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Research Article

Experimental Approach of Various Controller Tuning Methods for Integrating Processes With Dead Time

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Abstract. PID control is widely used in industrial control systems in order to adjust the controller gains according to change in plants. In this proposed work, controller tuning is performed automatically based on various tuning formula. The responses of various tuning methods for integrating process are analyzed for process with dead time.

Keywords. Tuning; PID Control; Dead time; Tuning; Controller; Inergrating process

MSC. 26A33; 26E70

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1. Introduction

The control system is an essential part of the industrial process. The process parameters need to be operated in particular set point. The PID controller is widely used to control the process data. The choosing of controller gain is the challenging task for higher order processes with dead time. The closed loop tuning is preferred for accurate control of process variable than open loop tuning. The selection of controllers and tuning methods vary depending upon the nature of the process.

2. First Order With Dead Time Process Model

Dead time (θ) is the time taken by the system to produce the response after applying the input. The dead time is the time duration during which the process output becomes zero [1,2].

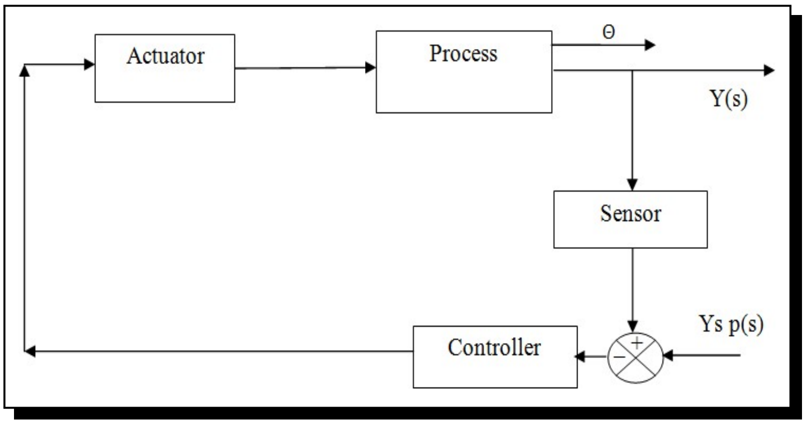

Figure 1. Block diagram showing dead time

Most of the systems either linear or non-linear have some degree of dead time. The process should have low dead time. The transfer function for first order process with dead time is given by:

$$G_p(s) = \frac{e^{-\theta d^s}}{\tau s + 1}.$$

Continuous controller modes

The proportional mode requires single parameter to tune and it produces slow response. The drawback is it gives offset. The integral mode has no offset and it produces more oscillations. The derivative mode makes the output more stable and fast response [3]. The combination of three modes gives the stable and quick response.

Software implementation

The MATLAB software is used in this proposed work to generate the responses of first order system with dead time process. The various tuning methods are used for analysis of different process in MATLAB.

3. PID Tuning Techniques

The PID controller is the popular feedback controller and is widely used in industrial process. The set point is given as input and the output is measured by using sensor [4,5]. The error is generated based on set point and process variable and it is given as input to the controller. Based on the error signal, the controller generated manipulated variable which inturn controls the process.

4. Open Loop Tuning Methods

The controller tuning is based on the process and the improper tuning may lead to instability. The tuning of controller is essential for setting the control parameters to the optimum values to get the desired response [6, 7]. It has no effect on the process output they are,

- Ziegler-Nichols Open Loop
- Cohen-Coon
- AMIGO

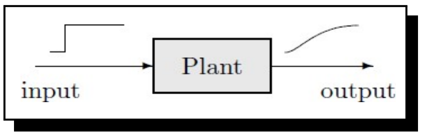

Figure 2. First order system

Ziegler-Nichols Tuning Method

It relies heavily on dead time (L) as descriptive parameter for the process. The open loop test will predict large controller gain and small dead time is obtained.

The higher value of slope is determined and the tangent is drawn from the point on the step response curve Theone quarter decay ratio is obtained for the step response These methods are still widely used, due to their simplicity.

Approximated M-Constrained Integral Gain Optimization (AMIGO)

The AMIGO tuning methods were developed both for interacting and non-interacting processes.

The Astrom and Hagglund proposed a method which is known as AMIGO (*Approximated M-constrained Integral Gain Optimization*), includes a set of equations used to calculate the controller gains in a similar way to the procedure used in the Ziegler-Nichols method.

5. Closed Loop Tuning Method

Closed loop method utilizes the feedback. The feedback makes the process becomes stable. The various closed loop tuning strategies based closed loop step response are:

- Internal Model Control (IMC)
- Ziegler-Nichols tuning method
- Minimum Error Integral Criteria method

- Relay feedback response
- Tyreus-Lyuben
- Cooper

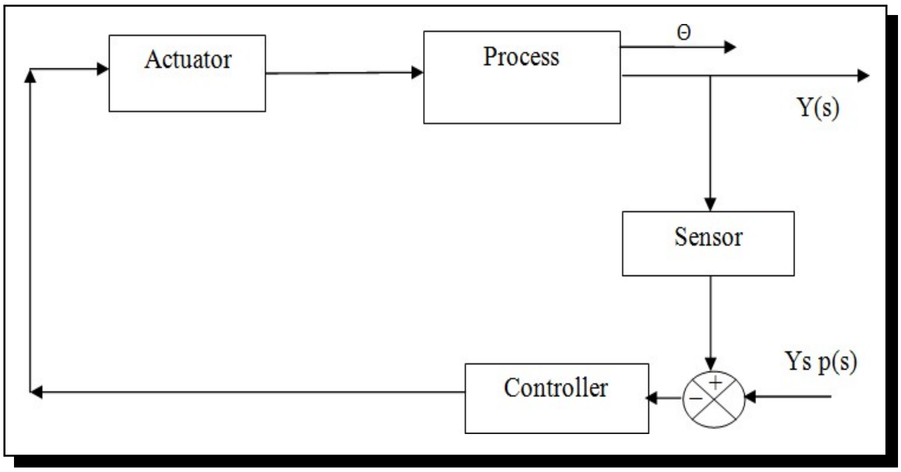

Figure 3. Basic closed loop systems

Internal Model Control (IMC)

The IMC approach has two majorbenefits,

- It considers the model uncertainty.
- It makes control performance robustness to process dynamics and modeling errors.

The requirements of IMC method for designing the control system are:

- Model of the Process
- Uncertainty of the Model
- Input type (step, ramp, etc.)
- Performance objective (ISE, overshoot, etc.)

The experimental model is preferred when the process is not subjected to fundamental principles. In the IMC method, the integral square error is implied.

A smaller gain for proportional mode, larger reset time for integral mode and smaller derivative time for derivative mode is required for conservative controller. The following steps are required for designing the PID controller. They are:

- Design level of operation need to be specified
- Dynamic process data as near as practical to this design level should be collected
- FOPDT model to be fitted to the process data
- Initial controller tuning values to be obtained

Ziegler-Nichols Closed Loop Tuning Method

The steps to be followed in closed loop tuning are:

- Integral and derivative control parameters should be zero.
- Proportional gain (Kc) should set at low value.
- Controller to be put in Auto mode.
- Make a controller set point to a low value
- Process response is monitored
- Increase the controller gain (Kc) if the controller does not continually cycle and repeat from step 4.
- Controller gain is the ultimate gain Kcu, when the controller starts oscillating.
- The time period is measured and this is the ultimate period Pu.

6. Robustness

Special considerations are needed for the processes where the appropriate setting of one parameter depends on the setting of another.

Figure 4 shows the robustness of the gain value obtained by various tuning methods.

