, current values and other data, enabling to grasp the operating

\*1: Demand over: Exceeding the upper limit of the contracted power reception amount.

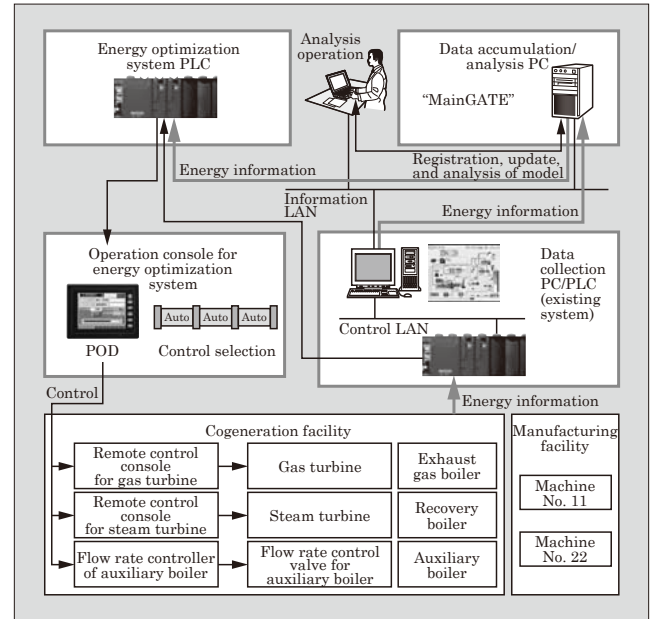


Fig.2 Configuration of energy optimization system

Table 1 Functions of energy optimization system

| Unit                                             | Function                                                                                                                                                                                                              |
|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Data accumulation/analysis PC                    | Accumulates and displays data to promote visualization.                                                                                                                                                               |
|                                                  | Estimates the characteristics of the boiler and turbine by using collected data.                                                                                                                                      |
| PLC of energy optimization system                | Optimizes the state of the cogeneration facility during normal operation. (Input load increase and decrease signals, etc. into the remote control console for the existing gas turbine.)                              |
|                                                  | Optimizes the state of the cogeneration facility when steam is excessive. (Input load increase and decrease signals, etc. into the remote control console for the existing steam turbine.)                            |
|                                                  | Optimizes the state of the cogeneration facility when steam is insufficient. (Input setting values, etc. into the flow rate controller for the auxiliary boiler.)                                                     |
| Operation console for energy optimization system | Activates and deactivates the automatic operation of the energy optimization system. In automatic control, displays necessary information on the POD. Inputs constants and setting values of parameters with the POD. |

state of this energy optimization system at a glance. In addition, all parameters for tuning can be set and changed on the screen and are easy to adjust. Output from this energy optimization system is input directly into the remote control console for the existing gas turbine and steam turbine, and flow rate controller of the auxiliary boiler.

#### 3.2 Features of the energy optimization system

Optimum operation means preventing demand over or reverse power flow, reducing the volume of steam released to zero, selecting more inexpensive

fuel, and reducing the volume of fuel consumption. However, optimum operation is, in fact, difficult to achieve in manual mode because constant monitoring is required and there is difference in performance among operators. Great energy saving and operation efficiency can be expected by employing automatic operation using the energy optimization system.

This energy optimization system is characterized by the software and hardware functions described below. The system is intended to implement automatic operation in real time with adequate consideration given to safety, and it realizes optimum operation by making the most of the measurement and control devices for the existing gas turbine and steam turbine.

#### (1) Functional features of software

An existing control system has been prepared for controlling each of the existing gas turbine, steam turbine and exhaust gas boilers.

This energy optimization system is positioned as a set point control (SPC) system that gives these control systems setting values. From the viewpoint of making use of the existing measurement and control devices and ensuring safety, the energy optimization system was designed as a speed type SPC that gives differences from current set values, not a position type SPC designed to give setting values to lower-order control systems. Thus, even if an error occurs to this energy optimization system, the cogeneration facility can continue operating safely by separating this energy optimization system.

