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1 Introduction

The energy consumption of the Japanese iron and steel industry accounts for more than 15% of the nationwide total and has a significant impact on total production costs in the industry. Hence, the need for energy saving is strong, and energy control has a long history. In response to these circumstances, Mizushima Works had, by 1980, already developed by-product gas utilization techniques, which included a mixed-gas supply technique using the combustion equivalent (A_0I)[1], and established, in particular, the first energy system, which was aimed at the effective use of the LD gas.

This existing system was refurbished into a comprehensive energy system covering the range of energy-related activities from the energy supply and demand planning in full coordination with the production process control system, to the practical operation of the system. In the new energy system, importance was laid on the stabilized supply and optimal control of energy and the rationalization of operation. In particular, optimization techniques for gas supply were developed as part of the new system, aiming at efficient operation of the Joint Electric Power Plant, which consumes more than 40% of the by-product gas generated by the works, and the application of AI (artificial intelligence) to steam-supply management.

In the following, the background of the system development and the outline of the system are described.

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2 Background of System Development

With the oil crisis as a turning point, Mizushima Works became an oil-less steelworks in 1980; the entire steelworks is now considered an energy conversion plant which uses raw-material coal as an energy source and produces energy in excess of its own needs. More recently, large-scale energy saving plans have been materialized, and several outside energy sales programs have been implemented.[2]

Wide fluctuations in energy supply and demand conditions characterize operations at an integrated steelworks. The works' complex consumption requirements are a burden on operators and make economical energy management difficult. Further, as synchronization and continuation of production lines progressed, the realization of a system to support these operations without causing disruptions from the energy side became an urgent problem.

Along with these developments, however, marked progress has been made in production control systems, and the completion of the information network has made it possible to obtain highly-advanced production and operation information. These factors have helped create the necessary environment for the construction of a comprehensive energy control system.

On the other hand, the Joint Electric Power Plant, which occupies an important position in the energy equation at Mizushima Works, has lost cost competitiveness with the shift at Chugoku Electric Power Co., Inc. from oil-fired thermal power generation to coal-fired generation, which is cheaper in terms of energy costs. The Joint Electric Power Plant was modified from a gas-oil mixture combustion to gas-only-combustion operation to improve its competitiveness, but this required a more stable gas supply.

To cope with such changes in the energy management environment, the old system was totally refurbished. In the new system, emphasis is placed on the following points:

(1) Stabilized supply of energy
(2) Establishment of energy control system
(3) Strengthening of operation monitoring function
(4) Flexible response to energy situation changes in the system

3 System Function and Configuration

3.1 System Design Concept

Based on the idea that the mission of the Energy Division lies in the "achievement, at low cost, of a stable supply of energy of guaranteed quality," the system design emphasizes the following matters:

(1) In the flow of a series of jobs ranging from the formulation of energy plans to their application to actual operation, the respective outputs must function effectively in succeeding processes.
(2) By active use of the existing information network, operational information from various production units can be accessed on a real-time basis, permitting quick response to changes, and by supplying energy information records to the units concerned, utility costs can be reduced.
(3) The man-machine interface is interactive and visualization of information is realized to support operator judgment.
(4) The operation monitoring system has a duplex system to enhance system reliability. In addition, advanced control and automation are achieved by the use of advanced control techniques.
(5) Through the automation of tasks carried out by operators in the past and the introduction of AI, manpower requirements are minimized.

3.2 System Function

The energy system consists of six subsystems, as outlined below.

3.2.1 Consolidated plan subsystem

In this subsystem, such functions as power supply and demand simulation are added to the existing total energy-cost evaluation system. The subsystem formulates a consolidated energy strategy and is used in the drafting of energy supply and demand plans ranging from short term (half year) to long term (5 years) and in the study of facility plans related to energy.

3.2.2 Production schedule adjustment subsystem

This subsystem formulates energy supply and demand plans on the monthly, weekly and daily levels. Linkage with the existing steel production scheduling system makes it possible for the subsystem to make timely schedule and production corrections.

3.2.3 Operation support subsystem

This subsystem receives information on the adjacent operation plans of the steel-making and hot-rolling mills on a real-time basis, permitting revision of energy supply and demand plans and their real-time prediction, and supports the optimization of the gas supply to the Joint Electric Power Plant and the consumption adjustment of electric power within Mizushima Works. Further, with this subsystem an AI (expert system) has been introduced, providing operator guidance for the control of the medium-pressure steam generation.

3.2.4 Evaluation subsystem

This subsystem evaluates energy supply and demand plans and actual operation records, providing visualized evaluation results to facilitate quick response to problems.

