A DESIGN OF ROBUST PID CONTROLLER FOR NON-MINIMUM NETWORK CONTROL SYSTEM

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ABSTRACT

We have designed a robust PID controller for controlling the delay induced in the Network control system (NCS). A robust PID controller for a Non –Minimum phase system subjected to uncertain delay is presented here. The previous achievements are extended to the Non –Minimum phase plant containing an uncertain delay time with specifications in terms of gain and phase. Controller design to meet the gain phase margin specifications have been demonstrated in the literature [4, 6].Synthesis and analysis presented in this paper, is an extension procedure in [1, 3]. The paper presents optimization in tuning controllers for varying time delay system using simulation. .The simulation results show the effectiveness of this compensation method.

KEYWORDS: *Delays, Network control system, Non-minimum phase system Compensation, Gain margin and Phase margin.*

I. INTRODUCTION

The robust PID controller is the modified form of PID controller in which the parameters of system are tuned to compensate for instability induce by time delays for non-minimum phase system and endows the system with robust safety margins in terms of gain and phase.
According to modern control theory, the information (signals) are transmitted along perfect communication channels, which involve network communication. New controllers, algorithms and demonstration must be developed in which the basic input/output are data packets that may arrive at variable times not necessarily in orders and sometimes not at all. When PID controllers receive the sensor information or transmit its output through a communication network, its parameters are difficult to tune using classical tuning methods; this is due to the delays introduced by the network. This paper presents the Ziegler-Nichols closed loop cycling methods for tuning the various parameter of a system.
Gain and phase margin is one of the most suitable methods for making the system stable. In this paper previous achievement is extended to the plant containing uncertain delays [1, 3].Controller designed to meet the gain phase margin specification have been demonstrated in the literature[4-6].

II. NETWORK CONTROL SYSTEM

In point to point control system, where centralized computer systems are used for each sensors and actuators respective for control signal calculation, sensing and actuation required for closed loop control is shown in fig 1. Such scheme has drawbacks that it requires huge wiring connected from the sensors to computer and computer to actuators and moreover becomes complicated on requirement of reconfiguring the physical setup and functionality. Further, diagnosis and maintenance are also difficult in such systems.

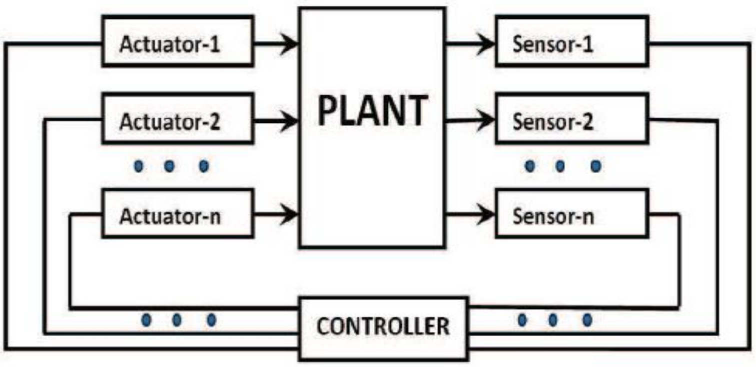


Figure 1. Point to Point Control Configuration

To overcome the above mentioned difficulties posed by the centralized system. Networked Control System (NCS) has received considerable attention with advances in control and communication technologies. When sensor and actuator data are transmitted over a network and the network nodes are used to work in tandem for completion of the controlling task, then we call such system as **Network Control System** (**NCS**). NCS uses a common bus for information exchange.Their sensors, actuators, estimator units, and control units are connected through communication networks as shown in fig 2. This type of system provides several advantages such as modular and flexible system design, simple and fast implementation, and powerful system diagnosis and maintenance utilities.

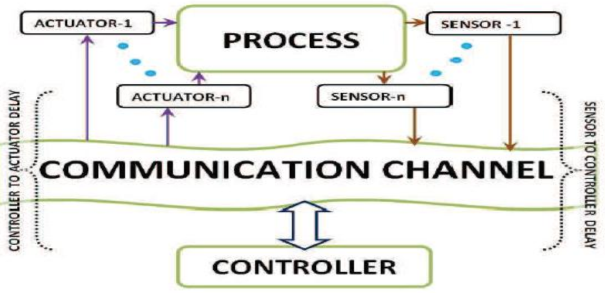


Figure 2. Network Control System

Fig (3) shows the timing diagram of delay in network control system. Delay in an NCS can be divided into different types on the basis of data transfers

i.e., i) sensor to controller delay. ii) Controller to actuator delay.

