International Journal For Recent Developments in Science & Technology
2581-4575
Crossref
A Peer Reviewed Research Journal

ANALYSIS OF AN AUXILIARY FUZZY LOGIC BASED STATIC SYNCHRONOUS SERIES COMPENSATOR

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ABSTRACT
Low Frequency Oscillations (LFO) occur in power systems because of lack of the damping torque .Low frequency oscillations (LFO) are a frequent adverse phenomenon which increase the risk of instability for the power system and thus reduce the total and available transfer capability (TT C and ATC). This brief investigates the damping performance of the static synchronous series compensator (SSSC) equipped with an auxiliary fuzzy logic controller (FLC). This manuscript investigates the damping performance of the Static Var Compensator (SVC) equipped with an auxiliary controller based on Adaptive Neuro-Fuzzy Inference System (ANFIS). First of all, a modified Heffron-Phillips model of the single machine infinite bus (SMIB) system installed with SVC is established. In the following an auxiliary fuzzy logic controller (FLC) for SVC is designed to enhance the transient stability of the power system. Next, an ANFIS based auxiliary damping controller is welldesigned and compared with the FLC. In order to evaluate the performance of the proposed ANFIS based controller in damping of LFO, the SMIB power system is subjected to a disturbance such as changes in mechanical power. The complete digital simulations are performed in the MATLAB/Simulink environment to provide comprehensive understanding of the issue. Simulation results demonstrate that the developed ANFIS based controller would be more effective in damping electromechanical oscillations in comparison with the FLC and conventional proportional-integral (PI) controller.

1. INTRODUCTION

Power systems are among the largest, most complex systems made by human beings. They exhibit various modes of oscillations due to interaction among system components. By interconnecting the large power systems, utilities have achieved more reliability and economical viability. However, low frequency oscillations (LFO) with the frequencies in the range of 0.2 to 2 Hz are one of the direct results of the large interconnected power systems. The power oscillations may come up to entire rating of a transmission line, as they are superimposed on steady state line flow. Hence, these oscillations would limit the total and available transfer capability (TTC and ATC) by requiring higher safety margins. These electromechanical modes of oscillations are usually poorly damped which may increase the risk of instability of power system. Thus, it is urgent and important to damp the electromechanical oscillations as soon as possible [1] in order to maintain the stability of the entire system. To mitigate the oscillations in the power system many different methods have been proposed .For many years, power system stabilizer (PSS) has been one of the traditionally devices used to damp out the oscillations [2]. It is reported that during some operating conditions, PSS may not mitigate the oscillations effectively. However, there have been problems experienced with PSSs over the years of operation. Some of these were due to the limited capability of PSS, in damping only local and not interarea 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 [3]. Hence, other effective alternatives are required in addition to PSSs [4]. 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 Different methods have been suggested to mitigate the oscillations in the power system. Power system stabilizer (PSS) has been one of the traditionally devices used to damp out the oscillations [3]. It is reported that during some operating conditions, PSS may not damp the oscillations effectively; hence, other effective substitutes are required in addition to PSSs [4]. Recently, emerging of the flexible ac transmission system (FACTS) devices has directed the way to a new and more versatile approach to control the power system in a desired manner [5]. FACTS controllers offer a series of remarkable capabilities such as reactive power compensation, voltage regulation, power flow control, damping of oscillations, and etc [6]. The static var compensator (SVC) is one of the shunt connected FACTS devices. Usually the SVC is a delta-connected Thyristor Controlled Reactor - Fixed Capacitor (TCR-FC) which connects in parallel with the load. The primary task of the SVC is to control its bus voltage across a protected load. The equivalent susceptance of the SVC is adjusted in each phase by controlling the conducting angles of the TCRs [5]. By this way it is possible to adjust the SVC susceptance in the value that is needed for reactive power compensation and hence voltage regulation. Along with its main duty, SVC is capable of realizing some other ancillary duties such as power oscillation damping (POD). In the literature, different methods have been proposed to design a POD controller for SVC. Phase compensation method is one of the earliest methods utilized to develop a supplementary damping controller for SVC. The main problem associated with this method is that the control process is based on the linearized power system model. Proportional-integral (PI) controller is the other frequently used approach. Although the PI controllers present simplicity and ease of design, their operation gets worth when the system conditions vary widely or large disturbances occur. In this field, some new stabilizing control solutions for power system have been presented. Recently, Fuzzy Logic Controllers (FLCs) and Artificial Neural Network Controllers (ANNCs) have appeared as an efficient tool to circumvent these drawbacks .

