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TRENDS OF ENERGY CENTER

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1 FOREWARD

In the iron and steel industry, which consumes about 15% of the total energy demand in Japan, the price of energy has a large affect on product costs.

Because of the abrupt rise in the primary unit price of energy caused by the world-wide energy situation of the past several years, iron and steel companies have been making every possible effort in saving energy in ironworks. As a result, energy saving has shown excellent results from year to year and are the highest level in the world.

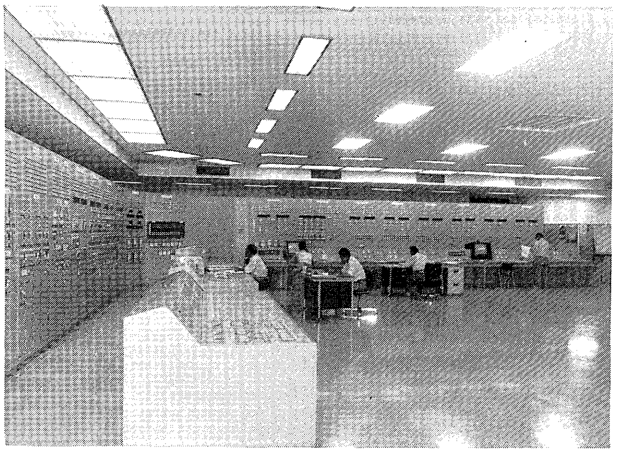
An ironworks uses a many different forms of energy, such as fossil fuels, electric power, steam, air, and so forth, in large quantities. Of these, the primary energy purchased from the outside consists of coil, petroleum, electric power, etc. These energy sources are converted into secondary energy (byproduct energy) such as gases, electric power, steam, etc. in the production process in the ironworks. Unlike other industries, the energy consumption of an ironworks is characterized by the production of byproduct energy. About 40% of the energy in an ironworks is this byproduct energy. These kinds of energy have a complex interrelationship and vary widely. Therefore, it is no exaggeration to say that whether or not energy operation is skillful has a large affect on the rationalization of the ironworks. Thus, almost all the ironworks in Japan have installed an energy center and have been making efforts to establish an efficient energy operation system, although their scale may differ somewhat.

The major purposes of these energy centers are:

(1) Stable supply of various kinds of energy to production plants.
(2) Energy saving by centralized management by energy center.
(3) Improvement of energy generation and consumption results management precision.
(4) Reduction of total energy cost.

In recent years, comparatively easy cases having an immediate effect have been reduced. Countermeasures for individual facilities have progressed to a large extent. However, a considerable energy saving in the ironworks as a whole by greater optimization and reduction of operating losses by operating the facilities with a closer interrelationship.

Fig. 1 Control room of energy center



Fuji Electric Company Limited has delivered energy centers to many users and contributing to energy and power saving. The need to improve the system functions is increasing.

The trend of recent energy center system function and a control mode aimmed at optimization of the energy center are introduced here.

2 TREND OF ENERGY CENTER SYSTEM FUNCTIONS

Recent trends shown that the energy center systems being planned are large scale systems using optimum distribution calculation and so forth by directly coupling production plans to minimize the total cost. As the functions required become more numerous and diverse, the configuration of energy systems is rapidly shifting to "decentralization of control" and "centralization of information" together with the development of digital information functions. The decentralized control method has also been shifting from a simple decentralized process I/O method to a decentralized control method with intelligent functions. A network system and a large hierarchal system have also been realized by organically connecting multiple computers together.

An energy center must centralize data outside the premises of the ironworks, as required. Therefore, the use of a dataway has considerable merit. An optical dataway has been put into practical use, and has often been introduced because of the reliability of the data and the security of cable.

1. Functions of energy center

Fig. 2 shows the functions of an energy center.

