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A Robust PID Controller Design For Network Control System

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ABSTRACT- We propose a robust PID controller for controlling the delay induced in the Network control system (NCS) .With regard to the problems brought by the network induced delay in NCS, this paper design a robust PID controller to overcome the influence of network induce delays on control system performance by using gain phase margin method. The controller gains are directly selected from parameter region and a design controller can guarantee the system at least a pre-specified safety margin to compensate for instability induced by time delays. The paper presents optimization in tuning controllers for varying time delay system using simulation. The simulation results show the effectiveness of these compensation methods.

Index Terms—- Non-minimum phase system, network control system, delays Compensation, gain margin, phase margin, PID controller, Distributed system.

1. 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. Now a day there is a trend in the research of control theory to investigate control loop that are stretched over a network.

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2. DISTRIBUTED SYSTEM

In distributed systems the controller and the process are physically separated and connected with a network. Their sensors, actuators, estimator units, and control units are connected through communication networks. 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. The disadvantage is that the analysis and design of an distributed system becomes complex Distributed system is shown in fig.1.

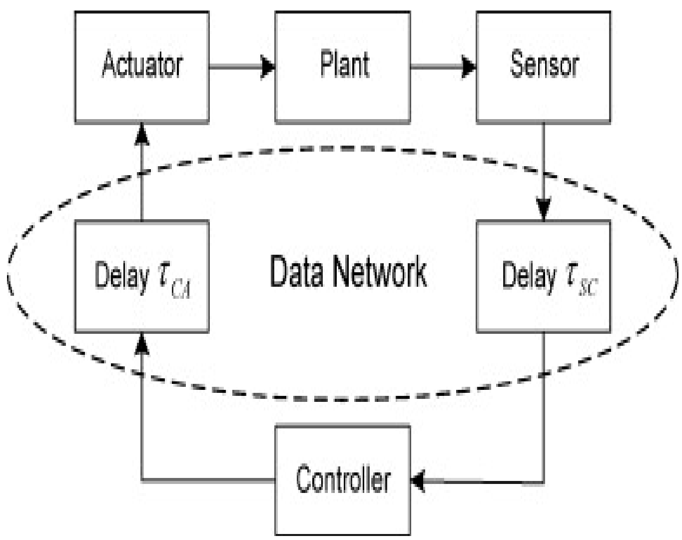


Figure 1. Distributed System

Fig (2) shows the timing diagram of network delay propagation. 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.

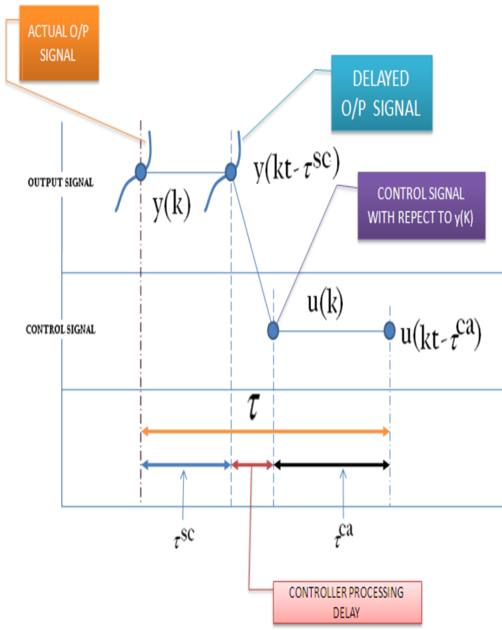


Figure2. Timing diagram of Network delay propagations

3. PID CONROLLER 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. 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

