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PID 제어기를 이용한 확장 적분 제어

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Extended Integral Control with the PID Controller

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Abstract - This paper presents an extended integral control with the PID controller by introducing the delay and decaying factors. The convolution integral control scheme is developed by substituting proportional convolution integral controls for the proportional-integral control. So far, the integral part of the PI controller produces a signal that is proportional to the time integral of the input of the controller. The steady-state operation points are affected forever by the errors in the past due to the input signal containing the information of the errors in the past. These phenomina may cause some disturbances for other control purposes related to the given PI control. Introduction of forgetting factors of the error in the past can resolve the disturbance problems. Various forgetting factors are developed using the delay, the decaying factors, and the combination of the delay and the decaying factors. The proposed various extended integral control schemes can be applicable to corresponding PI control designs in which the error in the past may badly affect to the current steady-state operation points and may cause some disturbances for other control purposes.

1. 서 론

The PID(proportional-integral derivative) controller has been received a great deal of attentions in the process control areas because of its simplicity, robustness, and successful practical applications.[1,2] Its commercial applications are easily found in the process industries. In order to fulfill some industrial control requirements, various efforts of modifing PID controller and tuning of PID controllers have been directed to find an enhanced control performance for various process models[3,4,5,6,7,8]. An advantage of the PI control technique reduces the steady-state error to zero by feeding the errors in the past forward to the plant.

However, in some control problems, due to effects of the unnecessary errors in the past, the PI control scheme makes some disturbances in other control purposes. For example, in the LFC(Load Frequency Control) system of power systems, the integration of the error in the past remains forever affecting the steady state operation point after the system state has been settled down. These phenomina may disturb other control purposes such as AGC(Automatic Generation Control).

In order to overcome these difficulties, an extended integral control with the PID controller is developed by subsitituting proportional convolution integral controls for the PI control. The feeding signal to the plant in PI controller contains the information of the error in the past by the integration of the error. In the proposed scheme, the key idea is reducing the effects of the error in the past using the forgetting factors which is made by substituting the delays or the decaying factors for the integral term of PI controller. Delay makes the input signal include the integral of the errors for the essential time periods. With introduction of the decaying factor, the past error terms are forgetting exponentially. Both of the delay and the decaying factor can be employed to some control models. These convolution integral controls can be implemented in circuits or some microprocessors. The main objective of the proposed scheme is minimizing the disturbances for other control purposes using the forgetting factors which can reject or reduce the effects of the unnecessary errors in the past. The results of the simulation to an application are obtained by Runge-Kutta method and discribed in Application(2.2). The proposed convolution integral scheme can enhance the design of PID contorller after investigation of a targeted control systems.

2. 본 론

2.1 PI Control Involving Convolution Integration

PI(Proportional-Integral) controllers are widely used to improve steady-state error in several control problems such as chemical engineering process problems, the LFC problem of power systems, the automatic steering of ships and so on[4,5]. Generally, the implementation of PI controller consists of feeding the proportional error plus the integral of the error forward to the plant. As shown in Fig.1, the general form of PI controller consists of proportional (K) and Integral ($H(s)= K_I$

/s).

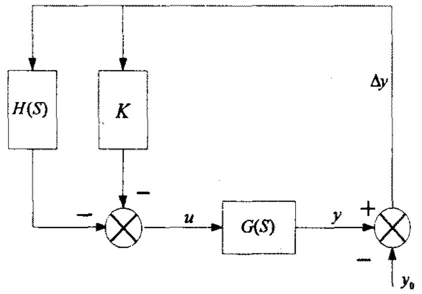


Fig. 1. Block diagram of general PI controller

The PI control technique perfectly reduces the steady-state error to zero. However, in some control problems, some disturbances result from the PI control are obstacles for other control purposes. Due to the feeding signal to the plant containing the unessential information of the errors in the past, the integration of those errors in the past affect badly continuously to the current steady-state operation points. For example, in the LFC system of power systems, the integration of the error in the past remains forever affecting the steady state operation points after the system state has been settled down. In other words, PI control causes some disturbances for AGC since the unessential information in the past badly affects to the current steady state operation points. For another example, in the speed control system for a steel rolling mill, the load on the rolls changes depending on the engaged bar in the rolls. It is obvious that the information of the change in speed resulted from the load disturbance in the past, should be ignored in the current steady state operation points. To do ignoring unnecessary information in the past, the convolution integration concept is proposed by substituting convolution integral for general integral term, H(s).

