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Investigations on the Critical Parameters of a 500 MW Utility Boiler

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Abstract: **Electricity is the prime indicator of the economic growth and standard of living of the people in a nation. Generation of power is mainly dependent on coal fired power plants throughout the world. Coal is known to be one of the most important natural resources in the world. The surplus availability, extensive distribution and versatility of coal makes it a significant source of electrical energy for all times. The major proportion of electric power is generated using coal rather than any other source of fuel. It is cheaper than other fossil fuels but it is hard to be burnt. For power units operating on fossil fuel, the sole, prime, operating cost is fuel. The fuel expenses account for about 50 - 60% of the cost of generating electricity. Hence, procuring fuel of lower price is often a major challenge. Despite this and other environmental concerns, coal is still found to hold a major share of the electrical energy consumption in future. Over 48% of the world's electric power supply is obtained from thermal power plants. A thermal power plant produces electrical power from fossil fuel, namely coal through several energy conversion processes, using water as a working fluid. It comprises a boiler, turbine, electric generator and other auxiliary equipments each of which serve a definite purpose. This paper deals with the mathematical model and the design aspects of the boiler and the system response when it is subjected to many inputs.**

Keywords: **- Process control, Utility Boiler, Chien-Hrones-Reswick tuning, feed control**

I. INTRODUCTION

A Fossil Fuel Power Unit (FFPU) is a multivariable dynamic system. The interchange of energy from chemical to electrical in a FFPU is a complex process. Mathematical model of this process enables operator to optimize the control of the actual plant and the designer to optimize the design of the future plants.

Controlling of main steam pressure and other vital parameters of an Utility boiler during variations of the calorific value of coal fed into boiler furnace (fuel switching) is quite complex. In this paper, classical Chien-Hrones-Reswick (CHR) tuning method is employed to study the performance of a 500 MW Utility boiler during fuel switching fully taking care of the performance requirements of Auto controls as indicated by plant owners .Instead of choosing the controller parameters using trial and error method or by soft computing techniques, CHR tuning method has been judiciously applied to obtain the PID controller parameters from the open loop step response of the boiler.

II. COMPONENTS OF THERMAL POWER PLANT

A. Feed Control Station

The feed control station consists of one low load valve (0 % to 30 % load) and two valves for full load conditions.

B. Economizer

They are located in the second pass of the boiler. An economizer is also a heat exchanger. The feed water before entering the boiler drum is sent to the economizer. The economizer increase the temperature of the feed water but not beyond the boiling point of water. Feed water is preheated because if the water enters the furnace with it in normal rroom temperature, most of the heat produced in the furnace will be utilized in rising the temperature of the feed water thereby reducing the production of steam. This affects the boiler efficiency. Hence an economizer is used to preheat te feed water. The flue gas is used to heat the feed water.

C. Circulaion System

It comprises of the boiler drum, down comer tubes and upriser(water walls) tubes. Sub cooled water from the economizer, enters the boiler drum and flows through the down comer tubes by natural circulation and into the upriser tubes which also are the water walls (furnace walls). The feed water in the water walls is converted into steam and the water and steam mixture in the water walls reach the boiler drum. The steam produced exists above the water level in the drum. Heat transfer takes place through direct radiation. At a given pressure, the temperature at which water reaches boiling state is called saturation temperature. At saturation

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temperature water boils and vapor formation takes place. Both steam and water remains at saturation temperature in the drum.

D. Boiler Drum

The boiler drum is a horizontally mounted cylinder-with both its ends enclosed by hemispherical structures. The bottom side has number of holes, fitted with tubes which join in a header that carries the down comer tubes. Similarly, there are relatively smaller holes present fitted with tubes that join the steam header. Steam produced in the riser tubes of the furnace, are joined to the steam header through which steam is taken to the top portion of the boiler drum. There are tubes fitted on top of the drum which takes the steam out of the drum to the steam headers which in turn takes the steam to the superheaters. The Schematic diagram of boiler furnace is given in Fig.1.

