The Scientific Temper (2024) Vol. 15 (1): 1773-1776
E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2024.15.1.27
https://scientifictemper.com/

RESEARCH ARTICLE

Modeling and control of boiler in thermal power plant using model reference adaptive control

G. C. Sowparnika*, D. A. Vijula

Abstract

The boiler is a multi-variable system, which is very difficult to control due to its nonlinear behavior, uncertainties, interactions between variables, and unmeasured and frequent disturbances. Instead of conventional control techniques, modern control techniques are being implemented in most boilers by industries. Mathematical modeling is a useful tool to analyze a complex system's performance and design a controller for the same. The mathematical model is derived from the open-loop data obtained from the process station. The mathematical equation is then derived using the decoupling technique in terms of transfer function. An adaptive controller is designed and implemented for the model and the simulation study for the same is carried out using MATLAB. The proposed method discussed in the paper can adjust the controller parameters in response to changes in plant and disturbance in real-time by referring to the reference model that specifies the properties of the desired control system.

Keywords: Boiler, Model reference adaptive control, Modeling, Multi-input, Multi-output, Simulation.

Introduction

The control of liquid level in the boiler is a basic problem in the process industries. Vital industries such as petrochemical industries, paper-making industries, and water treatment industries have boiler tank processes, and the level of fluid in the tanks and interactions between tanks must be controlled. It is essential for control system engineers to understand how boiler control systems work and how the level control problem is solved. The problem of level control in boiler processes are nonlinear behavior, uncertainties, and interactions between variables, unmeasured and frequent disturbances. Many control methods such as PID, auto-tuning PID and decoupling, have been applied to boiler processes for solving their problems.

This paper presents design methodology of the auto-adjustable PI controller using MRAC technique for solving the problem of boiler processes. The proposed method can adjust the controller parameters in response to changes in plant and disturbance real-time by referring to the reference model that specifies the properties of the desired control system. Therefore, this technique is convenient for controller design under the requirement of the system.

Materials and Methods

210MW Boiler

The boiler, turbine and generator are the 3 basic parts in a power plant. Boiler control plays a major role in power generation. Mathematical modeling of the boiler is the best way to analyze and control it.

The block diagram for the boiler modeling is shown in Figure 1. Modeling can be performed by selecting certain parameters like power from a generator, level and pressure from the boiler. Pressure and level is measured using a differential transmitter and pressure transmitter. Power is measured using a potential transformer. These measured signals are analyzed, conditioned and filtered by signal conditioning unit (SCU). The output of SCU is fed into the personal computer manually. Simulation of boiler model and controller are designed in a personal computer. The boiler model takes the input values from the signal conditioning unit to perform the control action by comparing the measured values to the desired values. The desired values

Department of Instrumentation and Control Systems Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India.

***Corresponding Author:** G. C. Sowparnika, Department of Instrumentation and Control Systems Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India, E-Mail: gcs.ice@psgtech.ac.in

How to cite this article: Sowparnika, G. C., Vijula, D. A. (2024). Modeling and control of boiler in thermal power plant using model reference adaptive control. The Scientific Temper, **15**(1):1773-1776.

Doi: 10.58414/SCIENTIFICTEMPER.2024.15.1.27

Source of support: Nil

Conflict of interest: None.

Received: 19/01/2024 **Accepted:** 12/02/2024 **Published**: 15/03/2024

denote the set point, given manually (Zhitarenko *et al.* 2020). The obtained control output is given to the control valves to regulate the fuel flow to the furnace, the water level of the boiler drum. These regulations have been implemented to maintain the real-time boiler parameters.

Mathematical Modeling

The model represents a boiler-turbine generator for overall wide-range simulations and is described by a third-order MIMO nonlinear state equation (Ivanitckii *et al.* 2021; Parshukov *et al.* 2018). The three inputs are normalized valve actuators positions that control fuel mass flow rates, steam to the turbine, and feed water to the drum. The state equations are as follows.

$$\dot{x_1} = -0.0018u_2 x_1^{9/8} - 0.9u_1 - 0.15u_3 \quad (1)$$

$$\dot{x_2} = \frac{(0.73u_2 - 0.16)x_1^{9/8} - x_2}{10} \quad (2)$$

$$\dot{x_3} = \frac{(141u_3 - [1.1u_2 - 0.19]x_1)}{85} \quad (3)$$

$$y_1 = x_1 \quad (4)$$

$$y_2 = x_2 \quad (5)$$

$$y_3 = 0.05\left(0.13073x_3 + 100a_{cs} + \frac{q_e}{9} - 67.975\right) \quad (6)$$

$$a_{cs} = \frac{([1 - 0.001538x_3][0.8x_1 - 25.6])}{x_3(1.0394 - 0.0012304x_1)} \quad (7)$$

$$q_e = (0.854u_2 - 0.147)x_1 + 45.59u_1 - 2.514u_3 - 2.096 \quad (8)$$

Where

The three inputs are

u_1 = Normalized positions of valve actuators that control the mass flow rates of fuel

u_2 = Normalized positions of valve actuators that control the steam to the turbine

u_3 = Normalized positions of valve actuators that control feed water to the drum

