AN IMPROVED METHOD TO CONTROL THE CRITICAL PARAMETERS OF A MULTIVARIABLE CONTROL SYSTEM

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Abstract:
The role of control systems is to cope with the process deficiencies and the undesirable effect of the external disturbances. Most of the multivariable processes are highly iterative and complex in nature. Aircraft systems, Modern Power Plants, Refineries, Robotic systems are few such complex systems that involve numerous critical parameters that need to be monitored and controlled. Control of these important parameters is not only tedious and cumbersome but also is crucial from environmental, safety and quality perspective. In this paper, one such multivariable system, namely, a utility boiler has been considered. A modern power plant is a complex arrangement of pipework and machineries with numerous interacting control loops and support systems. In this paper, the calculation of controller parameters based on classical tuning concepts has been presented. The controller parameters thus obtained and employed has controlled the critical parameters of a boiler during fuel switching disturbances. The proposed method can be applied to control the critical parameters like elevator, aileron, rudder, elevator trim rudder and aileron trim, flap control systems of aircraft systems.

Keywords:
Multivariable systems, boiler, PID controller parameters, Load Disturbance

1. INTRODUCTION

Power plants using coal as primary fuel is known as fossil fuel power plants (FFPP). Electrical energy plays an important role in determining the quality of life in today’s modern world. Coal continues to play a vital role in the generation of electrical energy because of its availability in abundance. The coal properties influence the design and performance of steam generators. The variation in the heating value of coal supplied change the critical process parameters like main steam pressure, main steam temperature etc.. The proportional, Integral and derivative constants of the PID controllers to control the critical parameters of a fossil fuel fired boiler had been calculated for satisfying certain performance requirements during specified disturbances emanating from inputs to the boiler such as variations in calorific value of the coal burnt (fuel switching) in the boiler.
2. SYSTEM DESCRIPTION

A thermal power station is a power plant in which the prime mover is steam driven. Coal and air is burnt in the furnace in which the chemical energy is converted to thermal energy. This thermal energy is used to heat water from the boiler drum to turn it to steam and superheat it. The superheated steam is used to drive a steam turbine. In this process, thermal energy is turned into mechanical energy. The steam turbine is coupled to the rotor of an electrical generator, where the mechanical energy is converted to electrical power as shown in Figure 1. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated. The path taken up by the water-steam in this process is called Rankine cycle. The boiler is a drum- and single reheat-type with tilting tangential firing and controlled circulation. The detailed, validated non-linear mathematical model available in the Centre of Excellence for Simulators, BHEL, Hyderabad, India has been utilized for simulation.

![Energy Conversion in a Fossil Fuel Power plant](image)

Fig 1. Energy Conversion in a Fossil Fuel Power plant

3. SIMULATION MODEL OF 500 MW BOILERS AT COE, CORPORATE R&D, BHEL, HYDERABAD

There exist detailed nonlinear mathematical models developed since late 70s by Sivakumar and Bhattacharya (1979), Sivakumar et al.(1980) and Ponnusamy et al. (1983), Sivakumar et al. (1983) and Sivakumar, Sankaran and Mathur (1983) for 120 MW, 210 MW and 500 MW unit sizes in The Centre of Excellence (COE) for Simulators, BHEL, Hyderabad, India.

![Diagram of 500 MW boilers](image)

The overall mathematical model had been developed based on the following modules:
3.1 Boiler Pressure parts

- Economizer system module
- Drum, Downcomers and Water Walls (Circulation system) module
- Furnace system module
- Super heater system modules (Low temp super heater, Divisional Panel super heater and Platen super heater)
- Desuper heater system module (in between LTSH and Divisional Panel SH)
- Reheater system module (Reheater Front, Reheater rear)

3.2 Boiler Auxiliaries

- Pulverizer (Mill) system module
- Fan system module (Primary air fans, Secondary air fans and Induced draft fans)
- Boiler Feed Pump system module (Two numbers turbine driven boiler feed pumps and one number motor driven boiler feed pump)

3.3 Miscellaneous Components

- Throttle Valve
- High Pressure Bypass and Low Pressure Bypass Valves (HPLP Bypass Valves)
- All necessary valves, vanes and dampers.

3.4 Control Loops

- Drum Level Controller
- Furnace Pressure controller
- Super heater outlet temperature controller
- Reheater temperature controller
- Master Pressure controller (Fuel flow controller, Total air flow controller with O\textsubscript{2} bias)

All the subsystems covered in Section 3 had been modeled by means of first principles approach. Conservation equations for mass, energy and momentum have been considered. Appropriate heat transfer and fluid flow correlations based on collaborators data as well as data from Heat transfer and Fluid Flow (HTFS) documents had been used. All the subsystems mentioned in Section 3.1 and 3.2 were modeled based on equipment performance curves as these are available with BHEL as Original Equipment Manufacturer (OEM). The control loops were synthesized based on ABB P13 hardware and all the logics have been software emulated for
integrating control loops with integrated boiler model using various subsystem models obtained as described above.

