MODEL BASED PID CONTROLLER FOR COMBUSTION OF BOILER

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Abstract – An innovative design for combustion control of utility boiler using control balance model based cascaded PID controller is proposed. The existing control schemes have difficulty to cope up with inherent time delay, nonlinearity due to uncertainty of the combustion process and frequent load changes, calorific value of the fuel etc. This paper presents the control balance model with PID controller to regulate fuel, cascaded with another control balance model based PID controller to regulate air for combustion process. An experimental setup is fabricated in the laboratory for fuel and air control and real time simulation studies were carried out using conventional PID, and by cascaded PID controller scheme based on control balance model. The performances of proposed scheme are evaluated by simulation and the results are compared with conventional controllers using real time data obtained from the thermal power plant. The advantages of the proposed scheme over the existing controllers are highlighted.

Key words: control balance model, utility boiler, cascaded PID controller, combustion control

1. INTRODUCTION

The main object of combustion control is to regulate the heat input to the boiler in terms of fuel and air supplied in relation of steam pressure is detected and supply of air and fuel is adjusted accordingly. The steam pressure decreases with increasing load and vice versa. The variation system consist of airflow and the fuel flow control loops that are driven by the firing rate demand signal through master steam pressure controller. Conventional PID (Proportional – Integral – Derivative) controller used for combustion control is simple in structure, reliable in operation and robust to certain extent in performance. But they are not generally suitable for non-linear, higher order, time delayed and complex systems that have no precise mathematical models. Further it needs frequent tuning, which is not an easy task and is also time consuming.

Al-Awami et al [1] proposed Coordinated trading of wind and thermal energy to mitigate risks due to those uncertainties and they obtained the optimal trade-off bidding strategy that maximizes the total expected profits while controlling trading risks. Bezerra et al [2] developed a stochastic optimization model for the creation of a bidding strategy for a generator in an energy call option auction. Rajanikanth et al [3] proposed a new approach based on finite difference method for the simulation of electrical conditions in a dc energized wire-duct electrostatic precipitator with and without dust loading. Yinsong et al [4] first introduced a nonlinear model combining boiler-turbine-generator dynamic characteristics for a thermal-power-generation unit. Based on the nonlinear model, a new coordinated control design is proposed using the backstepping method incorporating the coordinated passivation approach that considers the entire boiler-turbine-generator system as a whole. Gillelle Sreekanth et al [5] presented to handle the problem of premature convergence, an efficient approach for solving non-convex economic dispatch (NCED) problem using a modified particle swarm optimization (MPSO) combined with roulette wheel selection method. Lee et al [6] investigated a large-scale once-through-type ultra supercritical boiler power plant for the development of an analyzable model for use in developing an intelligent control system. Xiangjie Liu et al [7] used a coordinated control strategy to ensure a thermal
power plant to have a higher rate of load change, but without violating the thermal constraints. Biswal et al [8] proposed for development and implementation of supervisory control and data acquisition (SCADA) based process control and monitoring system. In order to utilize the robustness and advantages of the PID controller, a control balance model based cascaded PID controller is proposed [9-12].

2. PID CONTROLLER SCHEME FOR COMBUSTION PROCESS

PID control signal

\[ U(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s\right) E(s) \]

Where \( K_p, T_i, T_d \) are proportional gain, integral time and derivative time.

Fig. 1. Block diagram for PID Combustion Controller for a Utility Boiler

Fig. 2. Conventional PID Scheme for air and fuel control.
The load controller generates the demand to the steam throttle valve from the unit load demand and the measured generated power[13-18]. The throttle pressure controller generates heat rate to the combustion controller from the measured throttle pressure and the turbine inlet pressure set point. Finally combustion controller activates the fuel valve and air dampers. Block diagram for combustion control of boiler is shown in Fig.1. The arrangement for conventional PID controller scheme for air and fuel control is shown in Fig.2.