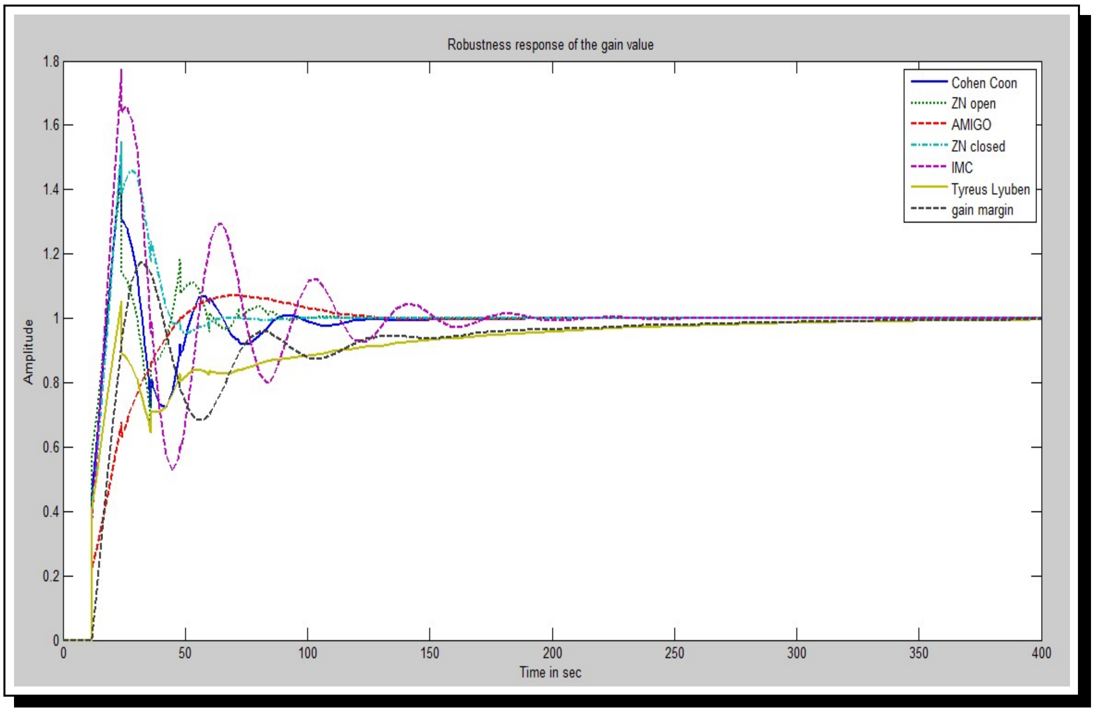

Figure 4. Robustness Response of the Gain Value

Figure 5 shows the robustness response of time constant value obtained by various tuning methods.

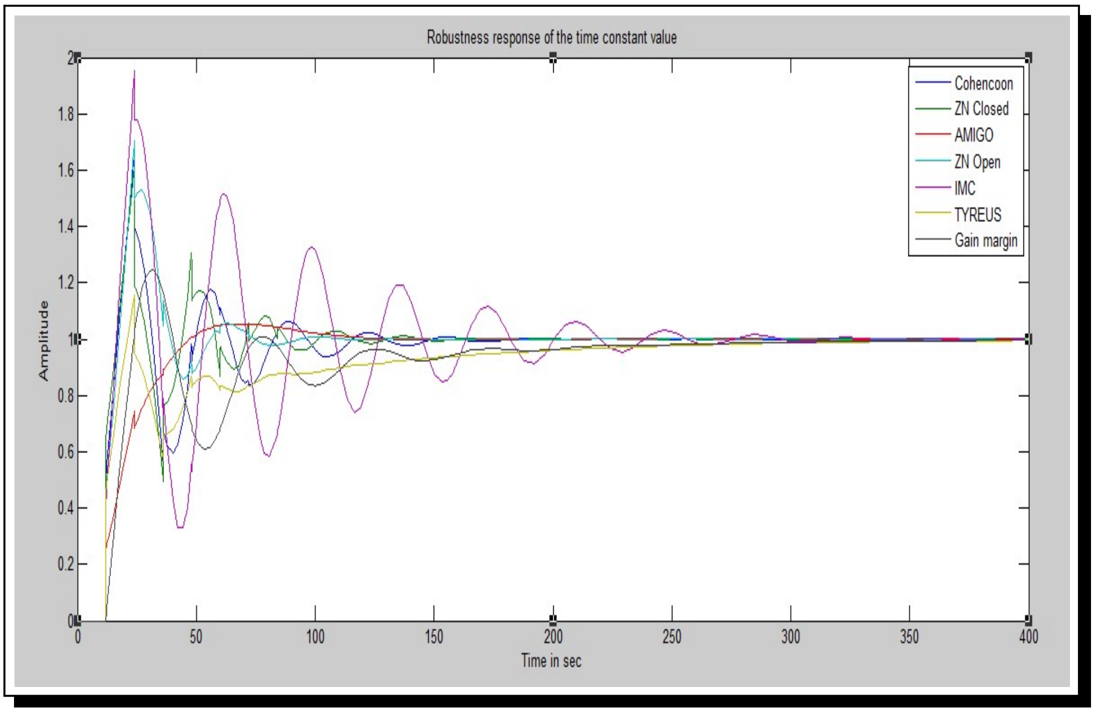

Figure 5. Robustness Response of the Time Constant Value

Figure 6 shows the robustness response of dead time obtained by various tuning methods.

