CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

During the early part of the 20th century, small oscillations in synchronous generators became a problem for power system engineers. This phenomenon came to be known as ‘hunting’. It was particularly noticeable when a generator was synchronized to the system through a long line. With the introduction of damper windings, the problem of hunting was significantly reduced.

In the 1960s, the problem of small oscillations in power systems presented problems in terms of system operation. These oscillations have been described as dynamic instability, small oscillations or low frequency oscillations in power systems. This chapter reviews the various approaches proposed in the literature for power oscillation damping.

Power system stability has been recognized as an important problem for secure system operation since 1920s. As power systems have evolved through continuing growth in interconnections, use of new technologies and controls and the increased operation in highly stressed conditions, different forms of system instability have emerged like voltage stability, angle stability. A clear understanding of different types of instability and their interrelationship is necessary for the satisfactory design and operation of power systems. The basic concepts of power system stability and
the classification of the oscillations are analyzed by Prabha Kundur et al (1994).

Present-day power systems are being operated under increasingly stressed conditions due to the prevailing trend to make use of most of the existing facilities. Increased competition, open transmission access, and construction and environmental constraints are shaping the operation of electric power systems in new ways that present greater challenges for maintaining the system stability. IEEE/ CIGRE joint task force report (Prabha Kundur and John Paserba 2004) provides (i) definition about power system stability inclusive of all forms, (ii) basics for the classification of power system stability (iii) classification of stability and (iv) related issues with power system reliability and security.

For a given system, any method of improving stability may not be adequate. The best approach is likely to be a combination of several methods judiciously chosen so as to most effectively assist in maintaining stability for different contingencies and system conditions. The methods of improving stability by

- High speed fault clearing
- Reducing system reactance
- Shunt compensation
- Dynamic braking
- Independent pole operation
- Single pole switching and
- FACTS devices

are discussed by Kundur et al (1994). Among these, the advancement in power electronics leads to better control of FACTS devices which in turn improves the power system transient and small signal stability.
2.2 POWER SYSTEM STABILIZERS FOR POWER OSCILLATION DAMPING

Damping of oscillation has been recognized as an important task in electric power system operations which improves the small signal stability of the power system (John Paserba et al 2006). In many power systems, PSS is installed to enhance oscillatory stability (Kundur et al 2004). The use of power system stabilizers to control generator excitation systems is the most cost-effective method of enhancing the oscillatory stability. This is achieved by modulating the generating excitation so as to develop a component of electrical torque in phase with rotor speed deviations. Levine (1995), Pal and Chaudhuri (2005) presented a control design method for a power system stabilizer in power systems to improve system oscillations. Historically in the power industry, each major advance in improving system performance has created some adverse side effects. For example, the addition of high-speed excitation systems over 40 years ago caused the destabilization known as the ‘‘hunting’’ mode of the generators. The fix was power system stabilizers, but it took over 10 years to learn how to tune them properly and there were some unpleasant surprises involving interactions with torsional vibrations on the turbine-generator shaft (Larsen and Swann 1981). Angquist (1993), Athay (20010) and Ashraf (2000) compared the general performance of series and shunt compensators for stability improvement. Abido (2005) proposed STATCOM based stabilizers for stability improvement. To improve the stability of the system the use of stabilizer is combined with FACTS devices. Al-Biati et al (2001) proposed a coordinated control method for the combination of stabilizer and SVC. Chen et al (2000) explained the performance of stabilizer and compared with SVC. A coordinated design of a Power System Stabilizer and SVC based controller to enhance power system stability is proposed by Abido et al (2005) in which a detailed model of power system is explained and the control algorithm is executed with advanced GA
using blended crossover method. A coordinated design of controller parameters of SVC is proposed by Khodabekshian (2009).

2.3 POWER OSCILLATION DAMPING THROUGH FACTS DEVICES

There has been increasing interest in the application of FACTS device to damp power system oscillations Hingorani (1999). FACTS controllers are power electronic based controllers which can influence transmission system voltage, currents, impedances and/or phase angle rapidly. Such controllers can improve the security of a power system by enhancing its steady state and transient stability or by damping the sub synchronous resonance oscillations. Gao (1992) proposed a new linearization method to control the power system devices.

