

Ziegler Nichols Based Integral Proportional Controller for Superheated Steam Temperature Control System

Amil Daraz, Suheel Abdullah Malik, Tahir Saleem, Sajid Ali Bhati

Abstract—In this paper, Integral Proportional (I-P) controller is employed for superheated steam temperature control system. The Ziegler-Nichols (Z-N) method is used for the tuning of I-P controller. The performance analysis of Z-N based I-P controller is assessed on superheated steam system of 500-MW boiler. The comparison of transient response parameters such as rise time, settling time, and overshoot is made with Z-N based Proportional Integral (PI) controller. It is observed from the results that Z-N based I-P controller completely eliminates the overshoot in the output response.

Keywords—Superheated steam, process reaction curve, PI and I-P controller, Ziegler-Nichols tuning.

I. INTRODUCTION

SUPERHEATED steam is one of the important origins for power generation. In boiler power plant, the temperature of the superheated steam is affected by the amount of fuel inputs, angle of the flame burner, boiler, load, etc. because fluctuation in temperature can cause to reduce the efficiency of the turbine [1]. Deviation in temperature is dangerous for the achievement of the system, because higher temperature circumstances may damage the metallic design of the boiler, while lower temperature circumstances may affect the efficiency of the turbine [2]. The steam temperature is typically restrained by injecting the water into the steam to chill. Therefore, it is very obligatory to rise the efficiency of the turbine by controlling the temperature of the steam system at the desired temperature.

In past, different authors have applied different techniques for superheated steam temperature control system. For Instance, the authors tested numerous varieties of controllers such as proportional, PI, and Proportional Integral Derivative (PID) with diverse tuning techniques like Z-N. Cohen Coon and CHR approaches for superheated steam temperature control system [3]. Bushra et al. applied PID controller with techniques of fuzzy logic to regulate the temperature of superheated steam system [4]. Begum et al. used PID controller with modified Z-N based tuning to control the temperature of superheated steam system [5]. Numerous former controllers with different approaches are tested to

control the temperature of superheated steam such as internal model control, genetic based active disturbance rejection controller, conventional and fuzzy controllers, cascaded controller, ADRC-PID, and neuro fuzzy network, see [6]-[12] and references there. In this research work, I-P controller with Z-N based tuning has been applied to control the temperature of superheated steam system.

The performance of Z-N based I-P controller is made with Z-N based PI controller. The rest of paper is organized as follows: In Section II, superheated steam system is briefly described which is followed by mathematical model of the system. Section III briefly describes about PI and I-P controllers. Section IV comprises of Z-N based tuning of PI and I-P controllers. Section V consists of simulation results. Finally Section VI provides certain concluding statements and future mechanism.

II. MATHEMATICAL MODEL OF THE SUPERHEATED STEAM SYSTEM

Fig. 1 shows the functional block diagram of the superheated steam system.

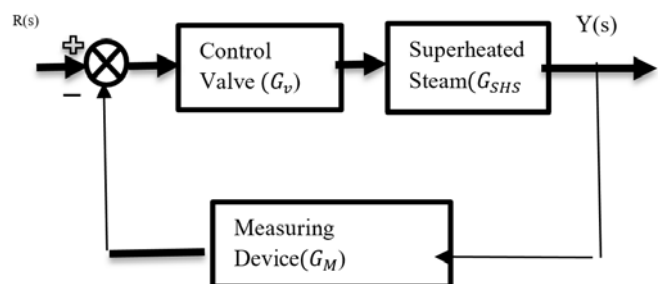


Fig. 1 Block diagram of superheated steam system

These transfer functions are given as [3].