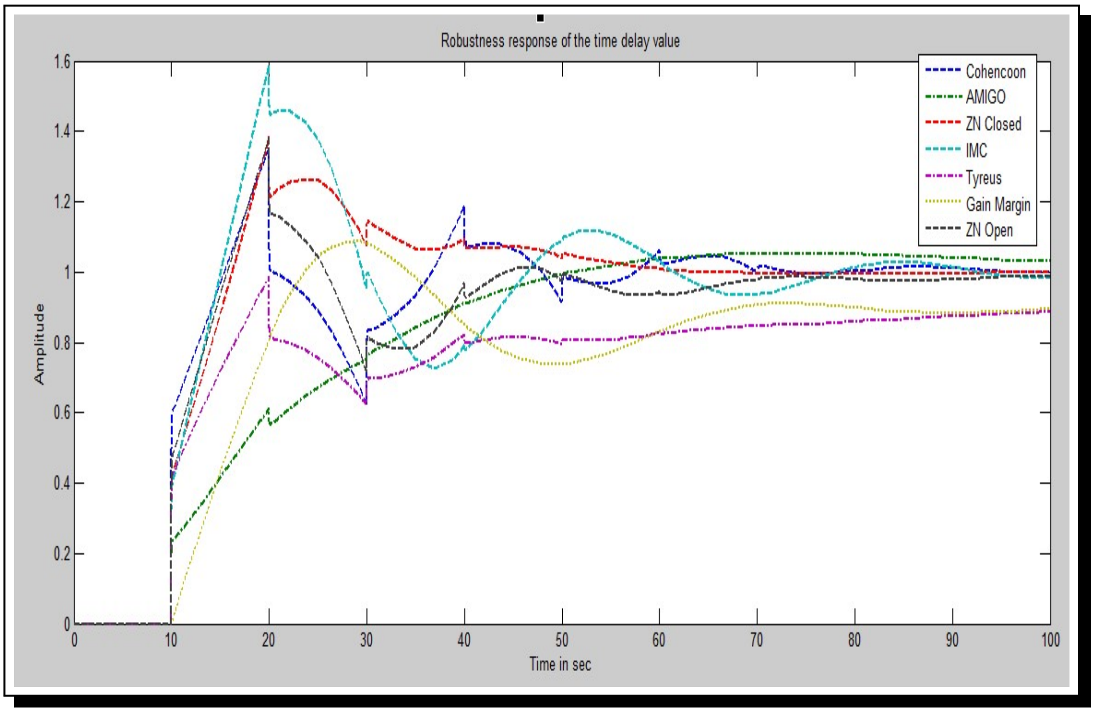

Figure 6. Robustness Response of the Dead time

7. Simulation Results

7.1 Simulation results of open loop methods

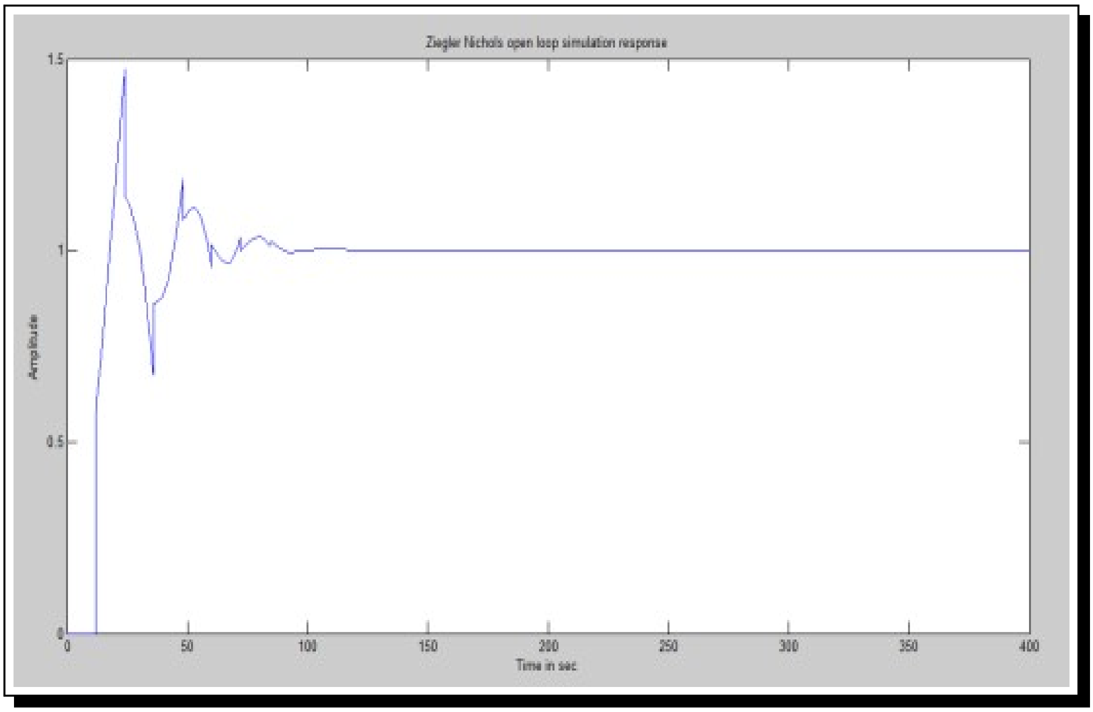

Figure 7. Cohen Coon Open Loop Simulation Response

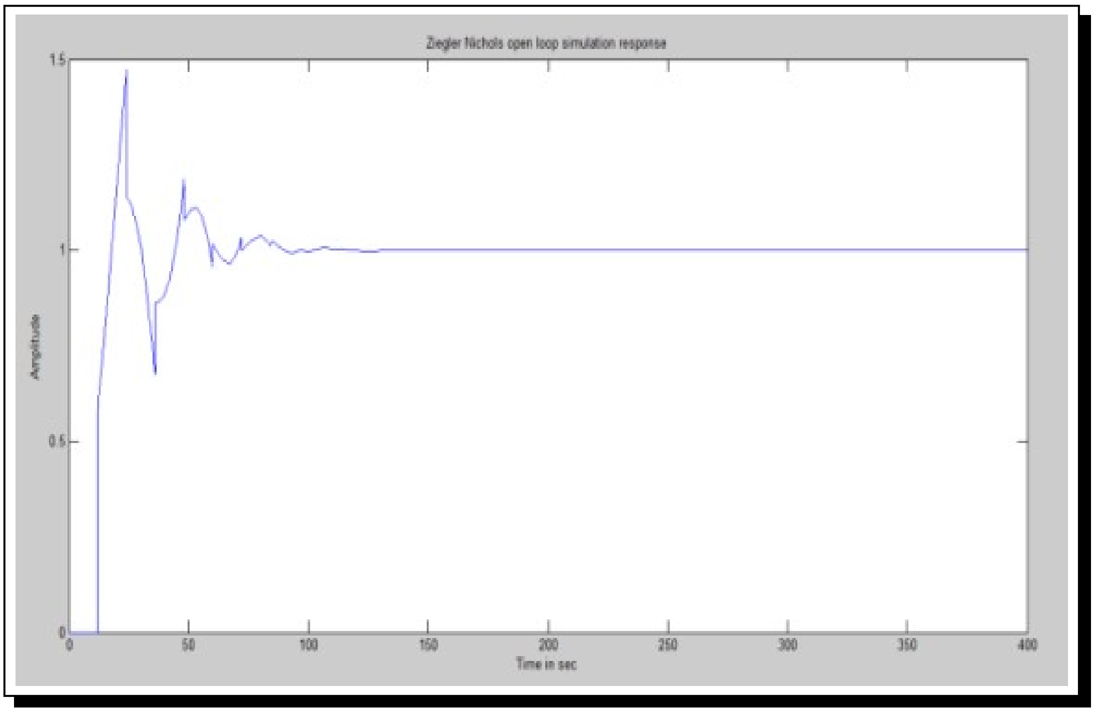

Figure 8. Ziegler Nichols Open Loop Response

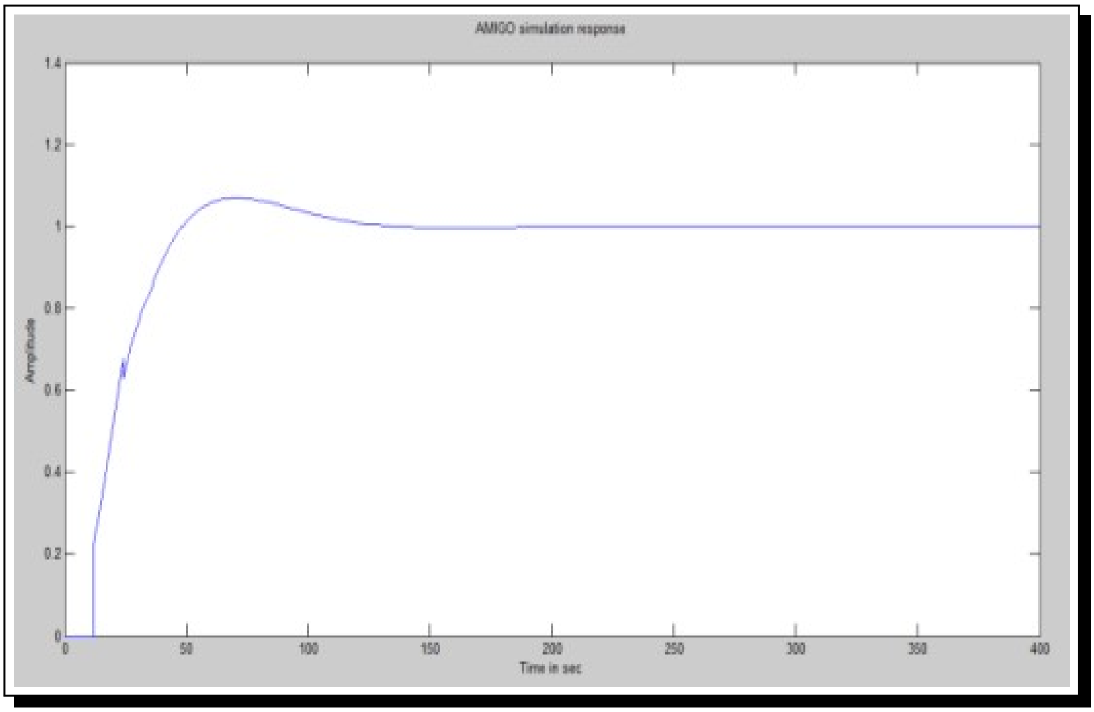

Figure 9. AMIGO open loop response

Table 1. Time domain specifications of open loop response methods

Method	Rise time	Peak time	Settling time	Delay time	Peak overshoot
Cohen-Coon	18	25	160	15	0.57
Ziegler-Nichols	12	20	200	10	0.50
AMIGO	48	52	150	10	0.08

8. Inference

- The first order process is preferred for process control. The varieties of tuning methods are available for first order process. The dead time is to be considered during process modeling.
- Ziegler-Nichols and Cohen coon methods can be regarded as '*load based tuning methods*'.
- *AMIGO stands for 'Approximate M-Constrained Integral Gain Optimization'.*
- Controller tuned by *Cohen coon* method has *large time delay* compared to other methods.
- Controller tuned by *Ziegler Nichols* method has *small rise time and peak time* compared to other methods.
- Controller tuning by *AMIGO* method has *large rise time and peak time.* It *has fast settling time* as compared to other tuning methods.

