ELSEVIER

Electrical Power and Energy Systems 24 (2002) 263–269

ELECTRICAL POWER & ENERGY SYSTEMS

www.elsevier.com/locate/ijepes

Extended integral control for load frequency control with the consideration of generation-rate constraints

Young-Hyun Moon[a,*], Heon-Su Ryu[a], Jong-Gi Lee[a], Kyung-Bin Song[b], Myong-Chul Shin[c]

[a]*Department of Electrical Engineering, Yonsei University, Shinchon-Dong, Seodaemoon-gu, Seoul 120-749, South Korea*
[b]*Department of Electronic Engineering, Keimyung University, Dalseogu, Taegu 704-701, South Korea*
[c]*Department of Electrical and Computer Engineering, SungKyunKwan University, Suwon 440-746, South Korea*

Received 30 October 2000; revised 28 February 2001; accepted 2 April 2001

Abstract

This paper presents an extended integral control to load frequency control (LFC) scheme with the presence of generation rate constraints (GRC) in order to get rid of overshoot of the conventional proportional-integral (PI) control. The conventional LFC scheme does not yield adequate control performance with the consideration of the singularities of speed-governor such as rate limits on valve position and GRC. In order to overcome this drawback, an extended integral control is developed for the PI control of the speed governor in the presence of GRC. The key idea of the extended integral control is using a decaying factor to reduce the effects of the error in the past. The decaying factor greatly affects the control performance, and should be carefully selected. This study determines the decaying factor in proportion to the degree of deviation in several levels. The computer simulation has been conducted for the single machine system with various load changes. The simulation results show that the proposed controller based on extended integral control yields much improved control performance, compared to the conventional PI controller. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Extended integral control; LFC; GRC; Decaying factor; Speed-governor

1. Introduction

The proportional-integral (PI) controller has been received a great deal of attentions in the process control areas [4,5]. An advantage of the PI controller reduces the steady-state error to zero by feeding the errors in the past forward to the plant.

In power systems, the PI control technique is applied to speed-governor system for load frequency control (LFC) scheme [6,7,8]. However, the inherent singular characteristics of speed-governor system have a great influence on LFC behavior, which makes it more difficult to maintain the required frequency accuracy. It is well known that the conventional LFC scheme does not yield adequate control performance with consideration of the singularities of speed-governor such as rate limits on valve position and GRC. The speed-governor system should be operated within the restricted control range of feedback gains due to the system instability. Moreover, in the deregulated environments, frequent on–off controls of large capacity units may bring about large amount of power disturbances, which has not been experienced before. This requires the modification of the conventional LFC scheme. In order to take these singular characteristics into consideration, Pan and Liew [9] proposed a load frequency controller consisting of an adaptive controller. The controller provided good performance except with GRC. Wang et al. [10] proposed a robust load frequency controller in the presence of GRC. Since the power system is assumed to be exposed to small changes in load, the controller is difficult to guarantee the stability for the wide range of disturbance. Moon et al. [1–3] have suggested a new LFC scheme adopting a modified PID control based on optimal tracking approach. However, in all kinds of PI controls, the integration of the error in the past remains forever affecting the steady-state operation point after the system state has been settled down. Due to effects of the unnecessary errors in the past, the PI control scheme makes some disturbances in other control purposes such as automatic generation control (AGC).

This paper develops an extended integral control to LFC scheme with the presence of GRC in order to get rid of overshoot of the conventional PI control. The proposed controller yields adequate control performance even with large changes in load. The key idea of the extended integral

* Corresponding author. Tel.: +82-2-2123-2771; fax: +82-2-312-7735.
E-mail addresses: moon@yonsei.ac.kr (Y.-H. Moon), kbsong@kmu.ac.kr (K.-B. Song), mcshin@yurim.skku.ac.kr (M.-C. Shin).

