Available online at www.sciencedirect.com
SCIENCE DIRECT®

Electrical Power and Energy Systems 28 (2006) 503–511

ELECTRICAL POWER & ENERGY SYSTEMS
www.elsevier.com/locate/ijepes

Application of ANN technique based on μ-synthesis to load frequency control of interconnected power system

H. Shayeghi [a,*], H.A. Shayanfar [b]

[a] Technical Engineering Department, The University of Mohaghegh Ardebili, Iran
[b] Electrical Engineering Department, Iran University of Science and Technology, Narmak, Tehran 16844, Iran

Received 9 July 2004; received in revised form 15 December 2005; accepted 24 February 2006

Abstract

A nonlinear artificial neural networks (ANN) controller based on μ-synthesis for solution the load frequency control (LFC) problem is proposed in this paper. Power systems such as other industrial plants subject to some uncertainties and disturbances due to multivariable operating conditions and load changes. In order to take large modeling errors and minimize the effects of area load disturbances, the idea of μ-synthesis theory is being used for training ANN based LFC controller. This newly developed design strategy combines advantage of the ANN and μ-synthesis control techniques to achieve the desired level of robust performance for all admissible uncertainties and leads to a flexible controller with relatively simple structure, which can be useful in the real world complex power system. A two-area power system is considered as a test system to demonstrate the effectiveness of the proposed method in comparison with the conventional PI and μ-based robust controllers under various operating conditions and load changes. The simulation results show that the proposed ANN based controller achieves good robust performance even in the presence of generation rate constraints (GRC) and is superior to the other controllers.

Keywords: LFC; Power system control; ANN; μ-synthesis; Robust control

1. Introduction

Load frequency control (LFC) is one of the most important issues in electric power system design and operation. The objective of the LFC in an interconnected power system is to maintain the frequency of each area and to keep tie-line power near to the scheduled values by adjusting the MW outputs the LFC generators so as to accommodate fluctuating load demands. The load frequency controller design with better performance has received considerable attention during past years and many control strategies have been developed [1–4] for LFC problem.

The availability of an accurate model of the system under study plays a crucial role in the development of the most control strategies like optimal control. However, an industrial process, such as a power system, contains different kinds of uncertainties due to changes in system parameters and characteristics, loads variation and errors in the modeling. On the other hand, the operating points of a power system may change very much randomly during a daily cycle. Because of this, a fixed controller based on classical theory [3,4] is certainly not suitable for LFC problem. Thus, some authors have suggested variable structure [5–7] and neural networks methods [8,9] for dealing with parameter variations. All the proposed methods are based on state-space approach and require information about the system states, which are not usually known or available.

On the other hand, various adaptive techniques [10,11] have been introduced for LFC controller design. Due to requirement of the prefect model, which has to track the state variables and satisfy system constraints, it is rather difficult to apply these adaptive control techniques to

* Corresponding author. Tel.: +98 21 88971630; fax: +98 21 88986563.
E-mail addresses: hshayeghi@gmail.com, h_shayeghi@yahoo.com (H. Shayeghi), hashayanfar@yahoo.com (H.A. Shayanfar).

0142-0615/$ - see front matter
doi:10.1016/j.ijepes.2006.02.012

LFC in practical implementations. Recently, several authors have been applied robust control methodologies [12–15] to the solution of LFC problem. Although via these methods, the uncertainties are directly introduced to the synthesis. But models of large scalar power system have several features that preclude direct application of robust control methodologies. Among these properties, the most prominent are very large (and unknown) model order, uncertain connection between subsystems, broad parameter variation and elaborate organizational structure.

In this paper, because of the inherent nonlinearity of power system we address a new nonlinear artificial neural network (ANN) controller based on μ-synthesis technique. The motivation of using the μ-based robust controller for training of the proposed controller is to take the large parametric uncertainties and modeling error into account. To improve the stability of the overall system and also its good dynamic performance achievement, the ANN controller has been reconstructed with applying the μ-based robust controller to power system in the different operating points under different load disturbances by using the learning capability of the neural networks. Moreover, the proposed controller also makes use of a piece of information, which is not used in the conventional and μ-based robust controllers (an estimate of the electric load perturbation, i.e. an estimate of the change in electric load when such a change occurs on the bus). The load perturbation estimate could be obtained either by a linear estimator, or by a nonlinear neural network estimator in certain situations. It could also be measured directly from the bus. We will show by simulation that when a load estimator is available, the ANN controller can achieve extremely dynamic response. In the work, a two-area power system is considered as a test system. Each area of power system consists of steam turbines, which include reheater. Therefore, there are the effects of reheater and generating rate boundaries in each area. For comparison, the considered system is controlled by using

(i) conventional integral controller,
(ii) μ-based robust controller and
(iii) ANN controller

for different cases of the plant parameter changes under various step load disturbances. The simulation results show that the proposed controller is very effective and gives good dynamic response compared to the conventional PI and μ-based robust controllers even in the presence of the plant parameters changes and generation rate constraint (GRC).

2. Plant model

A large power system consists of a number of interconnected control areas, which are connected by tie-lines power. There are different complicated nonlinear models for large-scale power systems. However, for the design of LFC a simplified and linearized model is usually used [16]. In advanced control strategies (such as the one considered in this paper) the error caused by simplification and linearization are considered as parametric uncertainties and unmodeled dynamics. A two-area power system is taken as a test system in this study. In each area, all generators are assumed to be coherent group. Fig. 1 shows the block diagram of the system in detail. Each area including steam turbine contains governor, reheater stage of steam turbine. The governor dead-band effects that are important for speed control under small disturbances is considered to

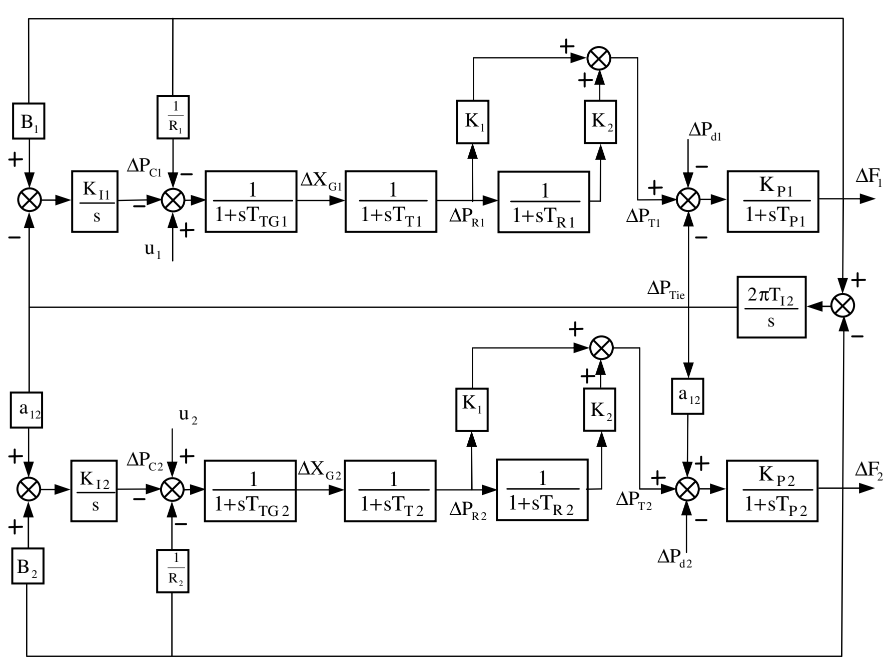

Fig. 1. Block diagram of a two-area power system.