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

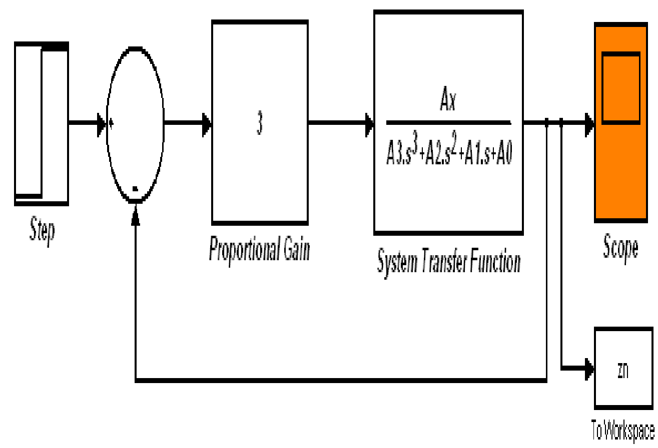


Figure3. Simulink Model for Z-N Tuning PID Controller

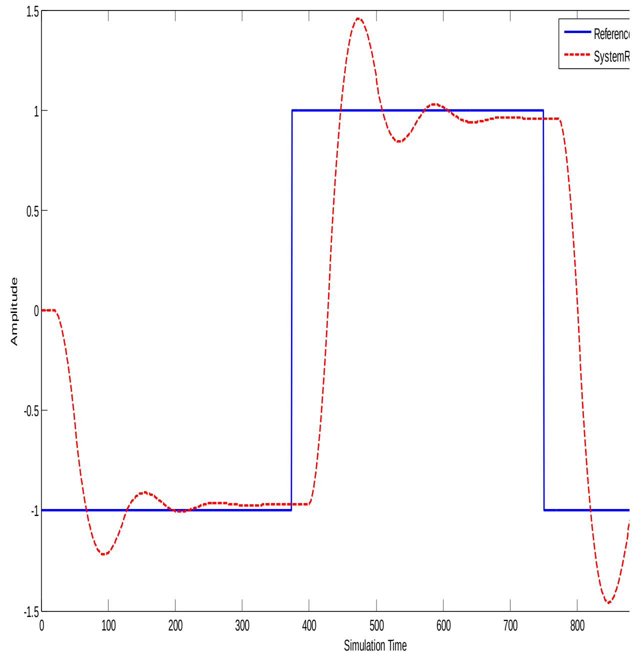


Figure 4. PID controller response with Z-N tuning and no delay

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

4. 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. 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.

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

Where, T is the delay time of the system.

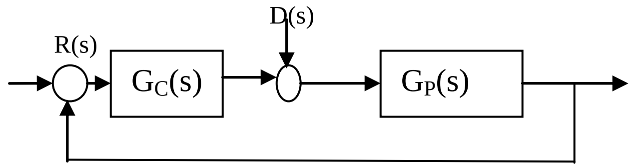


Figure 5. Block Diagram of a Typical PID Control System

An error-actuated PID controller has the general transfer function

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

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

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

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

Where,

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

$$\phi = \angle G_0(j\omega) = \tan^{-1}\left\{ \mathrm{Im}\left[G_0(j\omega)\right] / \mathrm{Re}\left[G_0(j\omega)\right] \right\}.$$
(6)

Substituting (4) and (3), one obtains

$$D(j\omega) - \frac{1}{|G_0(j\omega)| e^{j\phi}} N(j\omega) = 0.$$

(7)

Let

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

$$\theta = \varphi + 180.$$
(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,

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

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

The open loop transfer function defined as

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

putting s= $j\omega$ *and* Noting that $A^{-j\theta}$=Acos θ - jAsin θ,

$$N(j\omega) = (k_p j\omega + k_i + k_d (j\omega)^2) \times Ax \times e^{-Tj\omega}$$

$$= Ax(cos\omega T - jsin\omega T) \times (jk_p\omega + k_i - k_d\omega^2) \quad (13)$$

$$= Ax[\cos\ \omega T(k_i - k_d\omega^2) + \sin\omega T(k_p\omega) + j\{\cos\ \omega T(k_p\omega) - \sin\ \omega T(k_i - k_d\omega^2)\}]$$

Let us define

$$X_N = \cos\ \omega T(k_i - k_d\omega^2) + \sin\omega T(k_p\omega)$$

and $Y_N = \cos\ \omega T(k_p\omega) - \sin\ \omega T(k_i - k_d\omega^2)$ (14)

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

$$= Ax[(A\cos\theta\ X_N + A\sin\theta\ Y_N) + j(A\cos\theta\ Y_N - A\sin\theta\ X_N)] \quad (15)$$

$$D(j\omega) = j\omega((j\omega)^3 + A2(j\omega)^2 + A1\ j\omega + A0)$$

$$= \omega^4 - j\ A1\ \omega^4 - j(A2\ \omega^3 - A0\ \omega) \quad (16)$$

Let us define

$$X_D = (\omega^4 - A1\ \omega^2)\ and\ Y_D = (A2\ \omega^3 - A0\ \omega) \quad (17)$$

real parts:

