Robust PID Controller Tuning for a Networked Control System with Delay

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Abstract

This paper presented a robust PID controller design for time delay system. This controller will be utilizing the gain-phase margin method; a specification-oriented parameter region in the parameter plane that characterizes all admissible controller coefficients sets can be obtained. Tuning of a PID controller refers to the tuning of its various parameters (P, I and D) to achieve an optimized value of the desired response. The basic requirements of the output will be the stability, desired rise time, peak time and overshoot. A compromise between the performances of the system with Ziegler-Nichols method is also included. Here we are measuring the plant response with and without delay condition with respect to original reference signal. Small modeling error is encountered and it is gradually detuned to a PID controller.
Keywords: Delay, Networked Control System, PID Controller, Ziegler-Nichols

I. INTRODUCTION

In Control system any quantity of interest in a machine, instrument is maintained or altered with a desired manner [3]. Control system implementation uses point-to-point communication architecture for long time. But there is a limitation in point-to-point architecture due to expanding physical setups and functionality [1]. Hence, these system are no longer suitable to meet new requirements such as modularity, decentralization of control, integrated diagnostics, quick and easy maintenance, and low cost. But new system called networked control systems (NCSs) are evolved due to advance technology network availability results in giving network facilities to Control system [12]. The major advantages of these systems are modular and flexible system design, simple and fast implementation, and powerful system diagnosis and maintenance utilities [3].

There are two general NCS configurations Direct and Hierarchical Structures. In Hierarchical Structure approach Fig. 1 the plant is controlled by its own remote controller at remote station.

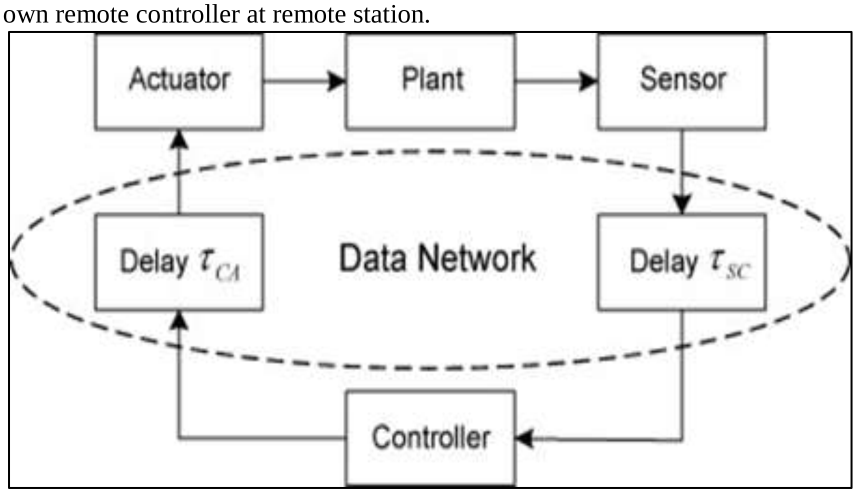

Fig. 1: Networked Control System Configuration.

The central controller provides the set point to the plant via remote controller and the sensor measurements of the system are sent from the remote station to central controller. The set points and sensor measurements are transmitted through network. This approach has a poor interaction between the central and remote unit because of not transmitting the control signal from central controller [12].

II. DELAYS IN NETWORKED CONTROL SYSTEM

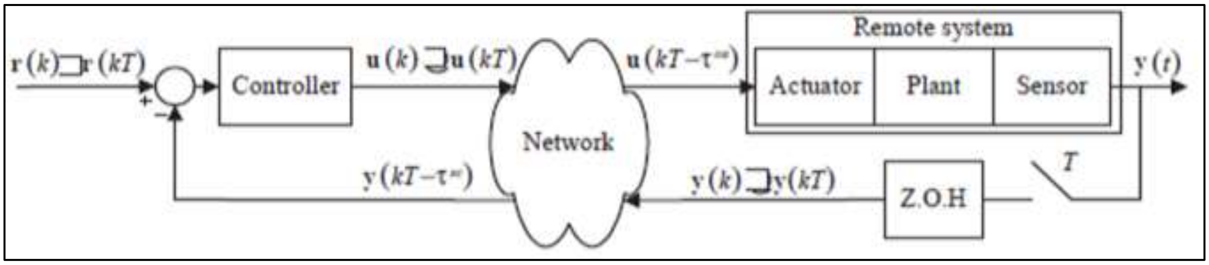

Fig. 2: General NCS Configuration and Network Delays for NCS Formulations

As the use of computer networks grows rapidly applications, such as networked control systems (NCS), have emerged. NCS suffer from varying time-delays that bring new problems to the control loop [3]. The problem is that the network induces varying time delays into the control loop, which have to be taken into account in the control design [2].

