APPLICATION OF CLASSICAL STEP RESPONSE METHOD TO EVALUATE THE PID CONTROLLER CONSTANTS FOR CONTROLLING THE CRITICAL PROCESS PARAMETERS OF A 500 MW STEAM GENERATOR IN A THERMAL POWER PLANT DURING FUEL SWITCHING

Dear Editor,

The authors would like to thank the reviewers and the editor for the valuable comments which has enabled us to fine-tune the manuscript and bring it out in its present form. The corrections that are incorporated in the manuscript are shown below against each comment.

Thank You.

Comment 1 : Please check and correct the signs of signals in figure 5.

As per the suggestion of the reviewer, figure 5 has been redrawn and signs of signals have been corrected. The corrected figure is shown below which is also incorporated in the revised manuscript in page number 2 section 4.

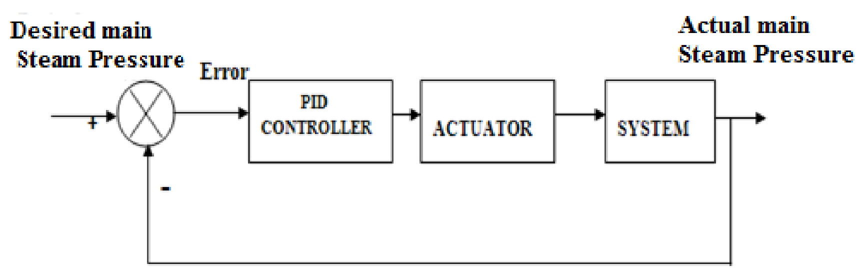

Fig.5. Block diagram of the system

Comment 2: : You must introduce equations. This is important for readers to see the parameters related to Table 1 and Table 2.

As per the suggestion of the reviewer, the equations related to Table 1 are introduced as Table 1 in the revised manuscript.

Table 1 PID controller Parameters for different tuning methods

Tuning Method	PID Controller mode		
	K_p	T_i	T_d
Ziegler-Nichols Method	1.2/a	2L	0.5L
CHR Method with 0% Overshoot	0.95/a	2.4L	0.42L
CHR Method with 20% Overshoot	1.2/a	2L	0.42L

Comment 3: You must present the equations that lead to Table 2.

As per the suggestion, the equations are included in section 7 of the revised manuscript as below :

The PID controller parameters viz. Kp = 2.0, Ki = 60 and Kd = 120 for the normal controller were determined based on the tuning map concept discussed by Astrom and Haggland[21]. Dharmalingam et.al., [17] applied the embedded controller during fuel switching with the PID parameters viz. Kp = 5.0, Ki = 60 and Kd = 120. The values of KP = 9.5, KP/TN = 96 and TN = 0.098, KP*TV = 16.8 and TV = 1.768 are used in the simulation.

Comment 4 : You must comment the colors of responses in fig.8 and fig.9 and also comment the results.

As per the suggestion, the colour responses and the comments on the results are incorporated in the revised manuscript under section 8 as below :

The main steam pressure, generated power (MW) and HP bypass flow variations are shown in blue colour for normal controller in Figures 8 and 9 respectively. The main steam pressure, generated power (MW) and HP bypass flow variations are shown in red colour for embedded controller in Figures 8 and 9 respectively. The main steam pressure, generated power (MW) and HP bypass flow variations are shown in green colour for CHR method controller in Figures 8 and 9 respectively.

Comment 5 : Fig.10 is not usable and not readable.

As per the suggestion, the comment on Fig 10 is included in Section 8. Which reads as below :

Figure 10. shows the response of the HP bypass flow variations wherein all the three controller tuning methods provide the closure of the bypass valve (0 tonnes/hr) which assures no wastage of steam that is generated.(All three controller outputs are merged together and is seen as green colour).

Comment 6: The details related to the simulations must be presented. You must present the detailed equations of the process used in simulations, of the controller and the values of all parameters.

