

Reactive Power Compensation in Transmission Lines by using SSSC

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Abstract: The continuous demand in electric power system network has caused the system to be heavily loaded leading to voltage instability. This paper describe the active approach to series line compensation, in which static voltage sourced converter, is used to provide controllable series compensation. This compensator is called as Static synchronous series compensator (SSSC). It injects the compensating voltage in phase quadrature with line current, it can emulate as inductive or capacitive reactance so as to influence the power flow in the line. In this paper the series compensation for the management of power flow control used to improve the performance of the power system. A PI controller is applied to regulate the amount of injected voltage to the transmission line. The 3-phase VSC is analyzed for controller design, and steady state operation of Static Synchronous Series Compensator (SSSC) without any external energy sources. This paper proposed the superior ability can only be achieved by appropriate control scheme and controller setting.

Keywords: Active And Reactive Power Flow Control, Control Operation Of SSSC, Flexible AC Transmission System (FACTS), Modes Of SSSC, Series Power Line Compensation.

I. INTRODUCTION

Nowadays, the need for flexible and fast power flow control in the transmission system is anticipated to increase in the future in view of utility deregulation and power wheeling requirement. The utilities need to operate their power transmission system much more effectively, increasing their utilization degree. Reducing the effective reactance of lines by series compensation is a direct approach to increase transmission capability. However, power transfer capability of long transmission lines is limited by stability considerations. [1] Power system planers, operators, and engineers have learned to live with this limitation by using a variety of ingenious techniques to make the system work effectively, but at a price of providing greater operating margins and redundancies. These represent an asset that can be effectively utilized with prudent use of FACTS technology on a selective, a needed basis. i.e. Proportional Integral Controller, Real and Reactive Power Flow, Voltage Stability. The FACTS devices (Flexible AC Transmission Systems) could be a means to carry out this function without the drawbacks of the electromechanical devices such as slowness and wear. FACTS can improve the stability of network, such as the transient and the small signal stability, and can reduce the flow of heavily loaded lines and support voltages by controlling their parameters including series impedance, shunt impedance, current, and voltage and phase angle. Controlling the power flows in the network leads to reduce the flow of heavily loaded lines, increased system load ability, less system loss and improved security of the system.

A Static Synchronous Series Compensator (SSSC) is a member of FACTS family which is connected in series with a power system. It consists of a solid state voltage source converter (VSC) which generates a controllable AC voltage at fundamental frequency. When the injected voltage is kept in quadrature with the line current, it can emulate as inductive or capacitive reactance so as to influence the power flow through the transmission line [2, 3]. While the primary purpose of a SSSC is to control power flow in steady state, it can also improve transient stability of a power system [6]. Series compensation is a means of controlling the power transmitted across transmission lines by altering or changing the characteristic impedance of the line. The power flow problem may be related to the length of the transmission line. The transmission line may be compensated by a fixed capacitor or inductor to meet the requirements of the transmission system. When the structure of the transmission network is considered, power flow imbalance problems arise. Inadvertent interchange occurs when the power system tie line becomes corrupted. This is because of unexpected change in load on a distribution feeder due to which the demand for power on that feeder increases or decreases. The generators are to be turned on or off to compensate for this change in load. If the generators are not activated very quickly, voltage sags or surges can occur. In such cases, controlled series compensation helps effectively.

II. VOLTAGE SOURCE CONVERTER

The series compensation scheme for a transmission line power controller, based on a series connected Voltage Source

Converter (VSC), is shown in Fig.1. The VSC is connected to the transmission line by a 3-phase transformer. The VSC converts a dc voltage to a controllable set of symmetrical 3-phase voltages. Various types of PWM or multi-pulse control techniques can be employed to perform this power conversion and minimize the production of harmonics to produce a high quality sinusoidal output waveform. By adjusting (a) the angular position of the 3-phase injected voltages with respect to the transmission line currents and (b) the magnitude of the injected voltages, the VSC is able to exchange reactive and/or active power with the transmission line. However, it is pointed out that only a VSC equipped with a (substantial) energy storage device in the dc side can actually supply (steady state) active power to the transmission line.

