INTELLIGENT DEMAND BASED CASCADED CONTROLLER FOR COMBUSTION OF UTILITY BOILER

Dr. T. R. Rangaswamy, Dr. S. P. Vijayaragavan
Professor 1, 2, Department of EEE, BIST, BIHER, Bharath University, Chennai.
rangaswamy.eee@bharathuniv.ac.in

Abstract — The main objective of the combustion controller in a thermal power plant is to regulate fuel and air in proper ratio to maintain the desired steam pressure at the turbine inlet, irrespective of the changes in steam demand. 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. In order to cope with the above problems, this paper deals with proposed design of intelligent demand based cascaded controller for combustion process in utility boiler. In this approach, fuzzy controller for fuel will get the set point with respect to demand considering turbine first stage pressure and throttle pressure and cascaded with fuzzy controller for air which will get the set point as a function of the fuel flow. Thus perfect air-fuel ratio will be maintained. Combustion system is simulated and lab scale experimental setup is fabricated for fuel and air control. Experimental studies were carried out using four control strategies namely conventional PID, cascaded PID, cascaded fuzzy and demand based cascaded fuzzy controller schemes. The performance of all the above control schemes were investigated quantitatively using both time domain specifications as well as error integral criteria by carrying out closed loop studies on the fabricated lab scale experimental set up. The advantages of the proposed scheme over the existing controller are highlighted.

I. INTRODUCTION

The utility boilers are large capacity steam generators used purely for the electrical power generation. In a Thermal power station, steam is produced in a boiler, expanded in the prime mover (Turbine) and condensed in a condenser before feeding it into the boiler again. The turbine shaft is coupled with generator, which is used to produce electricity. The various heat transfer sections [1] of a boiler can be grouped as follows: furnace, super heater, reheater, economizer and air heater. Automatic boiler control system consists of combustion control, super heater temperature control, drum level control, furnace pressure control and deaerator level control.

Combustion control in a utility boiler is one of the most important control loops in a power plant. Conventional PID (Proportional-Integral-Derivative) controller used for combustion control is simple in structure, reliable in operation and robust to a certain extent in performance. But it is 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. Several methods of tuning were suggested for the PID controller schemes [2-4].

In order to cope up with varying dynamics of the system, PID controllers have been evolved to include adaptive features such as gain scheduling and self-tuning. Adaptive control schemes [5] automatically adjust their control characteristics under various operating conditions in order to maintain effective control of a process.

During the last decade, extensive research has been carried out on adaptive control theory, methods and applications. Feng et al. [6] have proposed adaptive algorithm for PID controllers based on a theory of adaptive interaction. Aidan O'Dwyer et al. [7] have proposed a classification of techniques for the compensation of time delayed processes with parameter optimized controllers. Christos C. et al. [8] have proposed a deterministic adaptive control based on laguerre series representation.

After the introduction of fuzzy logic by L.A. Zadeh, many researchers applied it for several real time control applications. Even though many mathematical models are formulated for the boiler [9,10,11], fuzzy systems are being used successfully in increasing number of applications. They use linguistic rules to describe systems. These rule-based systems are more useful for complex systems where it is difficult to describe the system mathematically. J.Jaganathan et al. [12] have dealt with unknown non-linear dynamical system using a discrete time fuzzy controller. Pauli Villjamaa et al. [13] have developed a fuzzy logic system in PID gain scheduling. Young-Moon Park et al. [14] have proposed a self-organizing fuzzy controller for dynamic system using auto-regressive moving average (FARMA) model. Marcelo C et al. have proposed a Lyapunov based stabilizing control design method for uncertain non-linear dynamic system using fuzzy model. Al Ghaifari et al. have proposed application of fuzzy logic to steam power plants.

Although several methods have been developed, most of them are based on controllers with fuzzy system without incorporating any cascaded structure and its applications. The present work deals with the intelligent demand based cascaded fuzzy control scheme applied to the combustion control of utility boiler in a thermal power plant [15-19]. This paper is organized as follows: Section II describes the Conventional PID controller for fuel and air control. Section III briefs the cascaded PID scheme. Section IV deals with cascaded fuzzy scheme. Section V presents the proposed intelligent demand based cascaded fuzzy system for air and fuel control. Section VI describes the implementation of
proposed scheme on the lab scale hardware setup. The results, discussion and conclusion are presented at the end.

II. PID CONTROLLER SCHEME FOR COMBUSTION PROCESS

The load controller generates the demand to the steam throttle valve from the unit load demand and the measured generated power. The throttle pressure controller generates heat rate to the combustion controller from the measured throttle pressure and the turbine inlet pressure set point[20-25]. Finally combustion controller activates the fuel valve and air dampers. Oxygen trimming fine-tunes the air-fuel ratio.