1) Data base system

The recent trend has been to design energy center sys-

Fig. 2 Functions of energy center system

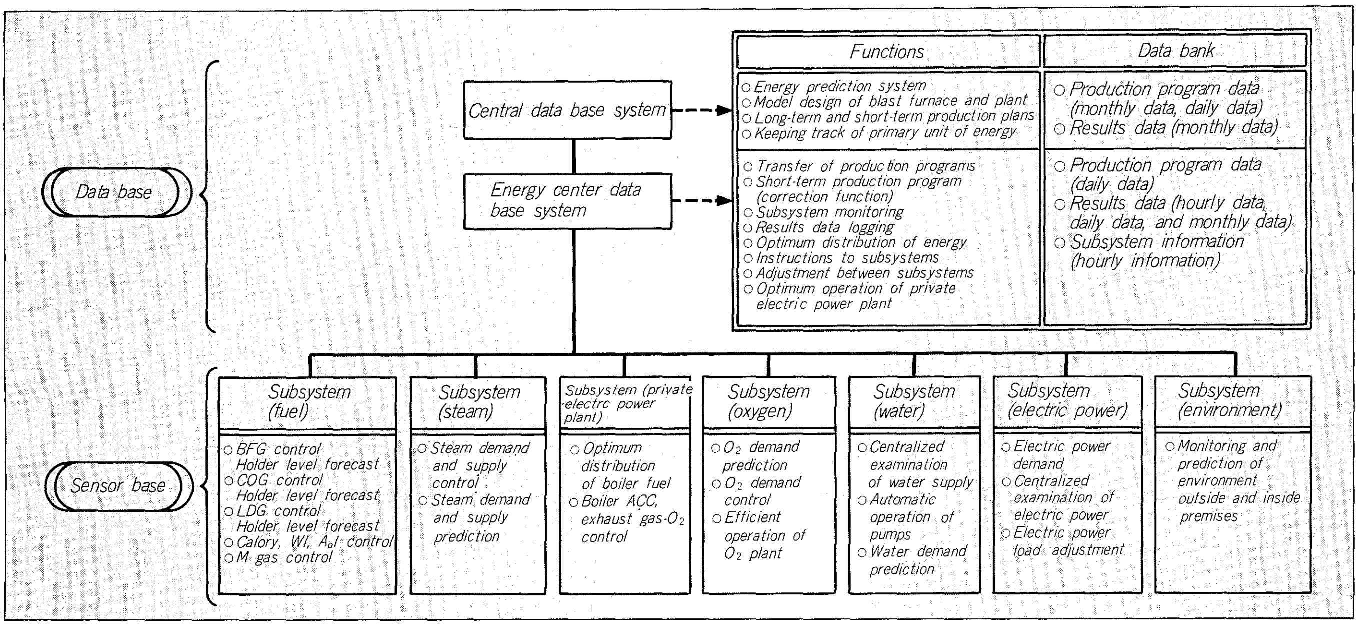
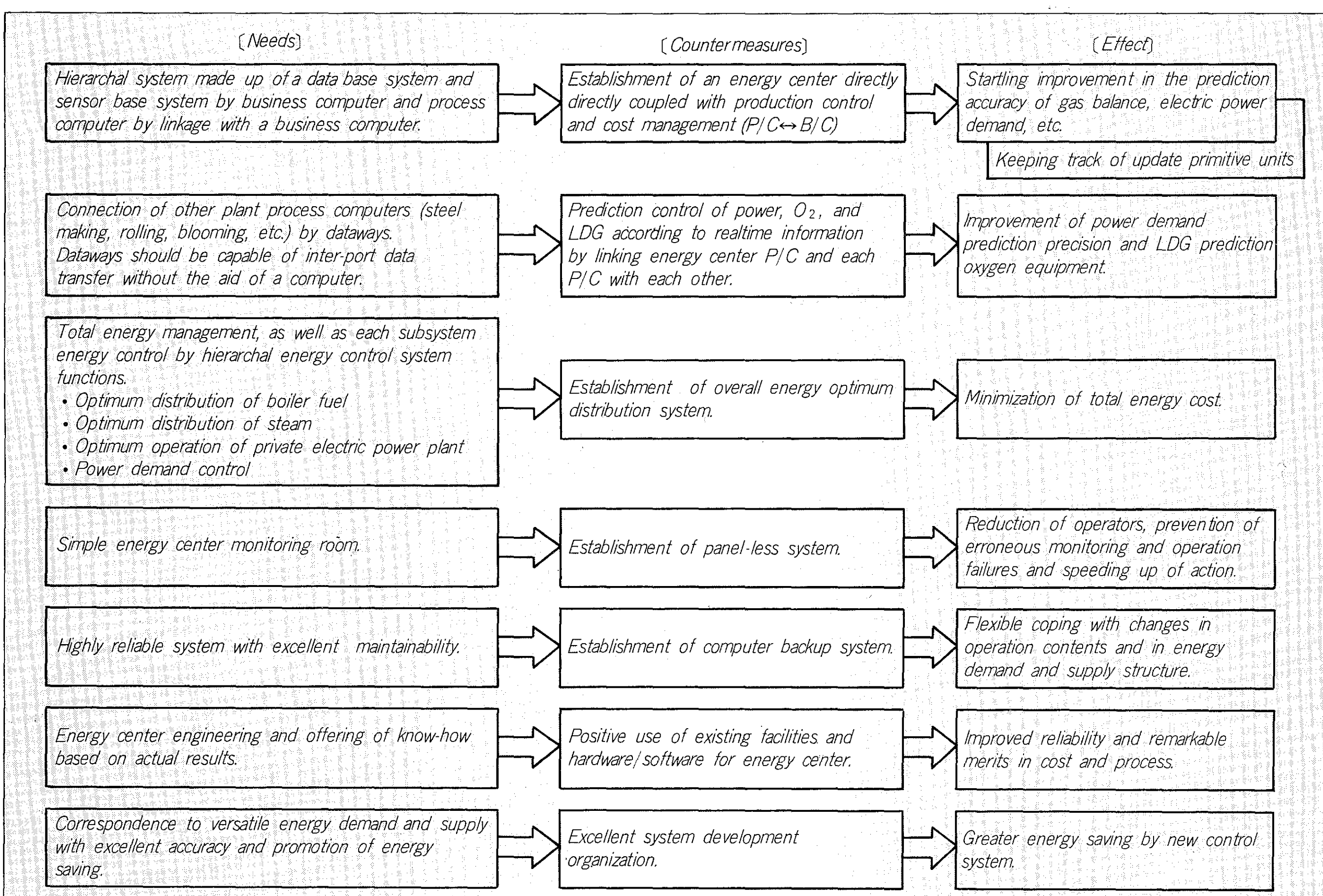


Fig. 3 Improvement of energy center system functions



tems as hierarchal systems. These systems can be classified into data base systems or sensor base systems according to the data to be processed. A data base system exceeds the range of an ordinary process control computer and must be considered to be integrated with the central control computer (business computer).