The three outputs are

y_1 = Drum steam pressure ($x1$)

y_2 = Electric power ($x2$)

y_3 = Drum water-level deviation (L in meters)

a_{cs} = Steam quality (mass ratio)

q_e = Evaporation rate (Kilograms per second)

The three state variables are

x_1 = Drum steam pressure (*P* in Kg/cm2)

x_2 = Electric power (*E* in Megawatt)

x_3 = Steam water fluid density in the drum (*ρf* in Kg/m2)

The nonlinear model is linearized using Taylor series expansion at the operating point,

$$y_0 = (y_{10}, y_{20}, y_{30}),\ x_0 = (x_{10}, x_{20}, x_{30}),\ u_0 = (u_{10}, u_{20}, u_{30}).$$

The result of linearization is as follows:

$$A = \begin{bmatrix} \frac{-0.0162}{8} u_{10} x_{10}^{1/8} & 0 & 0 \\ \left(\frac{6.57}{80} u_{20} - \frac{1.44}{80}\right) x_{10}^{1/8} & \frac{-1}{10} & 0 \\ \left(\frac{0.19}{85} - \frac{1.1}{85} u_{20}\right) & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 0.9 & -0.0018x_{10}^{9/8} & -0.15 \\ 0 & \frac{-0.73}{10} x_{10}^{9/8} & 0 \\ \left(\frac{0.19}{85} - \frac{1.1}{85} u_{20}\right) & \frac{-1.1}{85} x_{10} & \frac{141}{85} \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ \left(5\frac{\partial a_{cs}}{\partial x_1} + \frac{1.1\,\partial q_e}{9\,\partial x_1}\right) & 0 & \left(0.65 + 5\frac{\partial a_{cs}}{\partial x_3}\right) \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0.2533 & 0.00474x_{10} & -0.014 \end{bmatrix}$$

Boiler system is a MIMO system with more loop interaction. To avoid loop interactions, MIMO systems can be decoupled into separate loops known as single input single output (SISO) systems (Trojan, 2019; Ahamdi and Gaona, 2021). The SISO system matrices of the boiler is decoupled from MIMO system are obtained as follows in eq. 8, 9 and 10

$$GD_{11} = \frac{0.49291s^3 + 0.09907s^2 + 0.17153s + 0.12128}{0.27174s^4 + 0.09502s^3 + 0.2352s^2 + 0.000666s} \quad (8)$$

$$GD_{22} = \frac{0.49291s^3 + 0.09938s^2 + 0.17153s + 0.21}{0.0254s^4 + 0.0578s^3 + 0.03627s^2 + 0.00369s} \quad (9)$$

$$GD_{33} = \frac{0.49291s^3 + 0.0628s^2 + 0.17205s + 0.00151}{17.469s^3 + 009206s^2 + 0.0012s} \quad (10)$$

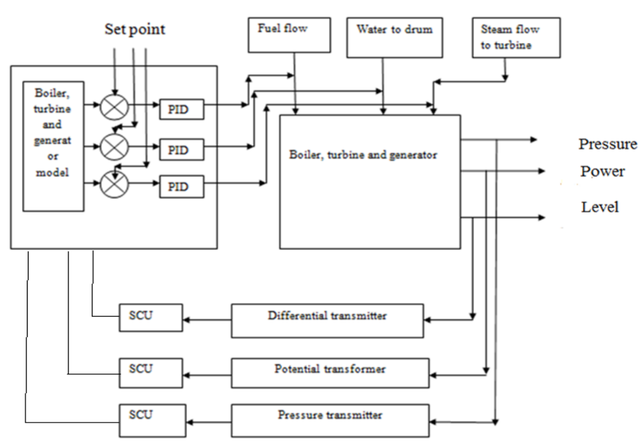

Figure 1: Block diagram of the boiler model

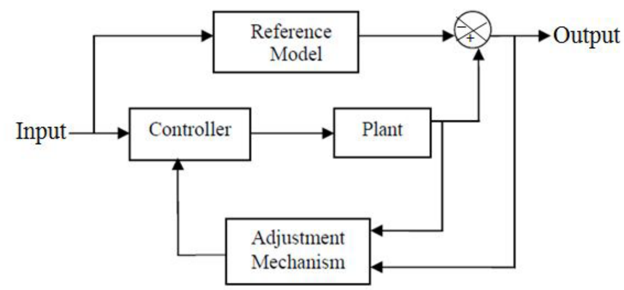

Figure 2: Block diagram of MRAC controller

Model Reference Adaptive Control

The block diagram in Figure 2 shows the structure of a model reference adaptive control (MRAC) system that is composed of a process, controller, reference model, and adjustment mechanism block (Abouheaf *et al.* 2021)).

