Study of Compensation of Variable Delay in Communication Link using Communication Disturbance Observer (CDOB) and Network Disturbance (ND)

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Abstract— With growing technology, number of control system elements is increasing. So, it is not possible to place entire control system at a same place. Therefore, separate control elements connected by a communication link are required, it introduces delay. This delay is either constant or random in nature depending on communication link. This delay destabilizes the overall system and can be compensated using smith predictor. But smith predictor is only applicable to constant delay communication links. In this paper, communication disturbance observer (CDOB) and network disturbance (ND) have been introduced to compensate variable delay in communication link.

Key words: Time delay, stability, communication disturbance observer (CDOB), network disturbance (ND)

I. INTRODUCTION

When a traditional feedback control system is linked through a communication channel, which may be connected with other nodes outside the control system, then the control system is called as network control system (NCS) [1]. The study of NCSs is an interdisciplinary research area in which network and control theory both are connected. Networked control systems eliminate unnecessary wiring, reducing the complexity and the overall cost in designing and implementing the control systems. They can also be easily modified or upgraded by adding sensors, actuators and controllers to them with relatively low cost and no major changes in their structure. Moreover, featuring efficient sharing of data between the controllers, NCS is able to easily fuse global information to make intelligent decisions over large physical spaces.

Astrom, Hang, and Lim [2] suggested a Smith predictor for controlling process using integrator and long dead time. Wenshan, Guo-Ping Liu and Rees [3] introduced a model-based networked predictive control scheme based on round-trip time delay measurement rather than separate consideration of the feedback channel delay (between the sensor and controller) and the forward channel delay (between the controller and actuator), which successfully avoids the requirement of synchronization.

Sufficient emphasis has not been given on compensation of variable delay in communication link using communication disturbance observer (CDOB) and network disturbance (ND). Therefore, authors have attempted to introduce CDOB and ND for unstable system to make it stable.

II. SMITH PREDICTOR/ PROBLEM FORMULATION

Block diagram representation of control system having delay is given blow.

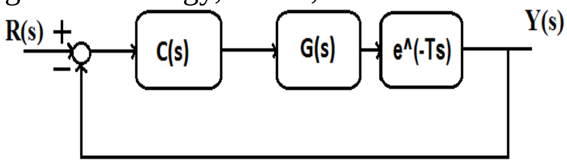

Fig. 1: block diagram of unit feedback control system with network induced delays (T)

Transfer function of above closed loop control system (CLCS) is

$$\frac{Y(S)}{R(s)} = \frac{C(s)G(s)e^{-Ts}}{1+C(s)G(s)e^{-Ts}} \quad (1)$$

Characteristic polynomial of system is

$$\Delta = 1 + C(s)G(s)e^{-Ts} \quad (2)$$

In the characteristic polynomial time delay element exists. This time delay element destabilized the overall system [4]. To compensate the time delay we utilize smith predictor.

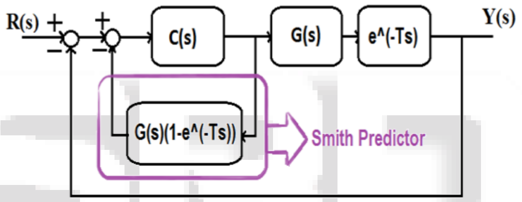

Fig. 2: Smith Predictor

As the smith predictor is applied to the system then close loop transfer function (CLTF)

$$\frac{Y(S)}{R(S)} = \frac{C(s)G(s)e^{-Ts}}{1+C(s)G(s)} \quad (3)$$

Characteristic polynomial of system with smith predictor

$$\Delta = 1 + C(s)G(s) \quad (4)$$

So in the new characteristic equation $\Delta(s) = 1 + C(s)G(s)$ there is no time delay element so effect of time delay is removed from system.