Fig. 2 shows network delays in the control loop, where **r** is the reference signal, **u** is the control signal, **y** is the output signal, k is the time index and T is the sampling period.

A. Delay Characteristics

The delay of data transmission between the units of NCS is one of the important problems of NCS .due to This delay some data packages spoiled or completely get lost. That is, the signals are weakened. The network – induced delay appears from two main parts as sensor-controller and controller-actuator. The control systems constructed without considering this delay have a low performance and Reliability.

B. Effects of Delays In-The-Loop

1) Performance degradation

Delays in a control loop are widely known to degrade system performances of a control system, so are the network delays in a Network Control System.

2) Destabilization

Delays in-the-loop including network delays in an NCS can destabilize the system by reducing the system stability margin. Depending on the technology used for making AVR.

The time delays in the NCS may deteriorate the system performance and cause the system instability. Therefore, it is necessary to design a controller which can compensate for the time delays and improve the control performance of the NCS. The main aim in NCS environment of the control system is to maintain Quality of Performance (QoP) of the control system irrespective of the delays in the network. The system should be enough strong to compensate the delay induced by the network.

III. PID CONTROLLERS IN NCS

The PID controllers have been successfully applied to many industrial control systems. The robustness of systems mainly depends on the Gain margin and phase margin. In this paper, the previous achievement is extended to the non-minimum phase plant containing an uncertain delay time with specifications in terms of gain and phase. The gain-phase margin tester method is used to test the stability bounder y in the parameter plane for any given gain or phase margin specifications.

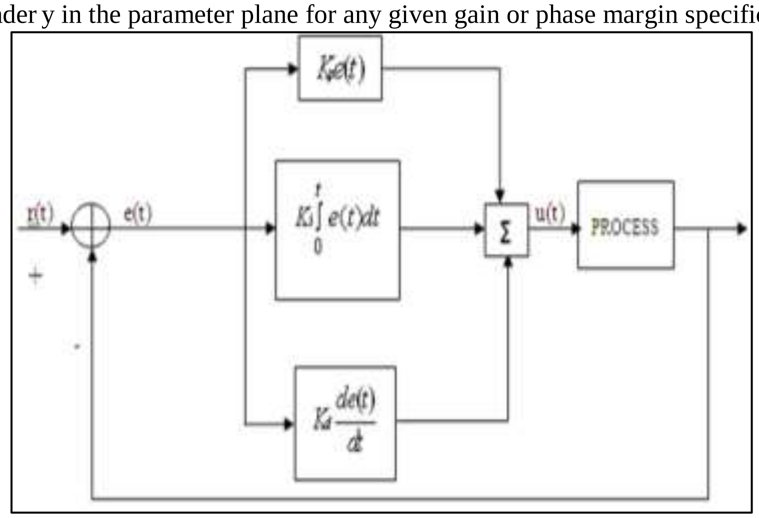

Fig. 3: Proportional- Integral Derivative (PID) Controller Block Diagram

PID control logic is widely used in the process control industry. PID controllers have traditionally been chosen by control system engineers due to their flexibility and reliability. P-I-D controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability. Fig. 3 shows the block diagram of an PID controller

PID controller equation is given by

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt}$$

Where K_p represents the proportional gain, K_i represents the integral gain, and K_d represents the derivative gain, respectively. By tuning these PID controller gains, the controller can provide control action designed for specific process requirements.

Various system performances resulting from the tuning of the adjustable parameters can be realized completely. PID controller with coefficients selected from the obtained parameter area stabilizes the non-minimum phase time delay systems with pre-specified safety margins. Especially when the delay time is uncertain, this method works well.