9. Simulation Results of Closed Loop Methods

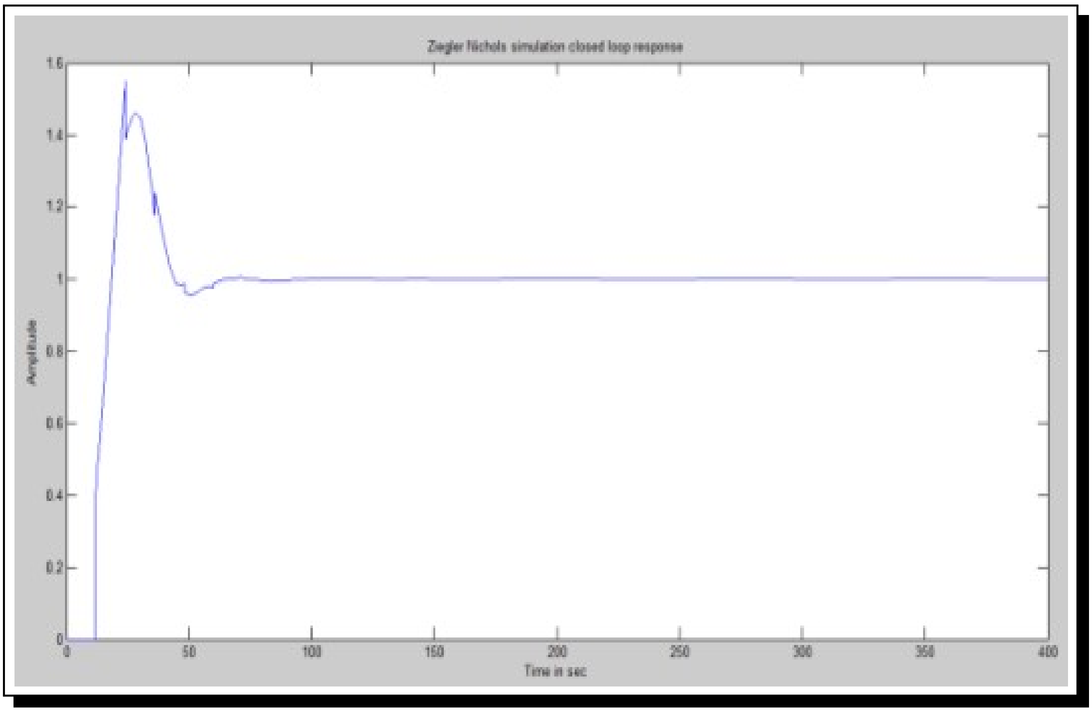

Figure 10. Ziegler Nichols Closed Loop Response

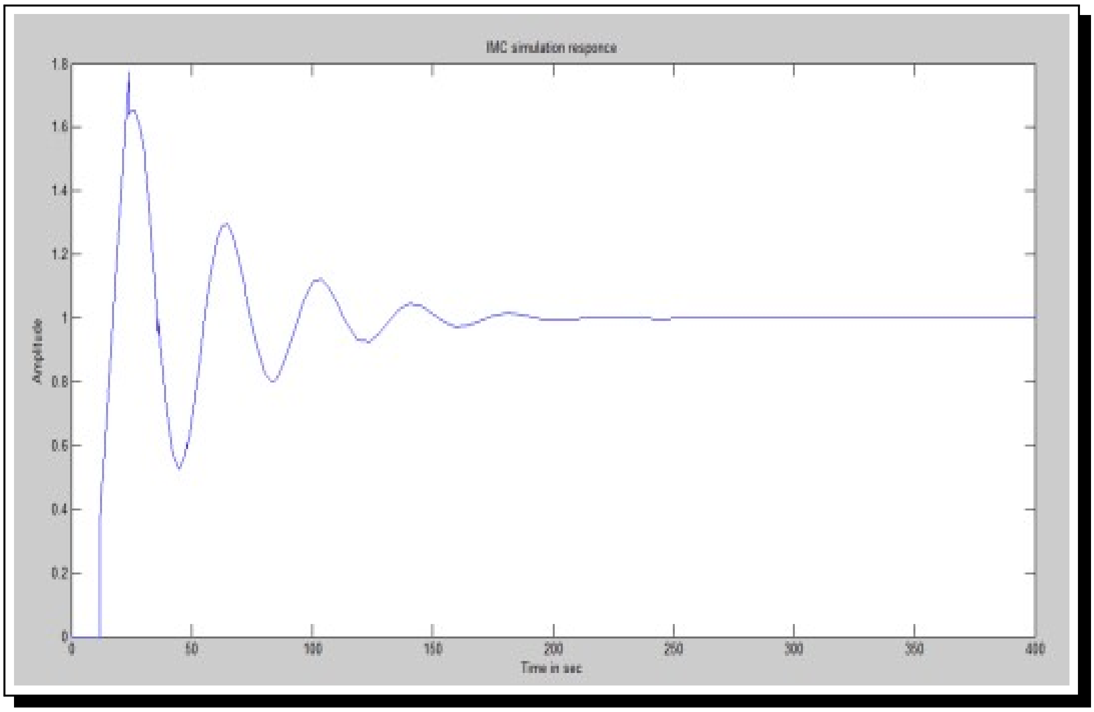

Figure 11. IMC Closed Loop Response

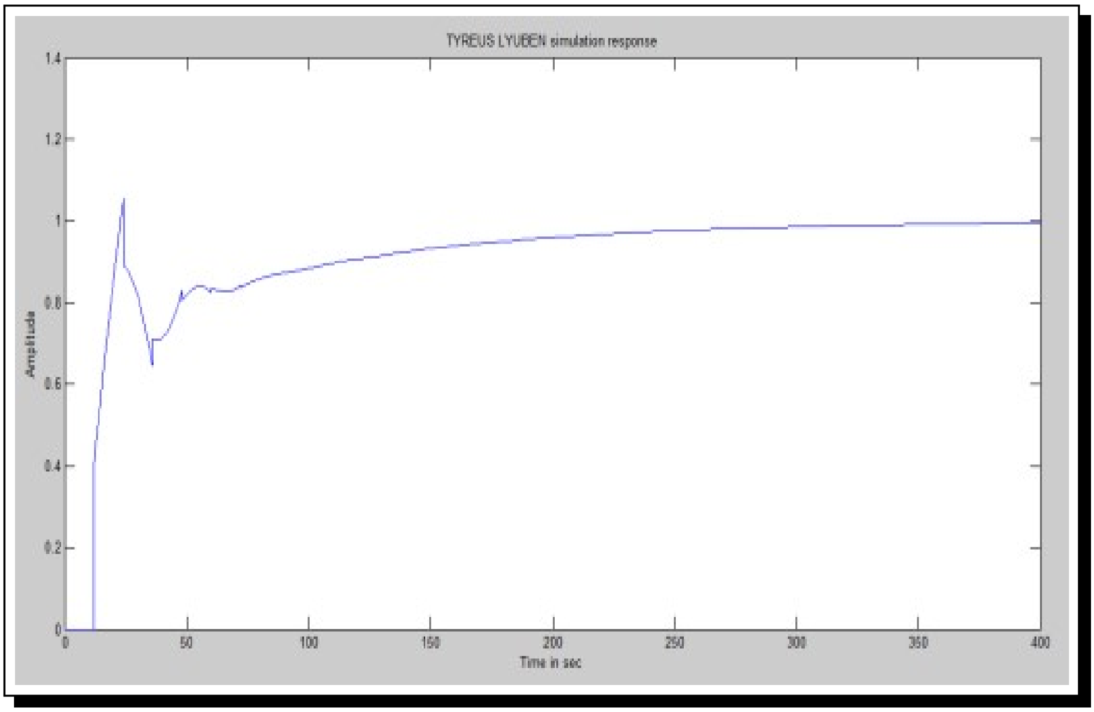

Figure 12. TyreusLyuben Closed Loop Response

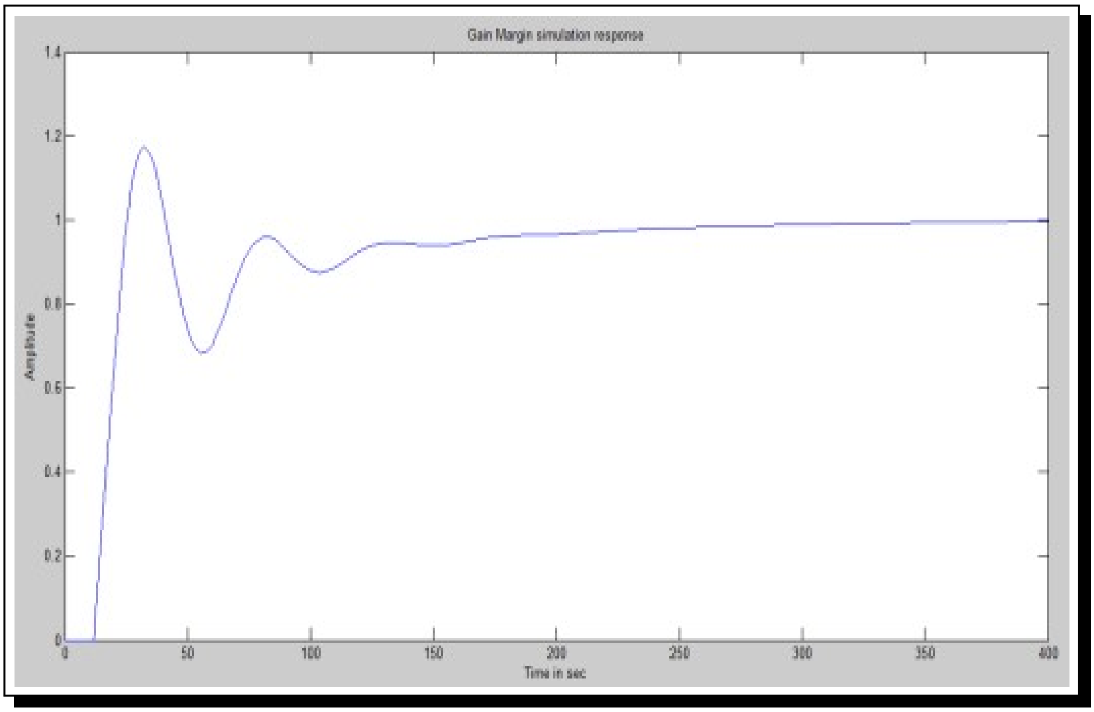

Figure 13. Gain Phase Margin Closed Loop Response

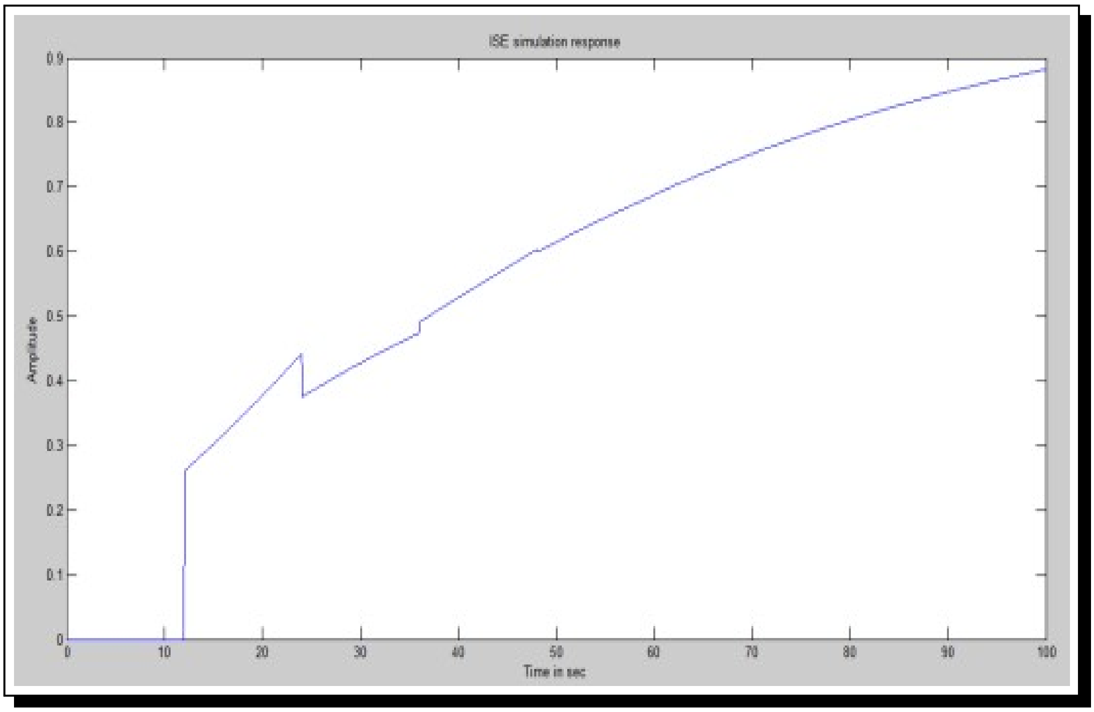

Figure 14. Integral of Square Error Closed Loop Response

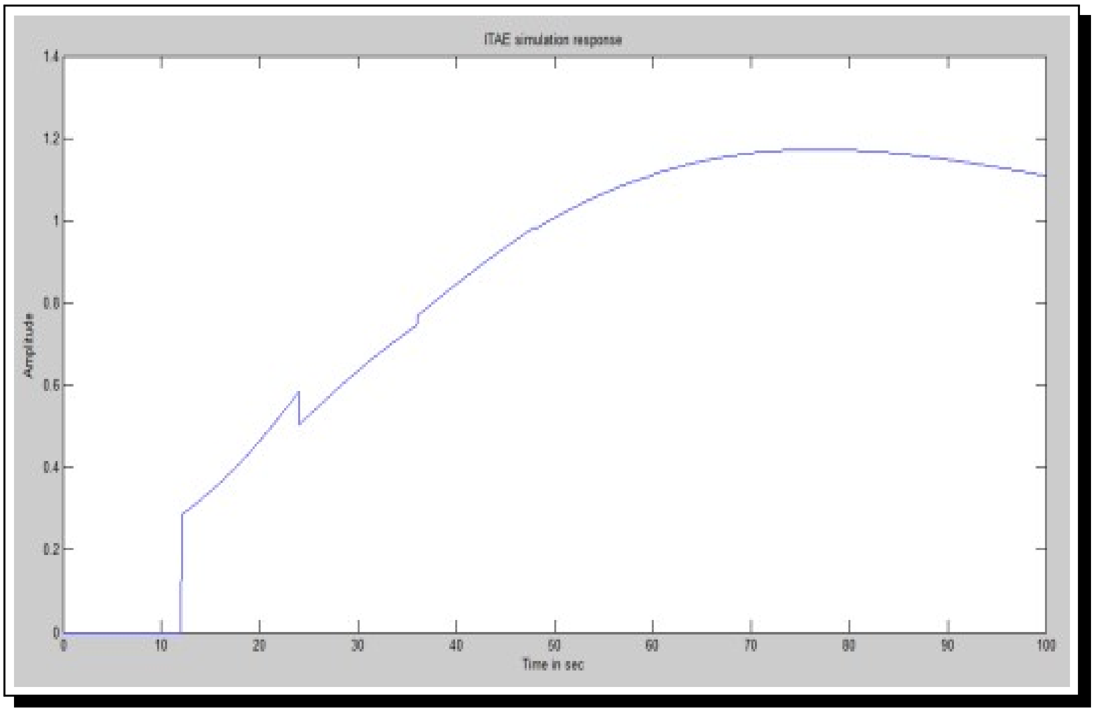

Figure 15. Integral of Time Absolute Error Closed Loop Response

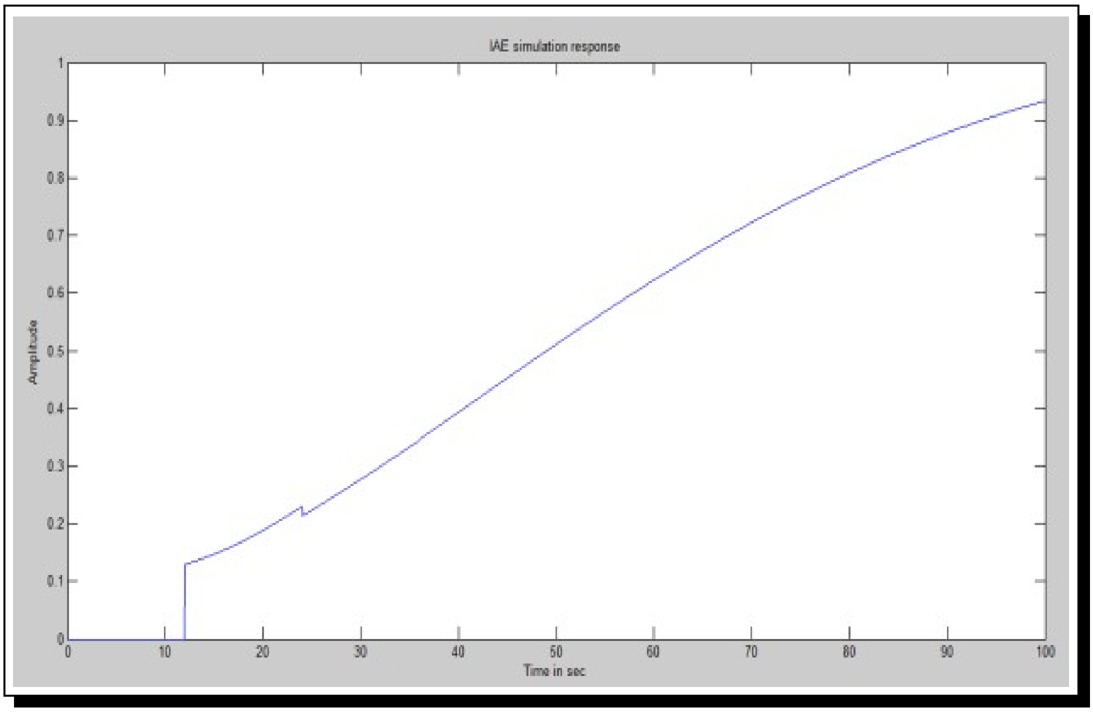

Figure 16. Integral of Absolute Error Closed Loop Response

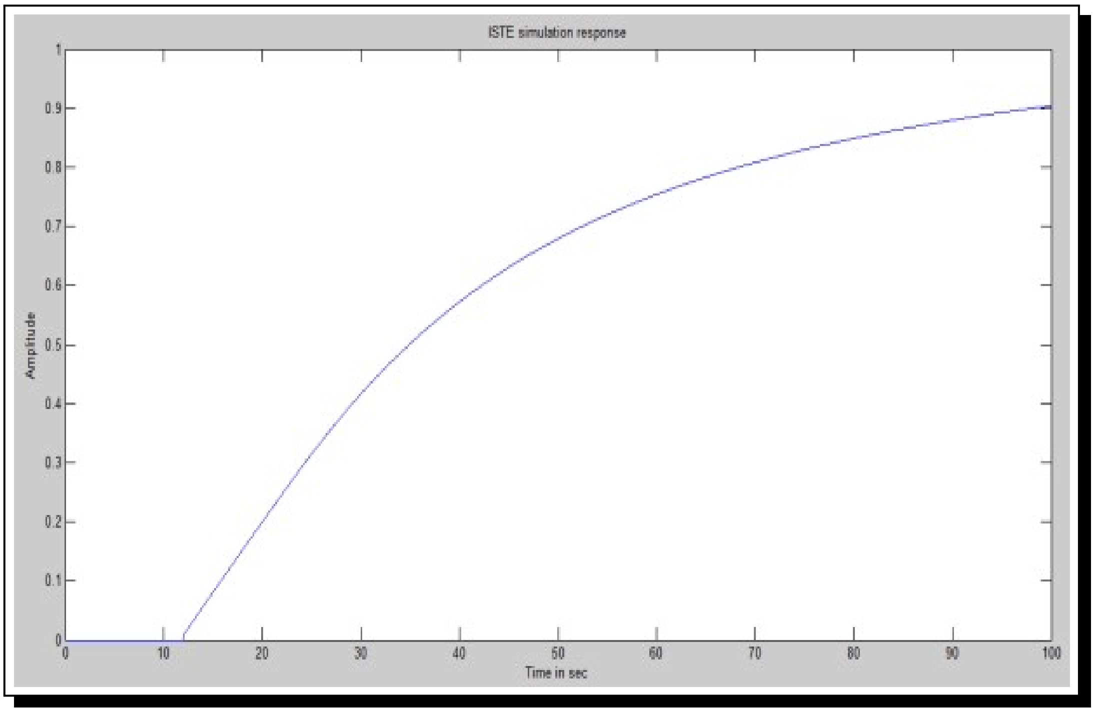

Figure 17. Integral of Square Time Error Closed Loop Response

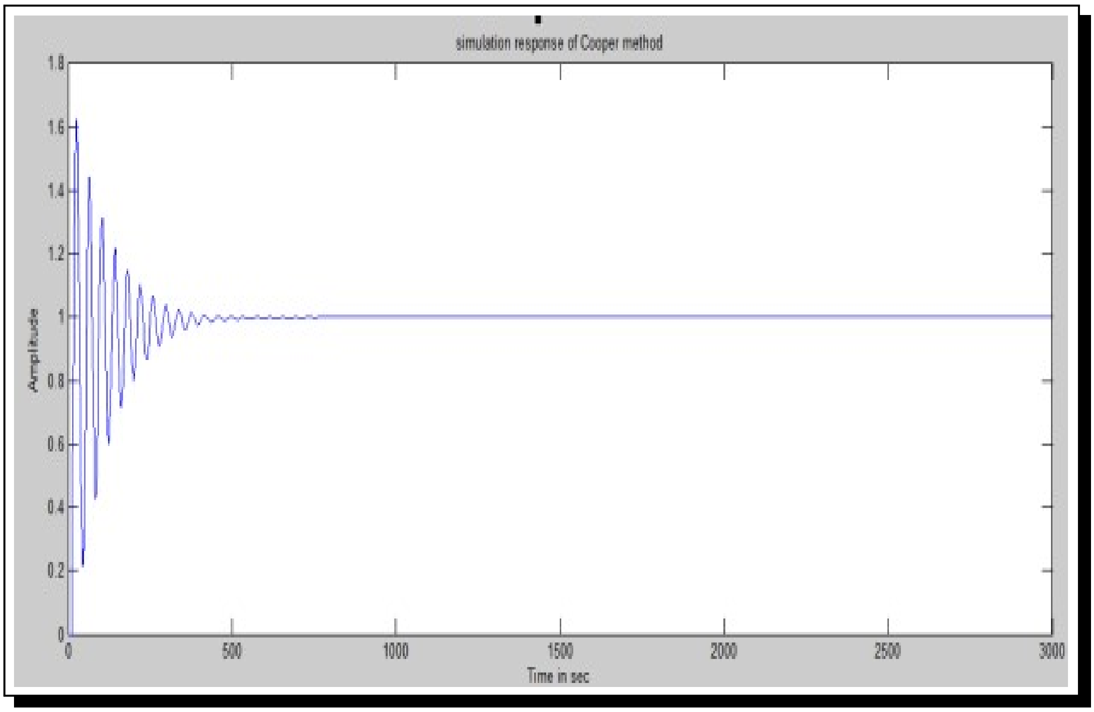

Figure 18. Cooper Closed Loop Response