A. *Effectiveness of Smith Predictor When Time Delay T Is Not Constant With Time (T)*

In many cases time delay is random in nature. Let time delay $T_d = T + \Delta T$

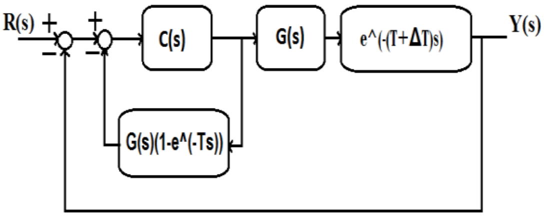

Fig. 3: Smith Predictor with variable time delay

$$\frac{Y(S)}{R(s)} = \frac{C(s)G(s)e^{-(T+\Delta T)s}}{1+C(s)G(s)+C(s)G(s)e^{-Ts}(e^{-\Delta Ts}-1)} \quad (5)$$

So characteristic equation

$$\Delta = 1 + C(s)G(s) + C(s)G(s)e^{-Ts}(e^{-\Delta Ts} - 1) \quad (6)$$

So we can see that time delay element still present in characteristic equation $\Delta(s) = 1 + C(s)G(s) + C(s)G(s)e^{-Ts}(e^{-\Delta Ts} - 1)$ after applying smith predictor.So smith predictor is not applicable to variable time delay system.

III. CONCEPT OF NETWORK DISTURBANCE (ND) AND COMMUNICATION DISTURBANCE OBSERVER (CDOB)

To compensate effect of time delay we use concept of network disturbance (ND) and communication disturbance observer (CDOB) [6]-[7].Effect of time delay is considered as disturbance in plant. So we can say that there is no time delay in close loop control system but network disturbance.

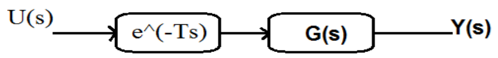

Fig. 4: plant with system induced delay

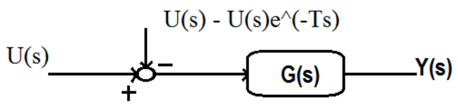

Fig 5: plant with no delay but network disturbance

To estimate ND we introduce CDOB. Design of CDOB is based on dynamic property of ND. CDOB evaluate both input signal of plant and output signal of plant and then generate network disturbance signal due to time delay. Network Disturbance (ND) only due to network delay in plant all other conditions are taken ideal. Design condition of compensator is based on dynamics of network disturbance.

A. *Design Condition*

Real part of CDOB pole (p_{CDOB}) should be smaller than real part of ND's pole (p_{nd})

$$\mathrm{Re}\,[p_{cdob}] < \mathrm{Re}\,[p_{nd}] \qquad (7)$$

Damping coefficient of CDOB (ζ_{CDOB}) should be smaller than that of ND (ζ_{ND})

$$\zeta_{CDOB} < \zeta_{ND} \qquad (8)$$

IV. SIMULATED RESULTS AND DISCUSSION

In this section to validate the design condition we use unstable close loop control system having finite system induced delay of 4 second along with applied delay compensation for this unstable system using MATLAB Simulink tool.

A. *Simulation without compensation*

Here we use sine wave as a command for close loop control system having 4 seconds delay in forward path.

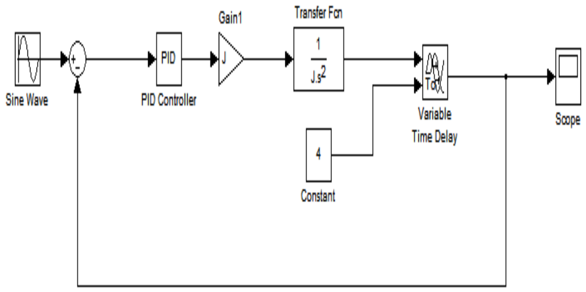

Fig 6: close loop control system with system induced delay 4 sec.