The objective in every PID controller is to find the optimal tuned parameter of K_p, K_i and K_d which together gives the best desired response of the process under concern. There are many tuning formulas like Cohen-Coon formula, Wang- Juang-Chen formula, formula can be used for tuning the PID controller gains. Ziegler-Nichols's step reaction curve method and closed loop cycling method are the two most popular tuning rules which are performed under proportional control around the nominal operating point.

IV. TUNING OF PID PARAMETERS

Tuning of a PID controller refers to the tuning of its various parameters (P, I and D) to achieve an optimized value of the desired response. The basic requirements of the output will be the stability, desired rise time, peak time and overshoot. Different processes have different requirements of these parameters which can be achieved by meaningful tuning of the PID parameters.

A. Ziegler–Nichols Rules for Tuning PID Controllers

There are two methods called Ziegler–Nichols tuning rules: the first method and the second method.

1) First Method

In this method we find experimentally the response of the plant for a unit-step input, as shown in Fig.4 If the plant involves neither integrator(s) nor dominant complex-conjugate poles, then such a unit-step response curve may look S-shaped, that S-shaped curve shown in Fig.5

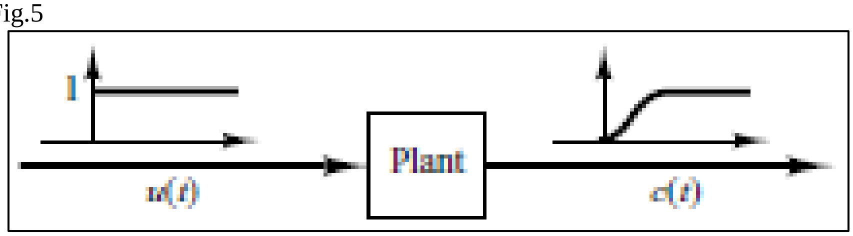

Fig. 4: Unit-Step Response of a Plant

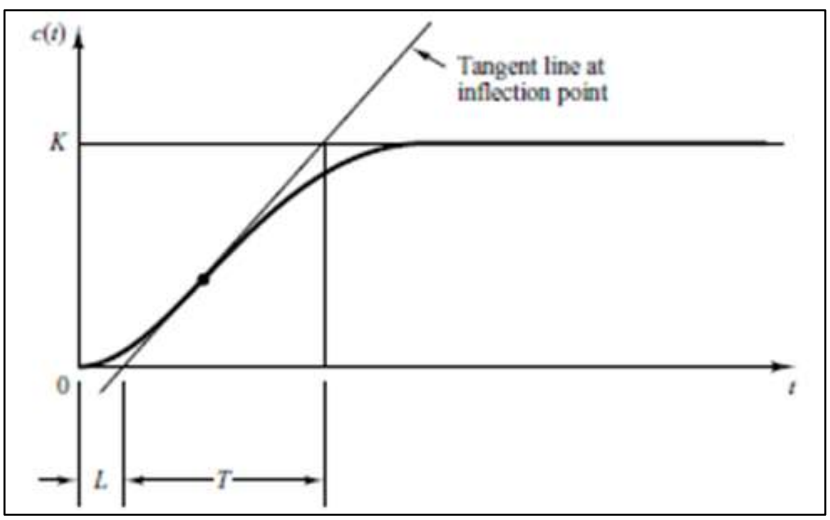

Fig. 5: S-Shaped Response Curve

The S-shaped curve characterized by two constants one is delay time L and another is time constant T. The transfer function C(s)/U(s) may then be approximated by a first-order system with a transport lag.

Table - 1
Ziegler–Nichols Tuning Rule Based On Step Response Of Plant

Type of Controller	K_p	K_i	K_d
P	$\frac{T}{L}$	∞	*0*
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	*0*
PID	$1.2\frac{T}{L}$	*2L*	*0.5L*

$$\frac{C(s)}{U(s)} = \frac{Ke^{-ts}}{Ts+1}$$

Ziegler and Nichols provided the set values of K_p, K_i and K_d according to the formula shown in Table 1
Notice that the PID controller tuned by the first method of Ziegler–Nichols rules Gives

$$G_c(s) = K_p(1 + \frac{1}{T_i s} + T_d s)$$
$$= 1.2\frac{T}{L}(1 + \frac{1}{2Ls} + 0.5Ls)$$
$$= 0.6T\frac{(s + \frac{1}{L})^2}{s}$$