This paper investigates the design of a supplementary ANFIS based controller to attenuate power oscillations by SVC. The investigation is performed for a single machine infinite bus (SMIB) power system installed with an SVC. In the following, the linearized Heffron-Phillips model of the investigated plant is developed. An auxiliary ANFIS based controller is utilized to modulate the equivalent susceptance of the SVC during the transients to enhance the stability of the power system. The initial setting of membership functions for the FLC is done based on the dynamical behavior of SVC. Then membership functions are optimized by the use of ANNC. Subsequently, aiming to provide a fruitful investigation, a comparative study is developed where the ANFIS based controller is compared with conventional FLC and PI controller. Simulation results using MATLAB/Simulink validates the superior damping of LFO obtained with ANFIS based controller. The Benefits of Flexible AC Transmission Systems (FACTs) usages to improve power systems stability are well known [5], [6]. The growth of the demand for
electrical energy leads to loading the transmission system near their limits. Thus, the occurrence of the LFO has increased. FACTs Controllers has capability to control network conditions quickly and this feature of FACTs can be used to improve power system stability.On the other hand, the advent of flexible ac transmission system (FACTS) devices has led to a new and more versatile approach to control the power system in a desired way . FACTS controllers provide a set of interesting capabilities such as power flow control, reactive power compensation, voltage
regulation, damping of oscillations, transient stability enhancement and so forth [7]. The static synchronous series compensator (SSSC) is one of the series FACTS devices based on a solid-state voltage source inverter which generates a controllable ac voltage in quadrature with the line current. By this way, the SSSC emulates as an inductive or capacitive reactance and hence controls the power flow in the transmission lines. In authors have
developed the damping function for the SSSC. It is a well-known fact that by properly designing an auxiliary power oscillation damping (POD) controller, the SSSC would be capable of suppressing the fluctuations as an ancillary duty. Different methods have been proposed in the literature to design a POD controller for SSSC. For example, in authors have used the phase compensation method to develop a supplementary damping controller for SSSC. The main problem associated with these methods is that the control process is based on the linearized machine model. The other frequently used approach is the proportionalintegral (PI) controller. Although the PI controllers offer simplicity and ease of design, their performance deteriorates when the system conditions vary widely or large disturbances occur. In this context, some new stabilizing control solutions for power system have been presented. Recently, fuzzy logic controllers (FLCs) have emerged as an efficient tool to circumvent these drawbacks. The qualitative

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and quantitative knowledge about the system operation through some hierarchy is integrated by FLC. Fuzzy logic provides a general concept for description and measurement of systems. Most of fuzzy logic systems encode human reasoning into a program in order to arrive at decisions or to control a system. Fuzzy logic comprises fuzzy sets, which is a way of representing nonstatistical uncertainty along with approximate reasoning and in fact includes the operations used to make inferences. There are some manuscriptswhich have demonstrated the successful application of FLC for transient stability enhancement of a power system. In Limyingcharone *et al.* have used a fuzzy supplementary controller with the aim of achieving low frequency oscillations damping`

2. POWER SYSTEM MODELING

The linearized Phillips-Heffron model of a power system installed with SSSC is used to investigate the impact of SSSC on damping oscillations in power systems. This section is dedicated to extract an exact linearized Heffron-Phillips model for the investigated power system. As depicted in Fig. 1, a single machine infinite bus (SMIB) system installed with SSSC is considered as the sample power system. In this figure, XT is the transformer reactance and XL corresponds to the reactance of the transmission line. Also, Vt and Vb represent the generator terminal voltage and infinite bus voltage respectively. A simple SSSC consisting of a three-phase GTO-based voltage source converter (VSC) is incorporated in the transmission line. It is assumed that the SSSC performance is based on the well-known pulse width modulation (PWM) technique. For the SSSC, XSCT is the transformer leakage reactance; VINV is the series injected voltage; CDC is the DC link capacitor; VDC is the voltage at DC link; m is amplitude modulation index and ø is the phase angle of the series injected voltage.

