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Adaptive fuzzy logic load frequency control of multi-area power system

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ABSTRACT

Based on indirect adaptive fuzzy control technique, a new load frequency control (LFC) scheme for multi-area power system is proposed. The power systems under study have the characterization of unknown parameters. Local load frequency controller is designed using the frequency and tie-line power deviations of each area. In the controller design, the approximation capabilities of fuzzy systems are employed to identify the unknown functions, formulate suitable adaptive control law and updating algorithms for the controller parameters. It is proved that the proposed controller ensures the boundedness of all variables of the closed-loop system and the tracking error. Moreover, in the proposed controller an auxiliary control signal is introduced to attenuate the effect of fuzzy approximation error and to mitigate the effect of external disturbance on the tracking performance. Simulation results of a three-area power system are presented to validate the effectiveness of the proposed LFC and show its superiority over a classical PID controller.

Introduction

Large scale power system consists of number of control areas and each area represents coherent group of generators. The control areas are interconnected through tie-lines. Each control area is equipped with primary and supplementary control actions. Depending on the governor droop characteristic and frequency sensitivity of the load, the primary control action provides steady-state frequency deviation for a change in system load. Restoration of system frequency to nominal value requires supplementary control action that adjusts the load reference set point through the speed-changer motor. Therefore, the basic means of controlling prime-mover power to match variations in system load is through control of the load reference set points of selected generating units [1]. The main objectives of the LFC are to regulate the system frequency to the specified nominal value and to maintain the interchange power between control areas at the scheduled levels.

A survey of different control schemes of LFC can be found in [2,3]. Many controllers have been proposed for power system LFC problems in order to achieve a satisfactory dynamic performance. The most widely employed controller is the fixed gain type, like a PI or a PID controller. A new control structure with a tuning method to design a PID load frequency controller for power systems is presented in [4]. Implementation of the LFC requires accurate information about the control area parameters, which are usually imprecisely modeled or varying due to wearing out of the components. To overcome this difficulty, intelligent control techniques have been used. The last two decades have witnessed increasing attention for applications of intelligent techniques such as fuzzy systems, artificial neural networks, genetic algorithms, etc. to deal with several aspects of power systems [5]. Adaptive fuzzy output tracking excitation control of power system generator is presented in [6]. In [7], application of a fuzzy gain scheduled proportional and integral controller for load-frequency control of two-area power system is presented. A control scheme based on artificial neuro-fuzzy inference system (ANFIS) is proposed in [8] to optimize and update control gains for automatic generation control (AGC) according to load variations. A fuzzy system is used in [9] to determine adaptively the proper proportional and integral gains of a PI controller according to the area-control error and its change for LFC. The LFC for power system subject to nonlinearities in valve position limits and parametric uncertainties is developed using T-S fuzzy system [10]. A method based on type-2 fuzzy system for load frequency control of a two-area interconnected reheat thermal system including superconducting magnetic energy storage (SMES) units is proposed in [11]. A Genetic Algorithm (GA) based fuzzy gain scheduling approach for load frequency control is presented in [12]. Two robust decentralized control design methodologies for LFC using linear matrix inequalities and genetic algorithms optimization are proposed [13]. Bacterial Foraging Optimization Algorithm (BFOA) is employed [14] to search for optimal LFC PID controller parameters to minimize the time domain objective function. A decentralized model predictive load frequency control was developed for multi-area power system

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[15,16]. Most of the fuzzy logic LFC available in the literature is based on the availability of fuzzy if–then rules for the control actions or T-S modeling of the power system.

The approximation capabilities of the fuzzy systems are exploited to design an adaptive fuzzy logic LFC scheme. This type of control scheme uses fuzzy logic system as controller [17]. In this paper, an approximation-based indirect adaptive fuzzy logic control scheme is developed for LFC of a multi-area power system that has the characterizations of unknown parameters (due to wearing out of components or variation of operating points), unknown interconnection among subsystems (due to unknown or variations in synchronizing power coefficients). In the controller design, fuzzy logic systems are used to construct the control law. The proposed controller of each area depends on the local states; namely, the frequency and tie-line power deviations and the tracking error. The key idea is to utilize the fuzzy logic system to develop a control law capable to achieve the LFC objectives and ensure global stability of the overall closed-loop system in the presence of unknown system parameters. An auxiliary control signal is incorporated to attenuate the effects of the fuzzy approximation errors, and the external disturbances in a H_∞ sense. The proposed adaptive fuzzy logic LFC does not rely on the availability of if–then fuzzy rules. To the best of author's knowledge, this is the first time to design such type of indirect adaptive fuzzy logic LFC.

The main contributions of the paper can be summarized as follows: (1) achievement of the LFC requirements in the presence of parameter uncertainties; (2) a set of if–then fuzzy rules are not required to implement the proposed controller. However, membership functions of system fuzzy variables should be known; and (3) attenuation of the effect of fuzzy approximation error and external disturbance, to achieve zero tracking of both frequency and tie-line deviations, is fulfilled by introducing an auxiliary control signal.

