Fuel, Electric Power and Steam Supply-and-Demand Guidance System in Steel Works

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Abstract:

In order to minimize the loss of energy such as fuel, electricity and steam in steel works, JFE Steel has developed a system to provide a guidance to operators on the optimal energy supply and demand operation. Conventional operation relied heavily on the experience and intuition of experienced operators, which limited the reduction of energy loss. By applying this system, the optimal operation can be carried out regardless of operators' experiences. As a result, JFE Steel was able to achieve a reduction in the amount of city gas used and the amount of by-product gas and steam emitted.

1. Introduction

Because the production processes in steel works require large amounts of energy in the forms of fuel, electric power and steam, and also emit large amounts of CO_2, minimizing energy loss is a critical issue from the viewpoints of energy conservation, improvement of cost competitiveness and reduction of CO_2 emissions.

JFE Steel developed a technique (hereinafter, supply-and-demand prediction model) that enables highly accurate predictions of the energy supply-and-demand condition up to several hours in advance based on various types of measurement data and the production plan data of each plant, and a technique (hereinafter, optimum management simulation) that obtains the optimal plan for energy supply-and-demand operation in order to minimize energy loss based on the results obtained from the supply-and-demand prediction model [1,2], and materialized these techniques in actual equipment as a system which supports optimal energy supply-and-demand operation by operators.

This paper first describes the features of energy supply-and-demand operation in a steel works, and then presents an outline of the above-mentioned system and an example of the results obtained by its application.

2. Energy Supply-and-Demand Operation in Steel Works

The energy flow in a steel works is shown in **Figure 1**.

The byproduct gases used as fuel in a steel works are mainly generated by the blast furnaces, coke ovens and Linzer Donawitz (LD) converters and are called B gas, C gas and LD gas, respectively. The mixed gas obtained by mixing these gases and adjusted the heating value is called M gas. The works has gas holders corresponding to the type of byproduct gas, which store these gases as a buffer. Although these gases are supplied to the plants in the steel works on a priority basis, when the supply is insufficient for demand on the plant side, this shortfall is covered by purchasing city gas from an outside supplier. Byproduct gases are also supplied to power plants, and here as well, when the supply is insufficient for the specified amount, the shortage is made up by purchasing heavy oil from outside. Conversely, when the supply of byproduct gases exceeds demand and also exceeds the upper limit of the storage capacity of the gas holders, the gases are detoxified and then emitted outside the works.

Electric power is generated by equipment such as coke dry quenching (CDQ) facilities, boiler turbine generators (BTG), etc. and supplied to the production plants, and when this is insufficient for demand by the plants, the shortage is covered by purchases from an external electric power company. However, the amount that can be purchased has an upper limit which is specified in the contract with the power company, and the unit price also differs depending on the time period of

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a day.

The steam used in the steel works is supplied by recovery of waste heat from the LD converters and sintering furnaces and extraction of steam from the CDQ and BTG boilers. Like byproduct gases and electric power, when supply does not meet demand, the shortage is covered by purchases from outside by maintaining supply-and-demand balance.

Operation management of the energy described above is performed by operators under a 24-hour, 365 day-a-year system by a department called the Energy Center. Allocations of byproduct gases to each production process, power generating facility, etc. and decisions on the amount of purchases of electric power, heavy oil, city gas and other outside energy are made with an orientation toward minimizing energy loss due to emission of byproduct gases and cost loss due to outside purchases.

However, because the energy supply-and-demand structure of a steel works is extremely complex due to the diverse combinations of those allocations and operational restrictions, it is difficult to perform the optimal energy supply-and-demand operation continuously without systematic support. Conventionally, this operation relied heavily on highly-experienced veteran operators, and as a result, there were limits to the reduction of energy loss and cost loss.

Based on the background outlined above, JFE Steel developed a guidance system which enables even young operators with little experience to continuously perform energy supply-and-demand operation that minimizes energy loss at the same level as experienced veteran operators.