In order to test and compare the performance of the proposed control balance model based PID controller with conventional controller it is required to obtain PID parameters[19-23]. The optimum PID controller parameters obtained by trial and error from the simulation test conducted in the lab scale experimental setup for various load conditions with respect to real time data collected from thermal power plant are presented in Table I.

**TABLE I PID PARAMETERS**

<table>
<thead>
<tr>
<th>Control loop</th>
<th>PID parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K_p</td>
</tr>
<tr>
<td>Fuel Controller</td>
<td>1.75</td>
</tr>
<tr>
<td>Air Controller</td>
<td>1.5</td>
</tr>
</tbody>
</table>

3. PROPOSED CONTROL BALANCE MODEL BASED CASCADED PID CONTROLLER SCHEME

The necessity for the boiler to maintain energy balance not only under steady state conditions but also under changing load demand[24-29]. To maintain the energy balance between boiler energy supplied and energy required under changing load, accounting for the energy storage characteristics of the boiler is a necessity. It is necessary to balance the control action fuel and air to equalize the energy demand and supply.

The control balance based cascaded scheme is shown in Fig.3.

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**Fig.3 Control Balance based cascaded scheme**
Control model has been developed to get variable fuel error.

\[ P_1 \text{ - Turbine first stage steam pressure} \quad \ldots \quad (1) \]

\[ P_t \text{ - Throttle steam pressure (Turbine inlet pressure)} \ldots (2) \]

\[ \dot{P}_d \text{ - Drum pressure differential} \quad \ldots \quad (3) \]

\[ P_s \text{ - is the set point for the throttle pressure} \quad \ldots (4) \]

Control balance error is proportional to

\[ (\text{Required Pressure}) - (\text{applied pressure}) \quad \ldots \quad (5) \]

This is proportional to the fuel error at any load varying condition. This will track a desired trajectory within the boundary region.

Fuel error = \( \frac{P_t}{P_s} \) \( P_1 \text{ - (applied pressure)} \quad \ldots (6) \]

Fuel error = \( \frac{P_t}{P_s} \) \( P_1 \pm \dot{P}_d \) \quad \ldots (7) \]

When load increases, the steam demand increases, throttle pressure decreases. The difference between the set-point & throttle pressure will produce the error signal to the combustion controller which will increase the airflow first & then the fuel flow to bring back the throttle pressure to the desired value[30-35]. There will be a time delay between the application of the input to the combustion controller and the resulting effect on it, which will degrade the total performance. To improve the performance, a control balance model has been developed to give the variable fuel error to the PID controller for fuel.

A control model for air has been developed which is proportional to variable fuel error is presented below.

For combustion control, if only the theoretical air required for complete combustion of fuel is supplied, substantial amount of soot and Carbon Monoxide will be observed in the flue gases. For achieving complete combustion excess air over and above the theoretically required quantity will have to be supplied to the boiler[36-41].

To maintain excess air, the set value for the air controller is proposed with respect to the fuel error derived from equation (7).

Set value for air controller = \( e_{\text{Model}} \times (e_{\text{Model}} \times \text{Weight factor}) \) \quad \ldots (8)

Where Weight factor = \( (W/100) \times e_{\text{Model}} \) \quad \ldots (9)

\[ W = 12 \text{ for less than 30\% of load or steam flow} \quad \ldots (10) \]

\[ W = 15 \text{ for 30\% to 50\% of load or steam flow} \quad \ldots (11) \]

\[ W = 20 \text{ for 51\% to 75\% of load or steam flow} \quad \ldots (12) \]

\[ W = 25 \text{ for 76\% to 100\% of load or steam flow} \quad \ldots (13) \]

The proposed value of the weight factor “W” for air is arrived after considering several dynamics of the boiler and also the knowledge obtained from the experts of thermal power station. This will also satisfy the control balance derived by practicing engineers and researchers[42-45].

The above control balance model based air set value will change the airflow immediately after dynamic or programmed load disturbance, which will always be in excess to the theoretical value.
The cascaded controller diagram is shown in fig. 4. Fuel error derived from the fuel model is cascaded to air model. When there is dynamic change due to grid disturbance the control balance model is proposed by considering turbine first stage pressure change, which is the first and immediate response, due to load disturbance and considered as feed forward information.