3.2.5 Operation monitoring subsystem

At the Energy Control Center, where the monitoring and control of energy at the steelworks are centralized, analog instrumentation has been replaced with digital equipment for all facilities concerned with fuel, electric power, water, and the environmental control (air and water quality), thereby realizing thoroughgoing automation.

3.2.6 Technical analysis subsystem

The technical analysis subsystem has been arranged so that all staff members can perform analysis jobs such as trend-indication and regression analysis of actual-record data items related to energy for any specified period.

3.3 System Configuration

The functions and hardware configuration of the energy system are shown in **Figs. 1** and **2**, respectively. The assignment of functions among the various computer levels is as follows:

Central Computer (C/C): Consolidated plans, production schedule corrections, evaluation, and technical analyses

Operation Computer (O/C) and Process Computer (P/C): Operation support

Instrumentation System: DDCs (direct digital controller) control of fuel, environmental control and steam, and TCCs (telemeter telecontroller computer) for control of electric power and water

Equipment supervised and controlled by the energy

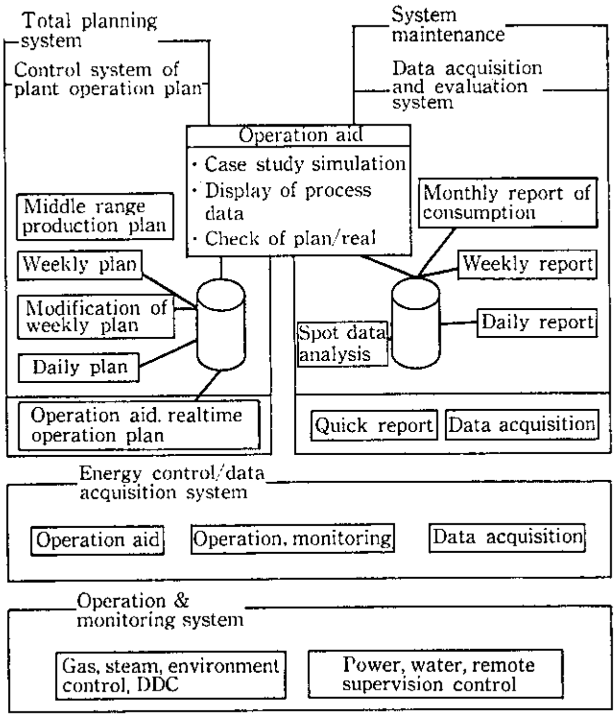

Fig. 1 Functions of the energy system

system is shown in **Table 1**. **Photo 1** shows new Energy Control Center.

Table 1 Equipment supervised and controlled by the system

System	Equipment	Number
Fuel	Gas holder	7
	Gas blower station	8
	Town gas plant	1
	H_2 gas plant	1
Power	Substation	30
	Emergency generator	4
Water	Recirculation pump station	31
	Water treatment station	2
	Industrial water pump station	1
Environment	Observation equipment for air pollution and water pollution	13

4 System Features

4.1 Operation Support Subsystem

It is a noteworthy feature of this subsystem that it controls the overall information flow ranging from the formulation of production plans to the control of process. The flow of information consists of the data collec-