A heuristic approach is used for the algorithm and is capable of bringing values to optimum ones with the appropriate process values from the existing measurement and control devices. Tools, such as the energy optimization assisting package “FeTOP,”<sup>(2)</sup> are used to conduct simulations while verifying the effectiveness of the algorithm.

#### (2) Functional features of hardware

The existing gas turbine and steam turbine are equipped with a remote control console, which, in combination with a dedicated controller, makes it easy for the operator to operate the turbines. These operation consoles were made available with this energy optimization system by modifying them to become capable of receiving pulse signals from the system. In addition, since the energy optimization system can be used with existing systems, the cogeneration facility can be operated and used in the same manner as before using the existing control device and remote control console when this energy optimization system is not used. This energy optimization system realizes energy saving and is designed to deactivate functions and promptly switch the cogeneration facility to operation by the operator in case of emergency.

### 4. Effect of Introduction

The scale and payback period of the energy opti-

mization system can be estimated by making a trial calculation of the effect of introduction. A trial calculation of the effect before introduction is extremely important for an optimization system like this energy optimization system because it significantly affects the decision of whether or not to introduce the system. It is also necessary to verify the actual effect of the system after introduction.

#### 4.1 Trial calculation of the effect of introduction

Fuji Electric has a standardized procedure for making a trial calculation of the effect when using FeTOP, and the same procedure was applied to this energy optimization system (see Fig. 3).

We made optimization calculations using an optimization model of the cogeneration facility and trial calculations of the effect of introduction under various conditions based on time-series data obtained from the customer, which indicated the operating state of the cogeneration facility. Time-series data was easily collected from this cogeneration facility with the aid of the data collection system “BEST” of Fuji Electric. Thus, we could make trial calculations effectively and efficiently in a relatively short period.

Based on the results of the trial calculations, we revealed problems in each of the three operation patterns shown below and solutions to them.

#### (1) During normal operation

A reverse power flow occurs when the gas turbine is operated with maximum load if the electric load of the factory is decreasing. The load of the gas turbine is required to reduce to prevent a reverse power flow, but it is difficult to set and operate the gas turbine in manual mode while monitoring received electric power at all times. For this reason, the gas turbine load was reduced, and as a result, the factory was operated in a state with excessive received electric power than required.

Received electric power can be reduced by predicting the electric load in real time and operating the gas

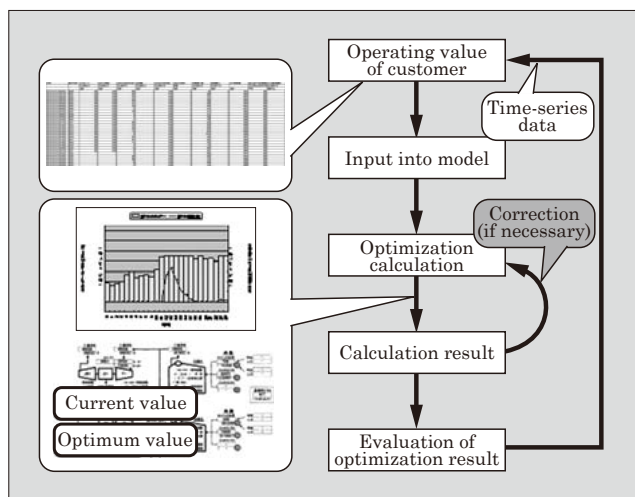


Fig.3 Procedure for trial calculation of introduction effect

turbine with limit load that does not cause a reverse power flow.

(2) When steam is excessive

It is desirable that the exhaust gas boiler be operated with minimum load to reduce the volume of steam released. This operation requires the output setting value of the steam turbine placed in output operation mode to be set while monitoring the pressure fluctuation of the exhaust gas boiler and other data.

