Use of ANFIS Control Approach for SSSC based Damping Controllers Applied in a Two-area Power System

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ABSTRACT
In an interconnected power system, low frequency electromechanical oscillations are initiated by normal small changes in system loads, and they become much worse following a large disturbance. Flexible AC Transmission System (FACTS) devices are widely recognized as powerful controllers for damping power system oscillations. The standard FACTS controllers are linear controllers which may not guarantee acceptable performance or stability in the event of a major disturbance. To overcome the drawbacks of conventional controllers, ANFIS (Adaptive Neuro-Fuzzy Inference System) control scheme has been developed in this paper, and it has been applied for the external coordinated control of series connected FACTS controllers known as Static Synchronous Series Compensators (SSSCs) employed in a two-area power system. In neuro-fuzzy control method, the simplicity of fuzzy systems and the ability of training in neural networks have been combined. The training data set the parameters of membership functions in fuzzy controller. This ANFIS can track the given input-output data in order to conform to the desired controller. Simulation studies carried out in MATLAB/SIMULINK environment demonstrate that the proposed ANFIS based SSSC controller shows the improved damping performance as compared to conventional SSSC based damping controllers under different operating conditions.

Keywords: ANFIS, FACTS, low frequency electromechanical oscillations, MATLAB/SIMULINK, SSSC.

1. Introduction

With increasing power transfer and heavier loading, power systems become gradually more complex to operate and they may become less secure for riding out major power outages [1, 2]. As a result, large power flows with inadequate control may be observed and excessive reactive power and large dynamic swings may be experienced in different parts of the system which will prevent the transmission interconnections from being fully utilized.

Power system exhibits various modes of oscillations due to interaction among various components. Most of the oscillations are due to synchronous generator rotors swinging relative to each other. Stressed power systems are known to exhibit nonlinear behavior. Load changes or faults are the main causes of power oscillations. If the oscillations are not controlled properly, it may lead to a total or partial system outage. If no adequate damping is available, these oscillations may sustain and grow to cause system separation [3].

In the past three decades, power system stabilizers (PSSs) have been extensively used to increase the system damping for low frequency oscillations. The power utilities worldwide are currently implementing PSSs as effective excitation controllers to enhance the system stability [4]-[6]. However, there have been problems experienced with PSSs over the years of operation. Some of these were due to the limited capability of PSSs in damping only local and not inter-area modes of oscillations. In addition, PSSs can cause great variations in the voltage profile under severe disturbances and they may even result in leading power factor operation and losing system stability. This situation has necessitated a review of the traditional power system concepts and practices to achieve a larger stability margin, greater operating flexibility, and better utilization of existing power systems.

In recent years, the concept of flexible ac transmission systems (FACTS) brought radical changes in the power system operation and control. The FACTS devices linked to the improvements in semiconductor technology opened new opportunities for controlling power and enhancing the usable capacity of existing transmission lines. As supplementary functions, damping the inter-area modes and enhancing power system stability using FACTS controllers have been extensively studied and investigated. In these years, Voltage Source Converter (VSC)-based series connected FACTS controllers, known as the new FACTS generation, which can inject a voltage with controllable magnitude and phase angle at the fundamental frequency, are found to be more capable of handling power flow control, transient stability and oscillation damping enhancement. In a recent literature [7], a novel methodology for tuning static synchronous compensator (STATCOM) based damping controller in order to enhance the damping of system low frequency oscillations has been described. This paper investigates the damping capabilities of static synchronous series compensator (SSSC), which is one of the VSC-based series connected FACTS controllers. SSSC is a solid-state controllable voltage source inverter that is connected in series with power transmission lines. With the injected voltage in quadrature with the line current and the capability of dynamically changing its reactance characteristic from capacitive to inductive, SSSC becomes an effective tool for power flow control [8]. In addition, an auxiliary stabilizing signal can be superimposed on its power flow control function to improve power system oscillation stability [9].

An attempt has been made to apply hybrid neuro-fuzzy approach for the coordination between the conventional power oscillation damping (POD) controllers for multimachine power systems. With the help of MATLAB, a class of adaptive networks, that are functionally equivalent to fuzzy inference systems, is proposed. The proposed architecture is referred to as ANFIS (Adaptive Neuro-Fuzzy Inference System) [10]-[14]. In this paper, ANFIS based SSSC controllers are developed where each controller uses the speed of a synchronous machine and its derivative as the inputs. The ANFIS based SSSC controller uses a first-order Sugeno-type fuzzy logic controller whose membership functions and consequences are tuned by backpropagation method. Fuzzy rules and membership functions of the controller can be tuned automatically by learning algorithm. The proposed technique is illustrated on a 3-machine, 9-bus power system. MATLAB/SIMULINK and fuzzy logic toolbox have been used for system simulation. The results demonstrate that the proposed self-learning ANFIS based SSSC controller provides a good damping performance over a wide range of operating conditions as compared to conventional SSSC based damping controllers.

This paper is organized as follows. The single-machine infinite-bus (SMIB) and multimachine power system models are described in Section 2. The design aspects of conventional SSSC based damping controller and fuzzy logic coordinated SSSC based damping controller, and the concept of ANFIS control scheme are discussed in Section 3. Simulation results and discussions are illustrated in Section 4. Some conclusions are given in Section 5.

2. Power system model

The recommended state space model for SSSC to study dynamic stability of a single-machine infinite-bus power system (SMIB) is given by Eqn. (1) [15].

$$\begin{bmatrix} \dot{\Delta\delta} \\ \dot{\Delta\omega} \\ \dot{\Delta E'_q} \\ \dot{\Delta E_{fd}} \\ \dot{\Delta V_{DC}} \end{bmatrix} = \begin{bmatrix} 0 & \omega_b & 0 & 0 & 0 \\ -\frac{K_1}{M} & -\frac{D}{M} & -\frac{K_2}{M} & 0 & -\frac{K_{pDC}}{M} \\ -\frac{K_4}{T'_{d0}} & 0 & -\frac{K_3}{T'_{d0}} & \frac{1}{T'_{d0}} & -\frac{K_{qDC}}{T'_{d0}} \\ -\frac{K_A K_5}{T_A} & 0 & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} & -\frac{K_A K_{vDC}}{T_A} \\ K_7 & 0 & K_8 & 0 & K_9 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta E'_q \\ \Delta E_{fd} \\ \Delta V_{DC} \end{bmatrix} + \begin{bmatrix} 0 \\ -K_{pu} \\ -K_{qu} \\ -K_{vu} \\ K_{dm} \end{bmatrix} \begin{bmatrix} \Delta u \end{bmatrix} \quad (1)$$