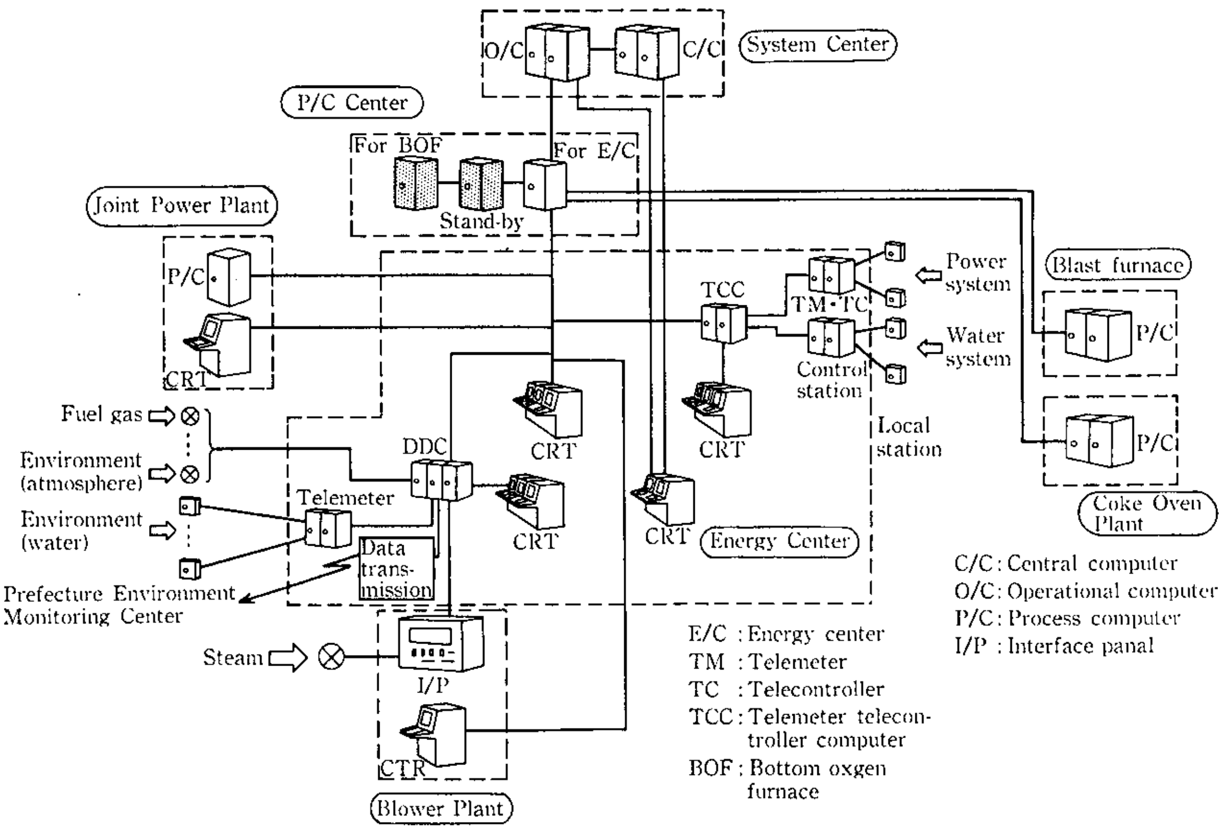

Fig. 2 Hardware configuration of the system

Photo 1 Energy Center at Mizushima Works

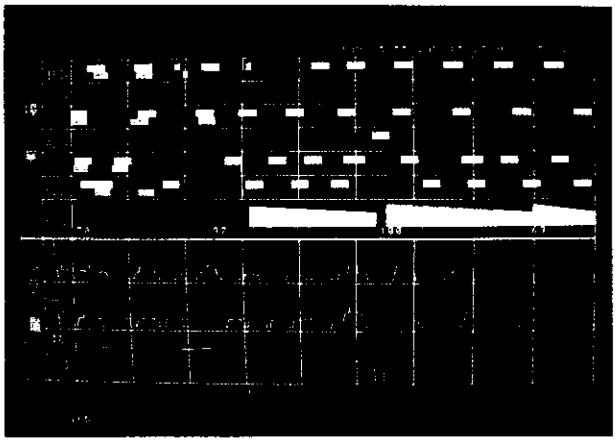

Photo 2 Display of real-time prediction

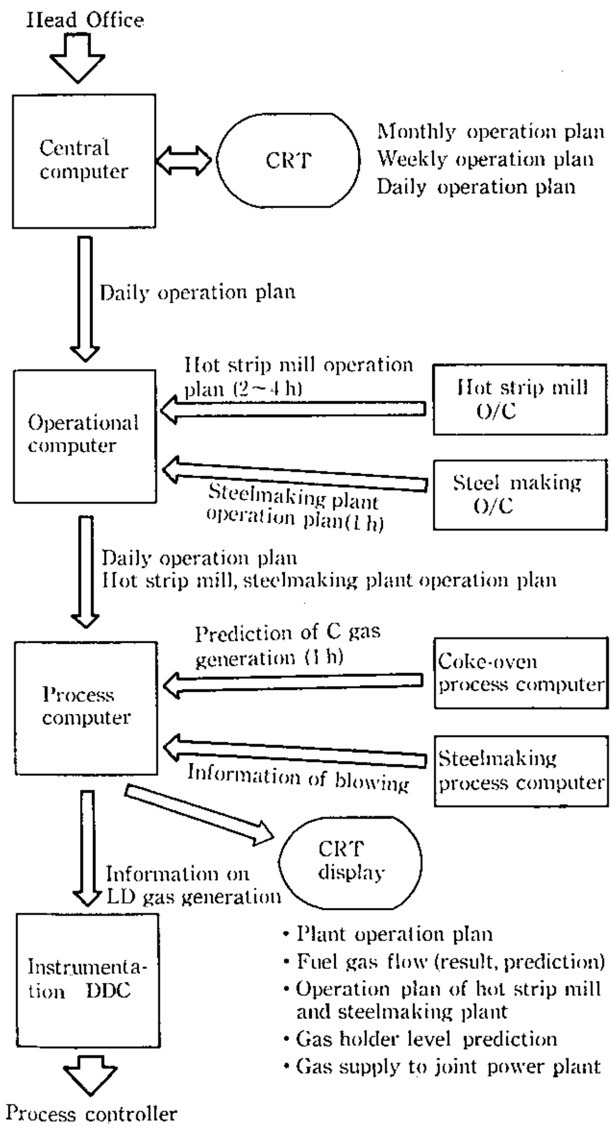

Fig. 3 Information flow of operation support subsystem

tion flow, which moves up from the support subsystems to the host system, and the operation support flow, which moves down from the host system. The operations support flow is shown in **Fig. 3**.