$$G_v = 0.557 \quad (1)$$

$$G_m = 1 \quad (2)$$

$$G_{shs} = \frac{1.3882}{(19s+1)^5} \quad (3)$$

The overall system transfer function is given as:

$$G(s) = \frac{0.7732}{(19s+1)^5} \quad (4)$$

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The transfer function in (4) is fifth order equation. The fifth order model can be converted into first order plus dead time model [3]. Different types of method are used for the conversion of higher order to lower order in which one of them is process reaction curve method [5] which is shown in Fig 2. Formula to identifying delay plus first order system is given by [14], [15]

$$G(s) = \frac{Ke^{-Ls}}{\tau s + 1} \quad (5)$$

where L= time delay; τ = time constant; and k= gain, which are calculated as [3]

$$L = 1.3t_1 - 0.29t_2 \quad (6)$$

$$\tau = 0.67(t_2 - t_1) \quad (7)$$

where t_1 is the time to reach its final step response of the system to 35.3%, and t_2 is the time to reach final step response of the system to 85.3%. $t_1 = 74.12$ sec, $t_2 = 138.2$ sec which yields $L = 56.278$ sec, $\tau = 42.938$ sec, and $k = 0.7717$ can be calculated from Fig. 2.

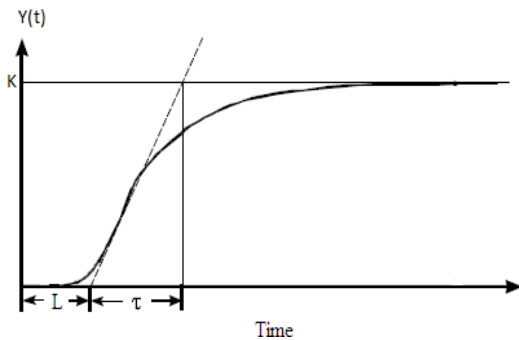


Fig. 2 Process reaction curve of the step response of the system

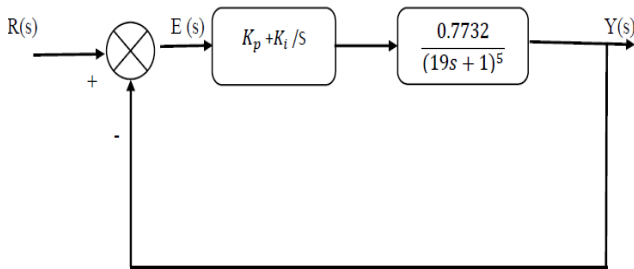


Fig. 3 Block diagram of the system with PI controller

Using the values of L, τ , and k in (5), we obtained

$$G_s = \frac{0.7717}{42.938s + 1} e^{-56.278s} \quad (8)$$

A. PI Controller

This is the conventional type of controller which has the main advantages of preserving a steady state error to a zero for a step change [13], [16], [17]. The block diagram of a superheated steam system with PI controller is shown in Fig 3. In PI controller, the proportional gain (K_p) and integral gain

(K_i) both are put in feed forward to produce zero steady state error. The PI controller has some disadvantages like highly starting overshoot, sensitivity to controller gain both K_p and K_i , and also instantaneous change to load torque.

The closed loop transfer function of the superheated steam system with PI controller is given in (9):

$$\frac{Y(s)}{R(s)} = \frac{(SK_p + K_i)0.7732}{s((19s+1)^5 + (SK_p + K_i)0.7732)} \quad (9)$$

B. I-P Controller

The block diagram of a superheated steam system with I-P controller is shown in Fig. 4. In I-P controller, the integral gain is put in feed forward, while proportional gain is in feed backward which acts like a feedback compensator.

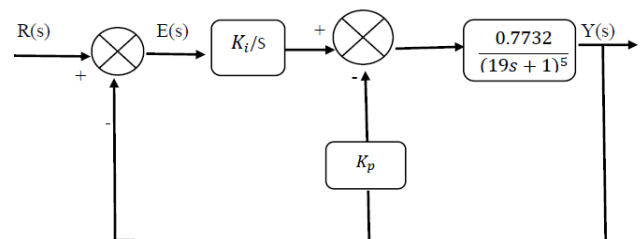


Fig. 4 Block diagram of the system with I-P controller

The closed loop transfer function of the superheated steam system with I-P controller is given in (10)

$$\frac{Y(s)}{R(s)} = \frac{K_i(0.7732)}{s((19s+1)^5 + (SK_p + K_i)0.7732)} \quad (10)$$