As per the suggestion, the details are included in Section 5 as below :

The ProControl P13 platform of ABB has been employed as distributed control system in the 500 MW plant and the same has been emulated in the simulator model. The PID structure of ProControl P13 is given by

$$G(s) = Kp[1 +(1/TN.s) + (TV.s/(1 + Ts.s))] \quad (1)$$

The four parameters (Kp, TN, TV, Ts) can be varied within the valid range. The calculated values of KP, TN and TV are shown in Table 3. In this work, the controller parameters calculated using CHR method with 0% overshoot is applied from Table 3 for analyzing the transient behavior of main steam pressure due to input side disturbance.

Table 3 Values of KP, TN and TV used in 500 MW plant simulations

Tuning Method	PID Controller mode		
	KP	TN	TV
Ziegler-Nichols Method	12	0.15	1.66
CHR Method with 0% Overshoot	9.5	0.098	1.768
CHR Method with 20% Overshoot	12	0.15	1.40

Once again, the authors wish to thank the reviewer and the editorial team for their valuable suggestions and enabling us to upgrade the manuscript in its present form.

Authors.

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Abstract: *The proportional, Integral and derivative constants of the PID controllers to control the main steam pressure of a fossil fuel fired boiler had been calculated for satisfying certain performance requirements during specified load disturbances. These constants have not been holding good when disturbances emanating from inputs to the boiler such as variations in calorific value of the coal burnt (fuel switching) in the boiler. To mitigate the negative effects of fuel switching on critical boiler parameters, an embedded controller with high gain had been proposed in the literature. In all these cases, the calculation of the controller parameters is based on tuning map concept. In this paper, the calculation of controller parameters based on classical tuning concepts has been presented. The controller parameters thus obtained and used has provided better transient response performance characteristics during fuel switching disturbances than the earlier published results.*

Key words: *Step response, main steam pressure control, calculation of PID controller parameters, fuel switching, fuel flexibility*

1. Introduction

It has been observed in recent times that the practicing control engineers and research community resort to the application of modern control algorithms, such as Fuzzy Logic Controllers, Model Predictive Controllers, State observer techniques with feedbacks etc., to control complex process variables [1-21]. The developments taking place so fast in this direction raise a doubt whether the application of PID controllers will survive in future. The main difficulty lies in obtaining appropriate controller parameter values for the PID controllers. These values are normally obtained by trial and error procedure or through heuristic iterative algorithms [15-17]. Having motivated by certain studies conducted by Electric Power Research Institute [18] and certain remarks expressed by Astrom [19], the authors have successfully applied the classical tuning control algorithms due to step response method of Chein, Hrones, Reswick explained in [20-21] for controlling the main steam pressure of a 500 MW coal fired boiler. It has further been demonstrated that the calculated PID controller constants hold good in effectively controlling the main steam pressure during fuel switching.

2. System Description

A Thermal power plant consists of three important components. They are Boiler, Turbine and Generator. Pulverized coal is burnt in boiler furnace where conversion of chemical energy to thermal energy (Products of combustion form the flue gas) takes place. Thermal energy converts water to high pressure steam. Steam drives the turbine and conversion of thermal energy to mechanical energy takes place. The turbine is coupled to a generator where conversion of mechanical energy to electrical energy is carried out. The schematic diagram of a boiler furnace is shown in Figure 1.

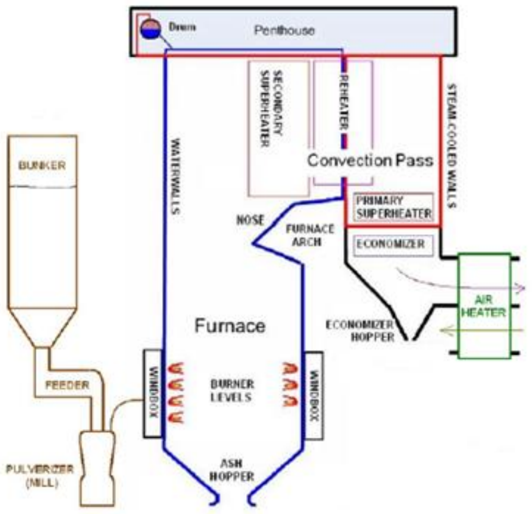

Fig. 1. Schematic diagram of boiler furnace

Coal is pulverized in the mill and the primary air carries the powdered coal to the furnace. Complete combustion is ensured by the additional supply of secondary air. Feed water after being preheated enters the drum. Water gets converted to steam and superheaters and reheaters are used in the next stages.