Features of note are described below.

(1) From the hot-rolling O/C system, the subsystem receives the operation schedule of the reheating furnace which is the largest-volume consumer of gas, and specifications of charged steels in charge-lot units, enhancing the prediction accuracy of the gas balance.

(2) To predict the timing of LD-gas generation, which occurs intermittently, the converter blowing schedule is received from the converter process computer on a real-time basis.

(3) The predicted, quantity of C gas generation based on the coal charging schedule is obtained by the coke P/C, and the predicted quantity is transmitted hourly for the subsequent 8 hours. This has enhanced the accuracy of prediction of generation of C gas, which has the highest calorific value and shows the highest rate of utilization.

(4) To effect automatic operation of the LD gas recovery blower, the blower receives blowing information (charging of hot metal, charging of scrap, blowing oxygen volume, etc.) from the converter P/C on a real-time basis. This data is transmitted from the P/C to a DDC so as to automatically determine the timing of blower start and the number of blowers to be used.

A P/C screen, which simultaneously displays information concerning the converter and hot-rolling plants, is shown in **Photo 2**. The actual use of information on the energy balance of these shops, which is collected by O/C and P/C, is discussed below in connection with typical examples.

4.2 Optimal Gas Supply to Joint Electric Power Plant

The gas supply system for the Joint Electric Power Plant is shown in **Fig.** 4. By-product gases, i.e., blast furnace gas (B gas), coke oven gas (C gas), and mixed gas (M gas), are used by the steelworks, and excess amounts are either stored in holders or supplied to the Joint Electric Power Plant. The Joint Electric Power Plant operates five boilers. While boilers from No. 1 to 5 use heavy oil and (B + M) gas as fuel, boilers No. 3, 4, and 5 can also use C gas.

Because heavy oil and C gas can also be used in boilers No. 3, 4, and 5, if a supply of the C gas can be guaranteed, the consumption of expensive heavy oil can be reduced. One limiting factor, however, is the switchover required when changing from heavy oil to all-gas (gas-only-combustion) operation. Changing fuel sources is disadvantageous, so it is desirable to maintain gas-only-combustion for a certain period once the switchover has been made.

The steelworks notifies the Joint Electric Power Plant beforehand of future gas supply quantities. Since the use of by-product gas in place of oil benefits both the Joint Electric Power Plant and the steelworks, the problem for actual operation is to formulate a proper plan for the quantity of the gas to be supplied to the Joint Electric Power Plant. This problem can be stated as follows: "For given predicted gas generation and gas consumption volumes, obtain a series of notification values which will maximize the objective function within a specified time range."

The objective function here is a complex relationship described below. In the present case, the period for each notification is 2 h and the specified time range is 8 h. Mathematical programming is applied to this problem. The constraining conditions include the following items:

(1) Upper and lower limits of holder levels.
(2) Upper and lower limits of the gas volume to be supplied to the Joint Electric Power Plant.
(3) Upper and lower levels of calorific values of M gas to be supplied to the Joint Electric Power Plant.
(4) The relational expression covering the supplied volume of C gas and the number of boilers of the gas-only-combustion.
(5) The conditional expression covering the continuity/discontinuity of gas-only-combustion.

The objective function consists of the following items:

(1) Evaluated value of the supplied volume of gas.
(2) Profit realized by gas-only-combustion/heavy oil reduction.
(3) Gas dispersion and gas shortage penalty.
(4) Gas-holder level fluctuation penalty.
(5) Penalty for discontinuation of gas-only-combustion.
(6) Penalty for changes in number of gas-only-combustion type boilers.

As the following are features of this problem:

(1) Variables 0-1 is included to indicate whether gas-only-combustion is adopted or not.
(2) This problem should be of a form in which the optimization problems for 2-h term are collected for 8-h periods.