Some comments on the methods are:

- Controller tuned by *Ziegler Nichols* method has *large rise time* and it *settled quickly* compared to other methods.
- Controller tuned by *Internal Model Control* method has *large peak overshoot* compared to other methods.
- Controller tuned by *Tyreuslyuben* has *small peak overshoot* compared to other methods.
- Controller tuned by *Gain-Phase Margin* method has *large settling time* compared to other methods.
- According to Integral Error Methods, *Integral of Square Error* method has *large rise time*, *Integral of Time absolute Error* has *large peak time*, and it *settled quickly*.
- *Integral of absolute error has large settling time and integral of square error has medium settling time.*
- *Integral of square time absolute error method* has *small peak time.*

Table 2 shows the time domain specifications closed loop tuning methods. The various parameters include rise time, peak time, settling time, delay time and peak overshoot are compared for various tuning methods. It is observed that *Integral Time Absolute Error* (ITAE) has less rise time as compared to other methods. The Ziegler-Nichols tuning method has quick settling time. The dead time is identical for all tuning methods.

Table 2. Time Domain Specifications of Closed Loop Methods

Method	Rise time	Peak time	Settling time	Delay time	Peak overshoot
Ziegler Nichols	15	20	100	10	0.6
IMC	12	23	260	10	0.8
Tyreuslyuben	12	24	350	10	0.1
Gain-phase margin	13	25	360	10	0.2
Integral Error Method (IAE)	12	30	260	10	0.1
ITAE	11	40	200	10	0.2
ISE	13	30	250	10	0.1
ISTE	12	25	260	10	0.2

The responses of open loop, Cohen-Coon, Ziegler-Nichols, Internal Model Control, ISE and ITAE are shown in the figure given below.