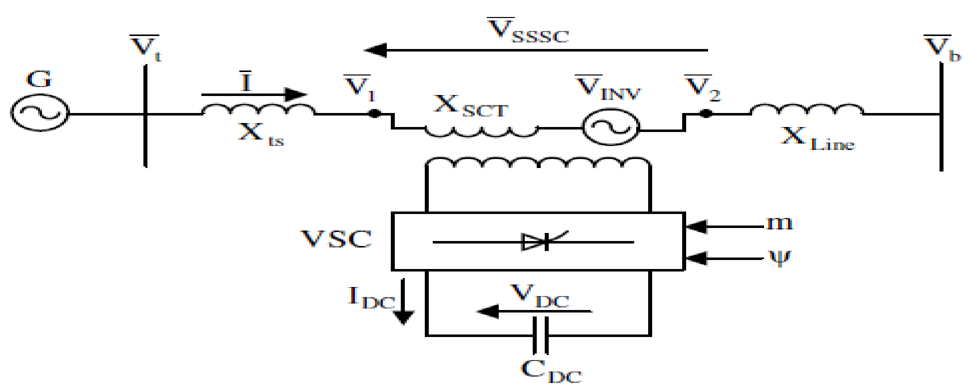

Fig. 1 A single machine infinite bus power system with a SSSC

2.1. Nonlinear Dynamic Model of the Power System with S S S C As the first step, a nonlinear dynamic model for the examined system is derived by neglecting the resistance of all the components including generator, transformer, transmission line, and series converter Transformer. The equations specifying the dynamic performance of the SSSC can be written as follows [16].

$$\bar{I} = I_d + jI_q = I\angle\varphi$$

$$\bar{V}_{INV} = mkV_{DC}(\cos\psi + j\sin\psi) = mkV_{DC}\angle\psi\,,$$
$$\psi = \varphi \pm 90$$
$$\frac{dV_{DC}}{dt} = \frac{mk}{C_{DC}}(I_d\cos\psi + I_q\sin\psi) \qquad (1)$$

Where k is the fixed ratio between the converter AC and DC voltages and is dependent on the inverter structure. For a simple three-phase voltage source converter k is equal with 3/4 [5]. Most of the times, SSSC performs as a pure capacitor or inductor; hence, the only main controllable parameter for SSSC is the amplitude modulation index m . For the work at hand, the IEEE Type-ST1A excitation system is considered. Fig.2 displays the block diagram of the excitation system where the terminal voltage Vt and the reference voltage Vref are the input signals. KA and TA are the gain and time constant of the excitation system respectively.

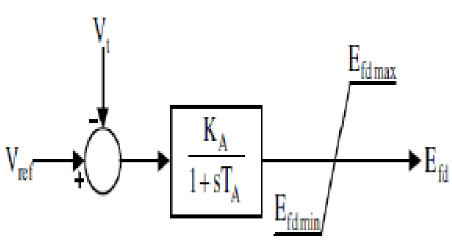

Fig. 2 IEEE Type-ST1A excitation system

3. LOW FREQUENCY DAMPING CONTROLLERS DESIGN

With the aim of damping the low frequency oscillations, three sorts of damping controllers are designed and compared with each other. As mentione d earlier, the equivalent susceptance of the SVC namely *SVC B* , provides a control signal to achieve a better damping of oscillations. In the following sections, each controller would be discussed in detail.

A . Conventional Proportional-Integral (PI) Controller

It is a well-known fact that the power system oscillations occur due to the lack of damping torque at the generators rotors. Hence, the damping controllers are designed to provide an extra electrical torque in phase with the speed deviation so as to increase the damping of oscillations [1]. Fig. 3 displays the conventional PI controller structure. It can be observed that the first block compares the actual generator rotor speed with its reference value. In the sequel, the error is let to pass through a PI controller to properly alter the equivalent susceptance of the SVC. Different techniques have been applied to design PI controllers such as try and error method, pole-placement, Ziegler-Nichols and so forth. In this study, try and error method is used to set suitable values for PI controller gain s.

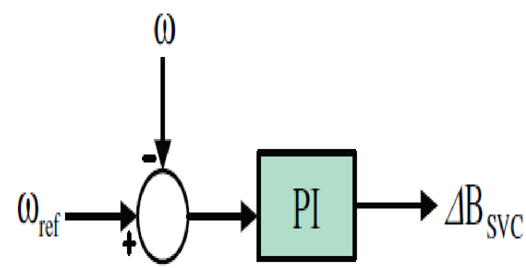

Fig. 3 Conventional PI damping controller

B . Auxiliary Fuzzy Logic Damping Controller

Although the PI controllers offer simplicity and ease of design, their performance depreciates when the system conditions vary in a wide range or large disturbances occur. As a result, to guarantee the effective performance of damping controller over wide range of system operations and also to increase the transient stability of the system, a supplementary fuzzy logic controller (FLC) based on the Mamdani's fuzzy inference method is designed for the SVC input. FLC generates the required small change for the equivalent susceptance of the SVC to control the magnitude of the terminal voltage. For the presented FLC, the centroid defuzzyfication technique is used. Fig. 4 depicts the FLC structure. Here, a two–input, one–output FLC is considered. The input signals are angular speed deviation ( ) and load angle deviation ( ) and the resultant output signal is the change of equivalent susceptance of the SVC.