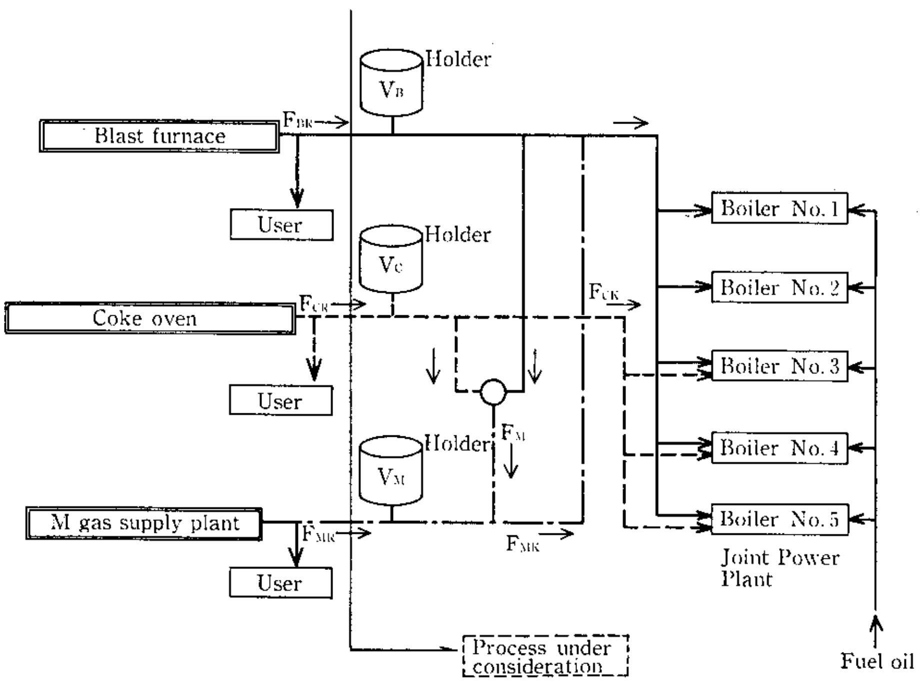

Fig. 4 Gas supply system for Joint Electric Power Plant

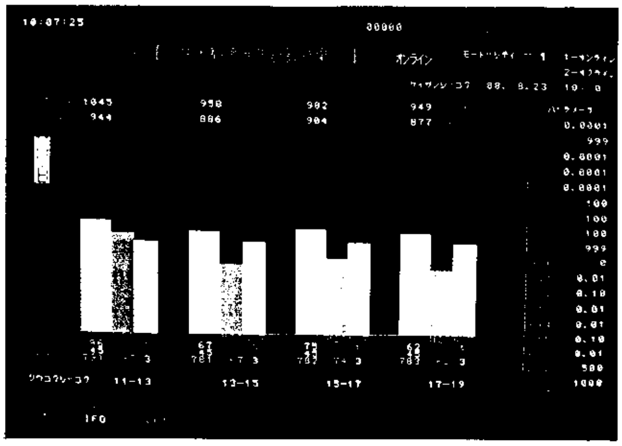

Photo 3 Display of gas supply prediction for Joint Electric Power Plant

(3) These 4-period problems are joined by a certain number of continuous variables.

Problems having such features are called mixed integer programming problems. In this case, the problem is solved by decomposition method[3] in a P/C on a real-time basis and the results are used by operators as reference in determining notification values.[4] A screen displaying calculation results is shown in **Photo 3**.

4.3 Application of AI Techniques to Steam Process

Steam occupies an important position as a power source in energy control. The steam system is classified by pressure into high, medium, and low pressure. In the new system at Mizushima, an expert system was introduced for the stable control of medium pressure steam ($14\ kgf/cm^2$ line), which is widely used in the works. An outline of the medium pressure steam control system is shown in **Fig. 5**.

Medium pressure steam is produced by the decompressing high-pressure steam generated by the blower plant and coke dry quenching plant (CDQ) using a mixed pressure turbine, back pressure turbine, and temperature and pressure reducer. In addition, steam generated by the heat recovery boiler for the sinter plant and converter and steam stored in the accumulator flow into the medium pressure system. In the past, frequent operator correction of the steam volume in the mixed pressure turbine, the back pressure turbine, and the accumulator was required in order to maintain medium-pressure steam at a constant pressure level. Since steam is frequently used in batches, however, simple feedback control is not adequate, and the operation schedule and operation quantity of the plant must be determined in a feed-forward manner.

Expert systems are well suited to the automation of processes of this kind, in which many types of information must be processed and evaluated empirically. First, a grasp of operational methods and judgment standards is obtained through interviews with experienced operators. The knowledge thus obtained is sorted and compiled in a rule base. The validity of the rule base is tested by simulation using a specially-created steam piping system model, and the rule base is then incorporated into a P/C. The magnitude of the action (i.e., steam volume of mixed-pressure turbine, etc.) to be taken is determined after taking into consideration current process values and trends, as well as the operation schedule of the RH degassing unit, which uses a large volume of