When gain K_I of the integration is set to a unit value, the well-known integral block is represented by H(s)=1/s and its transfer function in the time domain is as follows:

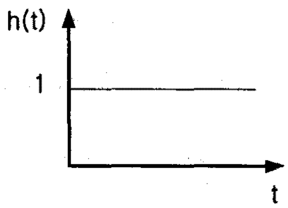


Fig.2. The representation of the integral block in the time domain

The feeding signal to the plant becomes

The feeding signal =

$$K\Delta y(s)+H(s)\Delta y(s)=h(t)*\Delta y(t)+K\Delta y(t) \ldots (1)$$

In the time domain, eq.(1) says that the feeding signal is the proportional of the current errors plus the integration of the error from the past(the initial time) to the current time. In order to reduce or reject the unnecessary information in the past, the integration term of the error in the feeding signal is modified by introducing the convolution integral concept.

In the convolution integral control scheme, h(t) , the inverse Laplace Transform of H(s), is chosen a convolution integral type among the following various convolution integral types:

$e^{-\lambda t}u(t)$

$u(t)-u(t-T)$

$u(t)-u(t-T)+e^{-\lambda(t-T)}u(t-T)$

The various convolution integral types are described the following graphical representation

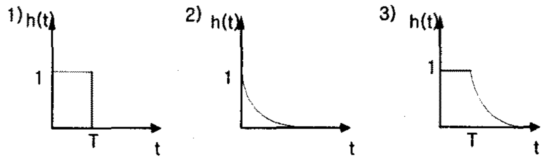


Fig. 3. The representation of the convolution integral block in the time domain

Let us investigate the improved input signal except the proportional error. The improved signal is made by the convolution of the error, $\Delta y(t)$, and one of the above three functions in Fig.3. The above three functions and the integral function are described in the time domain and the frequency domain as shown in Table 1. The best choice for the three convolution integral schemes can be made after investigating the characteristics of a targeted control system. The various convolution schemes of the Table 1 can be built in physical devices such as circuits or some micro-processors with the advancements of electronic circuits and signal processing technology.

Table 1. Realizable transfer function

h(t)	H(S)
$u(t)$	$\frac{1}{S}$
$u(t)-u(t-T)$	$\frac{1}{S}(1-e^{-sT})$
$e^{-\lambda t}u(t)$	$\frac{1}{S+\lambda}$
$u(t)-u(t-T)+e^{-\lambda(t-T)}u(t-T)$	$\frac{1}{S}(1-e^{-sT})$..

The improved input signal except the proportional error is given by

Input Signal=

$$H(s)\Delta\omega(s) = h(t) * \Delta\omega(t) = \int_{0-}^{t} \Delta\omega(t-\tau)h(\tau)d\tau \qquad \text{.......... (2)}$$

The equation (2) implies that the input signal forward to plant is made by the convolution of the error and the function h(t). In the case of h(t)=u(t)-u(t-T) where T is the time delay, the input signal includes the integral of the error for the essential time periods(T). Due to the time dely T, the input signal is not affected the error $\Delta y(t)$ after time period T. In the other hand, the errors of the unnecessary time periods(the information for T time periods previous to the current time)are rejected from the input signal. When h(t)is selected as $e^{-\lambda t}u(t)$, the past error terms are forgetting exponentially by decaying factor(λ). As the above both cases are combined, a delay and decaying factor can be considered as an improved input signal to the plant. That is $h(t)=u(t)-u(t-T)+e^{-\lambda(t-T)}u(t-T)$.

The proposed various convolution integral controls are applicable to some control problems in which effects of the error in the past disturb the other control purposes.

2.2 Application

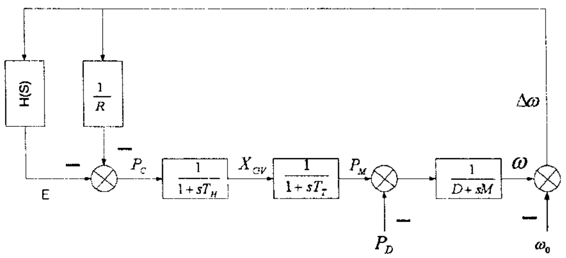


Fig. 4. Block diagram of general PI controller in the LFC of Power Systems

PI controller in the LFC system of power systems is adopted to simulate some examples and its block diagram is shown in Fig.4. In order to examine decaying factor(λ), delay(T) and the combination of decaying factor and delay, the block of H(S) is substituted by $\frac{1}{S+\lambda}$, $\frac{1}{S}(1-e^{-sT})$, $\frac{1}{S}(1-e^{-sT})+\frac{1}{S+\lambda}e^{-sT}$.

The parameters of the general PI control system are given in Table.2.