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

Define:-

$$B1 = (Ax\ A\ cos\theta \times sin\ \omega T \times \omega) + (Ax\ A\ sin\theta \times cos\ \omega T \times \omega)$$

$$= AxA\omega\sin(\theta + \omega T) \quad (19)$$

$$C1 = (Ax\ (A\ cos\theta \times \cos\ \omega T) - (Ax\ A\ sin\theta \times sin\ \omega T)$$

$$= Ax\ A\cos(\theta + \omega T) \quad (20)$$

$$D1 = \omega^4 - A1\ \omega^2 - Ax\ A\ cos\theta \times \cos T\ \omega^2 \times k_d + Ax\ A\sin\theta \times \sin\omega T \times \omega^2\ k_d$$

$$= \omega^4 - A1\ \omega^2 - AxA\omega^2 k_d co\,s(\theta + \omega T) \quad (21)$$

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

k_pB1+k_iC1+D1=0
(22)

Imaginary parts:

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

B2= $(Ax\ A\ cos\theta \times cos\ \omega T \times \omega) - (Ax\ A\ sin\theta \times sin\ \omega T \times \omega)$

$$= AxA\omega\cos(\theta + \omega T)$$

(24)

C2=$(-Ax\ (A\ cos\theta \times \sin\ \omega T) - (Ax\ A\ sin\theta \times cos\ \omega T)$

$$= -Ax\ A\sin(\theta + \omega T)$$

(25) D2=$-\ A2\ \omega^3 + A0) + Ax\ Acos\theta \times sin\ \omega T \times \omega^2 k_d + Ax\ Acos\omega^2 k_d$ (26)

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

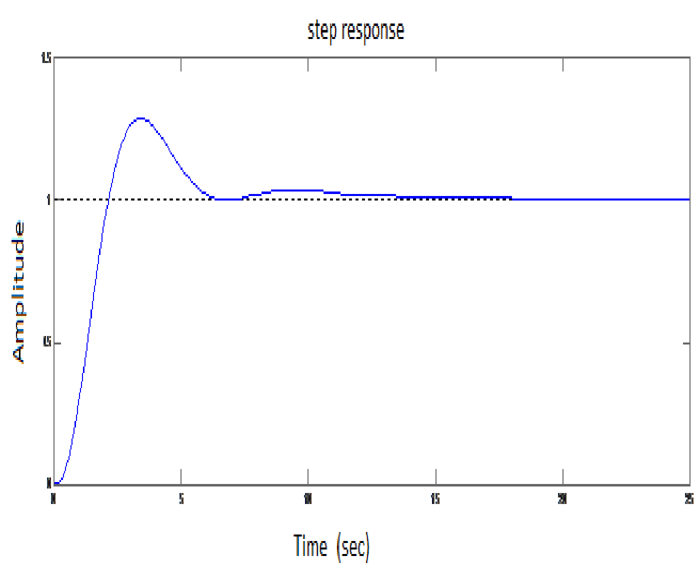
k_pB2+k_iC2+D2=0
(27)

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

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

5. 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 (6)



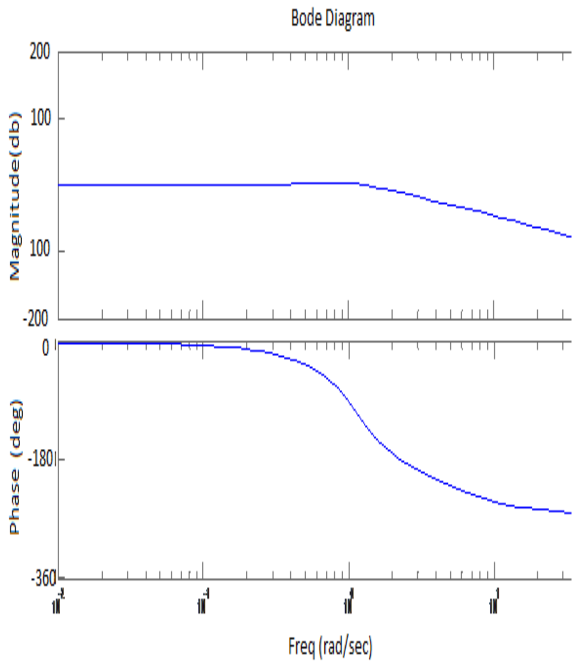


Figure6. Frequency and phase response of a system

6. CONCLUSION

The robust PID controller with certain variation in algorithms has made the system stabilized though various types of delays are present in the system. The advantage of this method is the guaranteed robustness with respect to plant variation and external disturbances. It promises the control system with good tracking and disturbance rejection behaviour. This method of achieving stability and good performance can be applied to the wide range of industrial applications.

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