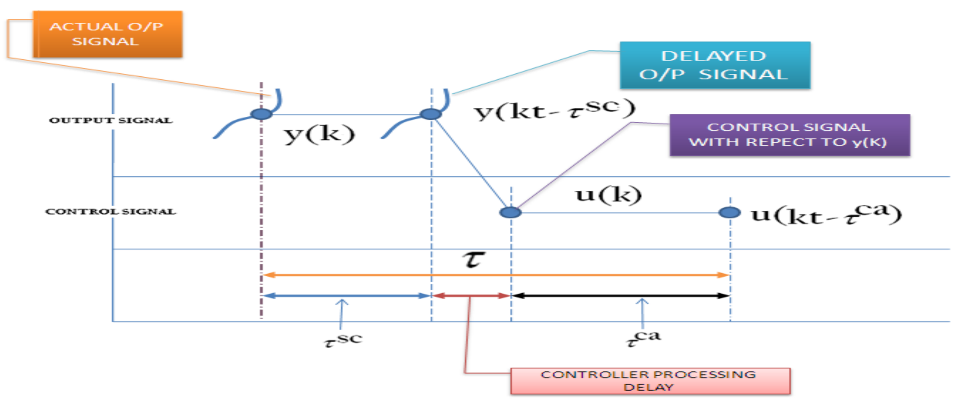


Figure 3. Timing diagram of Network delay propagations

III. PID CONTROLLER IN NCS

The PD controller could add damping to a system, but steady state response is not affected. The PI controller could improves the relative stability and improves the steady state error at the same time, but the rise time is increased .This leads to the motivation of using PID controller so that the best features of each of PI and PD controllers are utilized. The PID Control is one of the most popular control strategies for process control because of its simple control structure and easy tune .The transfer function of PID controller is

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

Where,

K_P = proportional gain constant,

K_I = Integral gain constant,

K_D = Derivative gain constant,

The PID controller is traditionally suitable for second and lower order systems. It can also be used for higher order plants with dominant second order behaviour[6]. In this paper we used Ziegler –Nichols closed loop cycling method and gain margin, phase margin tester methods for PID controller tuning.

Ziegler- Nichols closed loop cycling methods:

Procedure for tuning

1. Select proportional control alone.
2. Increase the value of the proportional gain until the point of instability is reached, the critical value of gain K_C is reached.
3. Measure the period of oscillation to obtain the critical time constant T_C.

Once the values for K_C and T_C are obtained, the PID parameters Can be calculated, according to the Design specification given in Table-1.