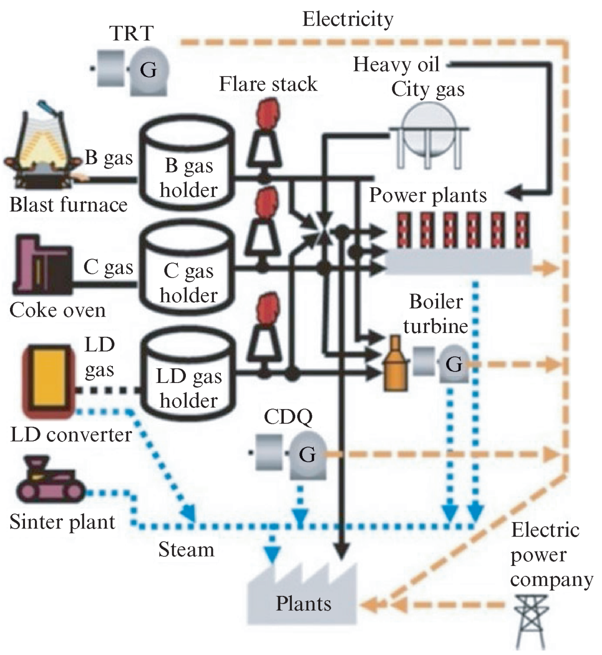

Fig. 1 Energy flow in steel works

3. Overview of Guidance System

The overall configuration of the guidance system is shown in **Figure 2**. The following sections describe the implementation environment and the information linkage functions, supply-and-demand prediction and optimization functions and screen functions that comprise this system.

3.1 Implementation Environment

This system is implemented on the JFE Steel private cloud called J-OSCloud, which belongs to the IT area.

Normally the management system and operational system are implemented in separate areas termed the IT (information technology) area and the OT (operational technology) area. For example, the user terminals which users use for email, document creation and the like belong to the IT area, and direct access to the OT area from a user terminal is in principle prohibited for security reasons.

Implementation of the new system in the OT area

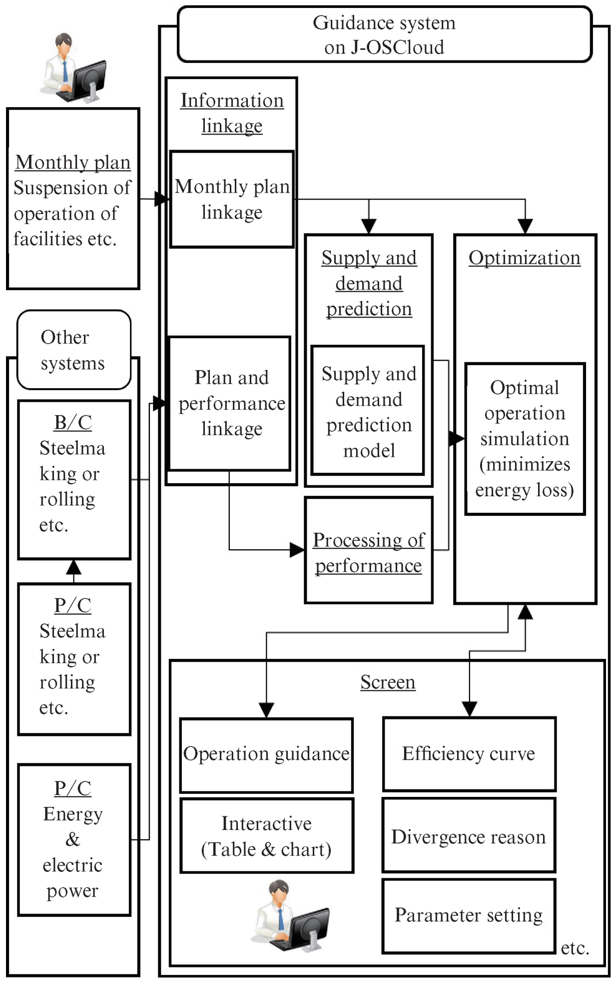

Fig. 2 Overall configuration of guidance system

would have the advantage that the optimal operational plans that provide guidance to operators could be linked easily to other operational systems in the future. However, the system was implemented on J-OSCloud, which belongs to the IT area, from that viewpoint that implementation in the IT area will enable higher work efficiency because technical staff who are not assigned full-time to the Energy Center can manage operations and analyze results remotely by sharing information with the operators in the Energy Center by accessing the system from their own user terminals, and the viewpoint that flexible adoption of state-of-the-art technologies can be expected when functionalities are expanded in the future.