Thus, the PID controller has a pole at the origin and double zeros at $s = -\frac{1}{L}$

2) *Second Method*

In this second method first we set $K_i = \infty$ and $K_d = 0$. Using the proportional control action only, increase K_p from 0 to a critical value K_{cr} at which the output first exhibits sustained oscillations. If the output does not exhibit sustained oscillations for whatever value K_p may take, then this method does not apply. Thus, the critical gain K_{cr} and the corresponding period P_{cr} are experimentally determined (shown Fig.6). Ziegler and Nichols suggested that we set the values of the parameters K_p, K_i and K_d according to the formula shown in Table 2

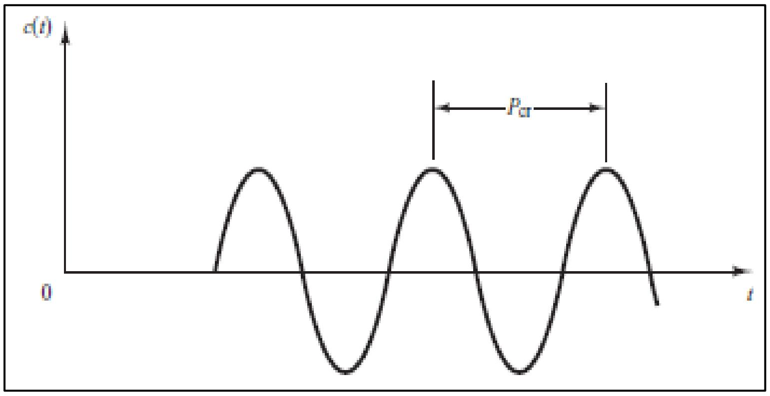

Fig. 6: Sustained Oscillation With Period P_{cr} (P_{cr} Is Measured In Sec.)

Table - 2
Ziegler–Nichols tuning rule based on critical gain K_{cr} and critical period P_{cr} (second method)

Type of Controller	K_p	K_i	K_d
P	$0.5K_{cr}$	∞	*0*
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	*0*
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

The PID controller tuned by the second method of Ziegler–Nichols rules gives :

$$G_c(s) = K_p(1 + \frac{1}{T_i s} + T_d s)$$
$$= 0.6K_{cr}(1 + \frac{1}{0.5P_{cr}s} + 0.125P_{cr}s)$$
$$= 0.075K_{cr}P_{cr}\frac{(s + \frac{4}{P_{cr}})^2}{s}$$

Thus, the PID controller has a pole at the origin and double zeros at $s = -\frac{4}{P_{cr}}$

Ziegler–Nichols tuning rules have been widely used to tune PID controllers to control different processes where the plant dynamics are not precisely known. Ziegler–Nichols tuning rules can be applied to plants whose dynamics are known [13].

V. SIMULATION RESULTS

Here we are designing a controller to deals with the instability introduce due to time delay for non- minimum phase system. The plant transfer function with time delay as shown below

$$plant\ transfer\ function = \frac{Ax}{s^3 + A_2 s^2 + A_1 s + A_0} e^{-Ts}$$

Where T is the time delay. By using second order approximation the time domain and frequency domain specifications are converted as interval gain margin and phase margin. Hence the PID controller connected in series with the plant to achieve the specification of $5\ dB \leq GM \leq 10\ dB$ and $30° \leq PM \leq 60°$.

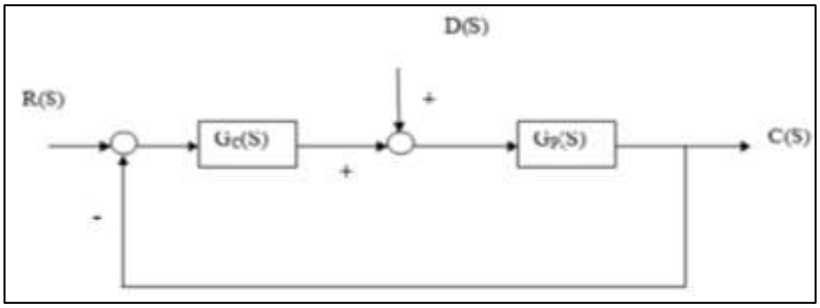

Fig. 7: Block Diagram Of A Typical PID Control System.