FACTS controller group employs self-commutated, voltage-sourced switching converters to achieve rapidly controllable, static, synchronous AC Voltage Source (SVS) or synchronous ac current sources. This approach, when compared to conventional compensation methods using thyristor-switched capacitors and thyristor-controlled reactors, generally provides superior performance characteristics and uniform applicability for transmission voltage, effective line impedance, and angle control. It also offers the unique potential to exchange real power directly with the ac system, in addition to providing the independently controllable reactive power compensation, thereby giving a powerful new option for flow control and the counteraction of dynamic disturbances. Haque (2004) used SVC and STATCOM for improving the first swing stability improvement. Static Synchronous Compensators (STATCOM), Static Synchronous Series Compensators (SSSC), Unified Power Flow Controllers (UPFC), and Interline Power Flow Controllers (IPFC) form the group of FACTS controllers employing switching converter-based synchronous voltage sources. The
STATCOM, like its conventional matching part, the SVC, controls transmission voltage by reactive shunt compensation Haque (2006). The TCSC offers series compensation by directly controlling the voltage across the series impedance of the transmission line, thereby controlling the effective transmission impedance Albert Del Rosso (2003). The UPFC can control, individually or in combination, all three effective transmission parameters (voltage, impedance, and angle) or directly, the real and reactive power flow in the line. The IPFC is able to transfer real power between lines, in addition to providing reactive series compensation, and, therefore, can facilitate a comprehensive overall real and reactive power management for a multi-line transmission system. Ghadir Radman (2008) proposed a dynamic model for all FACTS devices.

SVC is the most widely used shunt FACTS devices. It is well known for providing dynamic voltage support and reactive power compensation. The effect of SVC on power – angle curve and the basic control actions based on machine angle deviation ($\Delta \delta$) and machine speed deviation ($\Delta \omega$) to increase damping is analyzed by Zhou et al (1993). On the basis of bang - bang control, a non linear controller for SVC is proposed in Lerch et al (1991). Here the parameters are optimally selected during the disturbance conditions. Hammad (1986) analyzed the SVC based on the system stability. Adi Soeprijanto (2001) analyzed the design of controllers for SVC.

A control strategy based on non linear feedback linearization method which is employed at the voltage control block of the SVC controller is discussed in Wang and Chenin (2000). This approach is shown to be effective for small signal stability which limits the application of SVC for transient conditions. The performance of the SVC for damping power oscillations based on the input signals is also analyzed. Changaroon et al
(1999) proposed a neural network based methodology for controlling SVC. Chung (2000) proposed based on linear quadratic control (LQR) algorithm to improve the damping ratio when generator speed is given as input signal to the SVC controller. Farsangi (2004) proposed a methodology to select the FACTS device based on the input signals.

2.4 OPTIMAL CONTROLLER FOR SVC

To improve system damping using SVC, supplementary controller needs to be designed to provide sufficient damping torque by adjusting the equivalent shunt capacitance. Optimization is a powerful tool for design of controller. This method is conceptually simple. The controller parameters are specified as constraints. The important specification is the selection of objective function which is to be optimized. A classical optimization technique namely, gradient method (Armansyan (1999) is often used to find optimal values. The shortcoming of gradient descent methods are sensitivity to the selection of initial values and their tendency to lock into a local extreme point (Ju 1996). A robust controller for SVC based on GA approach is proposed by Elices (2004).

These optimization methods yield PID parameters by optimizing an Integral Square Error (ISE), Integral of Absolute value of Error (IAE) and Integral Time Square Error (ITSE) performance index (Krohling 2001). The disadvantage of the IAE and ITAE criteria are that they result in a response with relatively small overshoot but long settling time. The ISE performance criterion weights all errors equally independent of time and it can be used easily in mathematical operations. Jimme Cathay (2002) proposed the shunt FACTS device SVC to improve the generator output.
In all of these, tuning is obtained around an operating point where the model can be considered linear. This implies that there is sub-optimal tuning when a process operates outside the validity zone of the model.

Recently, Genetic Algorithm (GA) techniques (Goldberg 1989) have been proposed to tune the PID controller by taking into account all non-linearity and additional process characteristics. GA is a generalized search and optimization technique inspired by the theory of biological evolution.

