CHAPTER 3

POWER OSCILLATION DAMPING THROUGH STATIC VAR COMPENSATOR

3.1 INTRODUCTION

SVC is one of the shunt FACTS device used to provide automatic and continuous control for maintaining the bus bar voltage constraints. Besides the voltage control as a main task, SVC can be used to damp the power oscillations also. To achieve this, it is necessary to implement additional control scheme such that the output of the SVC can be varied. The variations must be such that damping torque or accelerating power is injected optimally to reduce the oscillations thus provides damping enhancement to the electric power system.

With measured signals at the SVC location, optimized design of the damping controller is determined using suitable optimization and identification procedure taking in to account non linear power systems. As a result, it is possible to increase power system damping considerably, in particular, at critical situations close to the stability limit, thereby to increase the transmission capability of the system.

This chapter explains the basic configuration, modeling and control schemes of SVC to increase power system damping. Basic issues related to the design of SVC controllers are also discussed.
3.2 STRUCTURE OF SVC

An SVC is a shunt connected static generator/absorber of reactive power in which the output is varied to maintain or control specific parameters of an electrical power system. SVC provides dynamic voltage support and reactive power compensation through which it can be used for voltage control, stability and damping control. A Fixed Capacitor–Thyristor Controlled Reactor (FC–TCR) is the most widely employed configuration of SVC in which the TCR provides continuously controllable reactive power in the lagging power factor range and the fixed capacitor provide reactive power in leading power factor domain. The block diagram representation of a FC – TCR configured SVC is depicted in Figure 3.1.

![Figure 3.1 One line diagram of a power system with SVC](image)

The fixed capacitor in practice is usually substituted, by a filter network that has the necessary capacitive impedance at the fundamental frequency to generate the reactive power required, but it provides low impedance at selected frequencies to shunt the dominant harmonics produced by TCR. The functional control scheme of the SVC is shown in Figure 3.2. The control scheme of FC-TCR type var compensator need to provide four
basic functions of (i) synchronous timing (ii) reactive current to firing angle conversion (iii) computation of the required fundamental reactor current and (iv) thyristor firing pulse generation.

Figure 3.2 Functional control scheme of SVC

The FC-TCR type SVC can be considered as a controllable reactive admittance which, when connected to the ac system, faithfully follows (within a given frequency band and within the specified capacitive and inductive ratings) an arbitrary input (reactive admittance or current) reference signal which is shown in Figure 3.3. The V-I characteristic of the SVC indicates that regulation with a given slope around the nominal voltage can be achieved in the normal operating range defined by the maximum capacitive and inductive currents of the SVC as shown in Figure 3.4. The V-I characteristic represents steady state relationship. A typical V-I characteristic determines the range of inductive and capacitive current supplied by the SVC.
Figure 3.3 SVC employing FC - TCR

The dynamic behavior of the compensator in the normal compensating range can be characterized by a specific transfer function based on the variable impedance which is controlled by the converter based arrangements.
3.3 SUPPLEMENTARY CONTROL OF SVC

The SVC voltage regulator processes the measured system variable and generates an output signal proportional to the desired reactive power compensation. It is observed that a voltage controlled SVC does not contribute significantly to system damping. A significant contribution to system damping can be achieved when an SVC is controlled by auxiliary signals superimposed over its voltage control loop. Auxiliary control of SVC based on supplementary control signals, such as bus frequency, line current, line active / reactive power, generator angular velocity is employed to enhance the damping of electro mechanical oscillations through SVC.

The effect of SVC integrated with the voltage regulator and the auxiliary POD controller in damping electro mechanical oscillations is shown in Figure 3.5. The SVC can provide damping to the power system only if the auxiliary damping controllers are incorporated in the SVC control, which modulate the bus voltage in response to a control signal sensitive to power
oscillations. Although both synchronizing and damping torque coefficients are influenced by the generator excitation systems, only the damping torque is affected by the system loads and turbine governors.

SVC voltage regulator generates a susceptance reference signal $\Delta B_{svc}$ that primarily causes the bus voltage to change by $\Delta V_B$ through a function $K_{VB}(s)$ representing the network response. The same susceptance output, $\Delta B_{svc}$, also generates a synchronous torque contribution by acting through a function $K_{TB}(s)$. The SVC voltage regulator is represented by the transfer function $V_{reg}(s)$

$$V_{reg}(s) = \frac{K_R}{1 + sT_R}$$

(3.1)

![Figure 3.5 Block diagram of power system with SVC voltage regulator and auxiliary damping controller](image-url)
An auxiliary control signal, $\Delta x_c$, is provided as input to the SVC auxiliary controller which is the function of modal speed deviation. The auxiliary controller is modeled by the transfer function contributes an additional modulating input, $\Delta V_{\text{mod}}$, to the voltage regulator. The SVC suceptance, $\Delta B_{\text{SVC}}$, generates an inner loop response, $\Delta X_{\text{IL}}$, which influences the auxiliary signal through the transfer function $K_{xB}$ (s). The output represents the compensation value of SVC controller. In the design of electromechanical mode damping controllers, the linearized incremental model around a nominal operating point is usually employed.