Fig 7 shows the typical PID controller. Where controller $G_C(s)$ connected in series with plant $G_P(s)$ and D(s) is external disturbance. An error-actuated PID controller has the general transfer function

$$G_C(s) = K_P + \frac{K_I}{s} + K_D s$$

The output is the simulation result obtained with the help of MATLAB at different plant conditions.

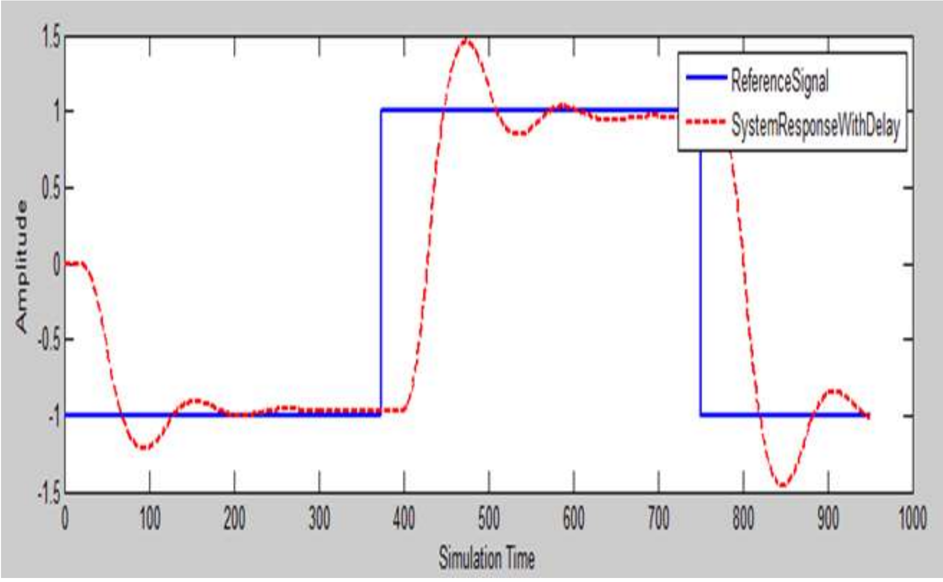

Fig. 8: System response with delay and absence of controller

Above figure shows the plant response with delay and absences of controller. It is clear from fig. 8 the system response lags in rise time as compare to reference signal and it has maximum overshoot.

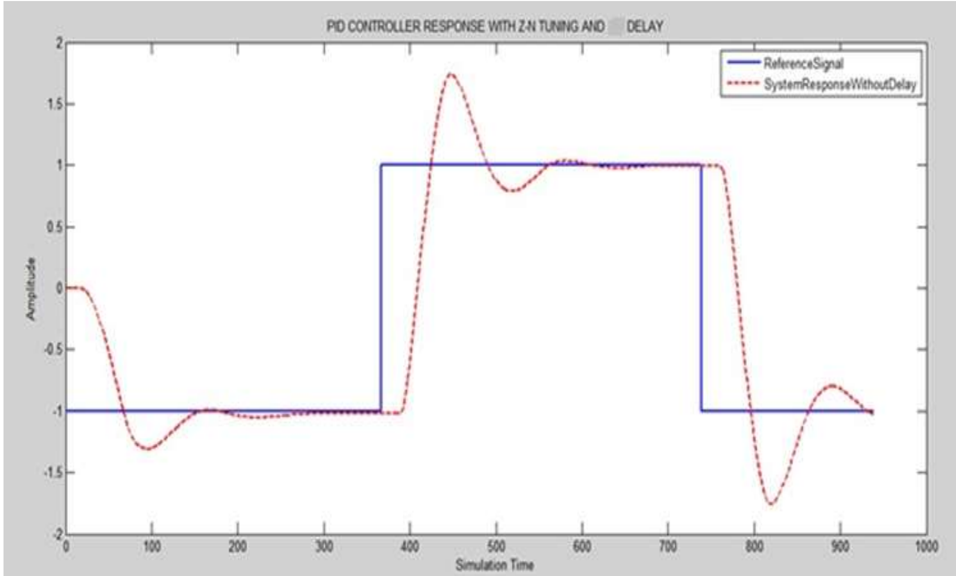

Fig. 9: System response with delay and in presence of PID controller

Above figure shows the system response with PID controller. It is clear from fig.9 the system response has improved rise time as compare to system without controller. From the figure it is clear that the amplitude of maximum peak, maximum overshoot is more than the 1.5.