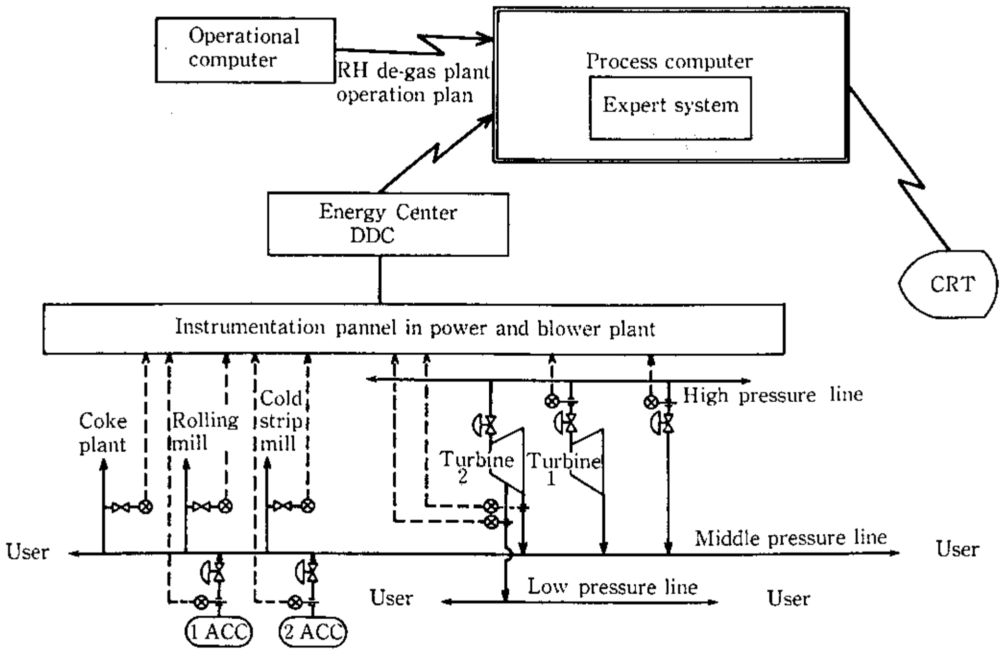

Fig. 5 Outline of steam pressure control guide system

steam within a short time span. The program is run every 5 min, and the results are displayed by CRT as guidance to the operator.

Input data includes about 40 items, and the rules (production rules in if-then form) number about 60. In the application of this operation support subsystem to process control on a real-time basis, the test function in the off-line mode and the simulation function using on-line data were greatly improved.

4.4 Automation of Mixed Gas Blower

At Mizushima Works, combustion equivalent method is used to equalize each A_0I value of various by-product gases to achieve a mixed gas supply. This process allows greater flexibility in the use of various gas types and makes it possible to use a single M-gas distribution system. In the M-gas blending process, the A_0I value (an index obtained by dividing the theoretical combustion air volume by the square root of gas density) of different types of gas are balanced. This process, however, requires a complex arrangement of gas-mixing and pressure-boosting blowers, and has in the past placed a considerable burden on operators. In the recent refurbishing, a major task was the automation of blower operation.

The mixed gas M23G (B gas + C gas) plays an important role in the overall M gas balance and is produced by a total of 8 blower units. Decisions on M23G production volume must take a comprehensive view of the amounts of M26G (LD gas + C gas) generated in each converter blow as well as the conditions of use at the reheating furnaces for hot rolling. The flow chart for determining the production volume of M23G is shown in **Fig. 6**. The variety of types of information involved are processed mainly by DDC in the new system to realize automation of the start and stop of the blowers.

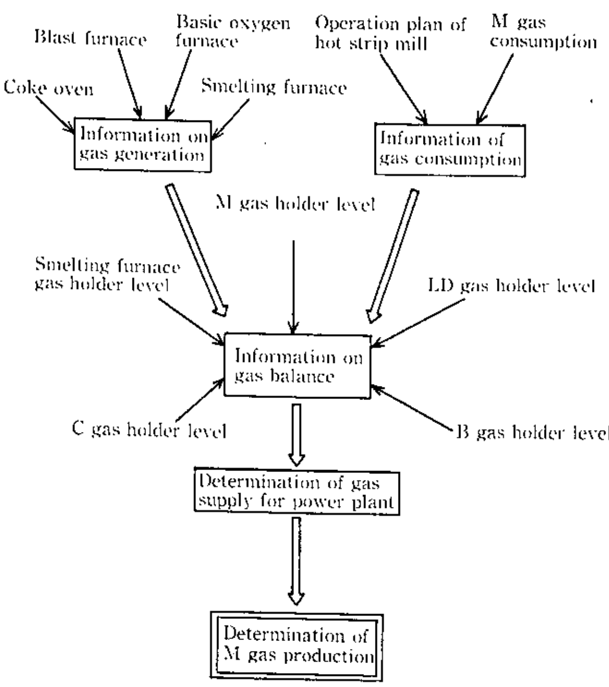

Fig. 6 Information flow of M gas production

Further, the operation of the M26G blowers is determined by the blow-timing of the corresponding converters and the quantities of LD gas generated. This operation has now been automated, with information transmitted on a real-time basis from the converter P/C to the energy system P/C, and then fed to the DDCs which control the blowers. Through these improvements, the necessity of human intervention in blower operation control has been eliminated.