Table -1: Design specification

Control	K_P	K_I	K_D
P	0.5 K_C		
PI	0.45 K_C	1.2T_C	
PID	0.33 K_C	2 T_C	0.33 T_C

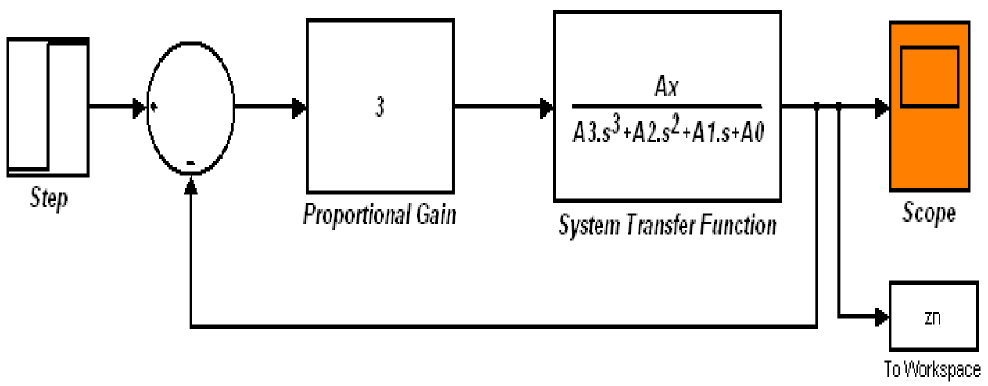


Figure4. Simulink Model for Z-N Tuning PID Controller

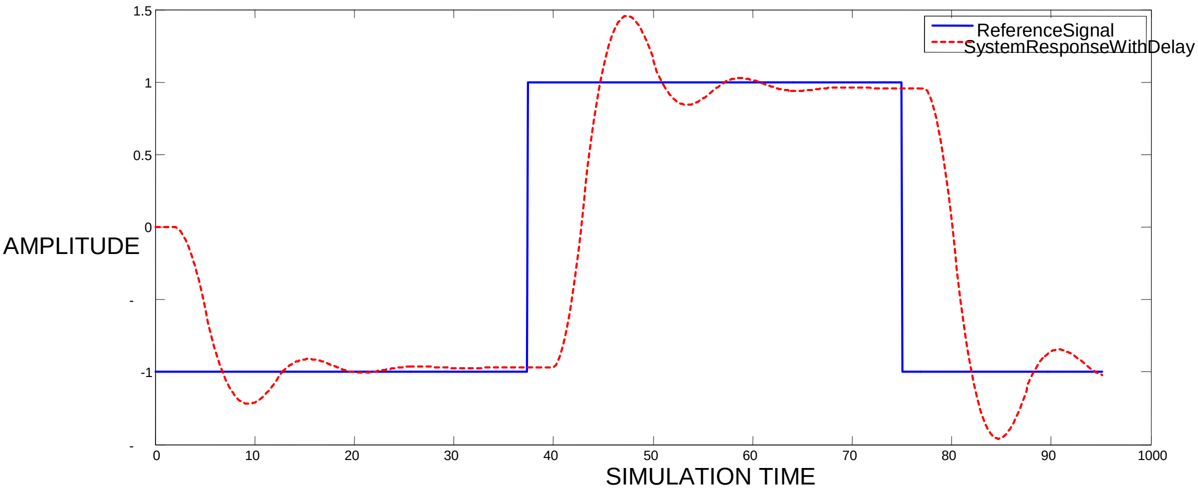


Figure 5. PID controller response with Z-N tuning and no delay

The PID Controller is suitable for second and lower order system and when delays is introduce in the system, performance of the system is degraded and also de-stabilized the system by reducing the system stability margin, thus a Robust PID Controller design is introduced in this paper for higher order non-minimum system which contains the time delay element

IV. A ROBUST PID CONTROLLER DESIGN

Whenever there is a delay between the commanded response and the start of the output response time delay occurs in the control system which decreases the phase margin and lowers the damping ratio and hence increases the oscillatory response for the closed loop system [12]. Time delay also decreases the gain margin, thus moves the system closer to the instability.

In this paper, suitable algorithms are introduced for the instability induced by the time delays. For a high -order non -minimum phase system which contains the time delay element, whose transfer function is as shown [10].

$$\text{Transfer function} = \frac{AX}{S^3 + A2S^2 + A1S + A0} e^{-Ts} \quad (1)$$

Where, T is the delay time of the system.

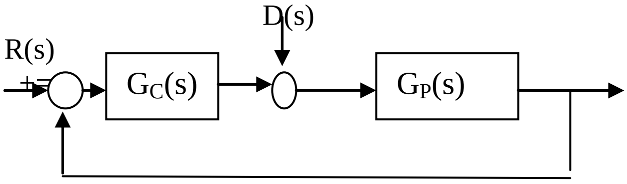


Figure 6. Block Diagram of a Typical PID Control System

An error-actuated PID controller has the general transfer function

$$G_C(s) = K_P + K_D S + \frac{Ki}{S} \quad (2)$$

The forward open-loop transfer function of the control system shown in Fig. 5 is

$$G_0(S) = G_C(S).G_P(S) = \frac{N(S)}{D(S)} \quad (3)$$

By letting $S=j\omega$, and Re $[G_0(j\omega)]$ and Imaginary $[G_0(j\omega)]$ be the real part and imaginary part of the $G_0(j\omega)$, respectively, one has

$$G_0(j\omega) = |G_0(j\omega)|e^{j\emptyset} \tag{4}$$

Where,

$$|G_0(j\omega)| = \sqrt{Real[G_0(j\omega)]^2 + Img[G_0(j\omega)]^2} \tag{5}$$

$$\emptyset = \tan^{-1}\left\{\frac{Img[G_0(j\omega)]}{Real[G_0(j\omega)]}\right\} \tag{6}$$

Substituting (4) and (3), one obtains

$$D(j\omega) - \frac{1}{|G_0(j\omega)|e^{j\emptyset}} N(j\omega) = 0 \tag{7}$$

Let

$$A = \frac{1}{G0(j\omega)} \tag{8}$$

$$\theta=\varphi+180. \tag{9}$$

When $\theta=0$, A is the gain margin of the system, and when $A=1$, θ is the corresponding phase margin. Now we define the gain-phase margin tester function as,

$$F(j\omega) = D(j\omega) + A^{-j\theta}N(j\omega) \tag{10}$$

(7), (8), (9) and (10) imply that the function $F(j\omega)$ should always be equal to zero. This indicates that the gain margin and the phase margin of the PID control system can be determined from the characteristic equation.