2) Sensor base system

Each subsystem is called a sensor base system. Systems of various configurations can be designed according to the scale, area, control method, and so forth. The following items must be studied when a sensor base system is applied to an actual system.

(1) Integration with instrumentation system (MICREX) and computer system.
(2) Decentralization and centralization ranges.
(3) Topographic profile of plant.
(4) Premises organization problems
(5) Maintenance

2. Improvement of energy center system functions

Improvement of the functions of the energy center must be studied from various points of view. *Fig. 3* shows an example.

3 ENERGY CENTER CONTROL MODELS

1. Control models trends

Optimization has progressed steadily for the purpose of energy saving and cost saving and it summarized from the standpoints of control models below.

(1) Optimization model of multivariable control system
(2) Optimization model of energy subsystem
(3) Overall energy optimization distribution system model with organic linkage of subsystems

The rapid progress made in modern control theory application technology, prediction theory application technology, and optimization theory application technology can be pointed out as the technical background for realizing these models. These control models are described below.

2. Optimization model of multivariable control system

1) PI regulator

This control system is established by applying optimum control theory to a conventional ratio control system. Its schematic diagram is shown in *Fig. 4*. This control system speeds up the response to abrupt changes in the load flow in furnace change and suppressed the mixed gas calory fluctuation to 60% of the conventional value. An energy saving of about 37,000 oil kl/y has been attained by improvement of the gas balance including this system.

2) INAM (Inverted Nyquist Arrangement Method)

This control system is established by applying non-interactive control theory to a processes which strong mutual interference. Its block diagram is shown in *Fig. 5*. This control system substantially reduces the mutual interference of the WI value and pressure against abrupt changes in the load flow, and supplies quality mixed gas to each load destination. This control system is designed by using an conversational CAD system and used INAM as the non interactive control theory.

Fig. 4 Schematic diagram of the PI regurator system

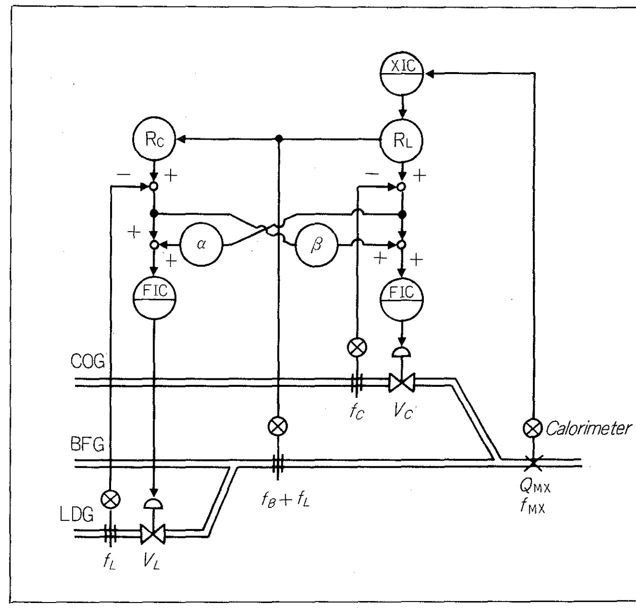
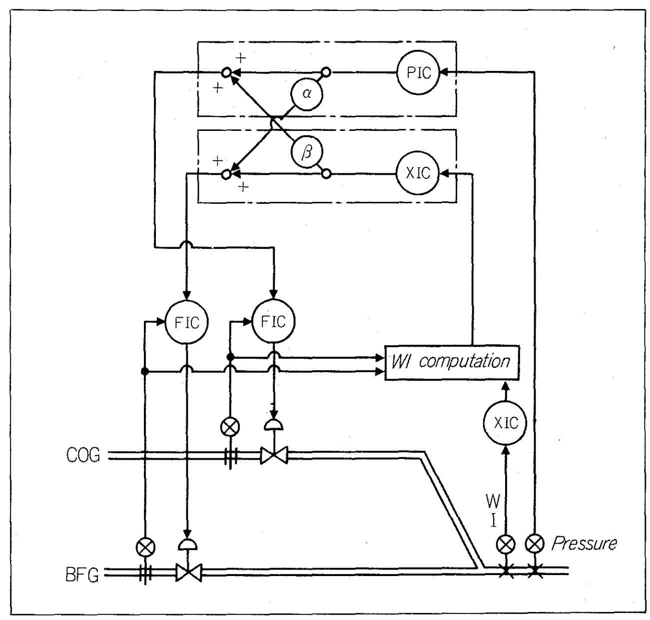


Fig. 5 Non interactive control system based on INAM



3. Optimization model of energy subsystem

1) Optimum operation of private electric power plant

The plant characteristic of a private electric power plant is generally nonlinear, and the nonlinear programming method is applied to it as the optimization theory. The nonlinear programming methods are described below.