3.2 Information Linkage Functions

The information linkage functions comprise the production plan and performance data linkage function and the monthly plan linkage function. The production plan and performance data linkage function collects the production plans of each plant, which are managed by business computers in the IT area, and the various types of measurement data and performance data managed by process computers in the OT area, which are located in each plant and the Energy Center. JFE Steel is promoting the unification of information by improving the data infrastructure through the use of data science and development of a cyber-physical system (CPS). The newly-developed supply-and-demand guidance system collects various data in real time, including data on LD converter blowing plans in the steelmaking process and data on reheating furnace charging plans in the hot rolling process, which are managed by business computers, the actual results of tapping from LD converters and charging to reheating furnaces, which are controlled by the process computers of each plant, and the actual results of generation and use of byproduct gases, steam and electric power for each plant and equipment, which are controlled by process computers in the Energy Center. On the other hand, the monthly plan linkage function collects data on the monthly operation plans of in-house power generating equipment, etc. and information accompanying changes whenever necessary, such as information on contracts with power companies, etc., from information input on screens or in specified formats.

3.3 Supply-and-Demand Prediction and Optimization Functions

The supply-and-demand prediction function predicts the energy supply and demand of each plant up to several hours in advance from the present time using a supply-and-demand prediction model. The targets of predictions are, for example, the amounts of byproduct gases generated by blast furnaces, coke ovens, reheating furnaces, etc. B gas and C gas are predicted based on patterns using stop plans and operation schedules, while LD gas and the M gas used in reheating furnaces are calculated by a multiple regression model using operation schedules.

The optimization function carries out optimal operation simulations for the operation that minimizes energy loss up to several hours in advance for the steel works as a whole, based on the predicted values calculated by the supply-and-demand prediction function, the actual performance values collected by the information linkage function, cost variables such as the unit cost of electric power, etc., and the variables and constraint values of equipment models. For details concerning the techniques related to optimal operation simulation, please refer to the report by Ogasahara et al.[1].

3.4 Screen Functions

Although the supply-and-demand prediction and optimization functions play the main role in this system, visualization is also a function of similar importance. This is because the granularity and easy visibility of the information displayed on screens and the easy use of the screen functions determine whether systems which support operator decision-making, such as the developed system, can be used continuously. Endo[3] proposed that visualization of problems can be classified by the following five points.

(1) Visualization of anomalies
Visualization and sharing of the event when an anomaly occurs.
(2) Visualization of gaps
Visualization of gap when divergence from the plan or target value occurs.
(3) Visualization of signals
Transmission of signals which make it possible to know that an anomaly has occurred, rather than the content of the anomaly as such.
(4) Visualization of the true cause
Clarification of the true cause of occurrence of the anomaly.
(5) Visualization of effects
In addition to formulation of problem-solving measures, indication of whether the expected effects will be achieved if those measures are carried out.

Based on these various types of visualization, the screen composition and functions were designed and implemented together with the technical staff and operators who will actually use the system. Representative screens are described below.

3.4.1 Operation guidance screen

Figure 3 shows the operation guidance screen. Because this is the main screen of this system which supports energy operation by operators, we were particularly conscious of visualization in this screen. The features reflected in its construction are described below for each of the above-mentioned categories of visualization.

(1) Visualization of anomalies
Anomalies such as gas emissions, steam emissions, etc. are shown on the screen in real time. Anomalies can be grasped by the type of energy because equipment handling the same type of energy is grouped together in the same area.

(2) Visualization of gaps
Gaps can be understood easily because the optimal values and actual values are always shown in the upper line and lower line, respectively, with color-coding for the respective types of energy operation.

(3) Visualization of signals
The operator is alerted when divergence exceeds a predetermined threshold value by emphasizing the location where action is necessary by a different color.

(4) Visualization of true cause
For easier investigation of the true cause of anomalies, the screen has a function which makes it possible to display setting screens such as the model accuracy evaluation screen, etc. (described below in section 3.4.3) from the equipment icons shown on the screen.

(5) Visualization of effects
The cost merit obtained by carrying out the optimal operation plan indicated by guidance is constantly displayed to encourage cost-consciousness in operators.