The high pressure steam flow to the turbine is controlled to meet the set load demand in three different ways. These are known as Boiler Following mode, Turbine following mode and coordinated mode. Depending upon the mode of selection, the boiler demand signal which ultimately regulates the combustion process is derived from the master pressure control of Boiler- Turbine- Generated unit. The method of deriving the boiler demand signal corresponding to different modes of operation is discussed in next section.

3. Boiler Demand Signal

For complex multi input and multi output systems/processes, the selection of input signal which is to be perturbed for this purpose is difficult. The boiler demand signal is identified as the manipulated signal to control the main steam pressure (MS). When the steam production in circulation system is equal to the demand of steam at the outlet of the boiler, the main steam pressure at the boiler outlet remains constant. The boiler demand signal is derived based on any of three modes of the operation of the steam power plant.

The three modes are: Boiler Following Mode, Turbine Following Mode and Coordinated mode. The schematic representations of the modes are given in Figures 2 - 4 respectively.

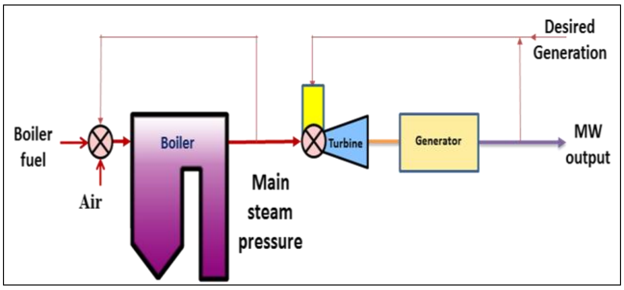

Fig. 2. Boiler following mode

Boiler Following Mode : The advantage of this mode is that it provides fast response to load changes - turbine being a fast acting device responds very rapidly to load demands using the thermal energy stored in the boiler.

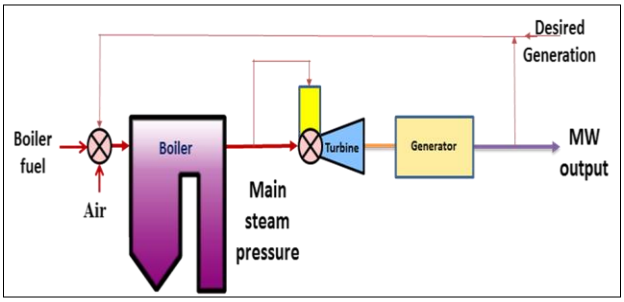

Fig. 3. Turbine following mode

*Turbine Following Mode***:** This mode provides a very stable response to load changes with minimal main steam pressure and temperature fluctuations, since load changes depend on the action of the boiler, a relatively slow process compared to the turbine.

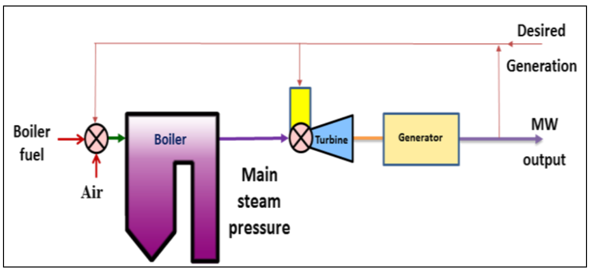

Fig. 4. Coordinated mode

Coordinated mode: This mode is a combination of the above two modes and provides stable response (due to Turbine Following Mode) and fast response (due to Boiler Following Mode).

4. Evaluation of PID controller constants

Figure 5 represents the general block diagram of the system.