(1) BFGS method

This technique is said to be the most efficient in solving a problem which can be expressed by,

minimize $f(x)$ $x \epsilon R^n$

The algorithm can be expressed as:

Step 0 $x^0 \epsilon R^n$, $H_0 \epsilon R^{n \times n}$ is treated as symmetric positive constant value matrix $k = 0$

Step 1 If $\nabla f(x^k) = 0$, stop.

Step 2 $d^k = H_k \nabla {}^t f(x^k)$

Step 3 If $\nabla f(x^k) d^k \geqq 0, H_k = H_0$, and proceed to step 2.

Step 4 $x^{k+1} = x^k + \alpha^k d^k \epsilon M_w(x^k, d^k)$

Step 5 Assuming that $\delta^k = x^{k+1} - x^k$,

$\gamma^k = \nabla {}^t f(x^{k+1}) - \nabla f(x^k)$

$$H_{k+1} = \left\{ I - \frac{\delta^k (\gamma^k)^t}{(\delta^k)^t \gamma^k} \right\} H_k \times$$

$$\left\{ I - \frac{\gamma^k (\delta^k)^t}{(\delta^k)^t \gamma^k} \right\} + \frac{\delta^k (\delta^k)^t}{(\delta^k)^t \gamma^k}$$

Step 6 Proceed to step 1 as $k = k + 1$.

Where, M_w is the linear search algorithm according to Wolfe's rule and is used to obtain ρ as,

$$\theta_1(\rho) = f(x^k + \rho d^k) - f(x^k) - \mu_1 \nabla f(x^k) d^k \geqq 0$$

$$\theta_2(\rho) = \nabla f(x^k + \rho d^k) d^k - \mu_2 \nabla f(x^k) d^k \geqq 0$$

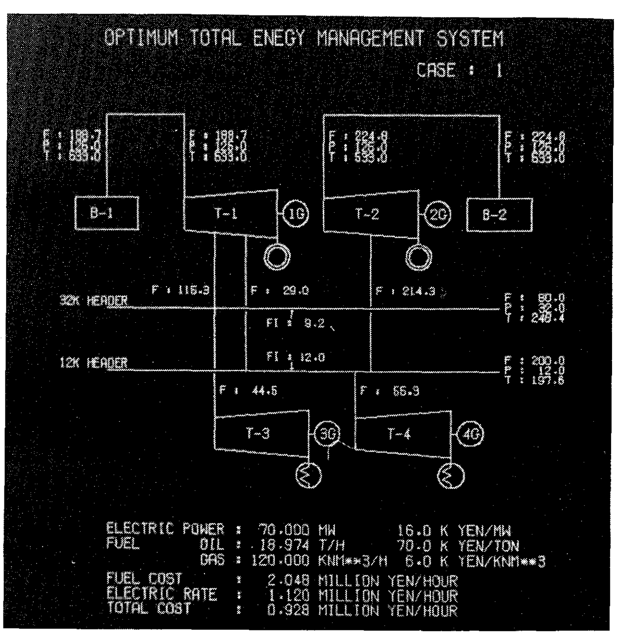
(2) Gradient projection multiplier method

The general process is formularized as:

minimize $f(x)$

subject to	$g_i(x) \geqq 0 \quad i = 1 \sim m$	Nonlinear inequality sign restriction
	$g_i(x) = 0 \quad i = 1 \sim q$	Nonlinear equality sig sign restriction
	$l_i(x) = \sum_{j=1}^{n} a_{ij} x_i \geqq b_i$	$i = q + 1 \sim r$ Linear inequality sign restriction
	$l_i(x) = \sum_{j=1}^{n} a_{ij} x_i \geqq b_i$	$i = r + 1 \sim s$ Linear equality sign restriction

Fig. 6 Optimum total energy management system by CAD



To solve this problem, the following function is constructed by using Lagrangian multipliers vector δ_i ($i = 1 - q$), assuming that $f(x)$ and $g_i(x)$ $i = i - q$ are penalty parameter t.

$$L(x, t, \sigma) = f(x) - \sum_{i=1}^{q} \sigma_i g_i(x) + \sum_{i=1}^{q} t \{ g_i(x) \}^2$$

$$+ \sum_{i=1}^{m} \begin{cases} t \{ g_i(x) \}^2 & g_i(x) \leqq 0 \\ \dfrac{\sigma_i t \{ g_i(x) \}^2}{t g_i(x) + \sigma_i} & g_i(x) \geqq 0 \end{cases}$$

The gradient projection multiplier method is defined as a technique for obtaining the optimum solution efficiently by combing the BFGS method described in (1) and the gradient projection method, using function L as an object function.

(3) Example of implementation by CAD system

An online system using a process computer with an conversational CAD system for guidance will be introduced. In this system, the nonlinear programming method described is (2) is applied to optimum operation of a private electric power plant with a parallel thermal feed system having 2 boilers, 4 turbines, 4 generators, and 4 pressure lines. An example of the output CRT screen of this system is shown in *Fig. 6*.

2) Subsystem optimization package

An ironworks contains (1) converter gas (LDG), (2) oxygen plant (O_2), (3) blast furnace (BFG), (4) coke gas (COG), (5) steam, (6) electric power, (7) private electric power, and other subsystems. Standard package FODSS (Fuji integrated energy Optimum Dispatching Sub System) (1) ~ (7) are available for these subsystems to determine the overall distribution quantity from the predicted values and determine the individual optimum distribution quantities.