Whenever supply-and-demand prediction and optimization information is updated, in addition to the information guidance based on the visualization described above, the concrete content of instructions for the necessary actions for operational improvement can also be provided as guidance on the screen. This is intended for even young operators with little experience to be able to perform the optimal supply-and-demand operation in the same manner as experienced veteran operators.

3.4.2 Interactive function screen

The interactive function screen displays the optimal values and actual values for the past several hours with the current time as the starting point, together with the optimal values for several hours into the future. It consists of a table tab, multi-chart tab and individual chart tabs. The table tab shows numerical values in a table format like that used in Excel. The multi-chart tab displays any arbitrary data in the selected graph format based on the numerical values in the table tab, as shown in the top part of **Figure 4**. The individual chart tabs display the transitions of more specialized items, such as the gas holder level, gas generation and use amounts, etc., which are monitoring points necessary in operation, as shown in the bottom part of Fig. 4. These are also based on the numerical values of the table tab. However, in comparison with the operation guidance screen, which shows the most recent information, this screen visualizes the detailed anomalies and gaps for a wide-range time period by individual items.

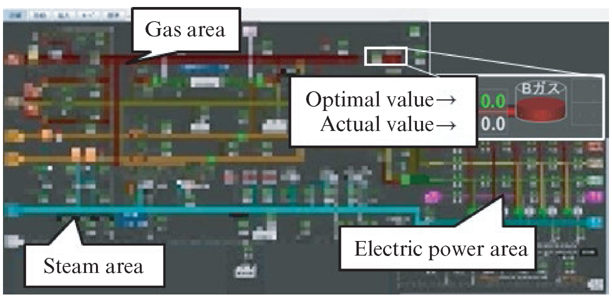

Fig. 3 Operation guidance screen

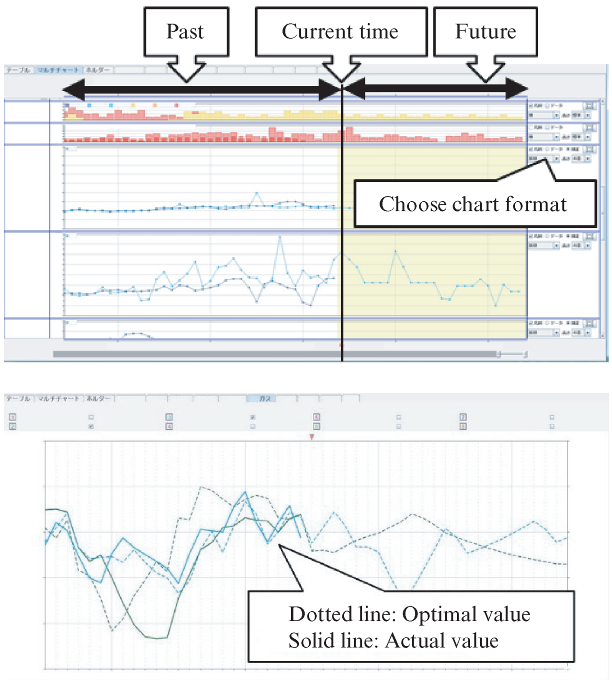

Fig. 4 Multi chart (top) and individual chart (bottom)

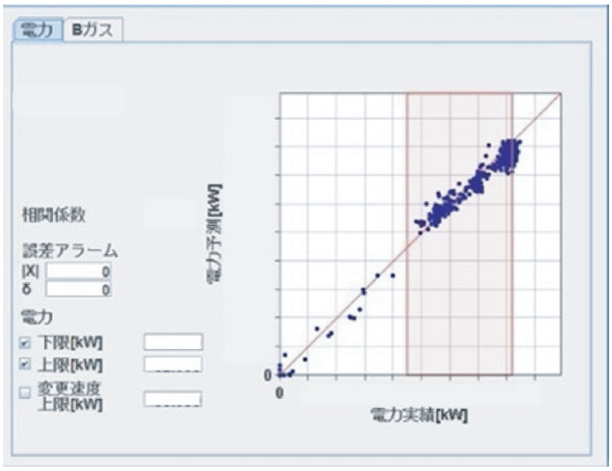

Fig. 5 Model accuracy evaluation screen

3.4.3 Model accuracy evaluation screen

The model accuracy evaluation screen, as shown in **Figure 5**, has the role of visualizing the true cause of anomalies by evaluating the divergence between the output values of each model and the actual performance values. Because it is possible to change the settings of the parameter values of the models from this screen, model accuracy can be maintained in this function.

