APPLICATION OF INTERNAL MODEL CONTROLLER FOR WIND TURBINE SYSTEM CONSIDERING TIME-DELAY ELEMENT

Faramarz Asharif, Shiro Tamaki, Tstomu Nagado
Faculty of Engineering, Ryukyu University, Okinawa, Japan

Nagata Tomokazu, Mohammad Reza Alsharif
Faculty of Engineering, Ryukyu University, Okinawa, Japan

Keywords: Internal Model Controller, Tele-Operation, H^2 norm, MIMO System, Wind Turbine.

Abstract: In this paper, we aim to modify the system which includes time-delay elements including closed loop system and uncertainty of the wind turbine system and time-delay elements. Time-delay will happen during the long distance communication. By observing and controlling the attitude of wind turbine system from distance, the transmitted control input and output signal will be delayed certainly. For this reason even thought wind turbine system is a stable system, but it will be an unstable system by time-delay elements. So, here we consider about the IMC method which is one of the robust controllers. IMC method is composed of optimum controller and uncertainty model of control object and time-delay elements. The optimum controller is designed by minimizing the coefficients of external disturbance of output signal by H^2 norm in order to stabilize the closed loop system considering the uncertainty of control object and predicted time-delay element and at the same time minimize the effects of time-delay element in sensitivity function. In this research controlling of the angular velocity and pitch angle of bale is considered. In order to have a stable angular velocity, we implied Internal Model Controller. As consequences, angular velocity converges to reference signal with good performance.

1 INTRODUCTION

In this research, we propose control of the time-delay system by using IMC (Internal Model Controller).There were many schemes and suggestions to consider about the designing controller for systems which including time-delay elements. For example the classical way is PID controller (Proportional, Integral Derivative). However, this scheme is not suitable for large time-delay. On the other hand, LQI (Linear Quadratic Integration) method which is modern way and it warranties the stability even for a large time-delay. However, for MIMO system, it is very difficult to construct a suitable controller due to existence of time-delay elements. Therefore, we consider IMC method to control the system including time-delay elements. Time-delay will happen during utilization of the long distance communication. The application of the long distance communication is an important issue in aerospace engineering. When we have a control object in the long distance, the transmitter's signal will be delay. Therefore the received signal at The control object will also be delayed. Moreover, the feedback signal to transmitter location will also be delayed. So, in this case, we have a round trip delay, one delay is to reach the control object and another delay is to receive the feedback signal for comparison with the reference signal. This comparison makes the error signal of the control system. This error must be decreased for a better controlling system. Moreover, control object will be unstable due to time-delay elements. Therefore, in this paper we consider the stability of control object and its uncertainty. Also, not only the uncertainty of control object, but also the uncertainty of time-delay elements which is estimated and approximated by using Pade approximation has been considered. IMC method is minimizing the coefficient of external disturbance of output signal by H^2 norm. Therefore, by this design problems of the system instability,

Asharif F., Tamaki S., Nagado T., Tomokazu N. and Reza Alsharif M..
APPLICATION OF INTERNAL MODEL CONTROLLER FOR WIND TURBINE SYSTEM CONSIDERING TIME-DELAY ELEMENT.
DOI: 10.5220/0003531601990202
In *Proceedings of the 8th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2011), pages 199-202
ISBN: 978-989-8425-74-4

uncertainty and external disturbance have been overcomes. Then, it can be solved by one of the robust controller such as IMC method.

2 THE BASIC THEORY OF TIME-DELAY SYSTEM AND BACK GORUND OF RESEARCH

As we express in introduction in this research, we have a round trip time-delay system which means one delay element to reach the control object and another delay element to feedback the output signal in order to compare with reference signal. Figure.1 shows the block diagram of a round trip time-delay system without controller.

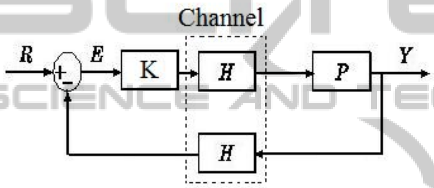

Figure 1: Conventional feedback control.

Here "Y","H","R","P" and "E" are the output signal of the system, time-delay element, reference signal, control object and error signal of the system, respectively. Through figure 1 it is clear that the sensitivity (S) and transfer function (T) are obtained as follows:

$$S = (I + PKH^2) \tag{1}$$

$$T = (I + PKH^2)^{-1} PKH \tag{2}$$

Generally, in feedback control system, by adding some controller such as "K" which is designed corresponding to control object, we can minimize the error signal. Therefore, in classical control usually PID controller and in modern control integrator operation and optimum gain such as LQI method are used. But, minimizing the error signal of the system is not enough. Also, we have to make the system stable if it is an unstable system. Especially, in this research, the system is unstable due to time-delay elements. As we expressed in the background of this research, we tried the classical control (PID Controller) and modern control (LQI method). As a result, for PID controller if time-delay is large, system could not preserve the stability. But for Modern scheme LQI method we could make the system stable without error. However, for high dimension and MIMO system we couldn't design the optimum controller because of complexity of solving the Ricatti equation. Therefore, in this research we propose the IMC method which is one of the robust controllers.

