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COMPUTER CONTROLS IN THERMAL POWER PLANTS

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I. INTRODUCTION

Computer controls in both thermal power plants of the electric utility can have many advantages including savings in labor, quantitative comprehension of plant operating conditions, improvements in control quality, preventive diagnosis of accidents and improved economy.

The main functions of computers in thermal power plants are operation automation and data processing in Japan. At present, efforts are being made to improve the quality of automation software and expand the automation range. Fuji Electric is now manufacturing a set of equipment with both automation and data processing functions. This equipment will undergo work-shop tests this autumn and will go into commercial operation in August of next year. Details concerning this equipment will be reported at a later date.

On the other hand, the introduction of computers into nonutility thermal power plants is generally not determined in accordance with some goal but depends on the position which it will occupy in the plant process. For example, when thinking of both steam and electric power supplied by a thermal power plant for a relatively large process which occupies part of a petroleum complex, the most suitable application of the computer to provide the most efficient process operation must be considered. On the other hand, computers are applied for economic fuel distribution when there are several boillers to be controlled. In this article, actual examples of applications based on Fuji Electric's experiences in this field will be explained for references.

II. FUNCTIONS

1. Logging

Logging is the compiling of data for daily and monthly reports for operation monitoring, administration and maintenance. More precisely, it includes the hourly print out of data of the plant conditions required in the above three cases as well as the administration indices processed from these data, print-out of abnormal values, average values, maximum and minimum values, and print-out during starting and stopping and during emergency conditions. The collection of redundant items and duplication with the trend recording meters must be avoided and the data must be compiled in the form of a daily report for operation administration.

2. Monitoring

Monitoring is the monitoring of plant operating conditions and the detection and display of alarms. A large number of measuring points in the plant are monitored at all times, processing conditions are analyzed on the basis of these data and the operators are informed only in cases of emergency or approaching-emergency. In other words, the basic concept is that primary data from many processes are processed in the computer, the amount of process data is effectively reduced and the information is obtained more directly from the computer.

The method of monitoring primary process data is to check the measuring range, the upper and lower limits, the upper-upper limits and the lower-lower limits, the change rate, etc. In this way, it is possible to detect computer input disconnections, analogue-digital converter breakdowns, amplifier breakdowns, detector accidents, etc. even when there is a plant emergency.

The preset values of the upper and lower limit values etc. which are compared with the process input values, etc. are stored in the write-inhibited area of the auxiliary memory and there is no danger of erroneous writing during operation.

Monitoring of points where there are no analogue meters installed and monitoring of plant characteristics values not measured by purely analogue meters is also possible by means of the digital display in the operator's console. As an example, there are ratio values of two types of characteristics values such as flow rates of confluent points obtained by subtraction and temperature/pressure compensation values of flow rates before spray attemperators.

3. Performance calculations

Performance calculations include calculations of the indices during generating plant operation and the maintenance/administration indices for long periods by combining the primary process data obtained from on-line operation and processing them.

During specified plant operation, there is almost no need to monitor the analogue meters which indicate the plant condition values directly, and it is sufficient just to watch for deviations from the standard values and the operation administration indices. At this time, it is essential to track the changes with time for more than several months and this has considerable significance for the maintenance/administration indices before and affer the periodical plant maintenance.

The efficiency calculations include boiler efficiency, turbine internal efficiency, turbine total efficiency, generator efficiency, plant efficiency, etc. as well as rates and load characteristics calculations such as boiler steam generation rate (amount of boiler steam/amount of fuel), boiler fuel units (oil flow/main flow), turbine steam consumption rate (turbine steam intake/generated power), water injection rate of spray attemperator, equivalent amount of steam for power generation, boiler load factor characteristics of internal steam ratio, boiler load factor characteristics of boiler efficiency, excess air rate characteristics of boiler efficiency, boiler load characteristics of exhaust gas temperature, and incoming voltage characteristics of incoming power factor.

These values should be detected with small significant differences since discrepancies in standard values and changes with time must be controlled. To achieve this, it is necessary to obtain values which are as absolutely correct as possible. For example, when obtaining the steam flow rate, the temperature and pressure of fluids near the orifice when measuring and the orifice design pressure and temperature values are considered and it is necessary to perform correction calculations by obtaining specific volumes for each case. Since it is also necessary to obtain values of enthalpy and entropy which are as correct as possible, a part of the steam table can be stored in the memory or the polynomial approximation can be used. In the case of computers for process control, it is especially essential to make the decision in consideration of the calculation time and the auxiliary memory capacity.

