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미분 평균 궤환에 기초한 잡음 독립 PID 제어

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Noise-Free PID Control Based on Feedback of Averaged Derivative

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Abstract - This paper presents a new PID control scheme based on the feedback of averaged derivatives to realize a noise-free differential control. The PID(Proportional, Integral and Differential) control is still one of the control methods in most wide use. In the paper, the conventional PID control adopting filtering technique is analyzed with new interpretation of filtering function. In order to overcome the drawbacks of the conventional PID control, this paper introduces the feedback of averaged derivatives in the noisy environment, and suggests a new PID control scheme using delay components to realize a noise-free differential control. The proposed PID control yields good performance much similar to the original system response in case of no noises. The proposed control scheme has been tested for the load frequency control of power systems.

KEYWORD: PID control, noise-free differential control, averaged derivatives, delay components, load frequency control.

1. 서 론

This paper presents a new PID control scheme based on the feedback of averaged derivatives to realize a noise-free differential control. The PID(Proportional, Integral and Differential) control is still one of the control methods in most wide use in various fields of almost all industries such as chemical process control and mechanical position and/or speed control due to its simplicity in implementation. [1,2]

However, the noisy environment has made it difficult to adopt the differential feedback loop since the derivatives of the signals deteriorated by high frequency noise causes the system instability. That is, the derivatives of signals vary too fast for the control device to follow, and/or the output of differentiator produces so high values that the feedback signal must be cut off for most of time interval, which makes it almost impossible to achieve the successful effects of differential control. Therefore, it is a recent trend to use the PI(Proportional and Integral) control rather than the PID control in the noisy environment. [6,7,8]

On the other hand, it is obvious that the PID control can provide much better performance than the PI control if the noise problem solved in some manner. There have been many trials to use the filtering technique for the differential feedback loop in the less noisy environment. [9] A low-pass filter can be added to the differential feedback loop serially to solve the noise problem. [10] However, it may cause some other problems: i) If the filtering function is strengthened, it reduces the feedback effects of the differential signal, ii) Addition of the filtering block changes the system behavior itself, which may bring about the instability problem with feedback gain controls.

In the paper, the conventional PID control adopting filtering technique is analyzed with new interpretation of filtering function.

In order to overcome the drawbacks of the conventional PID control, this paper introduces the feedback of averaged derivatives in the noisy environment, and suggests a new PID control scheme using delay components to realize a noise-free differential control. The proposed PID control yields good performance much similar to the original system response in case of no noises. The proposed control scheme has been tested for several sample systems.

2. 본 론

2.1 Analysis of Conventional Differential Loop Adopting a filtering technique

The conventional PID control has great drawbacks in the noisy environment since the differentiator amplifies the high frequency noise, which may put excessive strain on the system and give bad influences on the control performance. Consequently, most of PID control schemes adopt filtering techniques. A typical PID control scheme adopting filtering techniques is given in Fig. 1.

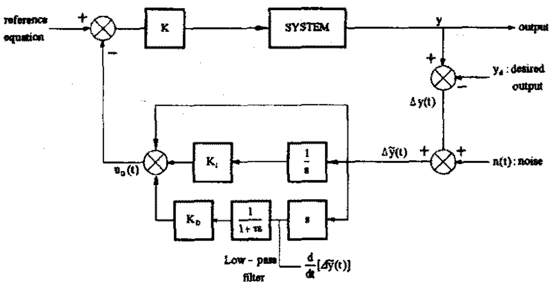
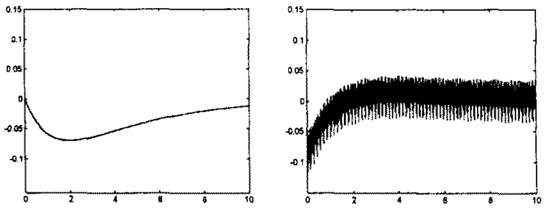


Figure 1. Conventional PID control scheme.

