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발전용 보일러의 예측 연소 제어

ANTICIPATORY FIRING CONTROL OF POWER PLANT BOILER

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1. INTRODUCTION

The operation of an integrated steel plant with large electric arc furnaces and rolling mills, whose power is supplied from either an isolated power plant or a power plant connected to a public supply system of small capacity, imposes crucial conditions on the power generating plant. The following shows the crucial characteristics which have to be considered to ensure proper design and reliable operation of the fossil power plant in the light of active power:

- Frequent load changes at different average load levels
- Severe stepwise and cyclic load increases and decreases due to electric arc furnaces
- Severe ramp load increase due to rolling mills

Meanwhile the conventional governor and boiler control systems[1] do not permit such rapid load fluctuations as are indicated above. Therefore the following problems are encountered in the operation of the power plant.

- Severe variation of system frequency
- Frequent interchange of tie line power when connected to the public supply system
- Severe fluctuation of boiler steam pressure and possibly beyond the acceptable limits
- Long term instability of the power system due to operational restrictions should specified limits be exceeded.

There are several possible choices to deal with the above active load problems. One method is to build a boiler with a large steam accumulator to cover the active power deficiency resulting from abrupt increases in load as well as to store the surplus energy on decreases in load. However this choice must involve a large investment cost. Another method could be to install several resistors on the load side which can be switched on and off in order to compensate for the active power fluctuation. However this choice will result in a large energy loss.

In this paper a new control method to resolve the active load problems and to avoid the investment incurred by the alternative hardware application is presented. This method employs Anticipatory Firing Control. The Control algorithm and its dynamic simulation in a sample power system supplying the steel plant load are presented in the following sections.

2. ANTICIPATORY FIRING CONTROL

The anticipatory Firing Control system incorporates short term control of the turbine governor, long term anticipatory control of boiler firing and steam bypass control.

Note: 1. Conventional boiler firing rate is 5%/minute average to 10%/minute maximum.

2.1 Long Term Anticipatory Control of Boiler

The general governor control scheme supports all regulating load changes through the use of stored energy and boiler firing determined by a boiler pressure error control. With this scheme only, the severe load changes incurred by the electric arc furnaces and rolling mills must however perturb the boiler stored energy level resulting in severe pressure fluctuation and in some cases the unit would not be able to accomodate the pressure swing at the boiler. Thus a new method maintaining an approximate energy balance in the boiler is proposed. This method employs anticipatory firing control. That is, the information on switch on's and rolling mills as required by the production operations is transferred to the power plant via communication computer or hardwired connections. By this means the future load demand is anticipated and low pass filtered by an extrapolation technique. The filtered signal is then incorporated into the boiler firing control system in a manner of feed forward signal in order to increase the boiler pressure up to an acceptable level in advance of actual load increase.

2.2 Anticipatory Filtering of Future Loads for Electric Arc Furnaces and Rolling Mills

Let the future load demands at time $t+k\ T_s$ be $P(t,k)$, then the mean value of anticipated load for $t=t$ to $t+0.5\ T_{ba}$ in the steel plant is calculated as:

$$\bar{P}'ba(t) = \frac{1}{0.5K_{ba}} \sum_{k=1}^{0.5K_{ba}} P(t,k) \qquad (3)$$

where k : 1,2,3,...
T_s : sampling time interval
Tba : anticipated time length
Kba : no. of anticipated sampling intervals

Likewise the mean value during the period from time $t+0.5K_{ba}T_s$ to $t+K_{ba}T_s$ is

$$\bar{P}'ba(t) = \frac{1}{0.5K_{ba}} \sum_{k=0.5K_{ba}+1}^{K_{ba}} P(t,k) \qquad (4)$$