4. Energy center total energy optimum distribution system

The optimum total energy management concept is shown in *Fig. 7*. Since the energy center improves controlability and energy saving of each subsystem, this optimum total energy management system performs crosswise information transfer and information processing of this systems for optimizing energy saving.

"Optimum management" in an energy center means the smooth manipulation of the various energies inside the center and minimization of the purchase energy cost. This is formularized as:

$$\text{minimize } f = (f_1, f_2) \quad \ldots \quad (1)$$

$$\text{subject to } \sum_i {}^k x^i + \sum_j {}^k x^i = {}^k x\text{all} \quad \ldots \quad (2)$$

$$f_1 = \Sigma\Sigma\, \Delta^k C^i ({}^k x^i \text{aim} - {}^k x^i)^2 \quad \ldots \quad (3)$$

$$f_2 = \sum_k \sum_i \Delta^k D^j ({}^k x^j \text{aim} - {}^k x^j)^2 \quad \ldots \quad (4)$$

Where, ${}^k x^i$ and ${}^k x^j$ are the load quantities and ${}^k x^i$aim and ${}^k x^j$aim are the aim values. f_1 indicates the total balance of the energy cost. The other load quantities are represented by i, while the kind of energy is expressed by k (power, LPG, etc.). On the other hand, f_2 is related to the resources

Fig. 7 Flow diagram of optimum total energy management system

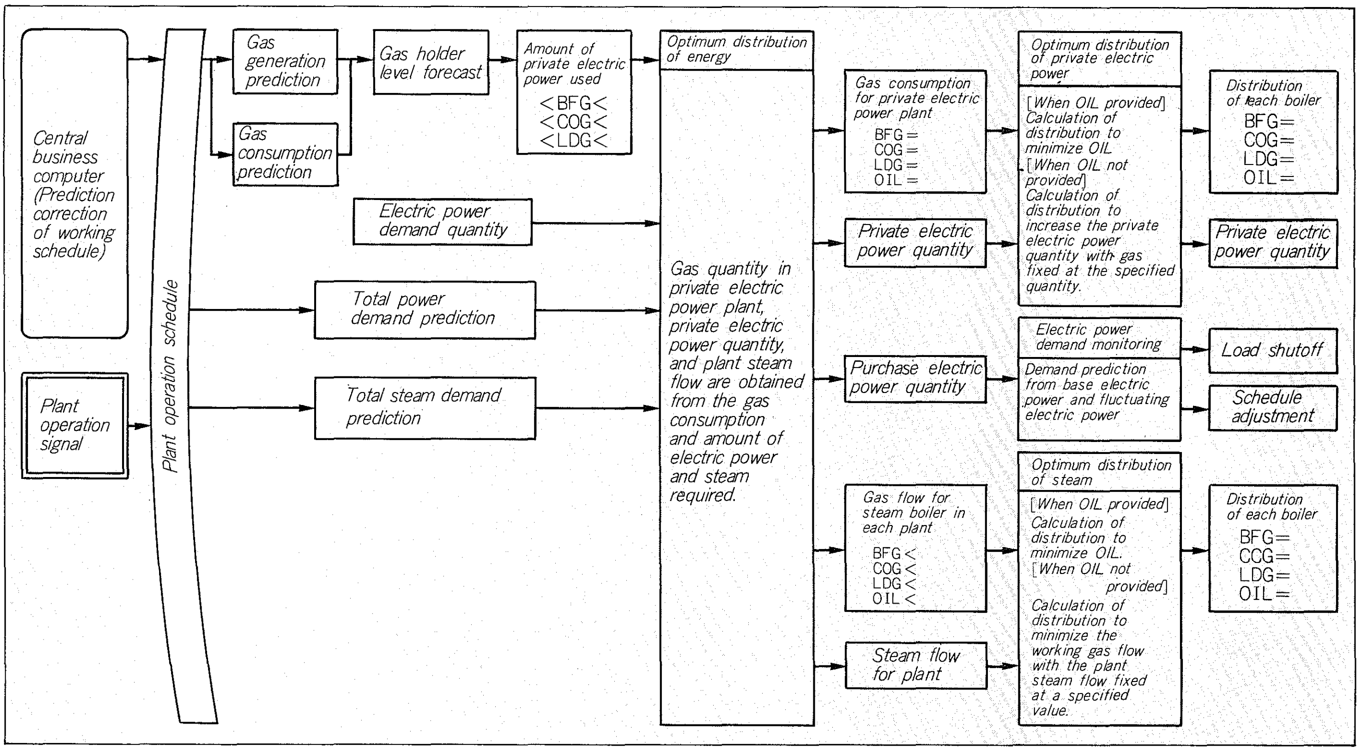


Table 1 Optimization technique

Mathematical programming method	Features
Optimization problem without restriction	• Basic theory of nonlinear program method
Linear programming method	• Object function, linear restriction conditions • Continuous variables
Nonlinear programming method	• Either object function or restriction condition or both object function and restriction condition are nonlinear • Continuous variables
Integral linear programming method	• Linear object function and restriction condition • Discrete variables (0, 1, integer)
Multipurpose programming method	• Multiple object functions • Linear, nonlinear, continuous, and discrete variables

which are not reflected in the cost and summarizes the load quantity of kind j according to the kind of energy corresponding to the consumption of the generation gas in the load adjusting plant.