Figure 3.6 shows the block diagram of an SVC with a lead lag compensator. The suceptance of the SVC is represented as ‘B’. $K_{\text{SVC}}$ and $T_s$ are control parameters in the voltage control loop. $K$, $T_w$, $T_1$ and $T_2$ are the feed back gain constant, washout time constant and time constants of auxiliary controller of SVC. The time constant for washout filter $T_w$ is provided with fixed value.

![Figure 3.6 SVC with its controller](image)

The controller design based on the modal analysis is discussed in the forthcoming section.
Generally, the damping function of SVC is performed mainly through the changes of the power delivered along the transmission line. With appropriate lead–lag compensation, the damping torque provided by SVC damping control is proportional to the gain of the controller. Since SVC is located in transmission systems, local input signals are always preferable.

POD controller design is based on the following procedure:

- Selection of the proper feedback signal
- Design of the controller using available input signals
- Test the controller under wide range of operation conditions

Considering the close loop system shown in Figure 3.7, where \( G(s) \) represents the transfer function of the original power system and \( H(s) \) is the transfer function of the SVC controller. The output signal \( y(s) \) can be chosen based on the maximum residue provided by the selected outputs.

![Figure 3.7 Transfer function representation of power system with SVC-POD controller](image)

As illustrated in Figure 3.4, SVC POD controller involves a transfer function which can be represented as follows:

\[
H(s) = K_p \frac{s^T_w}{1 + s^T_v} \left[ \frac{1 + s^T_{\text{lead}}}{1 + s^T_{\text{lag}}} \right] = K_p H_1(s) \tag{3.2}
\]
where $K_p$ is a positive constant gain and $H_1(s)$ is the transfer function of the lead lag block. $T_w$ is the washout time constant, $T_{\text{lead}}$ and $T_{\text{lag}}$ are the lead and lag time constant respectively.

### 3.3.1 Selection of Input Signals for POD Controller

While selecting the input signal for the POD controller in SVC following characteristics are to be considered.

- **Sensitivity** of the control signal should be high particularly at higher power levels.

- **Robustness** of the control signal in making positive damping contributions over wide range of system operating conditions.

Some of the locally measurable individual signals that can be potential inputs of the SVC damping controller are as follows:

1. **SVC bus frequency** which relates directly to the changes in the rotor speed near the generator.

2. **SVC bus voltage** which is the main control signal used for voltage regulation. The voltage magnitude is the function of the angular difference across the tie line connecting the two areas.

3. **Active power flow** which is dependent on the rate of angle change. This fact is evident from the linearized swing equation of the generator given in equation (3.2), assuming that the mechanical input power remains constant over the duration of controller action.

4. **Line current flows** which are also affected by the angular difference across the tie lines.
3.4 CONSIDERATIONS IN SVC-POD CONTROLLER DESIGN

While designing an auxiliary controller, following considerations are taken into account.

- The controller is designed primarily for the dominant mode frequency.

- The desired phase angle of the controller transfer function is obtained to the pure damping function. This phase angle is a function of the controllability and observability constants.

- A specific controller gain is fixed for the wide range of damping conditions subjected to the constraints of noise amplification, inner loop controller gain and sub synchronous modes.

- The efficiency of the auxiliary controller must be established for both forward and reverse power flow.

- The controller gain is optimally selected by performing stability simulations for the severe fault conditions in the absence of auxiliary controller, noting down the maximum variation in the auxiliary signal magnitude.

A lead lag compensator comprises a washout stage ($T_w$), high frequency filter stage with a gain ($K_s$). Tuning a control loop is the adjustment of its control parameters to the optimal values for the desired control response. The optimum behavior on a process change or set point change varies depending on the application. Generally stability of the response is required and the process must not oscillate for any combination of process conditions and set points.
3.5 CONCLUSION

In this chapter, the concept of the SVC controller design based on power oscillation mode has been reviewed. The need of auxiliary control for SVC has been presented. The basic configuration of FC-TCR type SVC and its V-I characteristics has been discussed. The design concept of SVC including both voltage regulator and auxiliary controller has been analyzed. The selection of input signals to the SVC and methods used to design the controllers are also discussed. The conventional and the intelligent controllers used for the selection of controller parameters have been outlined.