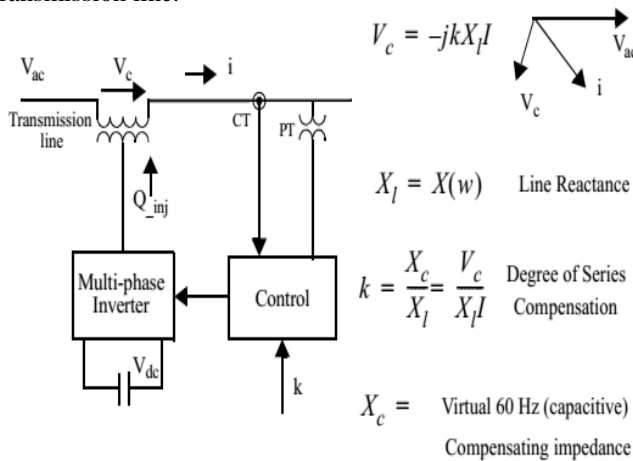


Fig.1. SSSC operates as a Series Capacitive Compensator [4].

The injected voltages can be controlled either directly by varying the converter's output to input ratio (modulation index) or indirectly by regulating the dc side voltage of the VSC. The indirectly controlled converters are simpler to implement than directly controlled converters. In indirectly controlled converters only the angular position of the injected voltages (with respect to the transmission line currents) are controlled and their magnitudes remain substantially proportional to the dc side voltage, and the converter is designed primarily to exchange reactive power with the transmission line. However, since the converter usually has some active power losses (i.e. due to imperfect switching devices and resistive losses) the dc voltage risks being depleted unless it can be supplied from either an external or an alternative source. A small amount of active power can be drawn from the transmission line if the injecting voltage is displaced in angular position to maintain the dc voltage. For simplicity and rapid simulation reasons, only a single 2-level PWM VSC operating at 900 Hz switching frequency is employed. For this reason, a small low-pass output filter is employed with the converter. In practical schemes, 4 or 8 multiple converters with a transformer arrangement will be used to reduce the harmonics generated and produce a very high quality sinusoidal output waveform with either 24 or 48 steps respectively; in this case, no output filter is needed.

III. POWER CIRCUIT

In Fig.2, the power circuit of the VSC is shown. A six pulse converter is used in a 2-level PWM topology. The resistor R in parallel with the dc capacitor C represents the VSC switching losses, and a low-pass delta connected filter (comprising of L_f and C_f) on the ac side eliminates the undesired harmonics generated by the converter. In a practical application, two or four such converters with a magnetic coupler would be used to elevate the pulse number and reduce the harmonics. For the moment, only a single bridge is used for academic purposes. Although the 2-level PWM topology used here offers a simple converter configuration, it has the following disadvantages [6]

- High dv/dt ratio,
- High switching frequency harmonic and
- Static and dynamic voltage sharing of series devices.

Consequently, snubber circuits and an output filter are needed. The snubber circuits and output filter are selected to minimize the output harmonics and switching stresses. Fig.3 shows the switch model with snubber circuits that are used in the converter model.

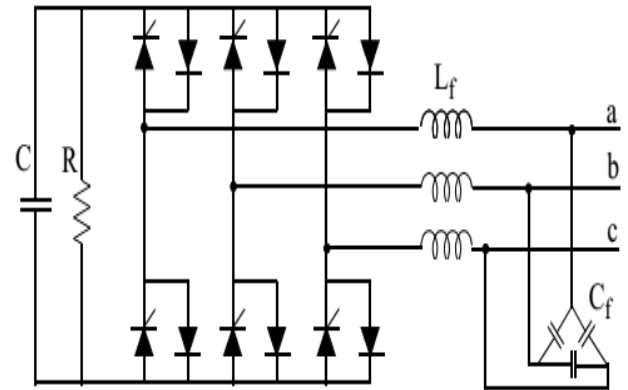


Fig. 2. Power circuit of SSSC.