The response of the system is more accurate if the value of PID parameter is closure to the stability boundary.

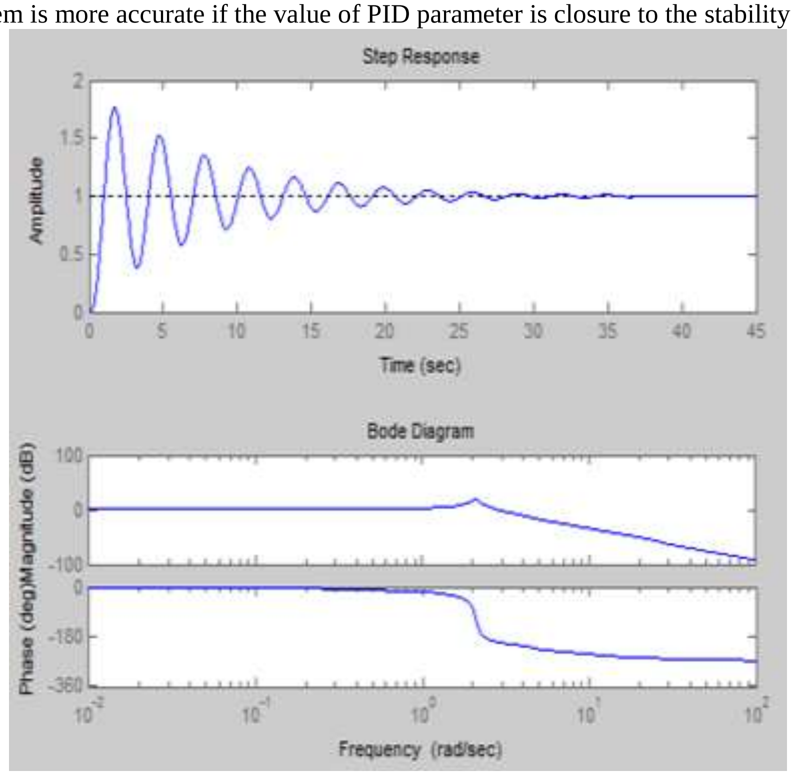

Fig. 10: (a) Output of PID Controller (b) Magnitude and (c) Phase Response at $K_p = 0.2$ and $K_I = 2$

This figure shows the system response in the case of $K_p = 0.2$ and Ki = 2. In this case system has maximum overshoot and settling time.