Approximating that

$$P(t,\ 0.25K_{ba}) \fallingdotseq \bar{P}'ba(t) \qquad (5)$$

$$P(t,\ 0.75K_{ba}) \fallingdotseq \bar{P}''ba(t) \qquad (6)$$

the future load $P(t,K_{ba})$ in the steel plant to be anticipated at time t for $t+K_{ba}T_s$ is approximated, with the liner extrapolation of $P(t,\ 0.25K_{ba})$ and $P(t,\ 0.75K_{ba})$, by

$$\bar{P}(t,K_{ba}) = 1.5\ \bar{P}''ba(t) - 0.5\ \bar{P}'ba(t)$$

$$= \frac{1}{Kba}\left[3\cdot \sum_{k=0.5K_{ba}+1}^{K_{ba}} P(t,k) - \sum_{k=1}^{0.5K_{ba}} P(t,k)\right] \qquad (7)$$

Figure 1 shows a comparison between an actual future load $P(t,K_{ba})$ and the corresponding filtered load $P(t,K_{ba})$ when applying an anticipated time of 2 minutes.

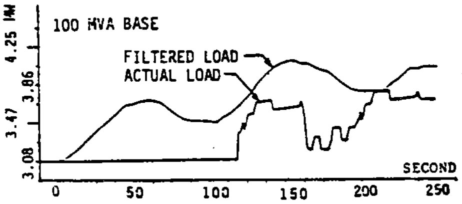

Fig. 1 Comparison between actual and filtered load curve

To ensure adequate control of boiler pressure the actual feed-forward signal at time t for boiler firing control is implemented by the following formula:

$$P^{i}_{ba}(t) = C^{i}.B\left[\bar{P}(t,Kba) - P_{tie,\ actual}\right] \qquad (8)$$

When B : multiplication factor to be determined experimentally in particular consideration of the lower limit of boiler steam pressure

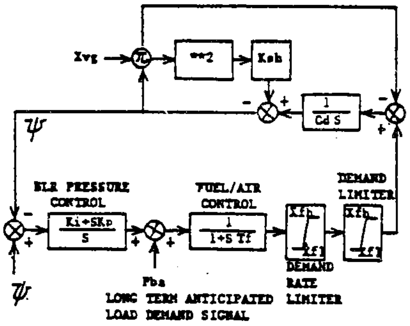

Fig. 2 Relationship of anticipatory control with boiler pressure control

2.3 Steam Bypass Control

In most cases the above anticipatory nature of the boiler firing control is able to maintain the boiler steam pressure within the permissible range. In order to prevent boiler pressure rise exceeding its maximum limit due to excessive overfiring in response to severely varying future load or load rejection, a steam bypass valve control algorithm is proposed. This will open or close the bypass valve as necessitated by the actual steam pressure and thereby initiating steam dumping to the condenser. The flow of bypass steam also allows the sufficient steam reserve against anticipated future load demand.

Steam Bypass Control Algorithm. The bypass valve position set point (X_{bpsp}) is controlled by sensing the boiler superheater outlet pressure. Although the control scheme is bascially such that the valve is opened up to X_{bpsp} in the case of steam pressure (ψ) exceeding the permissible upper limit (ψ_{up}) and is fully closed below this, the actual control algorithm is provided with a dead band $\psi_{up} - \varepsilon_{bp} \le \psi \le \psi_{up}$ in order to prevent frequent opening and closing of the steam bypass valve. The steam bypass control algorithm and its relevant dynamics are as shown in the Figure 3 and 4.