4.5 Management of Electrical Power System

An important problem in electric power system operation is the management of electric power consumption. Specifically, this means control of the use of electric power purchased from outside utilities in contractually stipulated amounts.

The key problems are to predict the power use of various shops as accurately as possible and devise means of coping quickly with situations in which power consumption is going to exceed the power available within the limits of outside contracts. The measures adopted in the present refubishing are:

(1) Operation start and stop patterns inherent to the respective shops are given in advance to the P/C, and on the basis of these patterns power requirements are predicted.

(2) The rolling schedule at the hot-rolling shop is displayed on the CRT of the on-line computer for operator reference use. If necessary, the hot-rolling shop can be requested to adjust its schedule.

Control of the electric power system operations is carried out by CRT and light pen, but in order to ensure the reliability of the system switching operation, a check system using operation sequence registration has been created. An typical CRT display is shown in **Photo 4**.

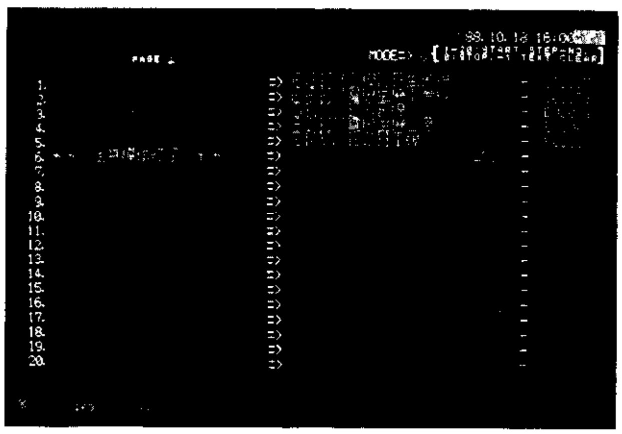

Photo 4 Example of display for operation check

In this method, the proper sequence of operations is input beforehand from the CRT to the controller in an interactive mode. Agreement between the actual operation and the proper sequence of operations is automatically checked to prevent errors caused by deviation from the prescribed operation. In the past, this procedure required one operator and one checker, but the new system has made one-man operation possible.

5 Evaluation of Records

5.1 Ratio of Gas-Only-Combustion at Joint Electric Power Plant

As mentioned in Sec. 4.2, the Joint Electric Power Plant plays an important role in maintaining the final balance between the generation and use of by-product gas and constitutes the largest energy-conversion facility in the steelworks. Stability of the gas supply and improved accuracy of the gas quantity notification have a significant effect on the operations of the Joint Electric Power Plant, which in turn greatly affect power management at Chugoku Electric Power Co., Inc. On the other hand, since decreased heavy oil consumption at the Joint Electric Power Plant reduces the cost of power generation, improvement in the ratio of gas-only-combustion was one of major aims of the new system for economic as well as production-related reasons.

Changes in the gas-only-combustion ratio are shown in **Fig. 7**, while **Fig. 8** shows a comparison of the frequency of C gas supply change notifications to the Joint Electric Power Plant with that in the past. The improved results are attributable to the more appropriate notification made possible by improvement in the accuracy of gas supply prediction.