C. Tuning of PI and I-P Controllers Using Z-N Method

Different types of methods are used for the tuning of PI and I-P controller, in which the most well-known method is Z-N method. Z-N method has two types; the first one is open loop method, and the other one is closed loop method. By using open loop method, we can find the gain parameters of the controllers by finding the value of time delay (L), time constant (τ), and gain k from the step response of the system and taking tangent line at inflection point as shown in Fig. 2. However, open loop control method is not applicable for superheated temperature system because $(L/\tau) > 1$. So, we can use closed loop Z-N tuning method which is given as [18], [19]:

$$K_p = 0.45 \times K_{cr} \quad (11)$$

$$T_i = \frac{P_a}{2} \quad (12)$$

where K_{cr} = ultimate gain which is observed when the sustained oscillation of the system starts, and P_a = period of oscillation across the phase cross over frequency.

By putting the value of $K_{cr} = 3.739$ and $P_a = 164.22$ in (11) and (12), we get the values of constant K_p and K_i which are given in Table I.

TABLE I
 VALUE OF K_p AND K_i USING Z-N TUNING

K_p	K_i
1.6825	0.0122

III. SIMULATION AND RESULTS

In this section, MATLAB simulations and results are presented. For these simulations, MATLAB/ Simulink version R2012b is used. The Simulink system model with PI controller is given in Fig. 5. The system is subjected to a unit-step input, and the system response is shown in Fig. 6.

It can be seen from Fig. 6 that oscillations are present in the

system response. In Table II, transient response parameters such as rise time, settling time, and maximum overshoot achieved using Z-N based PI controller are provided. Figs. 7 and 8 show the Simulink system mode with I-P controller and the system response with unit step, respectively. In Fig. 9, the comparison of step response of the system with PI controller is made with I-P controller. It is evident from the comparison that the I-P controller has removed oscillations completely, and there is 0% overshoot present in the system. Further, in Table II, comparison of transient response parameters between Z-N based PI controller and Z-N based I-P controller is given.

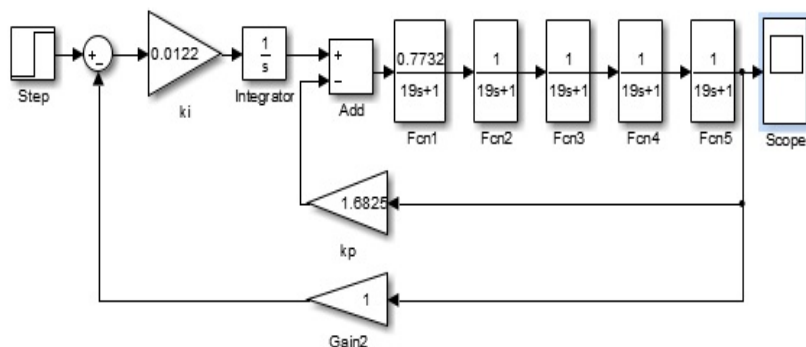


Fig. 5 Simulink model of the system with PI controller

Figs. 7 and 8 show the Simulink model of the system with I-P controller and the unit step response of the system respectively. In Fig. 9, the comparison of step response of the system with PI controller is made with I-P controller. It is evident from the comparison that the I-P controller has removed oscillations completely and there is 0% overshoot

present in the system. Further, in Table II, comparison of transient response parameters between Z-N based PI controller and Z-N based I-P controller is given.

The combined results for PI and I-P controllers and also for open loop system without controller are shown in Fig. 9.

