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ScienceDirect
Electrical Power and Energy Systems 29 (2007) 251–259
ELECTRICAL POWER & ENERGY SYSTEMS
www.elsevier.com/locate/ijepes

A particle-swarm-based approach of power system stability enhancement with unified power flow controller

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Received 29 July 2004; received in revised form 30 May 2006; accepted 19 July 2006

Abstract

The use of the supplementary controllers of a unified power flow controller (UPFC) to damp low frequency oscillations in a weakly connected system is investigated. The potential of the UPFC supplementary controllers to enhance the dynamic stability is evaluated by measuring the electromechanical controllability through singular value decomposition (SVD) analysis. Individual designs of the UPFC controllers and power system stabilizer (PSS) using particle-swarm optimization (PSO) technique are discussed. The effectiveness of the proposed controllers on damping low frequency oscillations is tested through eigenvalue analysis and non-linear time simulation.

Keywords: UPFC; Particle-swarm optimization; Power system stability

1. Introduction

As power demand grows rapidly and expansion in transmission and generation is restricted with the limited availability of resources and the strict environmental constraints, power systems are today much more loaded than before. This causes the power systems to be operated near their stability limits. In addition, interconnection between remotely located power systems gives rise to low frequency oscillations in the range of 0.1–3.0 Hz. If not well damped, these oscillations may keep growing in magnitude until loss of synchronism results.

Power system stabilizers (PSSs) have been used in the last few decades to serve the purpose of enhancing power system damping to low frequency oscillations. PSSs, which operate on the excitation system of generators, have proved to be efficient in performing their assigned tasks. However, PSSs may adversely affect voltage profile, may result in leading power factor, and may not be able to suppress oscillations resulting from severe disturbances, especially those three-phase faults which may occur at the generator terminals.

A wide spectrum of PSS tuning approaches has been proposed. These approaches have included pole placement [1], damping torque concepts [2], H_∞ [3], nonlinear and variable structure [4,5], and the different optimization and artificial intelligence techniques [6–12].

FACTS devices have shown very promising results when used to improve power system steady-state performance. Through the modulation of bus voltage, phase shift between buses, and transmission line reactance, FACTS devices can cause a substantial increase in power transfer limits during steady-state. Because of the extremely fast control action associated with FACTS-device operations, they have been very promising candidates for utilization in power system damping enhancement. It has been observed that utilizing a feedback supplementary control, in addition to the FACTS-device primary control, can considerably improve system damping and can also improve system voltage profile, which is advantageous over PSSs.

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doi:10.1016/j.ijepes.2006.07.006

A unified power flow controller (UPFC) is the most promising device in the FACTS concept. It has the ability to adjust the three control parameters, i.e. the bus voltage, transmission line reactance, and phase angle between two buses, either simultaneously or independently. A UPFC performs this through the control of the in-phase voltage, quadrature voltage, and shunt compensation. Till now, not much research has been devoted to the analysis and control of UPFCs.

Several trials have been reported in the literature to model a UPFC for steady-state and transient studies. Under the assumption that the power system is symmetrical and operates under three-phase balanced conditions, Nabavi-Niaki and Iravani [13] developed a steady-state model, a small-signal linearized dynamic model, and a state-space large-signal model of a UPFC. Stefanov and Stankovic [14] developed an analytical large-signal model for unbalanced operation of the unified power flow controller (UPFC). Zhang et al. [15] developed a model for the Generalized Unified Power Flow Controller (GUPFC), which can control bus voltage and power flows of more than one line or even a sub-network using one shunt converter and two or more series converters. In 1999, Wang developed two UPFC models [16,17] which have been linearized and incorporated into the Heffron–Phillips model [18].

A number of control schemes has been suggested to perform the oscillation-damping task. Huang et al. [19] attempted to design a conventional fixed-parameter lead-lag controller for a UPFC installed in the tie line of a two-area system to damp the interarea mode of oscillation. Mok et al. [20] considered the design of an adaptive fuzzy logic controller for the same purpose. It has been illustrated through computer simulation that the proposed fuzzy logic controller outperforms the conventional fixed-parameter controller as it considers a wide range of operating conditions. Mishra et al. [21] and Schoder et al. [22] developed a Takagi–Sugeno (TS) type fuzzy logic controller for a UPFC to damp both local and interarea modes of oscillation for a multimachine power system. However, the initial parameters adjustment of this type of controller needs some trial and error.

Dash et al. [23] suggested the use of a radial basis function NN for a UPFC to enhance system damping performance. The NN used either a single neuron or multiple neurons and the parameters were estimated using an error surface derived from the network inputs.

Robust control schemes, such as H_∞ and singular value analysis, have also been explored. Vilathgamuwa et al. [24] proposed an H_∞ controller to regulate line currents in both the shunt and series UPFC inverters. The controller parameters have been selected based on the two-Riccati-equation approach. Pal [25] used the linear-matrix-inequality (LMI) formulation to approach the UPFC controller design based on H_∞ control scheme. To avoid pole-zero cancellation associated with the H_∞ approach, the structured singular value analysis have been utilized in [26] to select the parameters of the UPFC controller to have the robust stability against model uncertainties.

Recently, an integrated linear and nonlinear control of a UPFC for stability enhancement of a multimachine power system was developed [27]. Three pulse-width-modulation (PWM) UPFC parameters were controlled by the conventional PID structure, and the analytical expression of the nonlinear control law for the UPFC phase angle was obtained by a feedback linearization method.

Furthermore, To avoid instability or loss of DC link capacitor voltage during transient conditions, Kannan et al. [28] proposed a real and reactive power coordination controller for a UPFC.

In this paper, singular value decomposition (SVD) is used to select the control signal which is most suitable for damping the electromechanical (EM) mode oscillations. This is done as SVD analysis can be readily used to evaluate the EM mode controllability of the PSS and the different UPFC controllers. A SMIB system equipped with a PSS and a UPFC controller is used in this study. The problem of damping controllers design is formulated as an optimization problem to be solved using PSO. The aim of the optimization is to search for the optimum controller parameter settings that maximize the minimum damping ratio of the system. Eigenvalue analysis and non-linear simulation are used to assess the effectiveness of the proposed controllers to damp low frequency oscillations under different disturbances.

2. Problem statement

Fig. 1 shows a SMIB system equipped with a UPFC. The UPFC consists of an excitation transformer (ET), a boosting transformer (BT), two three-phase GTO based voltage source converters (VSCs), and a DC link capacitors. The four input control signals to the UPFC are m_E, m_B, δ_E, and δ_B, where, m_E is the excitation amplitude modulation ratio, m_B is the boosting amplitude modulation ratio, δ_E is the excitation phase angle, and δ_B is the boosting phase angle.

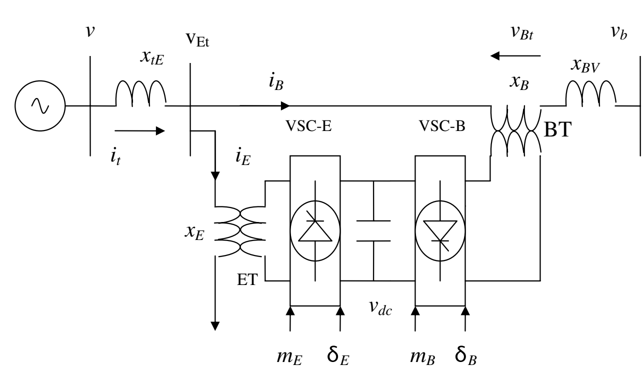

Fig. 1. SMIB power system equipped with UPFC.