The feature of this module is in finding the tradeoff point of f_1 and f_2 by considering f_2 so as not to change the programmed operating conditions too much, while aimming at economization of cost by minimizing f_1.

In model analysis of the optimum total energy management system, the prediction theory applies to load prediction and the optimization theory applies to the optimization calculations. The following are used as the prediction theory:

(1) Method of least squares
(2) Multiple regression method
(3) Self regression method
(4) Kalman filter

Prediction accuracy must be improved so that production is performed as programmed and unpredicted troubles are processed quickly. For this purpose, good programming process accuracy, stable production facilities, and a complete production management system are required. The techniques shown in *Table 1* are in optimization theory as handy techniques. The sequential calculation technique is available as a realistic technique.

Since the model is linear as shown by equations (3) and (4), the main job is giving the coefficients of $\Delta^k C^i$ and $\Delta^k D^j$ to meet the operating conditions when applying the model to an actual plant.

[4] FUTURE PROSPECTS

1. Total energy cost minimum control

In the past, minimum cost for gas, steam, electric power, and so forth has been pursued individually. In the future, control which minimizes the total cost will be necessary. (See *Fig. 8*.)

2. Maintenance and production plan base on energy plan

Today, when the energy cost ratio occupies a large part of the total costs of an ironworks, to minimize total cost, the energy plan must be fed back to the maintenance plan and production plan. (See *Fig. 9*.)

3. Improvement of system maintenance

As the importance of the energy center system increases, system trouble and down time become a serious problem. As a result, the system must be duplicated. (See *Fig. 10*.)