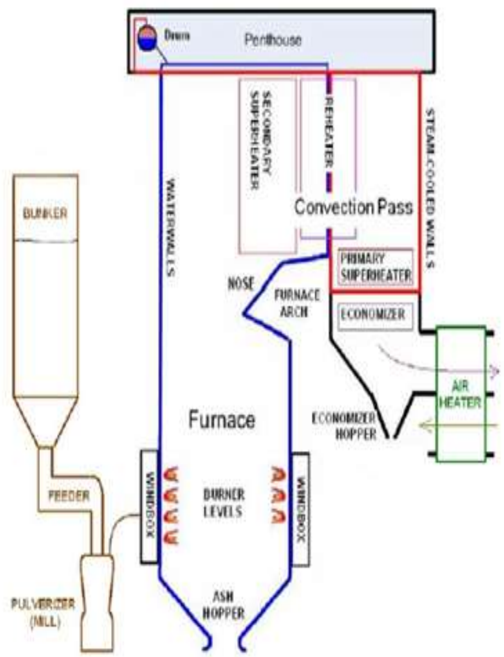

Fig. 1. Schematic diagram of boiler furnace

III. COAL QUALITY – FUEL SWITCHING

To take care of coal quality variation (specifically heating value of coal) , plant owners specify wide range of coal for the design of boilers. Specifying wide range of coals for design of boiler will not allow the boiler manufacturer to select optimum equipment for the particular power station. Due to coal property variations, the calorific value (heating value) of coal from the same mine does not remain the same, but varies randomly over an average value. During this situation, fluctuations in main steam pressure and temperature is noticed even when the load on the plant remains constant. These fluctuations are due to variations in the calorific value of the fuel burnt and the phenomena is often known as " fuel switching" (though the terminology was earlier used to refer to change of coal source, now it is also used to refer to wide variations in quality of coal received from the same mine). The effect of changes in heating value of coal is given below:

- As heating value changes, number of units (in kilograms) of fuel required to achieve the same heat input changes.
- If the heating value decreases by more than the excess capacity of the pulverizers, then the pulverizers will not be able to process enough coal for full-load operation of the boiler.

IV. MODEL OF THE BOILER

A nonlinear mathematical model developed and validated for a 500 MW Unit available at Centre of Excellence for Simulators, Corporate R&D, BHEL, Hyderabad is considered for this research work. All the subsystems covered in Section II 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 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. From the point of view of overall modeling and simulation of FFPUs, the contributions of Kwatny et al. and Åström et al. (2000) are noteworthy and their works include

- Mathematical equations for most of the sub systems,
- Integration of sub systems and
- Simulation of integrated model for various disturbances.

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

These nonlinear mathematical models are significantly different in the following aspects from other models by Chien et al. (1958) and Mc Donald and Kwatny (1970).

- The radiative and convective modes of heat transfer have been regarded for all heat transfer surfaces.
- Heat transfer coefficients both on the gas side as well as on the steam side have been continuously updated with changes in operating parameters.
- Heat transfer by direct radiation to water walls, panel super heater, platen super heater, reheater sections and the flue gas temperature at furnace outlet plane have been fairly detailed taking into account the burner tilt and the mills in service (burners in service).
- As OEM of boilers, heat transfer correlations which have been validated are used.

V. 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.

VI. CONTROL LOOPS IN BOILER

For the boiler-turbine control system, the central task is to adjust the output power to meet system demand while minimizing unwanted steam pressure and temperature variations. In a FFPU, thermal stresses due to steam pressure and temperature fluctuations are particularly important. They are the critical process parameters in a thermal power plant. Thick walled steam generator components undergo severe stress during quick startup, sudden and large variations and fuel property variations. Hence the authors have considered main steam pressure and main steam temperature variations for the various studies during fuel switching disturbances However while carrying out the simulation studies, the data pertaining to other controlled variations have also been collected but not included in the paper, since the focus is on critical process parameters. The main Control loops are

- 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 O2 bias)

VII. SIMULATION

The dynamic simulation studies on the boiler for variations in the calorific value of the coal have been carried out and the performance has been analyzed. The results obtained have been quiet encouraging and it proves the efficacy of the results obtained by CHR method of tuning. The calorific value has been changed from 3300 KCal/Kg to 3700 Kcal/Kg. The variation in the critical parameters like Main Steam Pressure, Power, Primary Air Flow and Secondary Air Flow are shown in Fig 1, 2, 3 and 4 respectively The PID Controller parameters employed for this study is Kp = 2.0 , Ki = 60.0 Seconds , Kd = 120.0 Seconds. The Performance Metrices considered are Overshoot and Undershoot and the result is portrayed in Table 1.