4. Boiler fuel gas distribution control

The generation conditions of blast furnace gas (BFG) and cokes oven gas (COG) in the steel plant are maintained so that they are consummed as desired by the energy center and a stable balance of the amounts of BFG and COG is maintained at any one time. In the energy center, the amounts of BFG and COG for combustion in the boilers are communicated to the power station but in the power station, it is necessary to find out how these specified amounts should be distributed among the boilers. The role of the computer in controlling this distribution will be described here.

In the setting panel in the energy center, the increase or reduction amounts for the BFG and COG are set and at this time these values are displayed on the operator's console in the central control room of the power station several hundred meters away. When the operator pushes the button to start the calculation, the computer reads the set values, and starts the calculation. The computer compares the current plant conditions and makes the calculations so that the set distribution amounts are consumed as much as possible. The numerical values of the distribution amounts for each burner level are displayed in the operation control desk for each boiler. The boiler operators observe these values and if they find that there are no unsuitable values among the specified distribution amounts, they push the confirmation button. The combustion control system starts the setting motor of the analogue flow controller by means of a pulse width signal from the computer when the controller is in 'auto' position and the specified changes take place. When the control system is in 'manual' position, the operators can control the operation as they see fit. *Fig. 1* shows the connections between the pulse width signal from the computer and the analogue controllers.

The basic principle of the gas fuel distribution calculation is that the burner ignition and extinction operations should be as few as possible. Manual flow regulation operations are as few as possible increases or reductions in the amount of BFG and COG are compensated with heavy oil under the constant load. The distribution of COG is decided prior to that of BFG. The maximum burner load value which is limited by the air/fuel ratio in each burner level is not exceeded.

The information required when the distribution calculations are made is divided into items related to the actual process conditions and items which are set manually by the operators. The former includes the gas flow, heavy oil flow, burner ignition/extinction conditions, auto/manual position of the

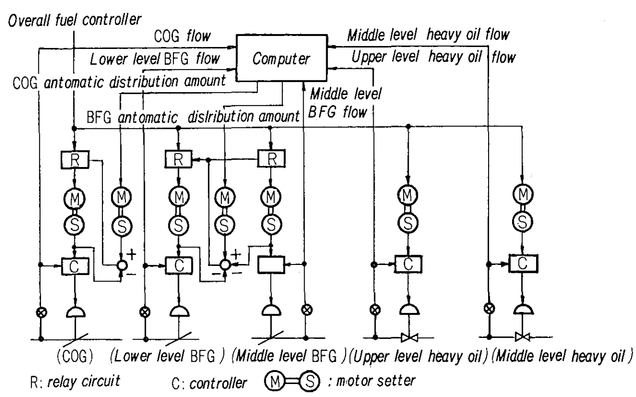

Fig. 1 Fuel distribution control system for one boiler only

fuel flow controllers, load regulation/constant load regulation of the controllers and evaluation of whether the boiler is operating or not. The latter includes the boiler priority sequence for distribution, boilers and burners which are not subject to the distribution calculation and the upper and lower flow limits for each burner.

As an example, when the instruction from the energy center is BFG○○Nm³/h, and COG× ×Nm³/h increase, the calculations are as in (1) to (6) below.

(1) The amounts of distribution to upper level and middle level heavy oil burners are calculated on the basis of the excess amounts obtained increasing the BFG.
(2) The amounts of distribution to the upper level and middle level heavy oil burners obtained by reduction are calculated on the basis of the amount obtained by increasing BFG, the ignition of extinguished burners and the possibility of BFG operation. The burners are not ignited or extinguished at the (1) and (2) steps.
(3) The value needed if the middle level heavy oil burners are extinguished is calculated on the basis of the excess amount obtained by increasing the BFG.
(4) The calculation of the item (3) is used to calculate the amount for extinguishing the upper level heavy oil burner.
(5) The calculation for extinguishing the middle and upper level heavy oil burners is made on the basis of the value for which the burner which can extinguish the BFG is ignited.
(6) The calculations from (1) to (5) are made for COG.

When some instruction other than the above 「BFG increase, COG increse」 is received such as 「BFG decrease, COG decrease」, 「BFG increase, COG decrease」 or 「BFG decrease, COG increase」, the distribution calculation concepts are all based on the calculations given in (1) to (6) above.

5. Changes in boiler air/fuel ratio

This program controls the boiler air/fuel ratio so that maximum efficiency of boiler operation is maintained.

The maximum value of boiler efficiency is obtained by the "mountain climbing" method. The air/fuel ratio is changed by minute amounts by trial and error and the boiler efficiency is calculated. The values calculated for boiler efficiency in a set period before and after there changes are processed statistically, the significant differences are tested and the summit of the mountain is nearly reached. The amount of air flowing into the boiler makes it known whether the direction of approach to the summit is the direction of air increase or the direction of air decrease.