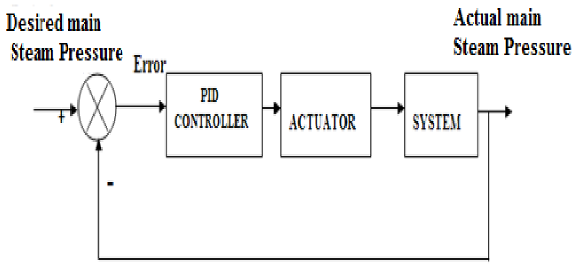

Fig.5. Block diagram of the system

The important task in the entire system is to determine the optimum PID parameters. The boiler demand signal is the manipulated signal to the boiler to control the main steam pressure. A step change in the manipulated variable is given and the main steam pressure response is obtained.

5. Generation of step response

A detailed first principle, non linear mathematical model for a 500 MW coal fired power plant is available in The Centre of Excellence for Simulators, BHEL, Hyderabad, India. This model has been extensively validated from experimental results obtained including field dynamic experiments carried out and used to build plant simulator. Impact on critical process parameters of a power plant due to variation in the calorific value of coal fed to the boiler has also been simulated / studied utilizing the above validated mathematical model. This model has been used for the present study. The model has been initialized to operate at 500 MW load level with all control loops in auto mode. After some time delay, say 600 seconds, all control loops have been put into manual mode. After another 600 seconds, a step change in boiler demand signal is given and the open loop response of main steam pressure is recorded. The main steam pressure variation with respect to time is given in Figure 6.

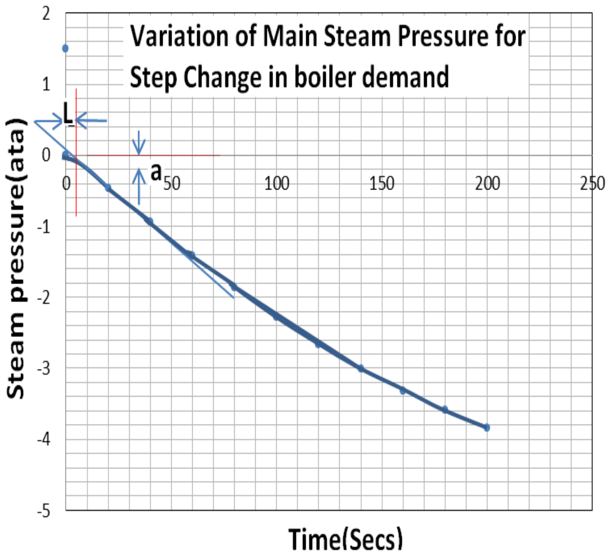

Fig. 6. MS pressure variation due to step change in Boiler Demand Signal

The values of 'a' and 'L' required for calculating the PID controller constants are extracted from Figure 6 (a = 0.1 ata and L= 40 seconds).

The equation for finding PID controller parameters for different tuning methods are given in Table 1. Based on these values, the PID controller constants determined using different methods are given in Table 2.

Table 1

PID controller Parameters for different tuning methods

Tuning Method	***PID Controller mode***		
	K_p	T_i	T_d
Ziegler-Nichols Method	1.2/a	2L	0.5L
CHR Method with 0% Overshoot	0.95/a	2.4L	0.42L
CHR Method with 20% Overshoot	1.2/a	2L	0.42L

Table 2

Calculated PID controller constants

Tuning Method	PID Controller mode		
	K_p	T_i	T_d
Ziegler-Nichols Method	12	80	20
CHR Method with 0% Overshoot	9.5	96	16.8
CHR Method with 20% Overshoot	12	80	16.8

The ProControl P13 platform of ABB has been employed as distributed control system in the 500 MW plant and the same has been emulated in the simulator model.

The PID structure of ProControl P13 is given by

$$G(s) = Kp[1 +(1/TN.s) + (TV.s/(1 + Ts.s))] \quad (1)$$

The four parameters (Kp, TN, TV, Ts) can be varied within the valid range. The calculated values of KP, TN and TV are shown in Table 3. In this work, the controller parameters calculated using CHR method with 0% overshoot is applied from Table 3 for analyzing the transient behavior of main steam pressure due to input side disturbance. The values of KP = 9.5, KP/TN = 96 and TN = 0.098, KP*TV = 16.8 and TV = 1.768 are used in the simulation.