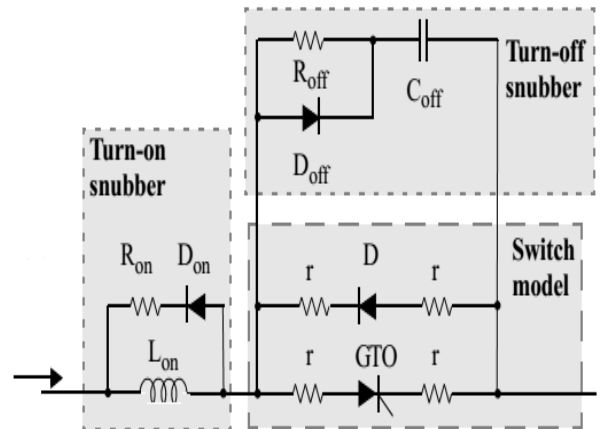


Fig.3. Model of the switch and snubber circuits.

The small resistors r, in series with the GTO and the anti-parallel diode, represent the switch conduction losses and assist in avoiding any singularity on the inversion of the conductance matrix of the circuit. The polarized series R-L turn-on snubber circuit (consisting of Ron, Lon and Don)

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limits the rate of rise of current, and the polarized parallel R-C circuit (consisting of R_{off}, C_{off} and D_{off}) limits the over-voltages during switch turn-off. The values of the snubbers were obtained from equation (1) [7] and fine tuned by trial and error. The high quality of the switching is evident and the over-voltages are contained. The time-step used is 10 μs to provide a good simulation. With a smaller time step, the waveform quality would be marginally improved but at the expense of a longer simulation time.

$$\begin{aligned}
 R_{on} &= \frac{\Delta V_{CE}}{I_o} \\
 \Delta V_{CE} &= 10\% U_d \\
 L_{on} &= \frac{\Delta V_{CE} * t_{ri}}{I_o} \\
 C_{off} &= \frac{I_o * t_{fi}}{2 * U_d} \\
 R_{off} &= \frac{5 * U_d}{I_o}
 \end{aligned}
 \tag{1}$$

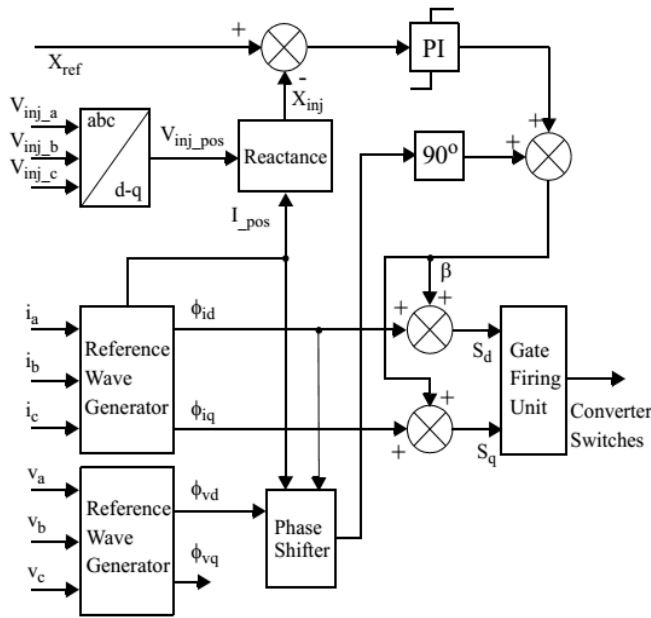


Fig.4. Indirect controller for series VSC.

Where t_{ri} and t_{fi} represent the current rise time and current fall time of the switch, and is the voltage drop during the turn-on across the switch as shown in Fig.4.

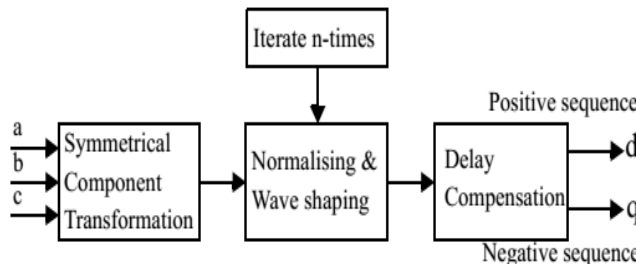


Fig.5. Block diagram for Reference Wave Generator [1].