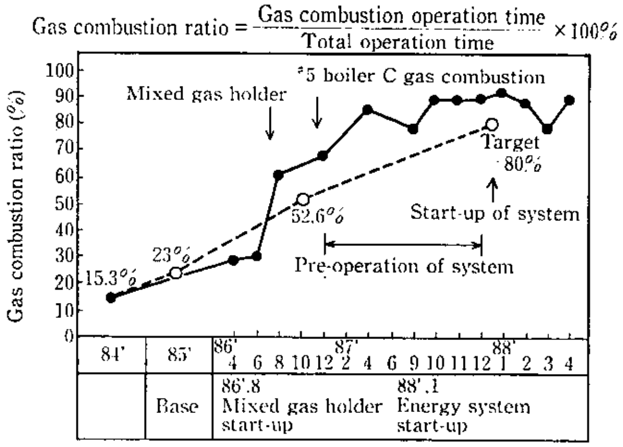

Fig. 7 Trend of Joint Electric Power Plant gas combustion ratio

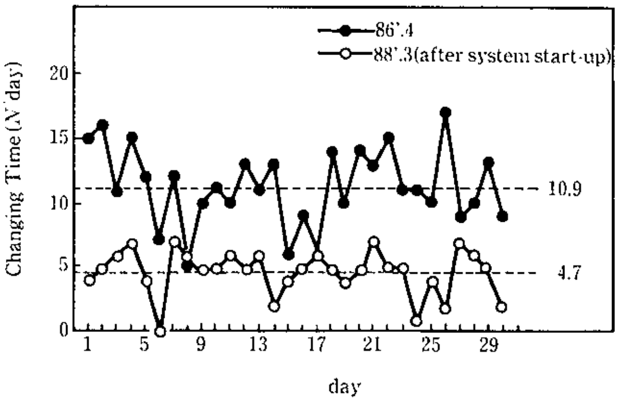

Fig. 8 Changes of C gas quantity to Joint Electric Power Plant

5.2 Power Consumption Shift Ratio from Daytime to Nighttime

Maximum use of relatively inexpensive nighttime power is desirable as it contributes to a decrease in overall energy costs. It is also desirable from the viewpoint of electric utilities because it flattens the electric load.

Because a shift from daytime to nighttime blast furnace operation is difficult in an integrated steelworks, increased use of nighttime power depends mainly on proper scheduling in the downstream process, taking into consideration differences in the unit power consumption of various steel types, differing production efficiencies of facilities, and other factors. In the present system, information on power unit consumption, etc., is fed into the process plan and incorporated in scheduling as a basis for maximizing the use of nighttime electric power. **Figure 9** shows the recent trend in the nighttime electric power ratio.

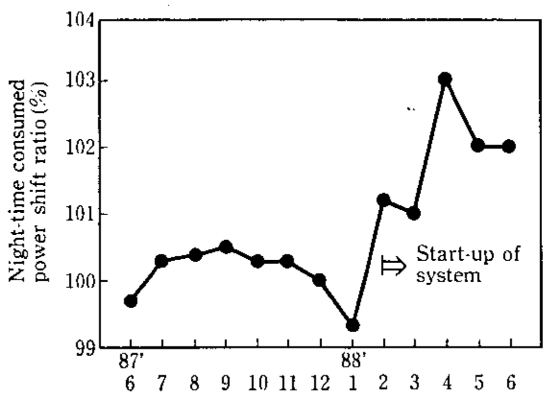

Fig. 9 Changes of night-time consumed power shift ratio

5.3 Increased Efficiency of Work

In the present system, consideration is given to achieving thoroughgoing automation and utilization of CRT operation to minimize the work load of operators.

Simultaneously, priority is given to better operational economics through information visualization techniques and human engineering. At the present level of development, only four operators are required to execute the range of tasks from planning to record evaluation for electrical, fuel, water, and environmental control facilities. As a result, the standardization of work has progressed and direct human intervention has been eliminated.

In addition to the concrete results of the new energy system discussed above, the improvement in electric power consumption pattern prediction techniques, improvement in the accuracy of M gas A_0I control, and the more effective utilization of energy information by consuming and related divisions have also greatly contributed to the improvement of the technical capabilities of the entire steelworks.

6 Conclusions

The energy control system at Mizushima Works was refurbished, aiming at stabilization of the energy balance and a reduction in energy costs with no loss of quality levels or quality consistency. The new energy system went into operation in January 1988 after more than two years of development. Its features are summarized as follows:

(1) To support the production operation plan of the steelworks from the viewpoint of energy supply and demand, the system makes it possible to formulate energy supply and demand plans in an interactive mode by means of CRT in conjunction with the Production Control Division.

(2) The system receives production and operation information on steelmaking, hot rolling, etc. on a real-time basis and permits timely revision of the energy supply and demand plan and real-time prediction of electric power and gas conditions; this has resulted in a dramatic qualitative improvement in the technical level of operations such as gas supply notification to the Joint Electric Power Plant and Mizushima Works' electric power consumption control.

(3) The Energy Control Center has refurbished the instrumentation of facilities for fuel, electric power, water, and environmental control with digital instrumentation to achieve thoroughgoing automation, allowing operators to concentrate on more sophisticated jobs requiring judgment.

(4) To support steam management, AI (expert system) tools have been introduced for steam production quantity control and guidance in connection with accumulator operation.

(5) Functions were added to the new system to permit operators to evaluate their own planning and execution performance; these functions have improved operator utilization and thereby encouraged the positive participation of operators in system improvement activities. This is a particularly significant result.

Although the energy environment is likely to continue to be coal-dependent for some time into the future, the conditions affecting energy producing and consuming facilities in the steelworks will vary greatly with changes in the overall energy environment, progress in technology, and other factors, requiring energy systems which can respond quickly and maintain optimal control of energy resources regardless of conditions.

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