3.4.4 Deviation reason input screen

The operator can input and share observed anomalies and gaps, desired improvements in the system, etc. The shared information can be tabulated on an Excel base and used in evaluations of model accuracy (see Fig. 5) and improvement of optimization parameters by the technical staff.

4. Results of Application

At JFE Steel West Japan Works (Fukuyama District), where this system was applied, various energy loss improvement effects were obtained in comparison with the levels before application, including reduction of the amount of city gas used and reduction of the amount of byproduct gases emitted.

As one example of this improvement effect, the effect on LD gas before and after application will be described. Because Fukuyama District has multiple LD converters in the same steelmaking plant and all units are in operation except at the timing of periodic furnace repairs, timings when blowing by two or more units overlaps and a large amount of LD gas is generated locally occur with high frequency. Before application, it was difficult to predict this timing and the amount of gas generation. As a result, a sufficient receiving capacity was not secured by discharging gas from the gas holder in advance, and it was frequently necessary to emit gas because the amount of gas exceeded the upper limit of the gas holder. **Figure 6** shows the transition of the gas holder level after application of the system. It is now possible to indicate the optimal value which does not exceed the upper limit of the gas holder, in other words, an operation plan for the gas holder which will not cause gas emission, and the actual values also follow the optimal values. The ability to make highly accurate predictions of LD gas generation, and to provide guidance to operators on the optimal timing and amount of discharges of gas based on those predictions, has made it possible to reduce the amount of gas emissions in comparison with the conventional level. Moreover, operation with the lower limit value of the gas holder more closely approaching the lower limit value of the equipment has become possible, thereby also improving the efficiency of gas holder operation.

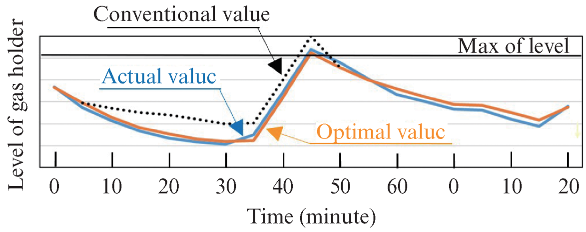

Fig. 6 Gas holder levels before and after application

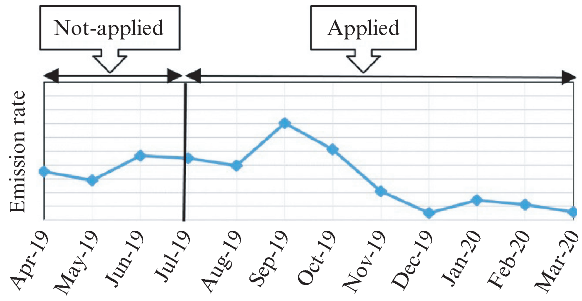

Fig. 7 Trends in emission rate of LD gas

Figure 7 shows the transition of the ratio of gas emissions to generation of LD gas (emission rate) before and after application. With the exception of an equipment inspection period, there has been a steadily decreasing trend since July 2019 when the system was applied. Thus, it can be understood that support of energy supply-and-demand operation by this system is contributing to reduction of energy loss over the long term.

5. Conclusion

In order to support optimal energy operation by operators, JFE Steel developed an energy optimal operation guidance system. The features of this system are as follows.

(1) The system was implemented on J-OSCloud, which is a private cloud of JFE Steel, and its functional configuration consists of an information linkage system for real-time information collection, supply-and-demand prediction and optimization functions based on data science and various screen functions.

(2) To ensure continuous use, the screen functions were designed and implemented together with the technical staff and the operators who will actually use the system, with a particular awareness of visualization.

By enabling optimal energy supply-and-demand operation, regardless of whether the operator is young person or an experienced veteran, the application of this system has resulted in a steady decrease in energy loss.

References

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