GA has the capability to solve non-linear and complex optimization problems. Porter and Jones (1992) proposed a GA based technique as a simple, generic method of tuning digital PID controllers. Avatchanakorn (1995) employed GA for on-line parameter identification and controller tuning in load frequency control of a power system. Valarmathi and Devaraj (2007) used GA technique for PID controller to optimize the pH process. Devaraj (2009) proposed a new algorithm with GA technique for tuning the PID controller parameter of AVR. Toranto (1998) used GA to design a robust controller for damping the power system oscillations. PID controller parameters are simple and easy to design, their performance deteriorates when the system operating conditions vary widely and large disturbances occur. Wang and Arrillaga (2003) demonstrated PID based SVC controller in which the controller parameters are optimized using genetic algorithm for the severe disturbance conditions and significant improvements in system damping was achieved.

In order to provide best controller gains for a wide range of disturbance conditions and to attain better dynamic responses, a self tuning controller with its gain settings adapted in real time based on on-line measurements must be employed. Genetic Algorithm techniques have been employed for tuning the PID controller performances which will result in good dynamic performance through optimized controller parameters. Toranto
et al (1998) proposed the design of linear robust decentralized fixed-structure power system damping controllers for SVC using genetic algorithms.

Damping of power oscillation using an adaptive SVC is proposed in (Chin-Hsing Cheng 1992). The PID controller parameters are optimized using GA. Though the GA technique results with the optimized values of controller parameters with the minimization of power system oscillations as objective function, this can be applied only in offline.

2.5 Fuzzy Logic Control of SVC for POD

To achieve the power oscillation damping with SVC controller in real time, on line application based methods are needed. Fuzzy logic applications are found to be suitable for on line control of SVC controller parameters. An attractive feature of fuzzy logic control is its robustness in system parameters and to operating conditions changes. Ghafori (2001) used a fuzzy logic controller for STATCOM proposed an injection model of SVC with fuzzy logic controller for damping the power oscillations where the locally measured signals of voltage and power are given as inputs to the fuzzy controller. In this approach, fuzzy controller replaces the conventional PID controller and the performance of the SVC for damping the inter area mode oscillations and local area mode oscillations are analyzed.

Aboul-Ela (1996), Hiyama (1999), Qun Gu and Anupama Pandey (2003) proposed a fuzzy logic control approach which uses the global signals of rotor angle ‘$\delta$’, machine speed ‘$\omega$’ and system frequency ‘$f$’ as input signals. An adaptive fuzzy logic is proposed by Hongesomput (2001) and Lu et al (2004) in which the adaptiveness of the fuzzy controller is achieved through least square error criterion. In this approach, a single parameter of power ‘$P$’ is considered as input to the fuzzy controller.
Non linear Takagi–Sugeno fuzzy controller for the FACTS devices is proposed by Dash et al (2003) for damping the multimodal power system oscillations. Takashi Hiyama (1999) proposed a fuzzy logic control scheme to enhance power system stability in which a variable gain in the auxiliary controller of SVC is tuned. Dash (1995) proposed the fuzzy logic approach for damping controller employing two input signals speed deviation and acceleration as input signals. In this approach, the output of the fuzzy logic damping controller are defuzzified and denormalized to obtain the crisp control signal. Denormalization and normalization factors are obtained using genetic algorithm. Combination of fuzzy logic and genetic algorithm for SVC leads to additional computational time. Ellithy (1996, 2000) proposed neuro fuzzy based approach to control the SVC. Fang (2004) proposed a adaptive methodology for control of SVC.

From the literature survey, it is inferred that an adaptive controller which can adjust to the system operating condition is necessary for achieving the satisfactory operation of the power system during transient period. In this thesis, an improved GA based approach for determining the optimal parameters of SVC controller is proposed. Further, the research is carried out to develop fuzzy logic approach based on fuzzy inference system to damp out power oscillations. The design aspects and their implementation in form of fuzzy-adaptive switching controllers are presented. This approach is realized in a large power system and is proved to be effective method for the adaptive transient control of FACTS devices. In addition, coordinated control scheme of SVC based on improved GA technique have been developed with global input signals such as speed deviation ($\Delta\omega$) and rotor angle deviation ($\Delta\delta$) to achieve improved damping. Simulation works are done through MATLAB Amos Gilat (2004).