3 INTERNAL MODEL CONTROL FOR TIME-DELAY SYSTEM

Internal Model Controller is an optimum controller which minimizes the effect of disturbance to output signal and considers the uncertainty of control object. Also in this research we consider the existence of time-delay elements. Hence most of systems would be an unstable system due to time-delay elements. We suggest the IMC method to modify the stability of the system and compensate the output signal. The main reason that we suggest the IMC method is due to consideration of the uncertainty of control object and time-delay elements. The effects of disturbance to output signal are minimized and it can be correspondence to MIMO (Multi Input and Multi Output) and high dimension systems. In order to modify the unstable system due to time-delay elements, we have designed the internal model controller. Figure 2 shows the IMC system which "D" is external disturbance to output signal, "K" is Internal Model Controller, "P", "H" and "$\tilde{P}$", "$\tilde{H}$" are actual system, actual time-delay element and model system, approximated and predicted time-delay element, respectively.

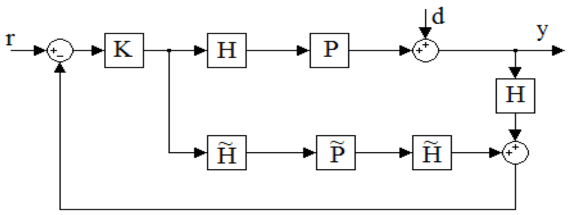

Figure 2: Internal Model Controller including a round trip time-delay elements and external disturbance.

Here through figure 2 the block diagram of IMC method, we obtained relation between output and reference signal as follows.

$$y = PHM^{-1}Kr + (I - PHM^{-1}KH)d \tag{3}$$

Where, $\Delta G = HPH - \tilde{H}\tilde{P}\tilde{H}$, $M = I + \Delta GK$

Since, in the above equation (3) external disturbance multiplied by " $I - PHM^{-1}KH$ " Which IMC method minimizes the effect of disturbance. As a result we consider the minimization of H^2 norm of this coefficient. Equation (4), below, shows how to derive "K" which is Internal Model Controller:

$$\min_K \left\| I - PHM^{-1}KH \right\|_2 \tag{4}$$

$$\frac{\partial}{\partial K}\sqrt{\frac{1}{2\pi}\int_{-\infty}^{\infty} Tr[(I - PHM^{-1}KH)^*(I - PHM^{-1}KH)]d\omega} = 0$$

$$\Rightarrow \frac{d}{d\omega}\left[\int\left[\frac{\partial}{\partial K}\sqrt{\frac{1}{2\pi}\int_{-\infty}^{\infty} Tr[(I - PHM^{-1}KH)^*(I - PHM^{-1}KH)]d\omega}\,\partial K\right]\right]^2$$

$$= \frac{d}{d\omega}\left[\int 0 \partial K\right]^2$$

$$\Rightarrow Tr[(I - PHM^{-1}KH)^*(I - PHM^{-1}KH)] = 0$$

$$\Rightarrow \left\| I - PHM^{-1}KH \right\| = 0 \Rightarrow I - PHM^{-1}KH = 0$$

$$K = \widetilde{P}^{-1}Q \tag{5}$$

Where, Q is stable and minimum phase filter with condition of $Q(0) = I$.

4 UNCERTAINTY OF CONTROL OBJECT AND TIME-DELAY ELEMENT

In this case of IMC, we use the model of control object and the actual control object which it is an unknown system. So, as it obtained through equation (4) when "K" is the inverse system of model, it is optimum case. Although in the case of internal model controller except the model system, it requires to realize the predicted time-delay element. Therefore, it has used the Pade approximation for " $\widetilde{L}$ " which it is approximated time-delay i.e. time-delay elements that it can be indicate as" $\widetilde{H}$ " has shown as follows:

$$\widetilde{H} = Pade\ (\widetilde{L}, n) = e^{-s\widetilde{L}} \approx \frac{\sum_{k=0}^{n} (-1)^k c_k \widetilde{L}^k s^k}{\sum_{k=0}^{n} c_k \widetilde{L}^k s^k} \tag{6}$$

Where, $c_k = \dfrac{(2n-k)!n!}{2n!k!(n-k)!}$ for $(k = 0.,1,2,...,n)$

Here we consider this approximated time-delay element as a transfer matrix.

$$\widetilde{H} = \left[\begin{array}{c|c} A_{\widetilde{H}} & B_{\widetilde{H}} \\ \hline C_{\widetilde{H}} & D_{\widetilde{H}} \end{array}\right] \tag{7}$$

But, remember that the dimension "n" of approximated matrix must be the same as control object dimension. The reason of this is that in the multiplication of two matrix systems, both of them are required to have the same dimension, theoretically. Because of approximated time-delay element is considered as a system matrix.