As the input of the system is sine wave so for bounded input bounded output (BIBO) Stability response of system must be sine wave but may be different amplitude and phase shift. For the above system, response for the sine wave command is given below-

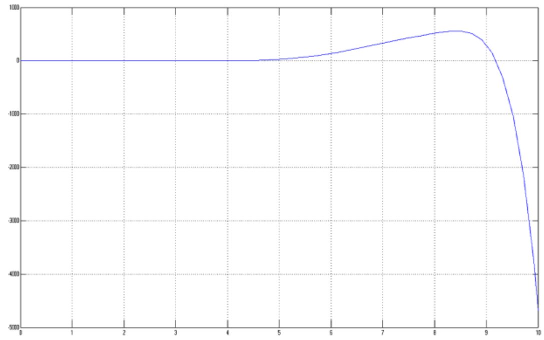

Fig 7: Response of the Uncompensated System

Due to existence of time delay overall system becomes unstable because output not follows the input so system is not bounded input bounded output (BIBO) stable.

B. *Simulation with compensation*

In this subsection we have shown block diagram of simulation of compensated CLCS.

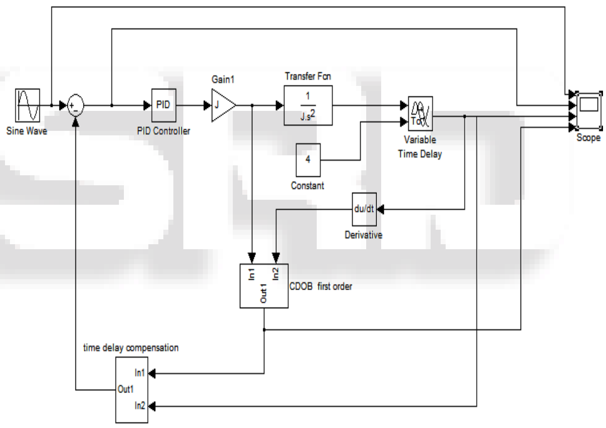

Fig 8: Block diagram of simulation of Compensated CLCS

Here we have applied communication disturbance observer (CDOB) to estimate network disturbance and then first order time delay compensation was applied. From our simulation, it is found that final response follow command signal and system becomes bounded input bounded output (BIBO) stable [5].

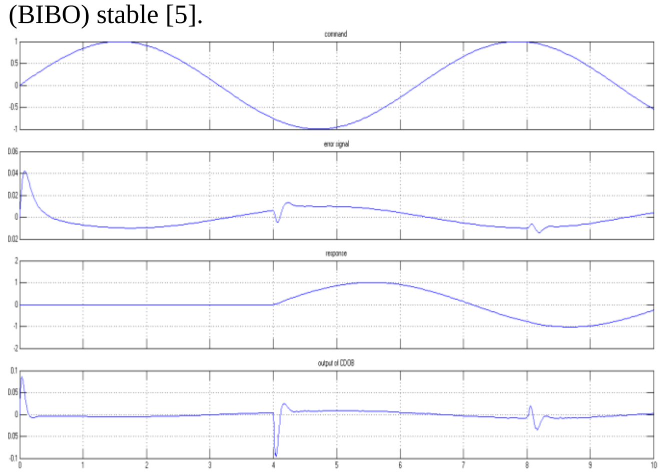

Fig. 9 simulated results of signal at different point of CLCS

It can easily be seen by fig.9 that -

- Minute phase shift between command signal and response signal
- Response signal is the magnitude scaled version of the command signal

So response follows command signal after 4 seconds and hence the system becomes stable.

In first simulation we introduce delay of 4 sec, due to this delay response of system is unstable and response does not follow the command. In second simulation we applied first order time delay compensation as a result the response doesn't grow exponentially with respect to time and follow the command signal after 4 sec.

V. CONCLUSIONS

In this paper we have shown, how time delay destabilizes the system but by applying appropriate compensation its effect can be rectified and the system can regain its stability. System's response is a replica of command signal with a time delay of 4 seconds. The effects of applying the compensator are given below-

- The compensator has removed the effect of variable time delay by a considerable amount.
- The reduction in effect of variable time delay causes a significant improvement in stability of the system due to which the system gives a satisfactory output after fixed time delay.

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