Reference Model

It is used to specify the ideal response of the adaptive control system to external command. This paper uses the critically damped second-order system as the reference model.

Controller

It is usually parameterized by a number of adjustable parameters. The values of these control parameters are mainly dependent on adaptation gain, which changes the control algorithm of the adaptation mechanism.

Adaptation Mechanism

It is used to adjust the parameters in the control law. MIT rule is used for this purpose. This paper uses the MIT rule. This rule was developed in the Massachusetts Institute of Technology and is used to apply the MRAC approach to any practical system. In this rule the cost function or loss function is defined by eq. 11.

$$F(\theta) = {e^2}/{2} \tag{11}$$

Where e is the output error and is the difference of the output of the reference model and the actual model, while θ is the adjustable parameter known as the control parameter.

In this rule the parameter θ is adjusted in such a way so that the loss function is minimized (Chen, 2021). Therefore, it is reasonable to change the parameter in the direction of the negative gradient of F, which is given by eq. 12:

$$\frac{d\theta}{dt} = -\gamma \frac{\partial F}{\partial \theta} = -\gamma e \frac{\partial e}{\partial \theta} \tag{12}$$

The partial derivative called term $\frac{\partial e}{\partial \theta}$ is the sensitivity derivative of the system. This shows how the error is dependent on the adjustable parameter; θ there are many alternatives to choose the loss function F. For example, it can also be taken as a mode of error. Similarly, dθ/dt can also have different relations for different applications (Gopi *et al.* 2021).

Sign-Sign Algorithm

$$\frac{d\theta}{dt} = -\gamma\left[\text{sign}\left({\partial e}/{\partial \theta}\right)\text{sign}(e)\right] \tag{13}$$

Or it may be chosen as:

$$\frac{d\theta}{dt} = -\gamma\left[\left({\partial e}/{\partial \theta}\right)\text{sign}(e)\right] \tag{14}$$

Where sign e = 1 for e›0

e = 0 for e = 0

e = -1 for e‹ 0

In some industrial applications, the choice of adaptation gain is critical and its value depends on the signal levels. So MIT rule has to be modified as follows:

$$\frac{d\theta}{dt} = -\gamma \delta e \tag{15}$$

Where $\delta = (\partial e / \partial \theta)$

Results and Discussion

In this paper model reference adaptive control scheme is applied to a second-order system using the MIT rule (Roshanian and Rahimzadeh, 2020). It is a well-known fact that an under-damped second-order system is oscillatory in nature. If oscillations are not decaying in a limited period, they may cause system instability. So, for stable operation, the maximum overshoot must be as low as possible (ideally

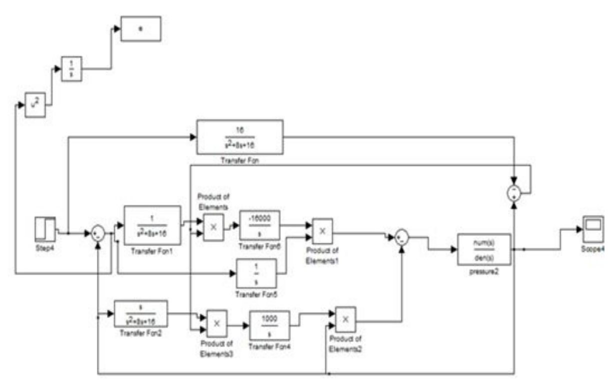

Figure 3: Closed loop model of MRAC for level

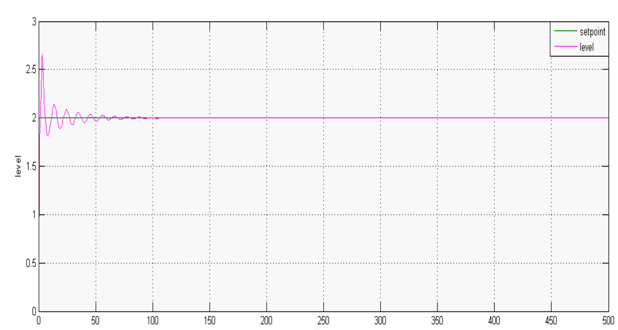

Figure 4: Closed loop response of MRAC for level

zero). This can automatically reduce the transient period of the system and improve its performance (Franco *et al*. 2022). A critically damped second-order system gives a characteristic without any oscillations, similar to the first-order system. But it is not feasible to achieve such system practically. This paper takes a second order under damped system with large settling time, very high maximum overshoot, and intolerable dynamic error as a plant. The object is to improve the performance of this system by using an adaptive control scheme. For this purpose, a critically damped system is taken as the reference model. Let the second-order system be described by eq. 16:
Assuming a=8 and b=600,