PII: S0142-0615(01)00036-9

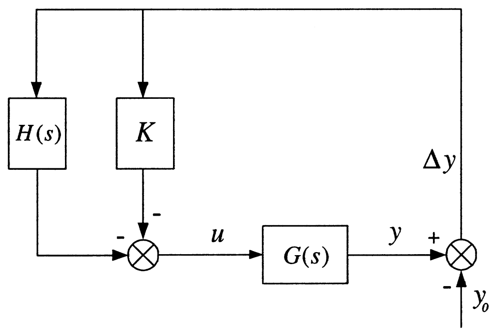

Fig. 1. Block diagram of a general PI controller.

control is using a forgetting factor to reduce the effects of the error in the past. The forgetting factors can be assumed to be given in the form of an exponential decaying function [3]. With the introduction of the decaying factor (λ), the extended integration feedback is represented by the convolution integral control.

The performance of the extended integral control is greatly dependent on the decaying factor. For an optimal or near optimal performance, it is necessary that the decaying factor as well as the feedback gains should be changed very quickly in response to changes in the system dynamics. However, because of the inherent characteristics of the changing loads and the system non-linearities such as GRC, there is no effective analytical method to determine optimal parameters quickly for real-time application. This study presents a pre-study for applicability of AI-based methods to determine the optimal parameters for the extended integral controller. From the case study on the basis of deviation degree and performance index, the system parameters should be determined to achieve the optimality of system performance. In LFC situation, the pre-determined parameters are applied in response to changes in the system dynamics.

In addition, this paper provides a new consideration of the characteristics of GRC. The earlier studies adopted too strict GRC such as 10% per minute to achieve adequate performance from the valve position control [9]. The main reason to consider the GRC is that the rapid power increase would draw out excessive steam from the boiler system to cause steam condensation due to adiabatic expansion. Since the temperature and pressure in the HP turbine are normally very high with some margin [14, p. 1906], it is expected that the steam condensation would not occur with about 20% steam flow change unless the boiler steam pressure itself does not drop below a certain level. Thus it is possible to increase generation power up to about 1.2 pu of normal power during the first tens of seconds. After the generation power has reached this marginal upper bound, the power increase of the turbine should be restricted by the GRC.

The computer simulation has been conducted for the single machine system with various load changes. The simulation results show that the proposed controller yields much better dynamic responses than the convention PI one. In the case where GRC is considered, the system with the proposed controller experiences small overshoot for a large disturbance. It is concluded that the proposed PI controller based on the extended integral control provides good performance even in the presence of GRC.

2. Extended integral control

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 ($H(s) = K_I/s$).

The PI control technique perfectly reduces the steady-state error to zero. However, in some control problems, some disturbances resulting 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 affects badly and continuously the current steady-state operation point. For example, in the LFC system of power systems, the integration of the frequency error in the past remains forever affecting the steady-state operation points after the system state has been settled down. In other words, the PI control causes some disturbances for AGC since the unessential information in the past badly affects to the current steady-state operation point.

In order to remove the above undesirable effects, an extended integral control is developed for the PI control of the speed governor. The convolution integration concept is proposed by substituting convolution integral for general integral term, $H(s)$ in Fig. 1. In the convolution integral control scheme, an exponential decaying function is chosen as a convolution integral type as follows:

$$h(t) = e^{-\lambda t}u(t) \tag{1}$$

It is noted that the key idea of the extended integral control is using a forgetting factor to reduce the effect of the error in the past. In this study, the forgetting factor is assumed to be given in the form of an exponential decaying function. With introduction of the decaying factor (λ), the extended integration feedback is given by

$$\int_0^t e^{-\lambda(t-\tau)}\Delta f(\tau)\,d\tau \tag{2}$$

with its s-domain function of $1/(s+\lambda)$

The graphical representation of the convolution integral type is shown in Table 1, compared with the conventional PI control.

In the extended integral control concept, it is obvious that the past error can be ignored in the integral of error forward to the plant after enough time has passed.

The extended integral control has another advantage to control frequency in LFC system of power systems. It is