10. Real Time Results of Open Loop Methods

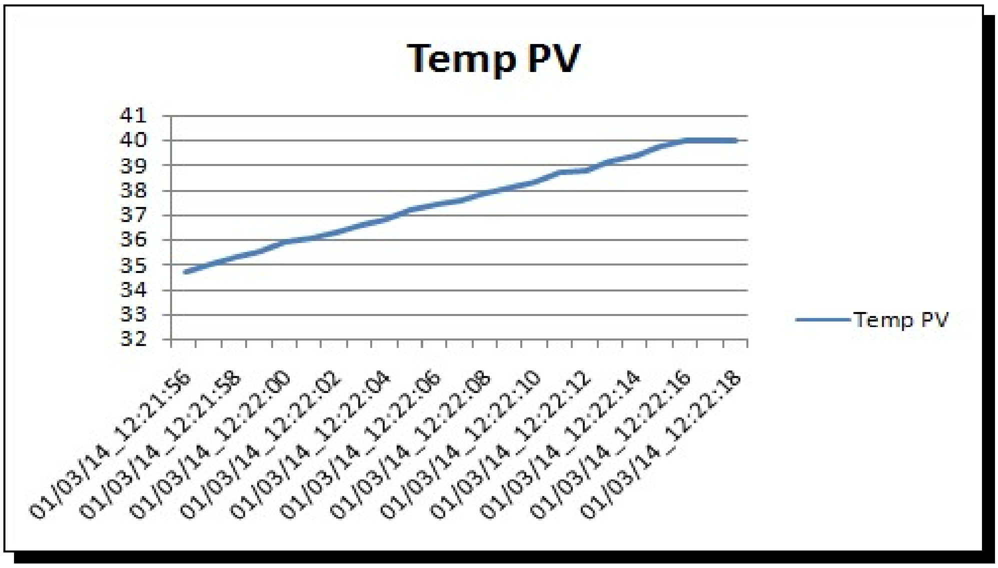

Figure 19. Real Time Result of Cohen Coon Method

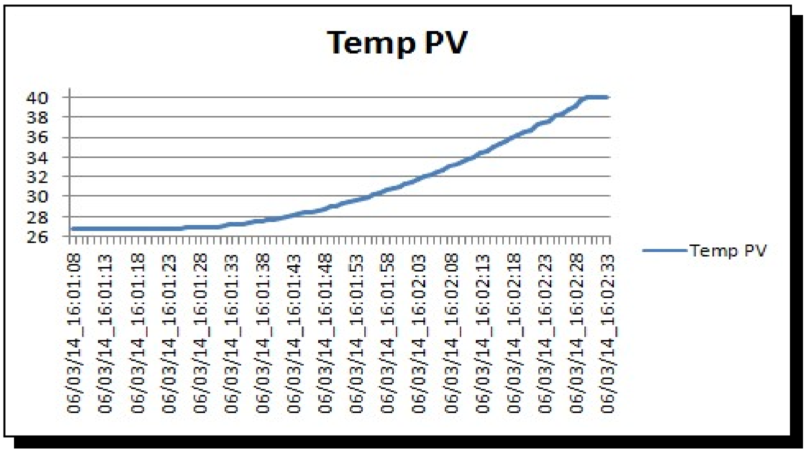

Figure 20. Time Result of Ziegler Nichols Method

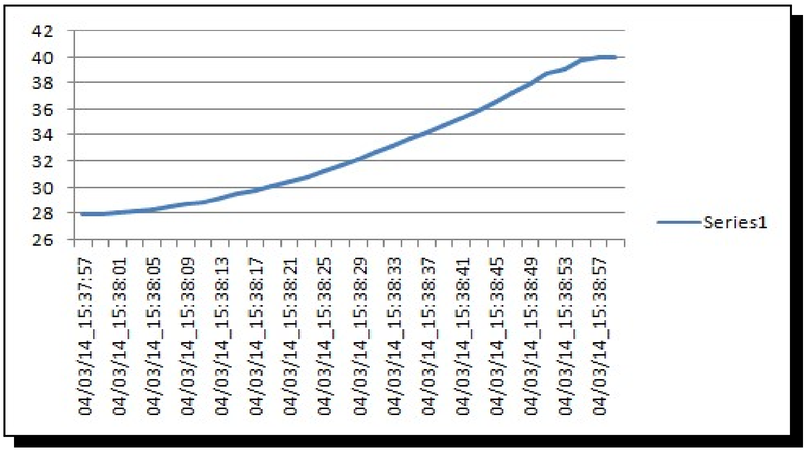

Figure 21. Real Time Result of Amigo Tuning Method

11. Real Time Results of Closed Loop Methods

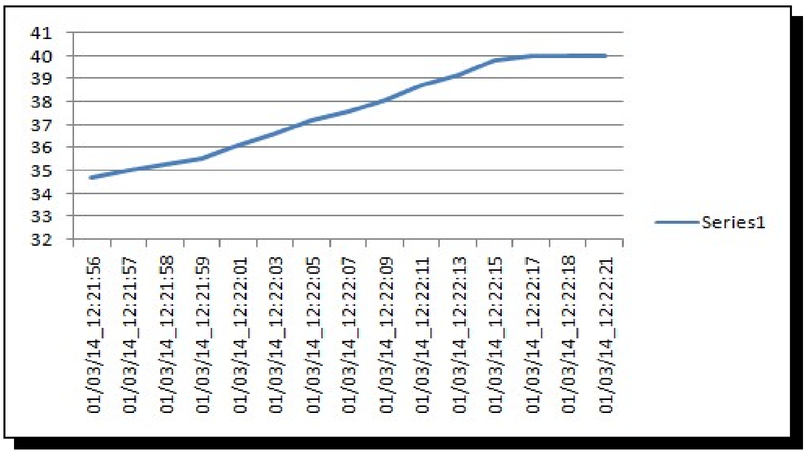

Figure 22. Real Time Results of Ziegler Nichols Method

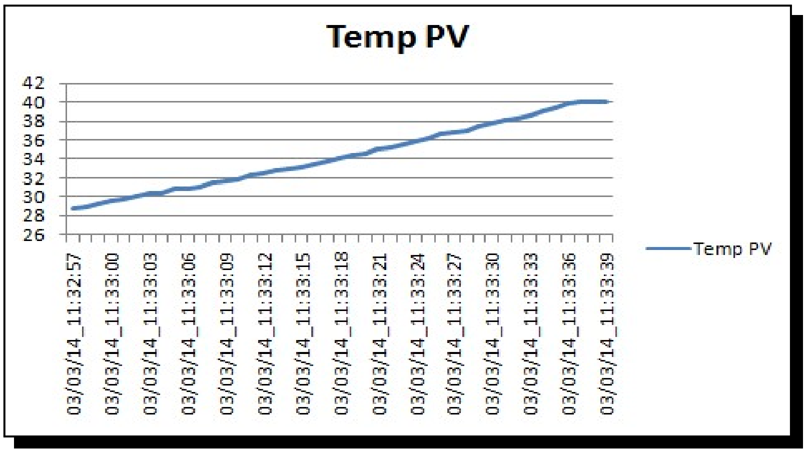

Figure 23. Real Time Results of Internal Model Control Method

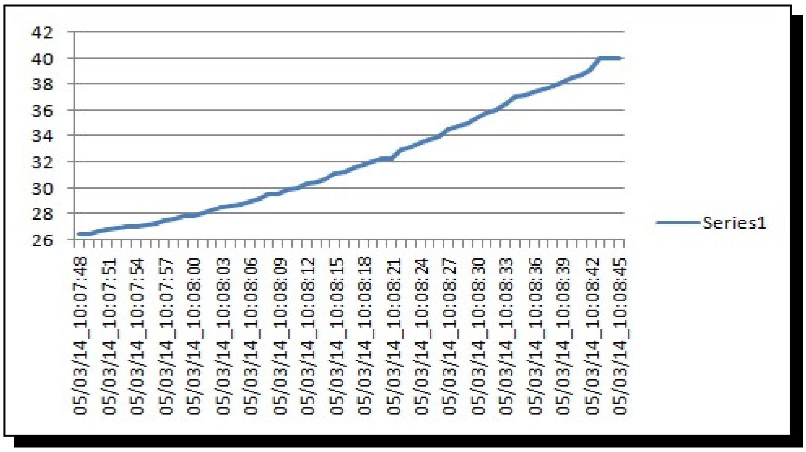

Figure 24. Real Time Results of TyreusLyuben Method

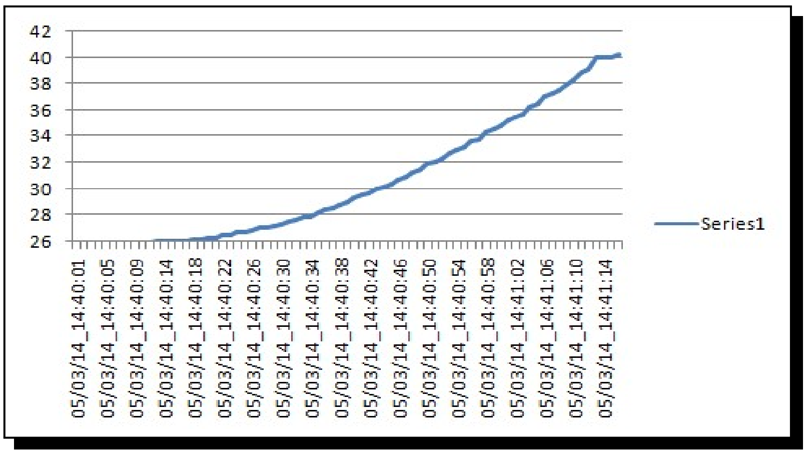

Figure 25. Real Time Results of Gain-Phase Margin Method

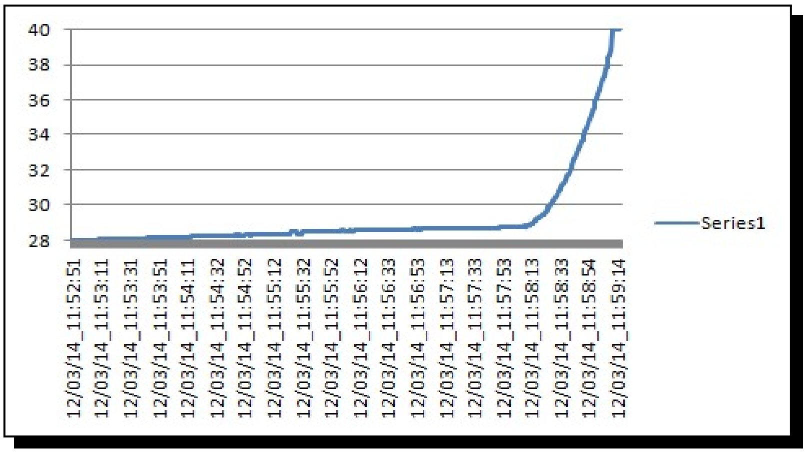

Figure 26. Real Time Response of Integral Square Error

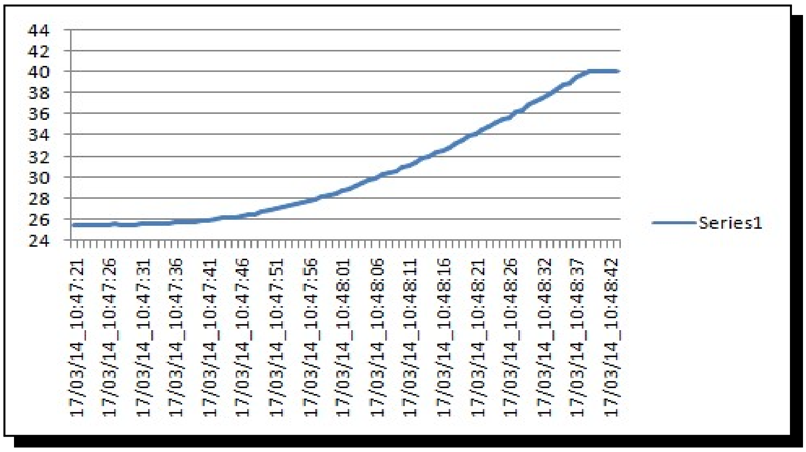

Figure 27. Real Time Response of Integral Square of Time Error