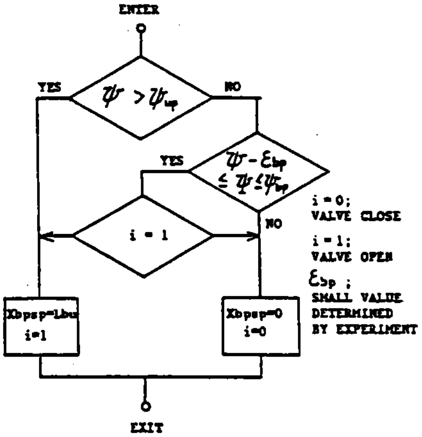

Fig. 3 Steam bypass control algorithm

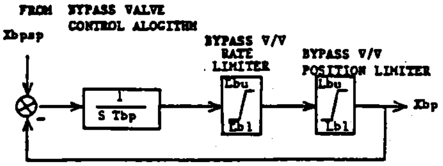

Fig 4 Block diagram of steam bypass valve

2.4 Power System Dynamics Models

For the purpose of simulation of the effectiveness of the aforesaid Anticipatory Firing Control, power system dynamics modelling has been applied to a power plant which is designed to supply power to electric arc furnaces and rolling mills. The models used in this study consist of the following principal components :

- Generator and Excitation system
- Governor and Turbine
- Boiler and Steam Bypass Valve System
- Load model

3. NUMERICAL EXAMPLE

Energy Deficiency without Anticipatory Control. Should the boiler be operated under a conventional firing (here firing rate is selected to be 7% TCMR per minute) without anticipatory control, the energy deficiency due to the severe load fluctuation causes the steam pressure of the boiler to drop below the acceptable limit, to say -5% of the rated pressure. Figure 5 shows the energy deficiency under operation with the conventional firing control as well as the steam pressure decrease at this condition.

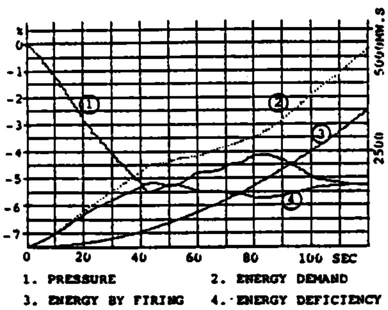

Fig. 5 Energy deficiency without anticipatory control and steam pressure drop

Dynamic Simulation Result. In the simulation the 5 generators in the power plant connected to the public system are supplying the worst case 2 minutes load demand which increases from the steady state load of 328 MW to 398 MW. The load demand is anticipated 2 minutes in advance of being actually imposed on the units and therefore the boiler firing is initiated at t = 0 and continues until t = 2 minutes within the maximum permissible rate limit of 7% TCMR/min. Initial tie line power flow-in is zero. The simulation results are described as follows :

Steam pressure at the boiler superheater outlet in the power plant gradually increases up to about 2.0% just before actual loading with the assistance of the Anticipatory Boiler Firing for the period of t = 0 to 120 seconds. When the load throw-on occurs, the pressure drops down to around the rated pressure 1.0 p.u. in 20 seconds (t = 140 sec) and continues to drop down to -0.5% (t = 160 sec) in the subsequent 20 second period. That steam pressure varies in the range of +1% and -0.5% in response to the further load fluctuations. Need to initiate flow of bypass steam does not occur. Meanwhile the steam pressure of the public supply system slightly varies within +/-0.5% which is fairly within its constraint.

4. CONCLUSION

The current practice of placing fossil fuel fired steam-generating units is primarily for base-load operation and generally do not have capability for large load fluctuation. This paper presents a feasible generation control algorithm, that is Anticipatory Firing Control which enables a fossil power plant connected to a small public supply system or even in isolation, to supply satisfactorily so severely fluctuating load demands as needed from electric arc furnaces and rolling mills. When the control algorithm presented in this paper is applied to the design and operation of the power plant, its system performance can be considerably improved as summarized in the following :

- The increased fluctuation of boiler superheater outlet steam pressure and its possible overrun beyong acceptable limits to be expected under a conventional control can be prevented by the anticipatory boiler firing control associated with the anticipatory filtering algorithm and thereby the thermal stress imposed on the turbine is reduced.

- By means of optimum pressure setting for steam bypass valve opening the anticipatory boiler firing can allow variable steam pressure operation without exceeding the pressure limit of bypass valve opening and in consequence the energy waste owing to the nuisance opening of the steam bypass valve is minimized.

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