The model also includes
- For a given coal history (elemental composition), coal flow, secondary air flow, burner tilt and the burner elevations, the Furnace model calculates the following:
  - the flow and the flue gas temperature at the furnace outlet plane.
  - Heat transferred to water walls, platen super heaters, final super heaters and reheaters by direct radiation
- The heat transferred by convection and non-luminous radiation to various heat exchangers such as platen, final and low temperature super heaters, reheaters, economizer and air heaters and thereby the transient variations in pressure, temperature of the inside fluid such as steam, water or air and metal temperature of the heat exchanger.
- Circulation system calculating the drum pressure and water level variations including the effects of swell and shrink.
- Turbine and generator systems, condenser, low pressure and high pressure heaters, de-aerator, condensate pumps and boiler booster pumps.

3.5 Model Validation

The integrated model had been tested first as design specific (process variables like pressure, temperature and flow for water, steam, flue gas at different nodes compared with predicted design values and those obtained from models). The error had been less than 0.5 to 1.0%. After the performance guarantee tests on the actual power plant, steady state data for different loads had been collected and the model had been tuned to plant specific. Further, over a period of time, specific open loop tests had been conducted to obtain the transient responses and the model had been further fine-tuned for plant specific. The accuracy limits during transient’s zones are well within 5.0 % for wide variety of disturbances.

4. BOILER CONTROLS

Automatic control of a process requires a thorough knowledge about the system to be controlled. Also the control of one parameter affects the other parameter under control. Boiler is such a system with highly interactive loops. It is essential that the main steam pressure, main steam temperature, drum water level, furnace pressure be tightly controlled. These parameters are called critical parameters and these controllers are called Class A controllers. PID and PI controllers are the usually employed in controlling the critical process parameters.

a. Master Pressure Control
b. Main Steam Temperature Control
a. Master Pressure Control

The objective of this control is to maintain the turbine throttle pressure constant at the desired value by adjusting the firing rate (both fuel flow and air flow). Turbine throttle pressure is measured with primary and redundant transmitters. The measured signal is compared with the set point and any error will have proportional and integral action. A proportional value of total steam flow and derivative of drum pressure signal are taken as feed forward feature for the control. An auto/manual station is provided. The output of A/M station is the air flow demand and fuel flow demand signal.

b. Main Steam Temperature Control

One of the critical control loops in a thermal power plant is main steam temperature control. The steam temperature is affected by variations in boiler load. The temperature of saturated steam from boiler drum is increased in super heaters. This temperature if goes beyond a particular limit, reduces the life time of the components of boiler and turbine. The manipulated variable is identified as the spray water flow to control the super heater steam temperature. Through the attemperator, the spray water is injected. It is essential that the control loop is tuned properly to compensate for the variations.

5. CLOSED LOOP PERFORMANCE OF THE BOILER DURING LOAD VARIATION

A typical Performance Requirements of Auto Controls for 500 MW boilers for load changes considered for the study is given in Table 1.

| Load Change(% of TMCR per minute) | Allowable deviations in Main Steam Pressure(Kg/cm²) |
|----------------------------------|-----------------------------------------------|
| - 3% for five minutes (Load is decreased from 500 MW to 425 MW in 5 minutes) | ± 2 |

The authors have employed the PID controller with controller constants Kp=5.0, Ki=60 and Kd=120 to control the critical parameters.

6. SIMULATION RESULTS

Using the mathematical model and tuning the master pressure controller constants to the parameters as above, a small variation in the load was introduced as shown in Fig 2. The boiler demand signal which is the manipulated variable is shown in Fig 3. The response of main steam
pressure which is the most critical parameter is shown in Fig.4. The simulation results for various parameters are given in Fig. 5 to 10.
It is well noted that all the critical parameters of a 500 MW boiler are controlled by the PID controller. All these parameters are within the limits. The main steam pressure of the 500 MW boiler is well within the allowable deviations. It can be concluded that the PID controller can be applied to any complex systems of aircraft modules.
7. CONCLUSION

The dominant tool to understand the transient behavior of the boiler and to develop improved control schemes for coal fired power plants depend on the availability of detailed first principle mathematical model. In this research, the PID controller is employed to satisfy the performance requirements of boiler has been demonstrated. The transient performance of main stream pressure for a change in the load has been obtained. The results prove that the controller parameters employed by PID controller is quite a promising one and can be applied to any complex systems like aircraft systems.

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