In case of the PID feedback signal where noise is included, noise is greatly amplified in magnitude by differential component and the input and the output signals of differential component are shown in Fig. 2.



(a)inputsignal (b)outputsignal

$(\Delta \tilde{y}(t))$ $\frac{d}{dt}\{[(\Delta \tilde{y}(t))]\}$

Figure 2. input and output signal of the derivative controller

In order to guarantee the least changes in the system behaviors due to the addition of block, a 1-st order low-pass filter is usually adopted for most of cases.

Here, we will consider the differential feedback loop. The total transfer function including the filter is given by

$$H_D(s)=\frac{K_D s}{1+\tau s} \quad (1)$$

where $||\tau|| \ll 1$

The obove transfer function can be rewritten as

$$H_D(s)=\frac{K_D\left[(s+\frac{1}{\tau})-\frac{1}{\tau}\right]}{1+\tau s} = \frac{K_D}{\tau}-\frac{K_D}{\tau}\left(\frac{1}{1+\tau s}\right) \quad (2)$$

In order to minimize the effects of the filter, the time constant envolved in the filter should be selected small. Since the selection of too small τ may result in insufficient filtering, the time constant τ is usually selected as the several time of the period of the lowest frequency noise. A new physical interpretation is possible by observing the time domain impulse response $h_D(t)$ correspondingly to $H_D(s)$. The impulse response $h_D(t)$ is given by

$$h_{D(t)}=\frac{K_D}{\tau}\delta(t)-\frac{K_D}{\tau^2}e^{-\frac{t}{\tau}}u(t) \quad (3)$$

where $\delta(t)$: Dirac delta function
$u(t)$: Unit step function

There, the differential feedback signal $u_D(t)$ is given by the following convolution integral.

$$u_D(t)=h_D(t)*\Delta y(t) = \frac{K_D}{\tau}\Delta y(t)-\frac{K_D}{\tau^2}\int_0^t e^{-\frac{(t-t')}{\tau}}\Delta\tilde{y}(t')dt' \quad (4)$$

where $\Delta\tilde{y}(t)=\Delta y(t)+n(t)$

From (4), one can realize that the differential feedback with a 1st- order filter provides merely the sum of two signals: one is a proportional signal and the other is to integrate the error with the forgetting factor $\lambda=1/\tau$. Therefore, the conventional differential feedback loop may not achieve successful differential control.

2.2 New PID Scheme

In the noisy environment, it is required to design a new type of PID controller to be free the noise effects. In order to solve the problem that the differentiator amplifies high frequency noises, this paper proposed a new PID control scheme adopting averaged derivative of the signal as the differential feedback signal in order to remove the effects of high frequency noises. The averaged derivative can be easily obtained by using delay elements as follows:

$$\left[\frac{d}{dt}f(t-\frac{T}{2})\right]_{ave}=\frac{1}{T}\int_{t-T}^{t}\frac{d}{dt}f(t)dt=\frac{1}{T}[f(t)-f(t-T)] \quad (5)$$

The LT(Laplace Transform) of the average derivative is given by

$$LT\left\{\left[\frac{d}{dt}f(t-\frac{T}{2})\right]_{ave}\right\}=\frac{1}{T}[1-e^{-sT}]F(s) \quad (6)$$

The average derivative can be easily implemented by using a delay element as follows:

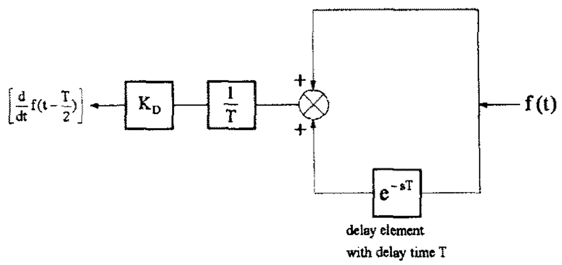


Fig. 3 Average Derivative Feedback Block

By taking sufficiently small T, we can obtain the average derivative that is close to the original derivative resulting from removing noise effects. Here, it should be noted that the delay time T should not exceed the smallest time constant of the system since large T causes large delay in the differential feedback.