4. Development and improvement of control logic to meet needs

Conventionally, operation by skilled operators were

Fig. 8 Control of minimization of total energy cost

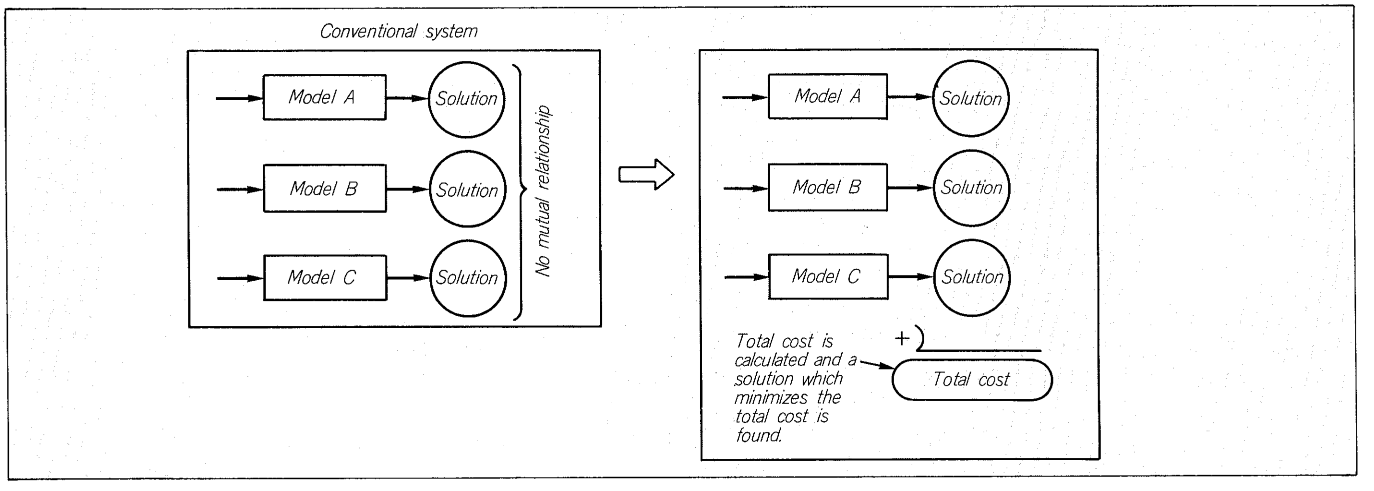


Fig. 9 Maintenance and production plan based on energy plan

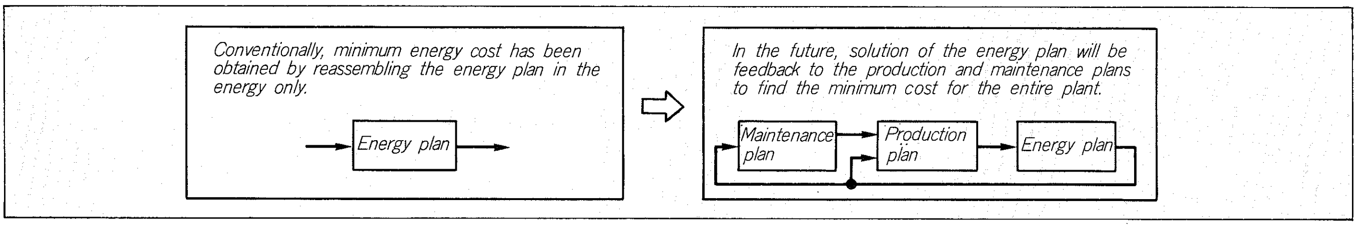


Fig. 10 Keep and level up for system

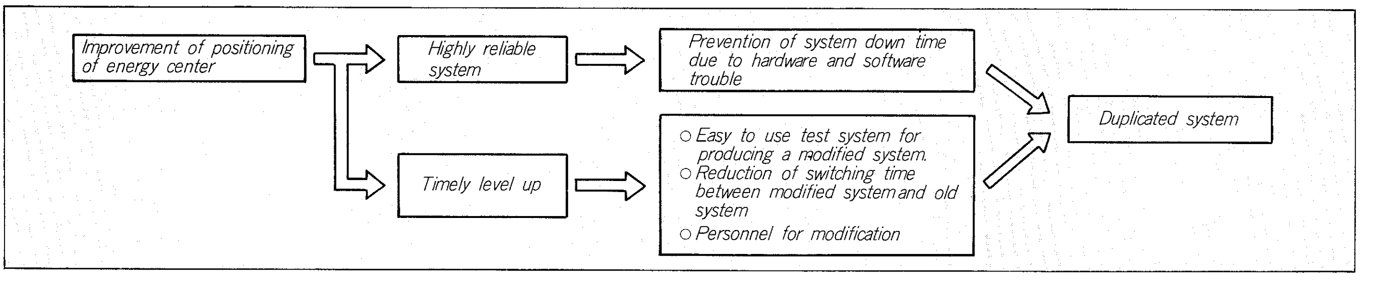


Fig. 11 Development and improvement of control logic

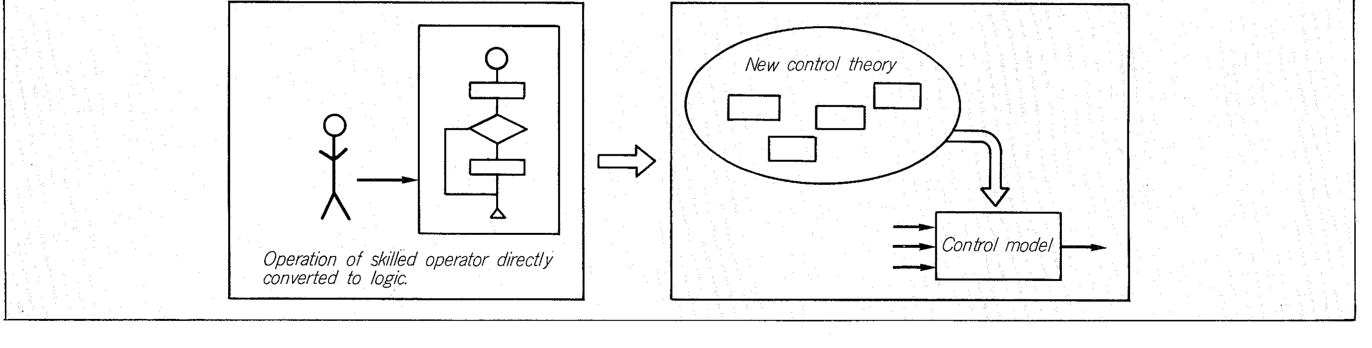


Fig. 12 Easy control system

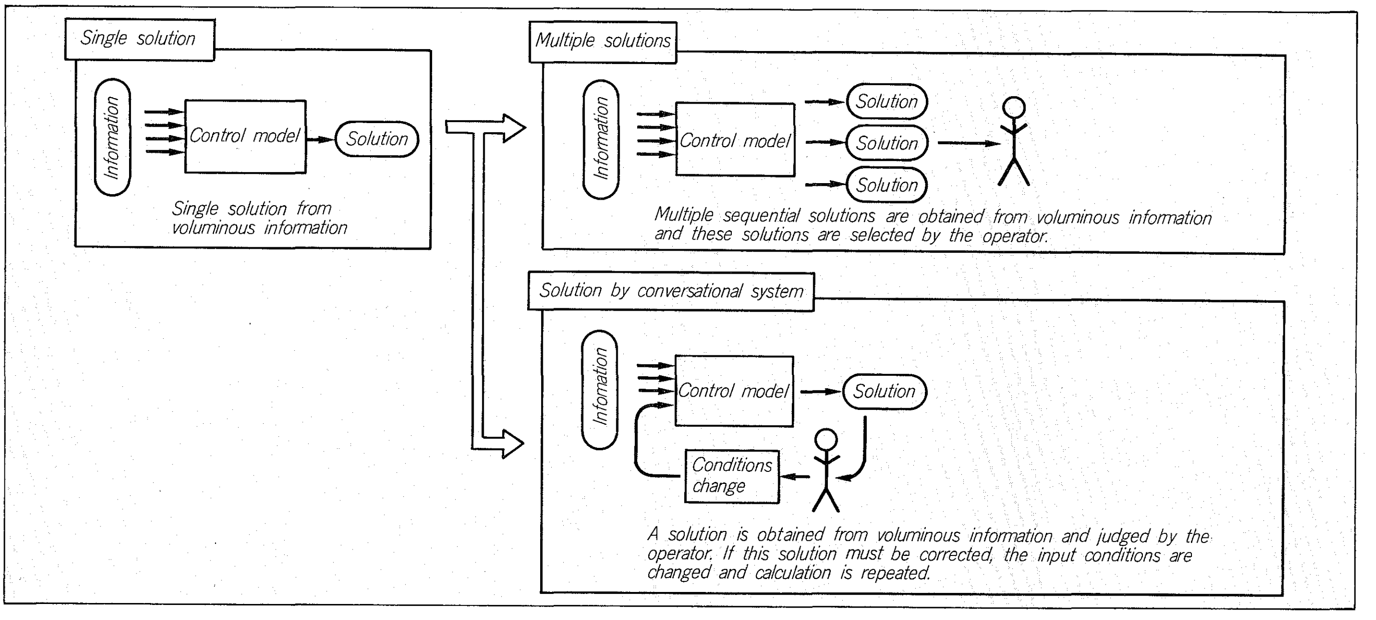


Fig. 13 From simple aim to complex aim

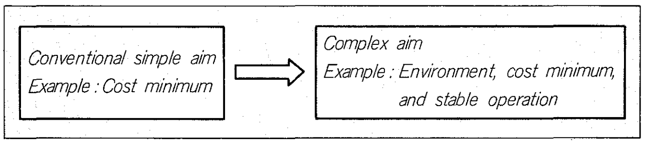
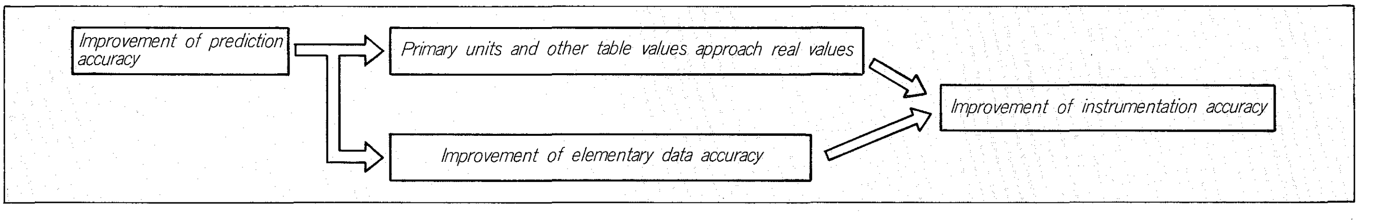


Fig. 14 Level up measuring accuracy



directly converted to logic and operated as a program. However, in the future, control models using new control theory must be developed. On the other hand, for more accurate solutions, the theory of uncertainty and so forth must be restudied based on the operator's experience. (See *Fig. 11.*)

5. Easy to use control system

An easy to use control system which allows the operator to judge multiple solutions obtained from control models and manual setting of conditions by conversational system must be considered. (See *Fig. 12.*)

6. From simple aim to complex aim

Conventionally, the solution of minimum cost and other simple aims was found. However, it is necessary to find solutions which simultaneously satisfy multiple aims, such as environment, stable operation, etc. (See *Fig. 13.*)