Table 2. The parameters of the PI controller in the LFC of power systems

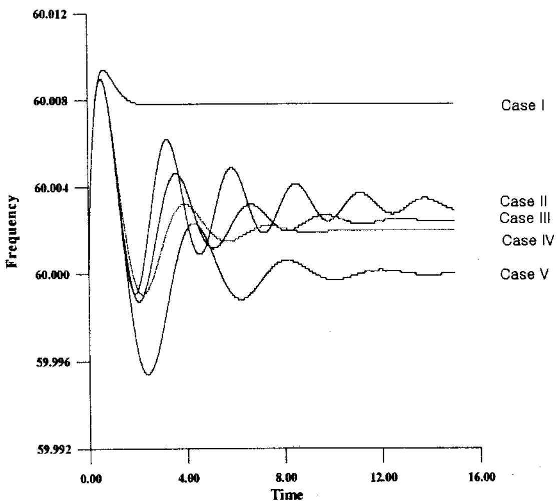
Parameter	Value
Inertia Constant H	6.175
Damping Factor D_{pu}	0.15
Frequency f_0	60
Decaying Factor λ	0.5
Governor Time Constant T_H	0.5
Turbine Time Constant T_T	0.3
Speed Regulation R	0.05

Note) $M = H/\pi f_0$, $D = D_{pu}/2\pi f_0$

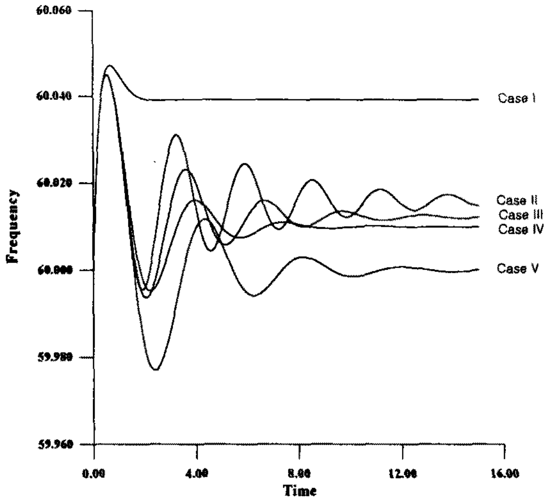
In the Fig. 5, the case I is the frequency response of the proportional control and the frequency response of the case II comes out from the convolution integral control involving the delay. The case III is the frequency response of the convolution integral control involving decaying factor and delay, the result of the case IV is considered the decaying factors only, and the case V shows the result of the conventional PI controller. The results of the simulation are obtained by Runge-Kutta method and summarized in Table 3.

Table 3. Design Example results

Controller	Percent overshoot	Steady-state error
Case I	0.01332	0.040
Case II	0.04832	0.016
Case III	0.05332	0.013
Case IV	0.05666	0.011
Case V	0.07500	0.0



a) P_D=-0.01



a) P_D=-0.05

Fig. 5. Frequency responses of five cases when disturbance PD=-0.01 and PD =-0.05.

As shown in Fig. 5(a), the PI control technique perfectly reduces the steady-state error to zero. In the LFC system of power systems, the integration of the error in the past remains forever affecting the steady state operation point after the system state has been settled down. These phenomina may disturb other control purposes such as AGC. It is obvious that the past error should be ignored in the integral of the error forward to the plant after enough time has passed. It is enough to consider the recent information to get the required engineering performance in the LFC. In order to get rid of effects of the past error to the current steady state, the extented integral scheme is proposed with its acceptable accuracy and fast settling time. Disturbances of AGC resulted from effects of the errors in past can be remarkably reduced.

One may first expect that the extended integral control shceme using the combination fo the delay and decaying factor would provide the better performance of the frequency response than Case II and Case IV. Unexpectly, the combined convolution integral scheme, the case III, is not enhanced in the accuracy of the steady-state error and settling time compared with the case IV since the delay term causes the oscillation. Investigation of the reasons of the oscillation caused from the delay remains for further researches.

3. 결 론

This paper presents an extended integral control with the PID controller by introducing the various forgetting factors which are the delay, the decaying factors, and the combination of the delay and the decaying factors. The extended integral control schemes are developed by substituting proportional convolution integral controls for the proportional-integral control. In the conventional PI control, the steady-state operation points are affected forever by the errors in the past due to the input signal containing the information of the errors in the past. These phenomena may cause some disturbances for other control purposes. The proposed various extended integral control scheme can be applicable to corresponding PI control designs in which the error in the past may badly affect to the current steady-state operation points and may cause some disturbances for other control purposes. The test results for the LFC of the power systems explain the reason why the proposed various extended integral controls can resolve the obstacles for other control purposes by introducing of forgetting factors of the errors in the past.

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