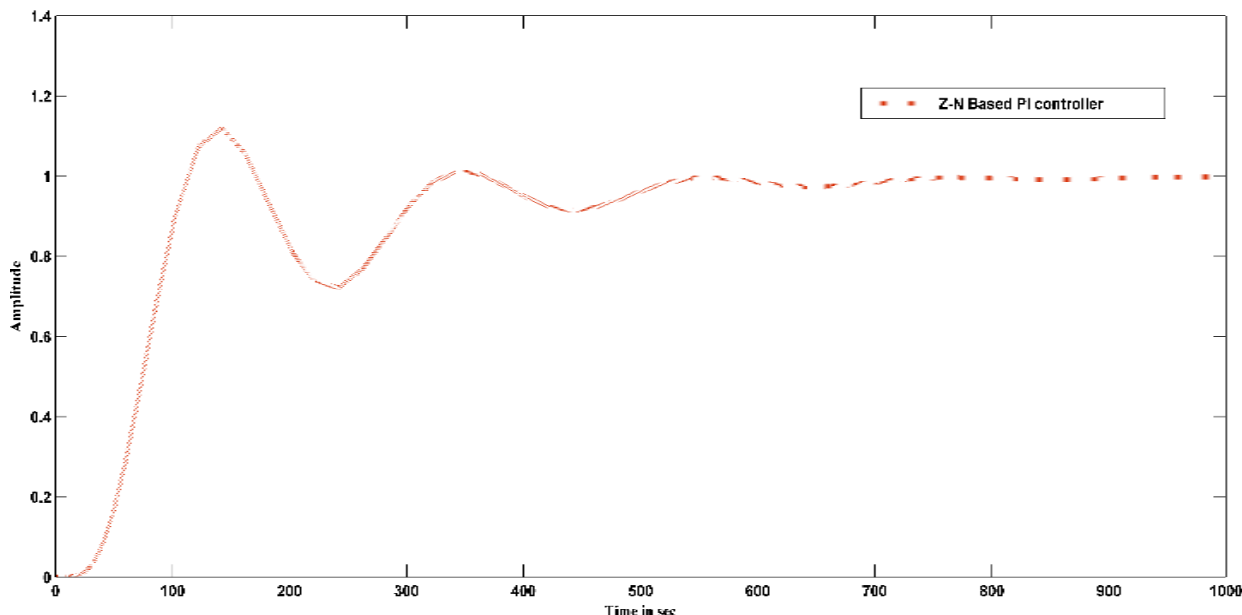


Fig. 6 System step response with PI controller

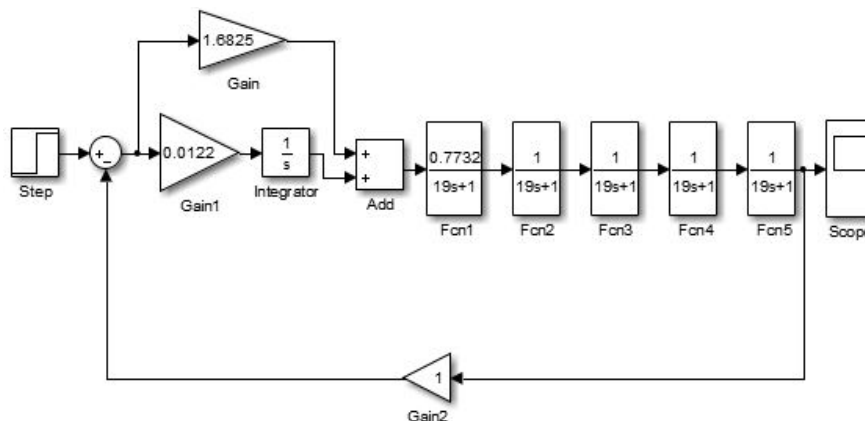


Fig. 7 Simulink model of the system with I-P controller

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The green line designates the result for open loop system response without controller. The reference line is indicated by dark blue color which is one, while the red dotted lines show PI controller which comprises highly overshoot and oscillation, but settles rapidly on the reference line. The blue solid line shows that the system has no overshoot. However, it is settling time, and rise time is higher due to longer delay time of I-P controller. It can be seen that I-P controller provides output with 0% percent overshoot, however at the cost of increase in rise time and settling time by 16% and 74%, respectively. Nonetheless, the maximum overshoot which may cause physical damage to the system has been completely eliminated by I-P controller. The result indicates that I-P controller completely eliminates overshoot at the output, and other transient response is also shown in Table II.