$$\frac{d^2y}{dt^2} = -a\left(\frac{dy}{dt}\right) - by + bu \quad (16)$$

Where y is the output of plant (second order under damped system) and u is the controller output or manipulated variable. The transfer function obtained is given in eq. 17:

$$\frac{Y(s)}{U(s)} = \frac{600}{s^2 + 8s + 600} \quad (17)$$

Similarly the reference model is described by eq. 18:

$$\frac{d^2y}{dt^2} = -a_m \frac{dy_m}{dt} - b_m y_m + b_m r \quad (18)$$

Take a_m=8 and b_m=16
Where y_m is the output of reference model (second order critically damped system) and r is the reference input (unit step), the transfer function of reference model is obtained as:

$$\frac{Y_m(s)}{R(s)} = \frac{16}{s^2 + 8s + 16} \quad (19)$$

This paper simulates the reference adaptive control model in MATLAB and simulink. Here the MIT rule is applied to the second order system. The simulation model is shown in Figure 3 and the controlled output response is shown in Figure 4.

Conclusion

The field of multi-variable control in boiler is very wide. This paper is an attempt to minimize the interaction problem by the utility of decoupling, which is a simple technique. Conventional controllers like PID make it very difficult to control the boiler system, which has inverse responses due to interactions. The design of PID controller using the decoupler technique for the boiler can adjust controller parameters in response to changes in plant and disturbance, which specifies properties of the desired control system. The response obtained with a decoupler settles faster than a simple PID controller. The response obtained with the decoupler interacts less with the PID controller. Still, it cannot cope up in situations of unpredictable faults and disturbances, for which MRAC is used here continuously. Automatic control is done and a response is obtained for the level process. The robustness of the control system can be further improved by using advanced adaptive control techniques like optimal control technique, model predictive control, etc. Better PID controller parameters can be obtained by optimized search algorithms like particle swarm optimization (PSO).

Acknowledgments

Nil

References

Chen, K.-Y. (2021). A new model reference adaptive control with the disturbance observer based adaptation law for the non linear servomechanisms. *Asian Journal of Control* , 2597-2616.

Gaona, T. A. (2021). Designing a Mathematical Model and Control System for the Makariza Steam Boiler. *Advances in Swarm Intelligence* (pp. 533-542). China: International Conference on Swarm Intelligence.

Ivanitckii MS, S. M. (2021). Development of mathematical model for evaluating the technical condition of boiler plants in terms of reliability and efficiency. *3rd International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE)* (pp. 1-4). Moscow: IEEE.

M. Abouheaf, W. G.-S. (2021). A Data-Driven Model-Reference Adaptive Control Approach Based on Reinforcement Learning. *IEEE International Symposium on Robotic and Sensors Environments (ROSE)* (pp. 1-7). Florida: IEEE.

Rahimzadeh, J. R. (2020). A Generalization for Model Reference Adaptive Control and Robust Model Reference Adaptive Control Adaptive Laws for a Class of Nonlinear Uncertain Systems with Application to Control of Wing Rock Phenomenon. *International Journal of Engineering , 33* (11), 2372-2383.

Rahul Shanmugam Gopi, S. S. (2021). Enhanced Model Reference Adaptive Control Scheme for Tracking Control of Magnetic Levitation System. *Energies , 14* (5), 1455-1468.

Roberto Franco, H. R. (2022). Model reference adaptive control: A finite-time approach. *International Journal of Adaptive Control and Signal Processing* .

Trojan, M. (2019). Modeling of a steam boiler operation using the boiler nonlinear mathematical model. *Energy , 175* (C), 1194-1208.

Vladimir Ivanovich Parshukov, A. A. (2018). Mathematical modeling of the waste heat boiler, part of the micro-energy complex for processing solid municipal waste. *International Journal of Civil Engineering and Technology , 9* (9), 2056-2065.

Volodymyr Zhitarenko, V. B. (2020). Adaptation of Mathematical Model of Heat and Energy Characteristics of Medium Pressure Boilers to Real Operating Conditions. *Technology audit and production reserves , 4* (54), 23-30.