7. Improvement of measuring accuracy

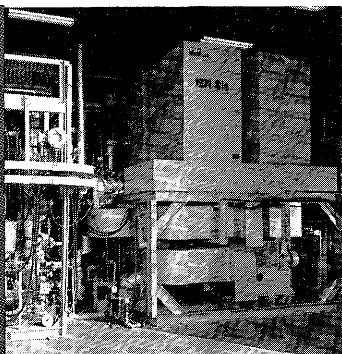
Up to here, efficient operation of the energy center has been studied. Measuring data is the foundation of these. Needless to say, improving the accuracy of this measuring data is of utmost importance. (See *Fig. 14.*)

5 CONCLUSION

A description of the trends of energy center functions and outline of control models have been given above. Various accumulated packages of control models are now being used by users. The energy situation needs are becomes more diverse and we will further develop systems matched to these needs. We ask for your opinions and needs in the future.

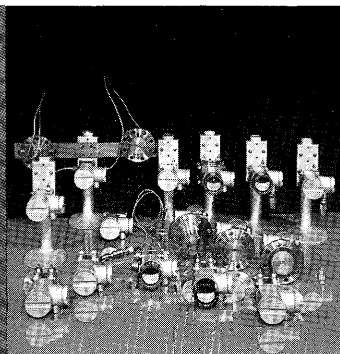
Outline of Products

Power and Industrial Electrical Machinery



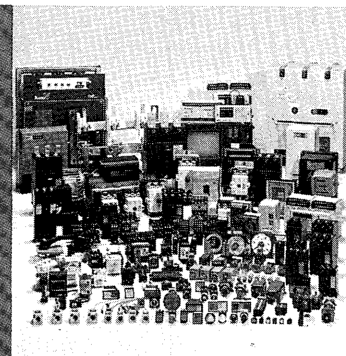
- Nuclear Power
- Power Generation and Distribution
- Transportation
- Environmental Equipment
- Industry
- Electrical Installation
- Mechatronics Equipment

Instrumentation



- Industrial Instrumentation
- Water Treatment
- Data Process Engineering

Standard Electrical Products



- Semiconductors
- Rotating Machines
- Standard Electrical Equipment

Vending Machines and Specialty Appliances

- Vending Machines
- Freezing & Refrigerating Open Showcases
- P.O.S. for Versatile Purpose Appliances
- Air Conditioning