$$plant\ transfer\ function = \frac{Ax}{s^3 + A2s^2 + A1s + A0} \tag{11}$$

The open loop transfer function defined as =

$$\frac{k_p s + k_i + k_D s^2}{s} \times \frac{Ax}{s^3 + A2s^2 + A1s + A0} e^{-Ts} \tag{12}$$

putting s= $j\omega$ *and* Noting that $A^{-j\theta}$=$A\cos\theta$ - $jA\sin\theta$,

$$N(j\omega) = \left(k_p j\omega + k_i + k_d (j\omega)^2\right) \times Ax \times e^{-Tj\omega}$$
$$= Ax(\cos\omega T - j\sin\omega T) \times \left(jk_p\omega + k_i - k_d\omega^2\right) \tag{13}$$
$$= Ax[\cos\ \omega T(k_i - k_d\omega^2) + \sin\omega T(k_p\omega) + j\{\cos\ \omega T(k_p\omega) - \sin\ \omega T(k_i - k_d\omega^2)\}]$$

Let us define

$$X_N = \cos\ \omega T(k_i - k_d\omega^2) + \sin\omega T(k_p\omega)$$
$$\text{and } Y_N = \cos\ \omega T(k_p\omega) - \sin\ \omega T(k_i - k_d\omega^2) \tag{14}$$

$$Ae^{j\theta} N(j\omega) = (A\cos\theta - j A\sin\theta)(Ax X_N + jAx Y_N)$$
$$= Ax[(A\cos\theta X_N + A\sin\theta Y_N) + j(A\cos\theta Y_N - A\sin\theta X_N)] \tag{15}$$

$$D(j\omega) = j\omega((j\omega)^3 + A2(j\omega)^2 + A1\, j\omega + A0)$$
$$= \omega^4 - j\, A1\, \omega^4 - j(A2\, \omega^3 - A0\, \omega) \tag{16}$$

Let us define

$$X_D = (\omega^4 - A1\, \omega^2)\ and\ Y_D = (A2\, \omega^3 - A0\, \omega) \tag{17}$$

real parts: $(\omega^4 - A1\,\omega^2) + Ax\, A\cos\theta\{\cos\ \omega T(k_i - k_d\omega^2) + \sin\omega T(k_p\omega)\} +$
$Ax\, A\sin\theta\, \{\cos\omega T(k_p\omega) - \sin\omega T(k_i - k_d\omega^2)\}$ (18)

Define:-

$$B1 = (Ax\, A\cos\theta \times \sin\omega T \times \omega) + (Ax\, A\sin\theta \times \cos\omega T \times \omega)$$
$$= AxA\omega\sin(\theta + \omega T) \tag{19}$$

$$C1 = (Ax\,(A\cos\theta \times \cos\omega T) - (Ax\, A\sin\theta \times \sin\omega T)$$
$$= Ax\, A\cos(\theta + \omega T) \tag{20}$$

$$D1 = \omega^4 - A1\,\omega^2 - Ax\,A\cos\theta \times \cos T\,\omega^2 \times k_d + Ax\,A\sin\theta \times \sin\omega T \times \omega^2 k_d$$
$$= \omega^4 - A1\,\omega^2 - AxA\omega^2 k_d \cos(\theta + \omega T) \quad (21)$$

Then we can write from (10), (18), (19), (20), and (21) as

$$k_p B1 + k_i C1 + D1 = 0 \quad (22)$$

Imaginary parts: $(A2\,\omega^3 - A0\,\omega) + Ax(A\cos\theta[\cos\omega T(k_p\omega) - \sin\omega T(k_i - k_d\omega^2)] -$
$$(A\sin\theta[\cos\omega T(k_i - k_d\omega^2) + \sin\omega T(k_p\omega)]) \quad (23)$$

$$B2 = (Ax\,A\cos\theta \times \cos\omega T \times \omega) - (Ax\,A\sin\theta \times \sin\omega T \times \omega)$$
$$= AxA\omega\cos(\theta + \omega T) \quad (24)$$

$$C2 = (-Ax\,(A\cos\theta \times \sin\omega T) - (Ax\,A\sin\theta \times \cos\omega T)$$
$$= -Ax\,A\sin(\theta + \omega T) \quad (25)$$

$$D2 = -A2\,\omega^3 + A0) + Ax\,A\cos\theta \times \sin\omega T \times \omega^2 k_d + Ax\,A\cos\omega^2 k_d \quad (26)$$