The paper is organized as follows: introduction is given in section 'Introduction' and dynamic model of the multi-area power system is presented in section 'Dynamic model of multi-area power system'. Indirect adaptive fuzzy logic control design and closed-loop stability are highlighted in sections 'Indirect adaptive fuzzy logic LFC and Stability analysis of the closed-loop subsystem' respectively. Simulation results of the proposed controller applied to a 3-area power system are provided in section 'Simulation results'. Conclusion is given in Section 'Conclusion'.

Dynamic model of multi-area power system

Consider a power system consisting of N LFC areas as shown in Fig. 1. Each area has a number of generators. All generators in one area are simplified as an equivalent generator unit [1]. Moreover, each area is assumed to have gas turbines of simple cycle and combined cycle types, and steam turbines of re-heat type. It is assumed that the proposed controller is installed to the gas turbines while the steam turbines have no control on the reference set point.

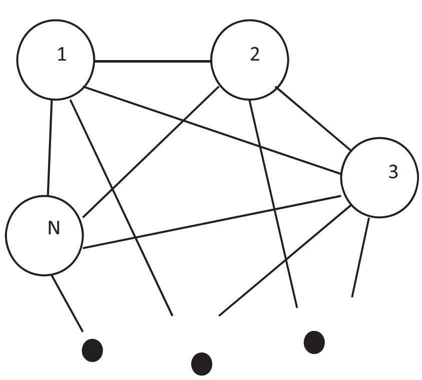

Fig. 1. N-area power system.

The dynamic model of each area can be written as

$$\Delta\dot{f}_i = \frac{1}{M_i}(-D_i\Delta f_i + \Delta P_{t1i} + \Delta P_{t2i} - \Delta P_{di}) \tag{1}$$

$$\Delta\dot{P}_{t1i} = \frac{1}{T_{t1i}}(-\Delta P_{t1i} + \Delta P_{g1i}) \tag{2}$$

$$\Delta\dot{P}_{t2i} = \frac{1}{T_{t2i}}(-\Delta P_{t2i} + \Delta P_{g2i}) \tag{3}$$

$$\Delta\dot{P}_{g1i} = \frac{1}{T_{g1i}}\left(-\Delta P_{g1i} + u_i - \frac{\Delta f_i}{R_i}\right) \tag{4}$$

$$\Delta\dot{P}_{ri} = \frac{1}{T_{ri}}\left(-\Delta P_{ri} + \left(1 - \frac{K_{ri}T_{ri}}{T_{g2i}}\right)\Delta P_{g2i} + \frac{K_{ri}T_{ri}}{T_{g2i}}\left(\Delta\bar{r}_i - \frac{\Delta f_i}{R_i}\right)\right) \tag{5}$$

$$\Delta\dot{P}_{g2i} = \frac{1}{T_{g2i}}\left(-\Delta P_{g2i} + \Delta\bar{r}_i - \frac{\Delta f_i}{R_i}\right) \tag{6}$$

$$\Delta\dot{P}_{tiei} = \frac{1}{2\pi}\left(\sum_{\substack{j=1,\\ j\neq i}}^{N} T_{ij}\Delta f_i - \sum_{\substack{j=1,\\ j\neq i}}^{N} T_{ij}\Delta f_j\right) \tag{7}$$

The block diagram of the ith LFC area in a multi-area system is shown in Fig. 2 [18]. Using state space representation, Eqs. (1)–(7) can be written in the following compact form:

$$\dot{\bar{x}}_i = \bar{A}_{ii}\bar{x}_i + \bar{B}_i\bar{u}_i + \bar{E}_i\Delta\bar{r}_i + \sum_{\substack{j=1,\\ j\neq i}}^{N}\bar{A}_{ij}\bar{x}_j - \bar{F}_i\Delta P_{di} \tag{8}$$

$$y_i = \bar{C}_i\bar{x}_i \tag{9}$$

where the state vector $\bar{x}_i$ and the control area matrices are defined as

$$\bar{x}_i = [\Delta f_i\ \Delta P_{t1i}\ \Delta P_{g1i}\ \Delta P_{t2i}\ \Delta P_{ri}\ \Delta P_{g2i}\ \Delta P_{tiei}]^T,$$

$$\bar{A}_{ii} = \begin{bmatrix} -\frac{D_i}{M_i} & \frac{1}{M_i} & 0 & \frac{1}{M_i} & 0 & 0 & -\frac{1}{M_i} \\ 0 & -\frac{1}{T_{t1i}} & \frac{1}{T_{t1i}} & 0 & 0 & 0 & 0 \\ \frac{-1}{R_iT_{g1i}} & 0 & -\frac{1}{T_{g1i}} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{T_{t2i}} & \frac{1}{T_{t2i}} & 0 & 0 \\ -\frac{K_{ri}}{R_iT_{g2i}} & 0 & 0 & 0 & -\frac{1}{T_{ri}} & \left(-\frac{K_{ri}}{T_{g2i}} + \frac{1}{T_{ri}}\right) & 0 \\ -\frac{1}{R_iT_{g2i}} & 0 & 0 & 0 & 0 & -\frac{1}{T_{g2i}} & 0 \\ \sum_{\substack{j=1,\\ j\neq i}}^{N} 2\pi T_{ij} & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\bar{A}_{ij} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2\pi T_{ij} & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$