Referring to *Fig. 2* and explaining somewhat in detail, the boiler efficiency, boiler air amount and boiler load rate are obtained every 30 minutes on the basis of related data read in every 2 minutes. First, it is confirmed that the boiler load rate is over 50% and the significant difference between this 30 minute boiler load rate and the previous 30 minute average value is tested. When there is found to be no significant difference, i.e. when there are very few changes in the boiler load, the boiler efficiency is tested. The significant difference between the current 30 minute boiler efficiency average value (η (now)) and the previous 30 minute boiler efficiency average value (η (before)) is tested and at the same time, the relation between the current 30 minute

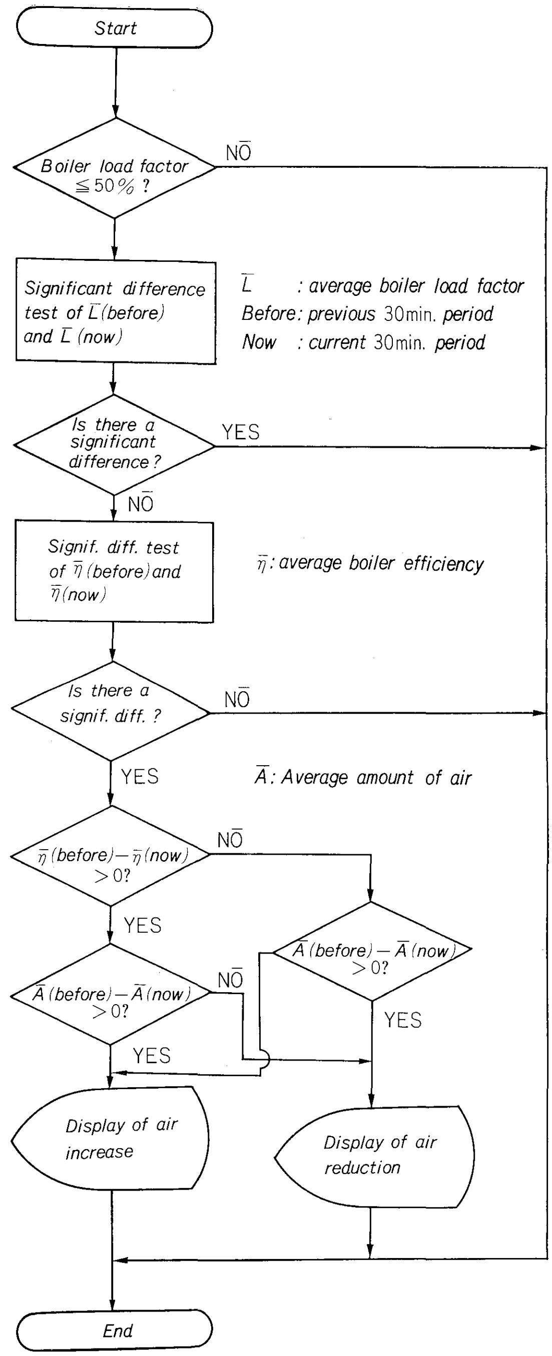

Fig. 2 Flow chart of air-fuel rate control program

amount of boiler air (air (now)) and the previous 30 minute amount of boiler air (air (before)) is cheked. As can be seen from *Fig. 2*, it is decided whether the air should be increased or decreased.

As is evident from the above, the steady state boiler load conditions are the conditions when the boiler load changes are very small. When the changes are over the set range of the boiler load, the optimum value of the air/ fuel ratio in respect to the load after the change is indicated and after some transient period passes, the optimum values mentioned above are adopted. When the boiler load rate is less than 50%, the main parts of this program does not operate.

6. Steam balance, turbine extraction capability display

When the power plant is operated under a condition, the excess amount of steam generated for process is calculated by considering the current operating conditions and the steam plant capacity. The results are displayed to the operators.

The steam which is used for the processes generally is under different pressures depending on the process and the amounts of steam under each pressure as well as the amounts of steam due to the extraction sequence etc. are calculated and displayed separately for each case.

The basic concept of the calculation is a solution based on limit conditions of heat and mass balances for the water and steam systems in relation to the plant. For example, as can be seen in *Fig. 3*, a plant with a simple water/steam system is considered in a somewhat ideal state. In this system, considering the material and heat balances, equation (1) can be established.

$$\left.\begin{aligned} G_1 &= G_{13}-(G_5+G_6) \\ G_{13} &= G_{11}\frac{i_{12}-i_{11}}{i_{12}-i_{13}} \equiv \gamma G_{11} \\ G_5 &= -G_2\frac{i_7-i_2}{i_7-i_5} \equiv -\alpha G_2 \\ G_6 &= -G_3\frac{i_8-i_3}{i_8-i_6} \equiv -\beta G_3 \\ G_{11} &= G_4-G_9-G_{10} \end{aligned}\right\} \cdots\cdots (1)$$

In these equations, G is the amount of steam or water and i is the enthalpy.