Then we can write from (10), (23), (24), (25), and (26):-

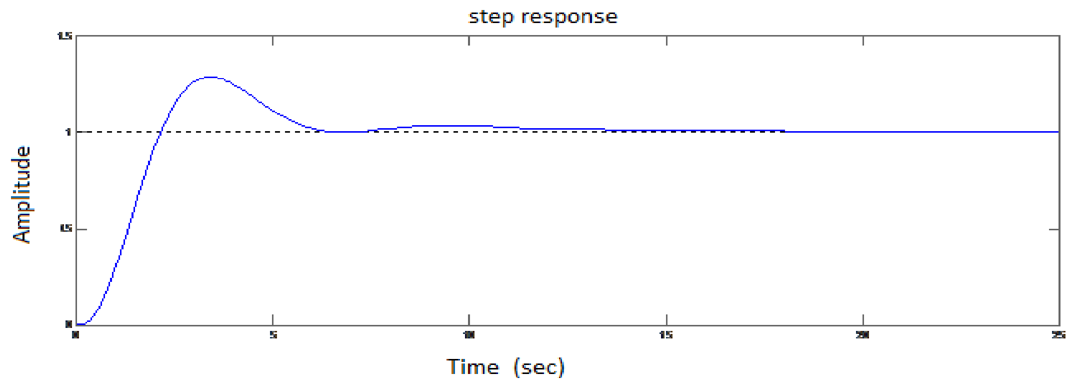
$$k_p B2 + k_i C2 + D2 = 0 \quad (27)$$

Solving the equations (22) and (27), we can find:-

$$k_p = \frac{C1 \times D2 - D1 \times C2}{B1 \times C2 - C1 \times B2} \quad \text{AND} \quad k_i = \frac{B2 \times D1 - B1 \times D2}{B1 \times C2 - C1 \times B2} \quad (28)$$

V. SIMULATION RESULTS

The simulation is carried out in MATLAB and SIMULINK. With the help of robust PID controller, system stability is achieved and the system with delay gets stable and gives high degree of performance as shown in fig (7)



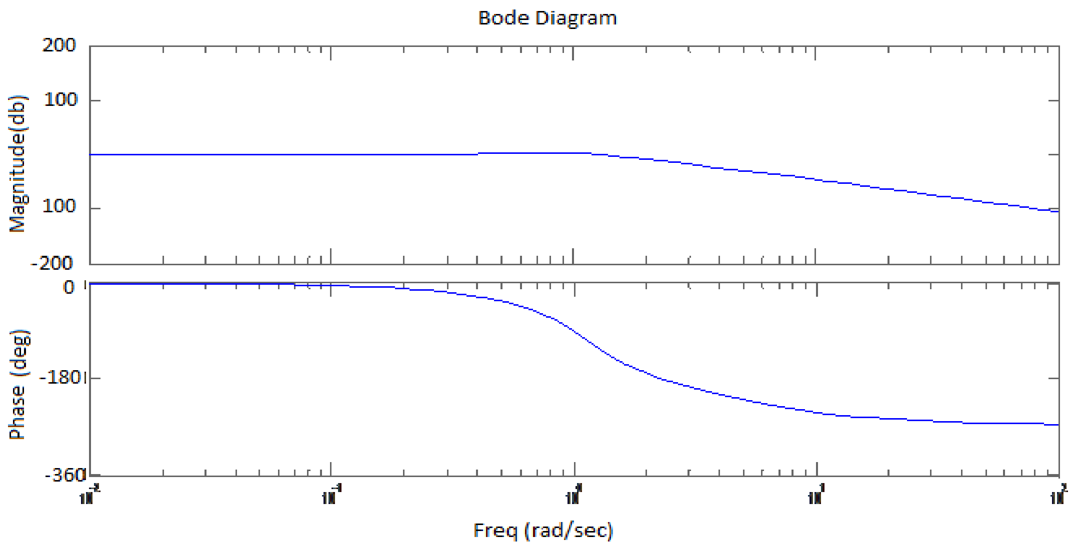


Figure7. Frequency and phase response of a system

VI. CONCLUSION AND FUTURE WORK

The robust PID controller designed in this paper presents straight forward technique for characterizing all admissible PID controllers in the parameters plane for the system with uncertain time delays .The advantage of this methods is the guaranteed robustness with respect to plant variations and external disturbances. It promises the control system with good tracking and disturbance rejection behaviour .This method of selecting PID controller settings can be applied to a wide range of industrial applications.

Further analysis of this will be the implementation of the hardware in loop simulation followed by real time implementation.

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