Table 3
Values of KP, TN and TV used in 500 MW plant simulation

Tuning Method	PID Controller mode		
	KP	TN	TV
Ziegler-Nichols Method	12	0.15	1.66
CHR Method with 0% Overshoot	9.5	0.098	1.768
CHR Method with 20% Overshoot	12	0.15	1.40

6. Boiler controls

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 stream pressure and temperature 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 coal quality within 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.

Using the mathematical model and tuning the master pressure controller constants to the parameters obtained as above, a small variation in the calorific value of coal was introduced after 150 sec. It was varied from 3300 kcal/kg to 3000 kcal/kg. The simulation results are given in Figures 7 to 10.

7. Simulation Results

To prove the efficacy of the proposed work, two of the results of the earlier methods applied for the control of main steam pressure have been considered i.e., normal controller and embedded controller. The normal controller was designed using tuning map concept [21]. Dharmalingam et.al.,[17] have come out with an embedded controller wherein the gain of the master pressure controller is changed to a higher value during fuel switching. This high gain has been obtained using tuning map concept. However an article by Astrom motivated the authors to have a revisit on the fundamental requirements in applying classical control theory. Accordingly, the authors have performed a step response test and obtained 'a' and 'L' and subsequently the controller constants using Ziegler and CHR methods [20-21]. The simulation with controller constants obtained through CHR method provided the best results and is used in this work. Figure 7 and 8 shows the variation of calorific value and main steam pressure with respect to time respectively.

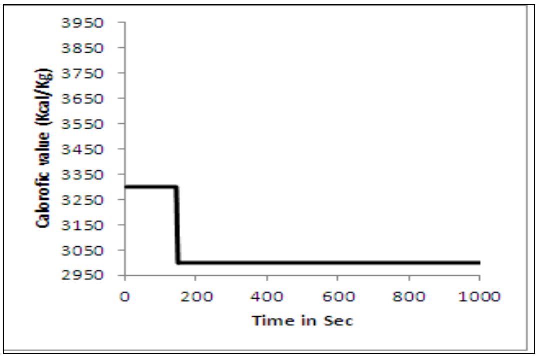

Fig.7 Variation in Calorific Value of coal

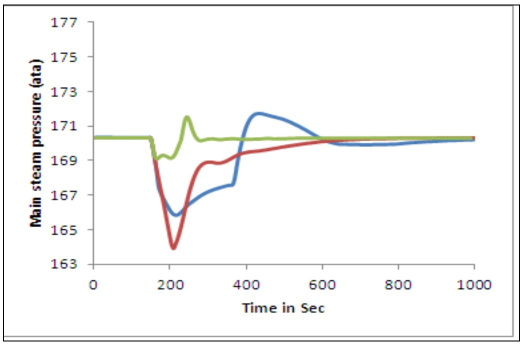

Fig. 8 Main Steam pressure

The power developed in MW for the time duration ranging from 0 to 1000 seconds is shown in Figure 9.

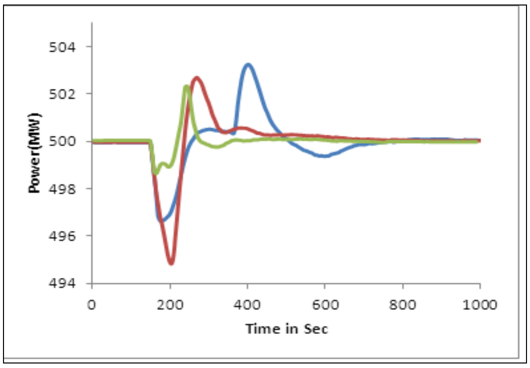

Fig. 9 Generated Power (MW)