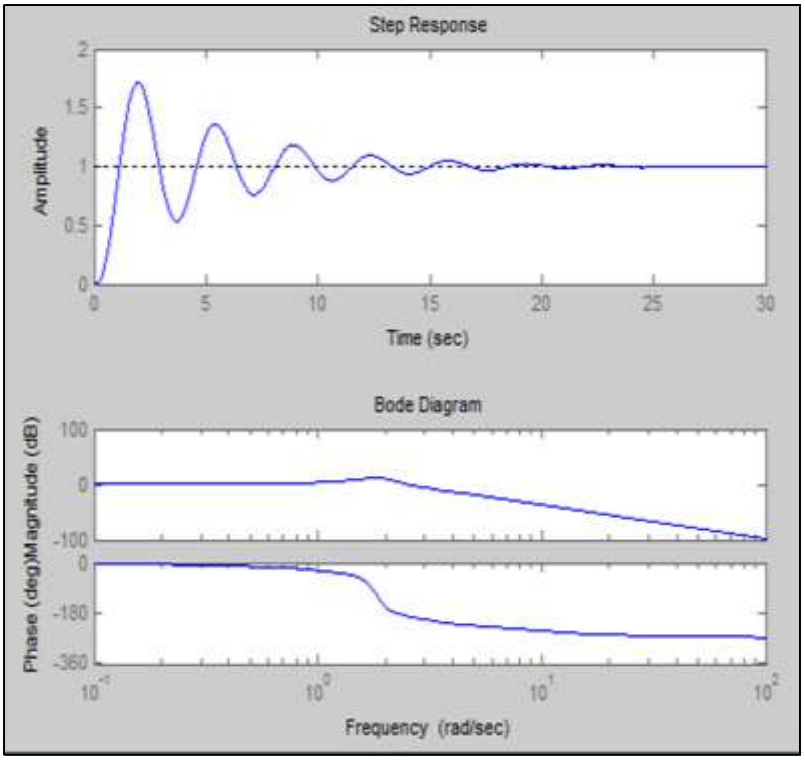

Fig. 11: (a) Output of PID Controller (b) Magnitude and (c) Phase Response at $K_p = 0.3$ and $K_i = 1.5$

This figure shows the system response in the case of $K_p = 0.3$ and $K_i = 1.5$. In this case system has moderate overshoot and lees settling time as compare to fig. 10.

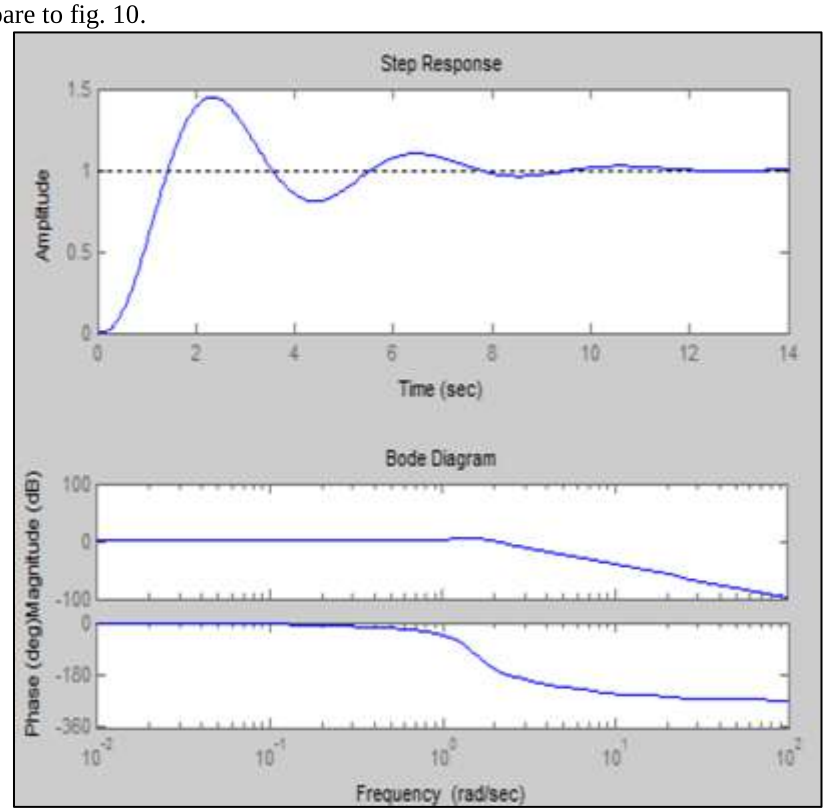

Fig. 12: (a) Output of PID Controller (b) Magnitude and (c) Phase Response at $K_p = 0.1$ and $K_i = 1$

This figure shows the system response in the case of $K_p = 0.1$ and $K_i = 1$. In this case system has moderate overshoot and less settling time as compare to figure 12

VI. CONCLUSION AND FUTURE SCOPE

P-I-D control and its variations are commonly used in the industries due to their high stability zero steady state error and improved rise and overshoot. The desired closed loop performances, such as fast response, zero steady state error and less overshoot are achieved through incorporation of P, I and D actions respectively. By using Ziegler – Nichols tuning method we implemented the robust PID controller. This makes the system performance satisfactory with delay.

But it is very difficult to reduce the effect of delay on the system performance. So this paper also opens up work to reduce the difficulties while using this robust PID controller. This paper also opens scope for designing of robust PID controller to control plant with uncertainty and delay for closed loop unity feedback system.

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