In order to test the performance of the proposed control balance model based PID controller, it is required to obtain PID parameters. The optimum PID controller parameters obtained by trial and error from the simulation test conducted in the lab scale experimental setup for various load conditions with respect to real time data collected from thermal power plant are presented in Table II. These values are considered as optimum because of satisfactory agreement with the real time response obtained from thermal power plant.

**Table 2**  
**The controller parameters for Control balance model based cascaded PID controller scheme**

<table>
<thead>
<tr>
<th>Control scheme</th>
<th>Control loop</th>
<th>KP</th>
<th>KI</th>
<th>KD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control balance model proposed</td>
<td>Air</td>
<td>1.5</td>
<td>1.2</td>
<td>0.5</td>
</tr>
<tr>
<td>scheme</td>
<td>Fuel</td>
<td>1.5</td>
<td>2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**4. IMPLEMENTATION OF LAB SCALE EXPERIMENTAL SET-UP**

The pressurized air from the compressor is regulated and fed to the control valve positioner and current to pressure (I/P) converter. One more tapping from air compressor is used as combustion air,
which is allowed to go to atmosphere via air control valve and airflow transmitter. (In practice, the airflow will be admitted to the boiler for combustion).

These analog signals are interfaced with the computer through I/O card. The processed signals from computer through I/O card are given to I/P converters as manipulated value to operate air and fuel valves.

5. SIMULATION STUDIES

Several experiments were conducted on the experimental set-up and the performances for both changes in the set point as well as in the load perturbation were studied. The responses obtained for positive and negative step change in load are shown in Figs. 5-6. Comparisons of time domain specifications and the performance criteria Integral Square Error (ISE) and Integral Absolute Error (IAE) for various step changes in load are presented in Table III & IV.

![Fig.5 Fuel flow response LOAD 21MW-42MW](image)

![Fig.6. Air Flow Response LOAD 21MW-42MW](image)
TABLE 3
Percentage Improvement in performance criteria (ISE and IAE).

| Control scheme          | Control loop | Load 21MW-42MW | Load 110MW-63MW |
|-------------------------|--------------|----------------|----------------|----------------|
| PID to proposed scheme |              | ISE            | IAE            | ISE            | IAE            |
| Fuel flow               | 18           | 8.1            | 11             | 4.5            |
| Air flow                | 17           | 10             | 9.2            | 9.8            |

TABLE 4. Percentage Improvement in performance criteria (Time domain specifications)

| Control scheme                        | Control loop | Load 21MW-42MW | Load 110MW-63MW |
|---------------------------------------|--------------|----------------|----------------|----------------|
| PID                                   |              | Rise time      | Peak time      | Sett time      | Under shoot   | Sett time   |
| Fuel flow                             | 14           | 28             | 28             | 73             | 20            | 55          |
| Air flow                              | 14           | 18             | 41             | 21             | 21            | 59          |
| Control balance model proposed scheme |              |                |                |                |               |             |
| Fuel flow                             | 14           | 28             | 34             | 20             | 20            | 55          |
| Air flow                              | 14           | 18             | 41             | 21             | 21            | 59          |

CONCLUSION

The results of this paper highlights the robustness of the control balance model based cascaded PID controller scheme for step changes in loads. The closed loop response of the control balance model based cascaded PID controller scheme shows satisfactory transient response with out much overshoot and settles down after about 34 and 32 steps of increment for air and fuel respectively.

This shows 48% improvement over conventional schemes in settling time for both air and fuel. The proposed control balance model based cascaded PID controller scheme results in least ISE and IAE values for the step changes in load showing 19% improvement for air and 23% improvement for fuel control when compared to conventional schemes. The qualitative and quantitative comparisons of the performance of the various control schemes reveal the superiority of the control balance model based cascaded PID controller scheme over the conventional schemes.

REFERENCES