Also we obtain next equations (2), and (3):

$$G_1=\gamma G_{11}+\alpha G_2+\beta G_3 \cdots\cdots (2)$$

$$G_1=\gamma(G_4-G_9-G_{10})+\alpha G_2+\beta G_3 \cdots\cdots (3)$$

Since G_9 and G_{10} are coefficients of the main steam amount G_1, therefore:

$$G_1=\gamma\left\{G_4-g_9(G_1)-g_{10}(G_1)\right\}+\alpha G_2+\beta G_3 \cdots (4)$$

On the other hand, the equation of the steam material balance at the turbine outlet is as follows:

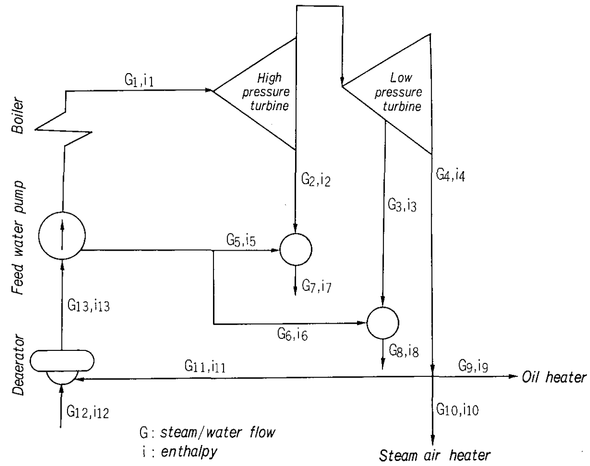

Fig. 3 Explanatry drawing of heat balance calculation

$$G_1=G_2+G_3+G_4 \cdots\cdots (5)$$

If equations (4) and (5) are solved as simultaneous linear equations, the variation relations among any three of the 4 variables G_1, G_2, G_3 and G_4 can be obtained.

For example, when finding out what value G_2 can be increased during operation when G_3 is constant, equations (4) and (5) are solved on the basis of physical limiting conditions such as the maximum flow of G_1, the maximum flow of G_2 and G_4, the generator capacity, etc. and the maximum value of G_2 is determined.

7. Selective cut-off of electrical feeders

When the incoming power is stopped, the internal power source feeder must be cut off in accordance with the previously set priority sequence. After the power system voltage and the frequency becomes stable, the data needed to achieve full boiler and turbine output is designated.

Selective feeder interruption will be performed by an on-line loop using the computer, but at present there is still a problem of the necessity of investigations into reliability at on-line points and high speed processing. Therefore, at this stage, the future on-line control programs are only being tested and off-line programs are used.

One power feeder is related to a certain amount of electric power plus a consumed amount of steam. When one feeder is cut off, the amount of decreases, the trubine extraction decreases, and the generator output also decreases. In other words, if we consider that there are no time discrepancies between power and steam cut-off, then a feeder is cut off up to the time the following is satisfied:

(cut-off power) ≧ (incoming power) + (reduced generator power).

However, after the feeder is interrupted, the number of feeders that can be considered as restored is the number to which the maximum recovery power which fulfills the following is equivalent:

(recovery power)$\leq$(generator surplus)

The basis of this calculation is the heat balance equation which is described in **6**. In other words, when the feeders of the equipment connected to G_2 and G_3 are interrupted, the flow of G_2 and G_3 change without relation to this. If G_2 and G_3 change, then G_4 changes and the generated power changes. In other words, to obtain the reduced power, it is necessary to determine how the back pressure G_4 changes due to the feeder interruption. When considering the varying parts of equations (4) and (5), these two equations become equations (6) and (7) respectively.

$$k\varDelta G_1=\alpha\varDelta G_2+\beta\varDelta G_3+\gamma\varDelta G_4 \cdots\cdots\cdots\cdots (6)$$

$$\varDelta G_1=\varDelta G_2+\varDelta G_3+\varDelta G_4 \cdots\cdots\cdots\cdots (7)$$

From these, the following relation can be derived:

$$\varDelta G_4=g_4(\varDelta G_2,\ \varDelta G_3)$$

Therefore $\varDelta G_4$ is obtained from $\varDelta G_2$ and $\varDelta G_3$. Generally the turbine and generator output change $\varDelta N$ is as follow equation (k_1, k_2 and k_3 are constants):

$$\varDelta N=k_1\,\varDelta G_2+k_2\,\varDelta G_3+k_3\,\varDelta G_4 \cdots\cdots\cdots\cdots (8)$$

The reduction in generated power can be obtained from $\varDelta N$.