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Adaptive decentralized load frequency control of multi-area power systems

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Abstract

This paper addresses the load frequency control problem of multi-area power systems. A decentralized adaptive control scheme is designed; the control scheme guarantees that the fluctuations of the load frequency converge to a range, which can be made very small. Simulation results for a three-area power system are given to illustrate the developed theoretical results. The simulation results indicate that the proposed control scheme works well and it is robust to changes in the parameters of the power systems and to bounded disturbances acting on the systems.

Keywords: Load frequency control; Adaptive control; Multi-area power systems

1. Introduction

Large-scale power systems are normally composed of interconnected subsystems or control areas. The connection between the control areas is done using tie lines or HVDC links. Each area has its own generator or group of generators, and it is responsible for its own load and scheduled interchanges with neighboring areas. Because loading of a given power system is never constant, and to ensure the quality of power supply, a load frequency controller (LFC) is needed to maintain the system frequency at the desired nominal value. It is known that changes in real power affect mainly the system frequency, and the input mechanical power to generators is used to control the frequency of the output electrical power.

The load frequency control (LFC) of power systems has been investigated by several researchers over the past decades; for example see [1–24]. This extensive research is due to the fact that LFC constitutes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specified limits. Robust and adaptive control schemes have been developed in [1–11] to deal with changes in system parameters and to improve the performances for multi-area power systems. The results reported demonstrate clearly the importance of robustness and stability issues in LFC design. In addition, several practical issues have been addressed in [1–24] which include recent technologies utilized by vertically integrated utilities, augmentation of filtered area control error with LFC schemes and hybrid LFC that encompasses an independent system operator and bilateral LFC.

This paper proposes a decentralized adaptive control scheme for load frequency control of multi-area power systems. Adaptive control is used because of the uncertainties on the parameters of the power system and because of the changes in the load demand. The simulation results under different operating conditions, indicate that the proposed controller works well and it is robust.

The remaining part of the paper is organized as follows. The dynamic model of a multi-area power system is presented in Section 2; the system consists of n interconnected subsystems. An adaptive control scheme for multi-area power systems is derived in Section 3. Simulation results for a three-area power system are presented in Section 4. Finally the conclusion is given in Section 5.

Notations**.** In the sequel, the Euclidean norm is used for vectors. W^t, W^{-1}, $\lambda(W)$, $Tr(W)$ and $\|W\|$ are used to denote, respectively, the transpose of, the inverse of, the eigenvalues of, the trace of, and the induced norm of any square matrix W. The notation $W>0$ ($W<0$) is used to denote a positive- (negative-) definite matrix W with $\lambda_M(W)$ and $\lambda_m(W)$ being the maximum and minimum eigenvalues of W. The identity matrix of appropriate dimensions is denoted by I. In addition, the arguments of a function may be omitted in the analysis when no confusion may arise.

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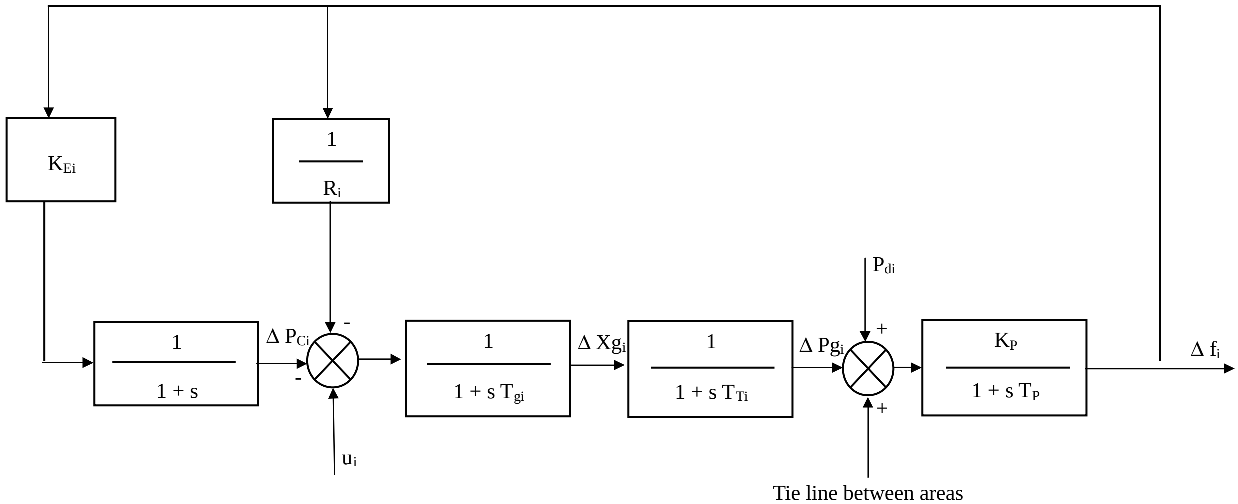