5 NUMERICAL ANALYSIS

For evaluating the IMC method we have select our plant as Wind Turbine System. In general, wind turbine is located in gale area in order to generate more energy. Therefore, observation and controlling the attitude of outputs of wind turbine is required from distance. Thus, in system there would be delay elements. The process of simulation is first to simulate the step response of closed loop system without controller then step response of disturbances and finally step response of system with IMC method for non-nominal case. Here, we assume that system has 2 seconds of delay for each time-delay element, forward delay and feedback delay. The linear system of WTS shown as follows:

$$P = \begin{bmatrix} P_\omega & P_{Interferen\,ce1} \\ P_{Interferen\,ce2} & P_\theta \end{bmatrix} = \begin{bmatrix} \frac{1}{16s+1} & \frac{1}{s+1} \\ \frac{1}{s+10} & \frac{1}{5s^2+10s+1} \end{bmatrix}$$

$$\widetilde{P} = \begin{bmatrix} \widetilde{P}_\omega & 0 \\ 0 & \widetilde{P}_\theta \end{bmatrix} = \begin{bmatrix} \frac{1}{20s+1} & 0 \\ 0 & \frac{1}{10s^2+2s+5} \end{bmatrix}$$

Actual Time-Delay Element: $H = e^{-2s} I_{2\times 2}$

Pade Approximation : $\widetilde{H} = Pade(2,2) I_{2\times 2}$

As it is clear for actual plant, it includes some interferences effects that is as the same as disturbances, due to plant is MIMO system. Hereby, the IMC proper filter set as follows:

$$Q = \begin{bmatrix} \frac{1}{s^2 + \Delta Ls + 1} & 0 \\ 0 & \frac{1}{s^2 + \Delta Ls + 1} \end{bmatrix}$$

Where, $\Delta L = \left| L - \widetilde{L} \right|$

Results

From figure 3 it is clear that interference effects the

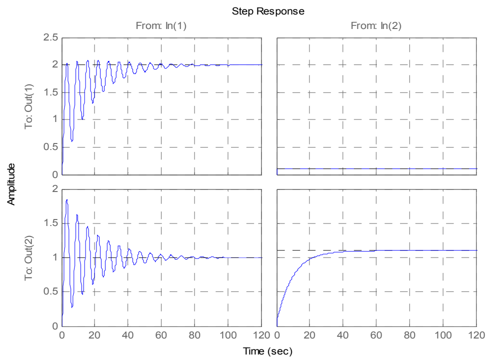

Figure 3: Step response without Controller.

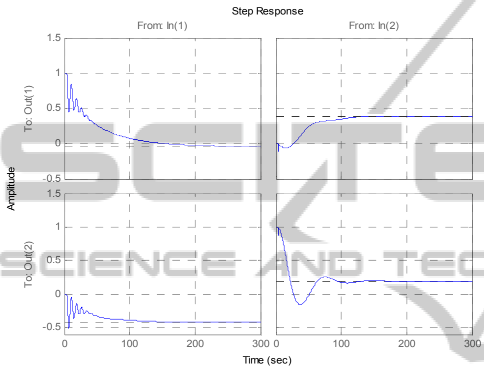

Figure 4: Step response of disturbance with Controller.

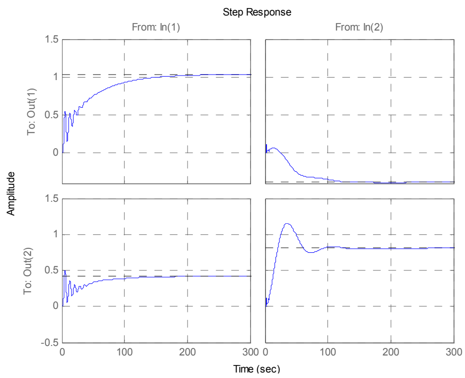

Figure 5: Step response of closed-loop with Controller.

output signal as the same as disturbances. This may cause the instability in closed loop system. Therefore, Internal Model Controller method is implied. Also the step response of disturbances is confirmed in figure 4 that it converges to zero. Figure 5, shows the step response of IMC. It is clear that even though the step response of closed-loop system contain with some effects of interferences, still it converges to reference signal. Also the effect of disturbances is almost cancelled. However, even though the closed-loop is stable but the performance of system is poor due to existence interferences and time-delay element. Therefore, for future works interferences cancelation and reduction of time-delay effects is required in order to improve the closed loop performances.

6 CONCLUSIONS

In this research internal model controller stabilize the closed-loop system including round trip delay. However, for proposed controller it considered the uncertainty of plant and approximated time-delay element. Therefore, even though system is non-nominal, internal model controller can be corresponded. For the system's performance it can be adjusted with proper filter and filter it's self automatically adjust the damping factor by ΔL which is uncertainty of time-delay, in other words the IMC proper filter is a semi-adaptive filter. However the demerit point of Internal Model Controller is for non-nominal case the performance of system is poor. Therefore, minimizing the uncertainty system ΔG is become one of the important issue. Also interference cancellation is required in order to realize better performance.

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