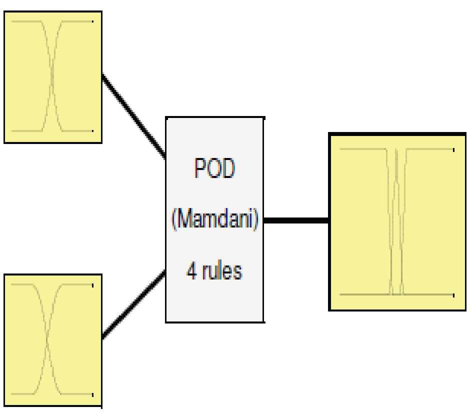

Fig. 4 Fu zzy logic damping controller structure

Membership functions of the input and output signals are shown in Fig. 5. Two linguistic variable are assigned for each input variable, including, “Positive” (P), and “Negative” (N). On the other hand, for the output variable there are three linguistic variables, namely, “Positive” (P), “Zero” (Z), and “Negative” (N).

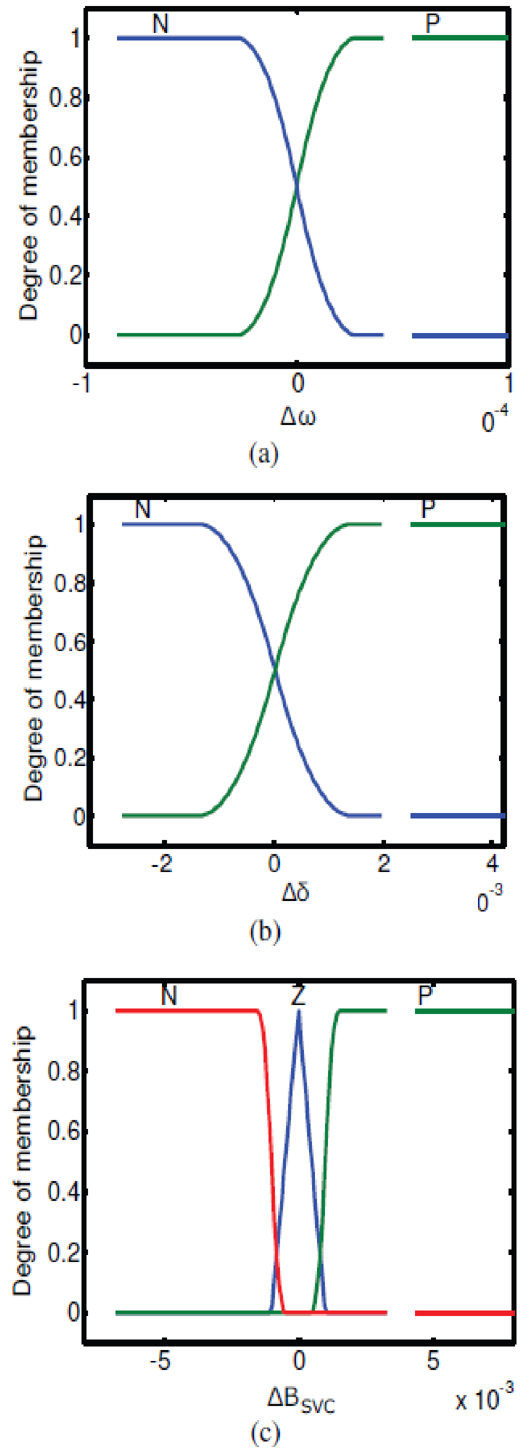

Fig. 5 (a), (b) inputs membership function, (c) output membership function

C. ANFIS Based Damping Controller

ANFIS was firstly proposed by [22]. In fact the ANFIS system is the same as the conventional fuzzy systems except
that computations at each stage is carried out by a layer of hidden neurons and the neural network's learning ability is provided to enhance the system knowledge. In this work, the structure of the ANFIS based controller is a linear Sugeno type fuzzy inference system with the parameters inside the FIS decided by the neural-network hybrid method that combines the least-squares estimator and the gradient descent method.

CONCLUSION

This manuscript serves an exact investigation to obtain a complete linearized Heffron-Phillips model for a single machine infinite bus power system equipped with an SSSC to study LFO damping with an auxiliary FLC. It was shown that a contingency in power system will cause to initiate power oscillations. In the sequel, two types of controllers, namely, the conventional PI and the FLC were designed to damp the system oscillations. A comparative study between the FLC and PI controller shows that the proposed FLC has superior performance and influence in transient stability enhancement and oscillations damping. Simulation results validate the efficiency of the proposed fuzzy logic damping controller and its better performance is emphasized. Consequently, the fuzzy logic controller would be a better option in the design of damping controllers.

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