Fig. 1. Block diagram for the ith area of a multi-area power system.

2. Dynamic model of the multi-area power system

Models for electric power systems are generally nonlinear. However, for load frequency control, the linearized model is generally used to design control schemes [1]. Fig. 1 shows a block diagram for the ith area of a multi-area power system.

The dynamic model of the ith area power system ($i=1,\ldots,n$) can be written as,

$$\begin{bmatrix} \Delta\dot{f}_i(t) \\ \Delta\dot{P}_{g_i}(t) \\ \Delta\dot{X}_{g_i}(t) \\ \Delta\dot{P}_{c_i}(t) \\ \Delta\dot{P}_{t_i}(t) \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_{p_i}} & \frac{K_{p_i}}{T_{p_i}} & 0 & 0 & -\frac{K_{p_i}}{T_{p_i}} \\ 0 & -\frac{1}{T_{t_i}} & \frac{1}{T_{t_i}} & 0 & 0 \\ -\frac{1}{R_i T_{G_i}} & 0 & -\frac{1}{T_{G_i}} & -\frac{1}{T_{G_i}} & 0 \\ K_{E_i} & 0 & 0 & 0 & K_{E_i} \\ \sum_j T_{ij} & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta f_i(t) \\ \Delta P_{g_i}(t) \\ \Delta X_{g_i}(t) \\ \Delta P_{c_i}(t) \\ \Delta P_{t_i}(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{T_{G_i}} \\ 0 \\ 0 \end{bmatrix} u_i(t) + \begin{bmatrix} -\frac{K_{p_i}}{T_{p_i}} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} P_{d_i}(t) + \sum_{\substack{j=1 \\ j\neq 1}}^{n} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ -T_{ij} & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta f_i(t) \\ \Delta P_{g_i}(t) \\ \Delta X_{g_i}(t) \\ \Delta P_{c_i}(t) \\ \Delta P_{t_i}(t) \end{bmatrix} \quad (1)$$

The output of the ith area power system ($i=1,\ldots,n$) is:

$$y_i(t) = \Delta f_i(t) \quad (2)$$

The definitions of the symbols used in the model of the system are as follows:

$\Delta f_i(t)$	incremental change in frequency for ith area subsystem (Hz)
ΔPgi(t)	incremental change in generator output for ith area subsystem (p. u. MW)
ΔXgi(t)	incremental change in governor valve position for ith area subsystem (p. u. MW)
ΔPci(t)	incremental change in integral control for ith area subsystem
ΔPti(t)	incremental change in the tie line power for ith area subsystem (p. u. MW)
Pdi (t)	load disturbance for ith area subsystem (p. u. MW)
TGi	governor time constant for ith area subsystem (s)
Tti	turbine time constant for ith area subsystem (s)
Tpi	plant model time constant for ith area subsystem (s)
Kpi	plant gain for ith area subsystem
R_i	speed regulation due to governor action for ith area subsystem (Hz p.u. MW^{-1})

The model of the ith subsystem ($i=1,\ldots,n$) given in (1) and (2) can be written in compact form as:

$$\dot{x}_i(t) = A_i x_i(t) + B_i u_i(t) + \sum_{\substack{j=1 \\ j\neq i}}^{n} E_{ij} x_j(t) + D_i w_i(t) \quad (3)$$
$$y_i(t) = C_i x_i(t)$$

where,