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. The function generator on the air flow measurement scales the air flow signal relative to the fuel flow signal to provide optimum air/fuel ratio[26-29].

The function generator values are determined by adjusting the fuel flow relative to airflow at each test load. This allows air and fuel flow set points to be driven by the same firing rate demand signal[30-34]. If an increase in the firing rate is needed due to increase in steam demand, the airflow leads the fuel. As the load curtails, the fuel decreases first, followed by a decrease in combustion airflow. This assures an air rich mixture always. A lower limiter is used in the air controller to prevent the airflow set point reduction less than 25% of full span[35-38].

III. CASCADED PID SCHEME FOR FUEL AND AIR CONTROL

A response graph between load vs. fuel flow is plotted with the data collected from thermal power plant and stored as the database. From the graph, the fuel set point corresponding to the desired load is derived[39-42]. The difference between the set point and the actual fuel flow is computed as the error signal. The control signal from the fuel controller is applied to the fuel control valve. Same signal is applied to a function generator, which develops a set point for the airflow loop with respect to the fuel flow. In general, in the cascade
controllers, the dynamics of the secondary controller are much faster than those of primary loop.

However, for the proposed combustion process, both the loops are considered as primary loops. The set point for the oxygen controller is derived as a function of airflow. The actual value is measured from the flue gas analyzer for the oxygen content of the flue gas at the economizer outlet of the boiler. The error signal is added with the airflow controller output, which trims the airflow to optimize the combustion process. The block diagram of cascaded PID scheme for Air and Fuel is shown in Fig.3.

![Fig.3. Cascaded PID Scheme for Air and Fuel](image)

### Table I

<table>
<thead>
<tr>
<th>Control loop</th>
<th>Cascaded PID parameter</th>
<th>$K_P$</th>
<th>$K_I$</th>
<th>$K_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Controller</td>
<td>1.75</td>
<td>1.0</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Air Controller</td>
<td>1.5</td>
<td>0.8</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>$O_2$ Controller</td>
<td>2</td>
<td>1.5</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

The optimum cascaded 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.

**IV. CASCaded FUZZY SCHEME FOR FUEL AND AIR CONTROL**

A response graph of load vs. fuel flow is plotted with the data collected from thermal power plant and is stored as the knowledge base. From the graph the fuel flow set point to desired load is derived. The difference between the set point and the actual fuel flow is computed as error signal. The error and change in error are taken as inputs to the fuzzy controller. The processed signal from the fuzzy controller is defuzzified and applied to the fuel control valve to maintain effective combustion. Same signal is applied to a function generator, which generates a set point for the airflow loop with respect to the fuel flow.

The difference between the set point and the actual airflow is computed as error signal. The error and change in error are taken as inputs to the proposed fuzzy controller for air. The processed signal from the fuzzy controller is defuzzified and applied to the air dampers to maintain proper combustion. The signal from the air controller is applied to a function generator, which generates a set point for the oxygen loop with respect to the airflow. The output from $O_2$ controller is used to trim the total air supply to the boiler.

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

A lab scale experimental set-up is designed and fabricated to carry out the closed loop studies of conventional PID, cascaded PID, cascaded fuzzy and demand based cascaded fuzzy controllers. For the present work, the manipulated variables are air and fuel flow to the boiler with respect to the set value. There are two distinct control loops, for air and fuel control. In the fabricated set-up, the fuel pumped from the fuel tank will return back to the tank via control valve, rotameter and flow transmitter (In practice, the fuel flow will be admitted to the boiler for combustion).

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). Fuel and airflow transmitters will give the analog signal corresponding to the actual flow. These analog signals are interfaced with the computer through input-output (I/O) card. The processed signals from computer through I/O card are given to I/P converter as manipulated value to operate the air and fuel valves.

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.

**VI. CONCLUSIONS**

The results of this paper highlights the robustness of the demand based cascaded fuzzy logic controller scheme for step changes in loads. The response of non-fuzzy control
system has 26% overshoot for air and 39% for fuel flow. It settles down after about 83 and 74 steps of increment for air and fuel respectively. The closed loop response of the demand based cascaded fuzzy logic controller scheme shows satisfactory transient response with out much overshoot and settles down after about 38 and 36 steps of increment for air and fuel respectively. This shows 50% improvement over conventional schemes in settling time for both air and fuel. The qualitative and quantitative comparisons of the performance of the various control schemes reveal the superiority of the demand based cascaded fuzzy controller over the other control schemes.

REFERENCES

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