However, the set output value tends to be slightly higher because it is difficult to operate the exhaust gas boiler in manual mode while constantly monitoring the pressure fluctuation of the boiler, etc., and the boiler has been operated in such a manner that the volume of steam released could not be reduced.

The fuel cost of the exhaust gas boiler can be cut down by safely operating it in automatic operation mode with load close to minimum load and reducing the volume of steam released.

(3) When steam is insufficient

The volume of steam from the auxiliary boiler is desired to minimize in view of energy saving. To achieve it, the load of the exhaust gas boiler should be maximized, but it is subjected to flow rate fluctuation at all times because the steam turbine is set in backpressure control mode. Maximizing the load of the exhaust gas boiler in this state involves a high risk and requires constant monitoring. However, constant monitoring operation is difficult to perform in manual mode, and the auxiliary boiler has been operated with a higher load.

The fuel cost of the auxiliary boiler can be reduced by safely operating the exhaust gas boiler in automatic operation mode with load close to the maximum.

Based on these operation modes and solutions, we converted loss in each operation mode into an amount of money and calculated how much could be saved annually.

When we added up the results of the trial calculations of the effect of introduction, it was estimated that the factory would be able to reduce its unit consumption rate in terms of LNG to approximately 1.5 Nm<sup>3</sup>/t of paper. This indicates that the cost invested in the introduction of the energy optimization system could be recovered in only two years.

#### 4.2 Actual effects of the introduction of the energy optimization system

We have confirmed that more than 3.0 Nm<sup>3</sup>/t of paper in the unit consumption rate in terms of LNG can be reduced annually on average when the calculated results of all patterns are summed up. This value is about twice the effect estimated from the trial calculation before introduction, which is equal to recovering the cost incurred by the introduction of the system in one year. The following three probable reasons are considered:

(a) When steam is excessive, the amount of gener-

ated electric power is decreased because of the suppression of the production of steam, and demand over is consequently apt to occur. In the past, the facility was operated with a higher amount of electric power generated than the necessary level to avoid this state. This energy optimization system succeeded in cutting down fuel costs by expanding functions during normal operation and operating the gas turbine in automatic operation mode with limit load that does not cause demand over. This effect was identified in adjustment operation after the introduction of the system.

- (b) When steam is insufficient, the amount of electric power generated is increased because the production of steam increases, and as a result, a reverse power flow tends to occur. In the past, the facility was operated with a lower amount of generated electric power than the necessary level to avoid this state. This energy optimization system successfully reduced received electric power by using functions during normal operation as they were and operating the gas turbine in automatic operation mode with limit load that does not cause a reverse power flow. This effect was also confirmed in adjustment operation after the introduction of the system.
- (c) The energy data analysis function of the energy optimization system made it possible to perform parameter tuning in order to bring the cogeneration facility close to the optimum operating state promptly and safely, resulting in extended optimum operation time and an expanded effect.

#### 5. Postscript

This paper described the energy optimization system introduced to cogeneration facility of a paper-making factory. This system was adjusted and delivered to the factory in November 2012 and has been operating in good condition since then.

With regard to production plants in other fields consuming much electric power and steam, their cogeneration facilities are similar in their configurations composed of turbine, generator and boiler as well as load patterns, although their quantities and capacities are different. Thus, the effects described herein can apply to the cogeneration facilities of production plants in various fields.

With the steady realization of the smart community concept, plants having a cogeneration facility will also be required to promote more advanced energy management, such as harmonization with nearby residents and peak saving of energy, as community members. We will further study energy-saving operation through the effective use of this energy optimization system, as well as new energy management systems.

## Reference

- (1) Azumaya, N. et al. Energy Management Solutions to Support Energy Conservation Activities. FUJI ELECTRIC REVIEW. 2012, vol.58, no.1, p.9-13.
- (2) Koide, T. et al. Optimal Operation System for Energy Plants. FUJI ELECTRIC REVIEW. 2008, vol.54, no.3, p.89-93.





\* All brand names and product names in this journal might be trademarks or registered trademarks of their respective companies.