Here, it is interesting to compare the two transfer functions for the differential loop by the proposed PID controller and the conventional filtered PID controller.

$$H_{D_{filt}}(s)=\frac{K_D s}{1+\tau s} = K_D s[1-\tau s-(\tau s)^2-(\tau s)^3-(\tau s)^4 - \cdots] \quad (7)$$

$$H_{D_{ave}}(s)=\frac{K_D}{T}(1-e^{-sT})$$

$$= \frac{K_D}{T}\left[Ts - \frac{1}{2!}(Ts)^2 - \frac{1}{3!}(Ts)^3 - \cdots\right] \quad (8)$$

Both of the transfer functions approach to $K_D(s)$ $T \to 0$. However, one can easily check that the transfer function (8) is much closer to $K_D s$ than (7) when τ and T are chosen to be same.

This means that the proposed PID control scheme mitigates the problem that the addition of filtering block changes the system behaviors especially in system stability associated with the feedback gain control.

2.3 Applications

For an example of practical field applications, we will consider the LFC(Load Frequency Control) problem in the power systems. Due to innumerable on-off switching operations in the customer side, the measurement of system frequency is usually deteriorated by noise. This noisy environment has lead power system engineers to prefer the PI control instead the PID control. However, Moon et al. shows that the application of PID control to the LFC provides much improved system damping [1,2]. A block diagram as shown in Fig. 4, in which the differential feedback loop has a simple differentiator, can represent the LFC system. By neglecting the effects of noise, we can perform stability analysis by examining the root locus of the system. Fig. 5 shows the root loci with increase in feedback gain K.

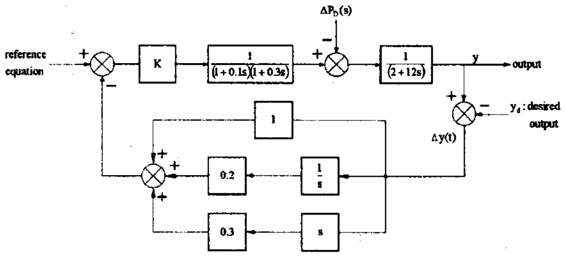


Fig. 4 System Block Diagram

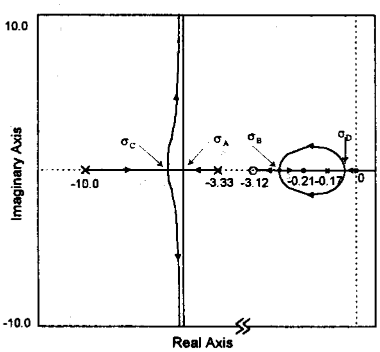


Fig. 5 Root Loci of the System

From the above root locus, it can be easily checked that the stability of the given system is perfectly guaranteed for all control range of the feedback gain K in the case where the system noise is negligible.[1,2]

In the noisy environment, the differential feedback loop should be replaced by the filtered differential loop or the proposed derivative feedback loop by using a delay element. Fig.7 shows the proposed PID control scheme using delay elements.