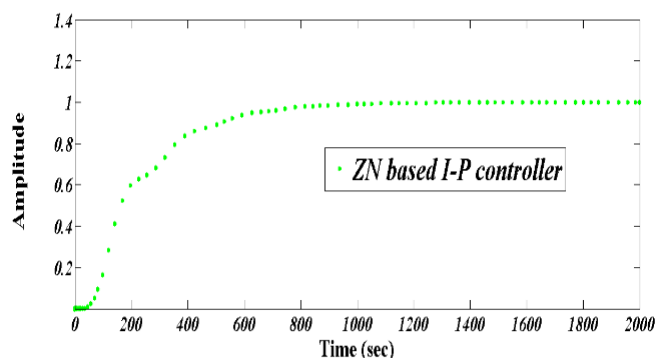


Fig. 8 System step response with I-P controller

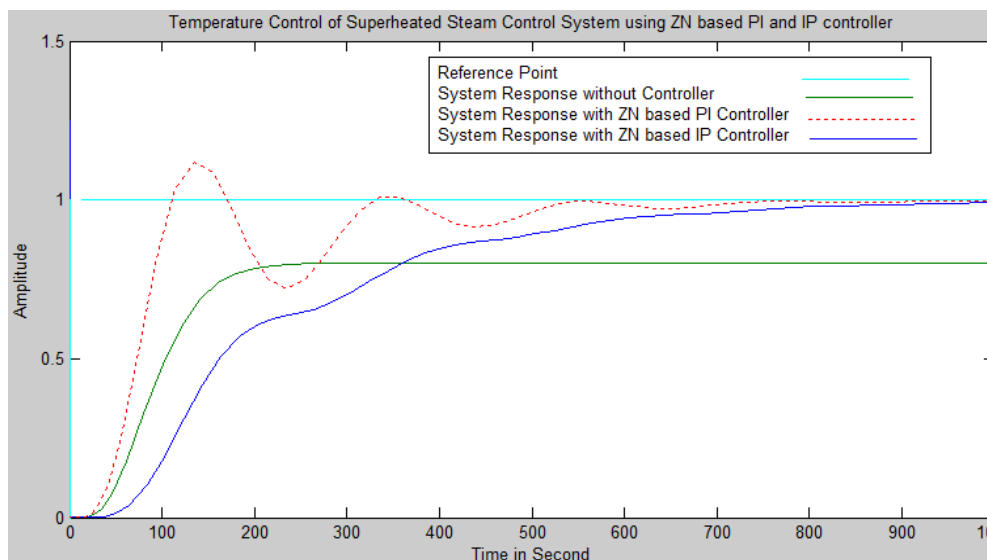


Fig. 9 Combined result of PI, I-P controller and open loop response

TABLE II
 TRANSIENT RESPONSE THE SYSTEM WITH PI AND I-P CONTROLLERS

Method	Rise time (Sec)	Maximum Overshoot (%)	Settling time (Sec)
PI-ZN	60.71	12.1	683
I-P-ZN	430	0	817

IV. CONCLUSION

I-P controller has been applied to the superheated system of 500 MW boiler. Z-N method has been used for the tuning of the controller. The transient response performance of the system with I-P controller has been assessed and compared

with Z-N based PI controller. From the comparison of the results, it can be concluded that I-P controller is better in terms of maximum overshoot. It is observed that Z-N based I-P controller completely eliminates the oscillations in the output, which is very prestigious for the system. In future, we aim to use evolutionary computation techniques such as Genetic algorithm (GA) and simulated annealing (SA) for tuning of I-P controller to improve its transient response performance.

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