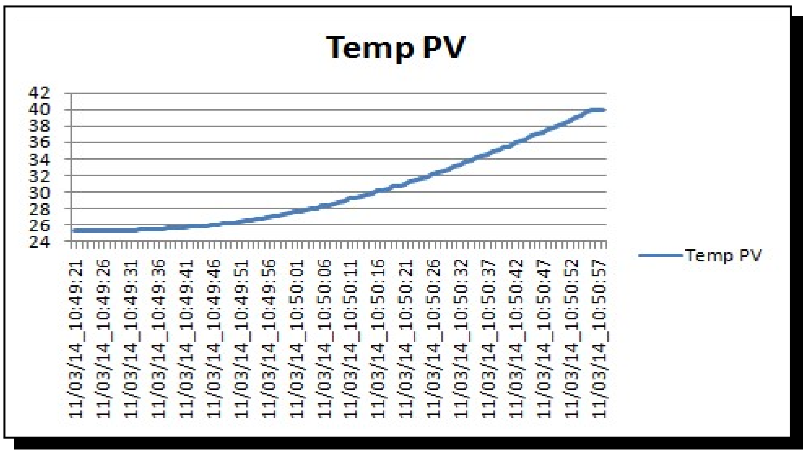

Figure 28. Real Time Response of Integral of Absolute Error

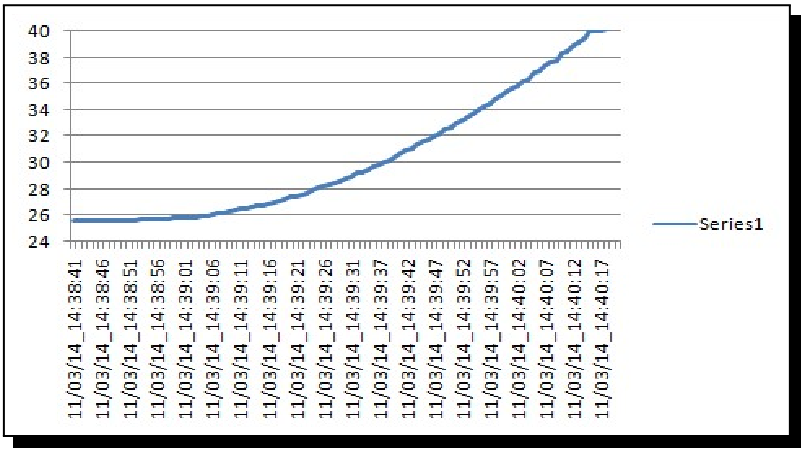

Figure 29. Real Time Response of Integral of Time Absolute Error

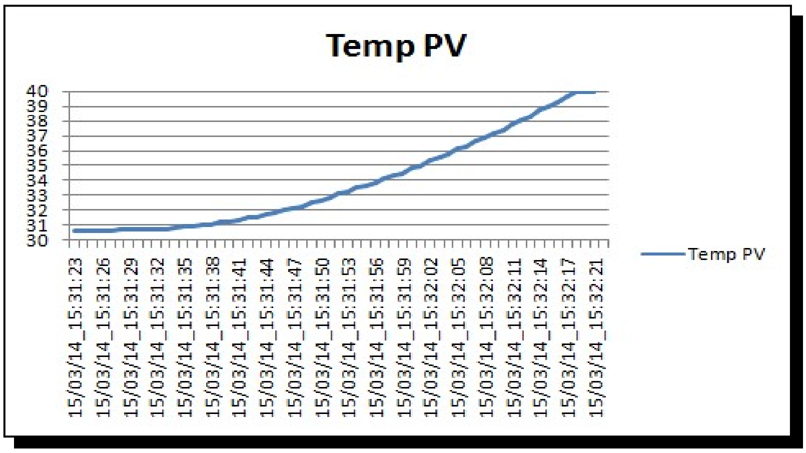

Figure 30. Real Time Results of Cooper Method

12. Conclusion

In this paper we proposed various types of PID tuning methods for FOPDT. The various response parameters are compared for tuning methods. A comprehensive comparative study is performed for different types of tuning methods and it is tested in MATLAB software. Robustness of the system was also performed. The various tuning methods are tested for FOPDT and it is implemented in real time. The responses for various tuning methods are obtained in real time. The different PID tuning techniques discussed in this paper work are further enhanced by *Fractional Order Controller* (FOC)

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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