Table 1 Performance Metrices for the critical parameters of a 500 MW Utility Boiler when subjected to coal variation disturbances

S. No.	Variable	Steady Flow Value	Maximum Overshoot	Maximum Undershoot	Final Settled value
1	Main stream Pressure in ata	170.3	5.66	-	170.3
2	Power in MW	500	16.6	-	500
3	SA Total (Tonnes/Hr)	1050	166	38	1163
4	PA Total (Tonnes/Hr)	550	-	17	522

VIII. RESULTS AND DISCUSSION

The validated model was simulated for a atep change in the calorific value of coal and the simulation results are shown in Fig 2 to 5

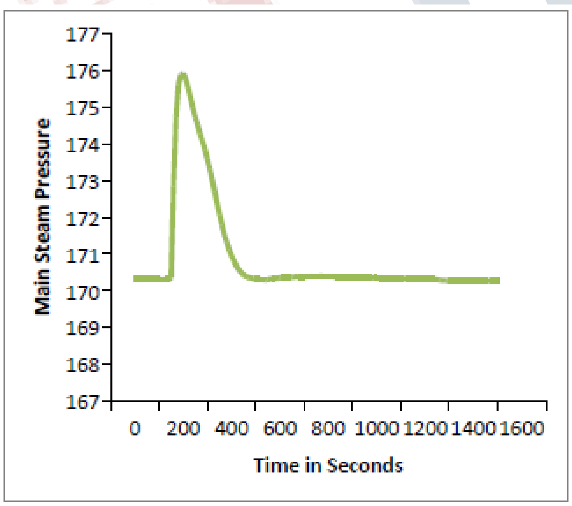

Fig 2. Variation in Main Steam Pressure

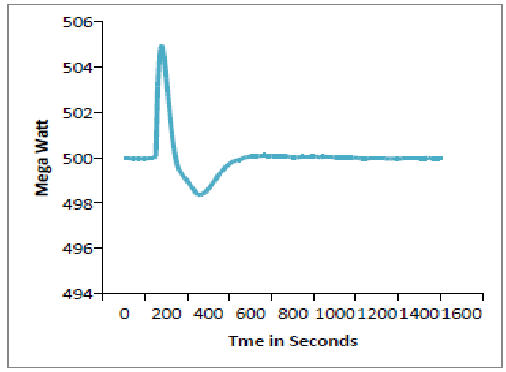

Fig 3. Variation in Power

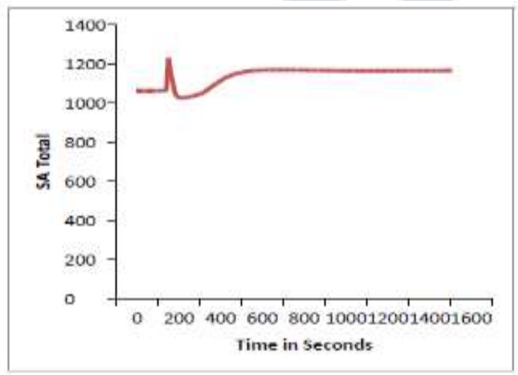

Fig 4. Secondary Air Flow

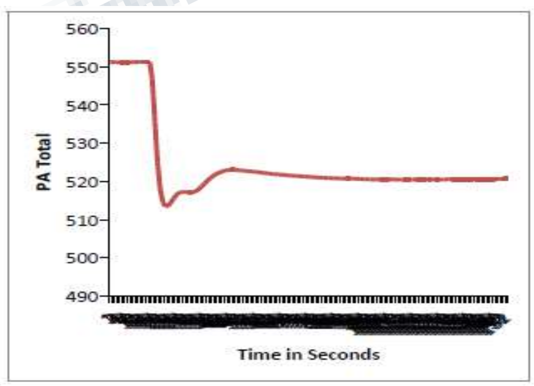

Fig 5. Primary Air Flow

The steady state value of Main Steam Pressure, Power, Secondary and Primary Air Flow are 170.3 ata, 500MW, 1200 tonnes/hr and 520 tonnes/hr. A change in the calorific value of the fuel was given from 3300 Kcal/ Kg to 3700 Kcal/Kg at 150 secs. Because of the fuel switching disturbance, there are variations in the critical parameters of the boiler. The PID controller is so efficient that it brings the variations to the steady state after few seconds. This shows the efficacy of the PID Controller employed in the control system of the thermal power plant.

IX. CONCLUSION

From the response given in Figures 2, 3, 4, 5 and Table 1, it is evident that the process parameter settle within the operating points inspite of the variations in the input side of the boiler (calorific value of the coal changes). The controller that is designed using the CHR method of tuning of PID controller suits well for the input side disturbances and it is proved in the complex process which is the 500 MW Utility boiler.

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