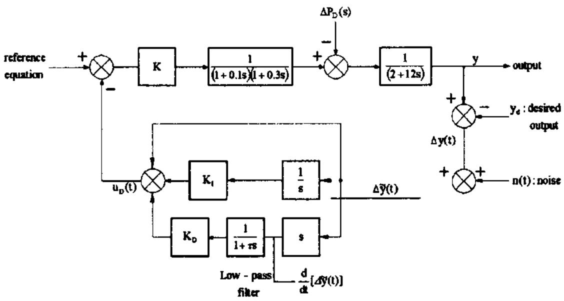


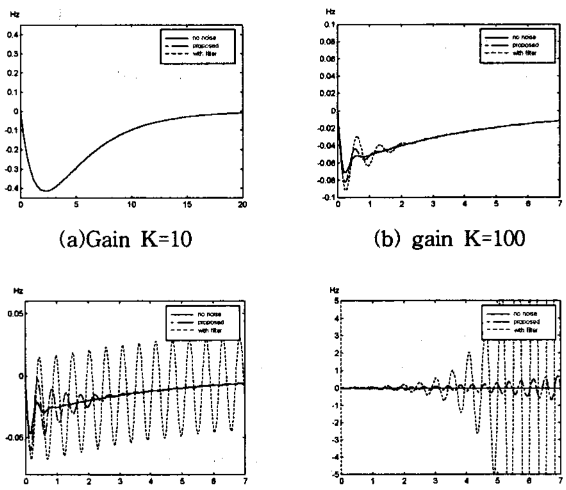
Fig. 6 Proposed PID control Scheme Using a Delay Element

In the above system, the delay time T is selected to be 0.1 sec.

In this study, we compare the outputs produced by three different systems: i) original PID control scheme neglecting the effects of noise as shown in Fig. 4, ii) proposed PID control scheme as shown in Fig. 6 and iii) conventional filtered-differential PID control scheme as shown in Fig. 1 with τ =. 0.1 sec.

The system disturbance is assumed to be a unit step disturbance of $P_D(t) = P_D u(t)$

The proposed system is tested with the use of various feedback gains of K. The outputs are compared with those by two other control schemes. The system performances have been examined by adjusting the feedback gain K from 10 to 300. The responses of frequency deviations are shown in Fig. 7. Fig. 8 shows outputs of differential circuits, i.e. the output of the differentiator, its filtered output and the output of averaged derivative.

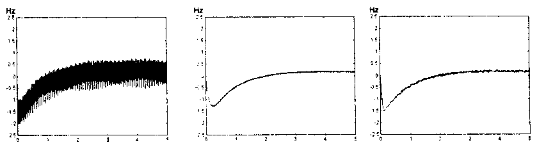


(a)Gain K=10 (b) gain K=100

(c)Gain K=200 (d) gain K=300

Legend no noise: Original PID control with no filter in case of any noise

Proposed: Averaged PID controls using a delay element
With filter: Conventional PID control with a 1st order filter
Fig. 7 Comparing the outputs of the three systems



(a) output of differentiator with noise (b) filtered derivative (c) averaged derivative
Fig. 8 Outputs of Differential Circuits with K=10

In case of K=10, the three PID control schemes produce almost same results as shown in Fig. 7 (a). However, the system response is not fast enough.

In case of K=100, the simulation results are shown in Fig. 7 (b), from which it can be directly checked that the proposed control scheme produces much better results than the conventional filtered PID control scheme. The system response is also much faster than that in case of K=10. Here, it is also noted that the proposed controller yields the outputs much closer to the output of the original PID control neglecting the noise effects. This demonstrates that the purpose of noise-free control can be well achieved by the proposed PID control using a delay element.

Fig. 7 (c) shows that the filter augmented to the differentiator may change the system behaviors with the increase in K as mentioned earlier. However, the proposed control scheme changes the system behaviors much less to remain in the stable condition.

In case of K=300, both of the proposed and the conventional filtered control schemes make the system unstable due to the too high feedback gain. On the other hand, it can be confirmed that the original control guarantees the system stability regardless of gain K when the noise effects are neglected, which is just the same as discussed earlier with use of the root locus.

3. 결　론

This paper presents a new PID control scheme based on the feedback of averaged derivatives to realize a noise-free differential control. The PID(Proportional, Integral and Differential) control is still one of the control methods in most wide use. In the paper, the conventional PID control adopting filtering technique is analyzed with new interpretation of filtering function. In order to overcome the drawbacks of the conventional PID control, this paper introduces the feedback of averaged derivatives in the noisy environment, and suggests a new PID control scheme using delay components to realize a noise-free differential control. The proposed control scheme has been tested for the load frequency control of power systems. The test results show that the proposed controller yields the outputs much closer to the output of the original PID control neglecting noise effects. This demonstrates that the purpose of noise-free control is achieved by the proposed PID control using a delay element.

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