Chapter 9
Comparison of Uncertainties in Membership Function of Adaptive Lyapunov NeuroFuzzy-2 for Damping Power Oscillations

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ABSTRACT

The direct focus of this chapter is to explore the potential of online Adaptive NeuroFuzzy Type-2 (ANFT2) control system for damping inter-area oscillations using Static Synchronous Compensator (STATCOM). The nonlinear ANFT2-based direct control scheme is proposed to damp inter-area oscillations by utilizing its model free and universal approximation capabilities. The Gaussian and triangular membership functions with different variations of uncertain mean and standard deviation are considered for ANFT2. The adaptation mechanism utilizes gradient descent-based back-propagation algorithm using Lyapunov stability criteria to update the rule parameters. The performance evaluation of proposed control strategy has been validated using two and three machine power systems. The nonlinear time domain simulations reveal that ANFT2 has excellent damping capabilities as compared to conventional PI control. Simulation results for different performance indices further emphasize the optimal performance of ANFT2 with uncertain mean and variance of triangular membership function in transient and steady state region.

DOI: 10.4018/978-1-4666-7258-1.ch009

INTRODUCTION

In a large interconnected power system, the machine angles of a group of machines oscillate against the others due to the imbalance of energy conversion resulting from a three phase fault, load outage and/or any other discrete event. These oscillations either decay with time restoring the system to its original or a new steady-state, depending upon the nature of the fault, or they may grow indefinitely resulting in system collapse. In the former case, the system has sufficient natural damping to diminish the effect of these oscillations with time, whereas, in later case the system cannot damp these oscillations and additional damping control is needed for secure and reliable operation (Mohagheghi, Venayagamoorthy and Harley, 2006; Mohapatra, Panda and Satpathy, 2013). Flexible AC Transmission System (FACTS) is a relatively new technology which optimizes the performance of a power system through one of the many ways like changing the effective reactance of transmission line, exchange of reactive power with transmission network and phase control of injected voltage (Obulesu, et al. 2009; Varma, 2011) etc.

STATCOM is a shunt connected controller, belonging to the second generation of FACTS, which maintains the bus voltage at a constant level by injecting or absorbing reactive power. Due to its efficient performance, STATCOM found extensive applications to optimize power system operation (Abido, 2005; Panda and Padhay 2008; Ganesh, Dahiya and Singh, 2014). Since, the primary objective of the STATCOM is voltage regulation, it may not perform well or even degrade the system performance in terms of damping inter-area oscillations (Gharaveisi, 2009). In order to damp the low frequency electromechanical oscillations, STATCOM is facilitated with some Supplementary Damping Control (SDC) in addition to the voltage control. The supplementary control must provide the STATCOM with the complete information of the system to perform efficiently. Due to highly nonlinear, multivariable and time varying nature of power system, the exact modeling of each component is almost impossible especially those which are not well-defined like different loads and distributed generations (Hiskens and Alseddiqui, 2006). This gives rise to the uncertainties in power system. Therefore, SDC must exploit some technique which could encounter the effect of the uncertainties in the system (Badar and Khan, 2012, 2013a).

In recent years, the emergence of NeuroFuzzy control systems is proven to be a better replacement of conventional control techniques like $H_{2,}$ pole shift, Linear Matrix Inversion (LMI), etc. for STATCOM SDC. NeuroFuzzy control systems are found in good agreement for performance improvement and implementation simplicity. Unlike conventional nonlinear adaptive control techniques, the adaptive NeuroFuzzy control systems are less sensitive to model uncertainties and their application domain is not constrained by specific operating point for which they are tuned. Mohagheghi et al. (2007) proposed adaptive critic NeuroFuzzy control for STATCOM using a quasi-online adaptive scheme and further reported that selection of membership functions significantly affects the performance of the control system. Many researchers have successfully applied the NeuroFuzzy paradigms and their hybrids with other linear controls for STATCOM SDC (Reddy and Ram 2010; Sharma and Ahmad, 2011). But these systems are usually based on Mamdani or Takagi-Sugeno-Kang (TSK) structures which utilize Type-1 membership functions to translate the available information from crisp to fuzzy space. Moreover, the parameters of the control system are tuned offline which cannot accommodate the new available information during system operation. Type-1 membership function cannot reflect the uncertainties in the knowledge base of the system due to well defined boundaries. Therefore, Type-2 membership functions were introduced which propagate the uncertain information in terms of uncertain mean or variance (Hidayat and Kyanak, 2010). This property of Type-2 fuzzy systems makes them a suitable choice for

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