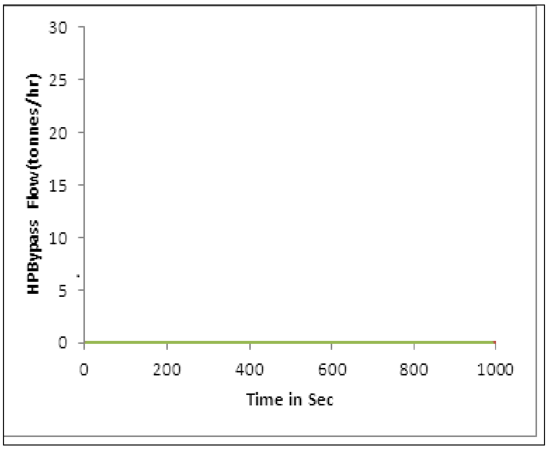

Fig. 10 HP Bypass Flow

Table 4
Calculated parameters for various controllers and its Colour representation

Controller	***Kp***	***Ki***	***Kd***	***Colour***
Normal Controller	2.0	60.0	120.0	Blue
Embedded Controller	5.0	60.0	120.0	Red
CHR Controller	9.5	10.0	16.8	Green

Table 4 shows the calculated PID parameters for Normal, Embedded and CHR controller and the colour representation for the response due to various controllers. The PID controller parameters are Kp=9.5, Ti=2.4*L =96, Kp/Ti=1/Ki, Ki=10 and Kd=Kp * T_D /Ts = 16.8.

The main steam pressure, generated power (MW) and HP bypass flow variations are shown in blue colour, red colour and green colour for the normal controller, embedded controller and CHR controller respectively. The variation in the calorific value is shown in Figure 7. The variation of the main steam pressure for all the three cases ie., normal controller, embedded controller and classical CHR tuning methods are shown in Figure 8.

The MW power generation variation is given in Figure 9. The HP bypass flow is given in Figure 10. The PID controller parameters viz. Kp = 2.0, Ki = 60 and Kd = 120 for the normal controller were determined based on the tuning map concept discussed by Astrom and Haggland [21]. Dharmalingam et.al., [17] applied the embedded controller during fuel switching with the PID parameters viz. Kp = 5.0, Ki = 60 and Kd = 120.

8. Results and discussions

Simulation shows the variation of the process variables due to the variation in the calorific value of coal from 3300 kcal/kg to 3000 kcal/kg. The main steam pressure, generated power (MW) and HP bypass flow variations are shown in blue colour for normal controller in Figures 8 and 9 respectively. The main steam pressure, generated power (MW) and HP bypass flow variations are shown in red colour for embedded controller in Figures 8 and 9 respectively. The main steam pressure, generated power (MW) and HP bypass flow variations are shown in green colour for CHR method controller in Figures 8 and 9 respectively. It is clear from the graph that in the response due to the normal controller shown, the variation in main steam pressure is high. When the embedded controller was used, the variation in main steam pressure and generated power (MW) is less when compared with normal controller. When the simple CHR tuning method of controller was applied, it is found that the variation in main steam pressure and generated power (MW) is very less and is controlled without the opening of HP bypass flow.

Figure 10. shows the response of the HP bypass flow variations wherein all the three controller tuning methods provide the closure of the bypass valve (0 tonnes/hr) which assures no wastage of steam that is generated.(All three controller outputs are merged together and is seen as green colour). It is quite heartening to observe that the PID controller parameters calculated based on step response method (Chein, Heins and Reswick) ensures better transient performance behavior during disturbances from boiler input side.

9. Conclusions

The availability of detailed first principle mathematical model for coal fired power plants provides a powerful tool for understanding the transient behaviour of the boiler, thus allowing the development of improved control schemes. In this paper, the PID controller tuned by CHR method to satisfy the performance requirements of boiler has been demonstrated. The transient performance of main stream pressure for a change in the calorific value of coal has been obtained. The results prove that the classical tuning methods obtained by CHR method is quite promising one and can be applied to any complex systems to find the PID parameters.

10. Acknowledgement

The authors would like to thank the Management of BHEL for the support and the authorities of Karunya University for their encouragement.

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