Further details about individual blocks in the controller are given below.

A. Synchronizing technique

The 3-phase transmission line currents (i_a , i_b and i_c) are used as the reference signals by the controller to generate either lagging or leading voltages by 90 degrees in series with the transmission line voltages. In [1] a Reference Wave Generator (RWG) (Fig.5), based on symmetrical components transformation, was introduced. The 3-phase transmission line currents are transformed into positive, negative and zero sequence components, as indicated by eq. (3):

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 1 & 1 \\ \sqrt{2} & \sqrt{2} & \sqrt{2} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}
 \tag{2}$$

Subsequently, a normalizing and wave-shaping block is applied to obtain the original wave under any conditions. And a delay compensation block is used to compensate for the delay caused by the previous wave-shaping block. The delay result of five iterations for a 60 Hz utility frequency and a 10 microsecond sampling time is 1.08 degrees. The output reference waves (positive and negative sequences) are synchronized continuously with the 3-phase input original waves which could be distorted or contain harmonics. When this approach is compared to a conventional Phase Locked Loop (PLL) technique [5] for extracting distortion free reference waves, this method has a very fast response to any distortion, and is almost without any transient delay [1].

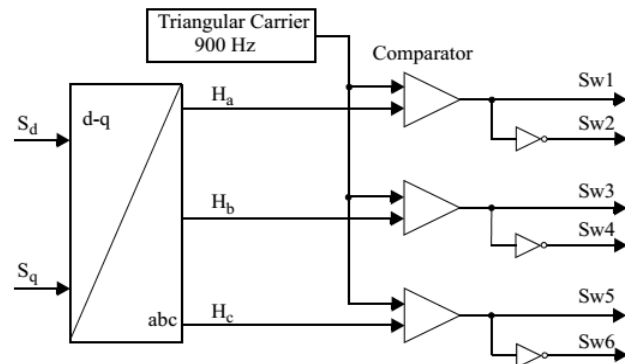


Fig. 6. Gate firing unit block diagram.

B. Gate Firing Unit (Fig.6)

This block provides the firing signals for the six VSC switches. First, the desired sinusoidal waveforms S_d and S_q are transformed from the d-q axes to 3-phase waveforms (H_a , H_b and H_c). Each phase waveform is then compared to a triangular carrier at 900 Hz, and produces the firing pulses to the six switches of the VSC.

C. Phase Shifter Unit (Fig.7)

This block determines the operational mode of the VSC i.e. whether it operates in capacitive or inductive mode. This decision is made based on either one of two factors:

- First, it senses the phase angle between the positive sequence components of the transmission line voltage ϕ_{vd} and positive sequence line current ϕ_{id} . Since the power system normally operates with an inductive load, the phase shifter output sign is negative, and sets the VSC to operate in the capacitive mode to compensate for the inductive load.
- Second, the positive sequence component of line current (I_{pos}) is compared to a fault current reference value (I_{lim}). This current reference value is pre-set as the condition of an over current limit. Should I_{pos} exceed this limit, the output sign of the phase shifter is made positive and sets the VSC operation mode in an inductive mode of operation.

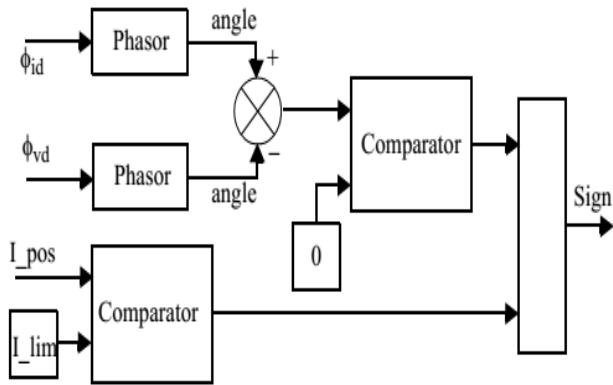


Fig.7.Phase Shifter block diagram.

IV. MATLAB/SIMULINK RESULTS

Simulation results of this paper is as shown in bellow Figs.8 to 11.

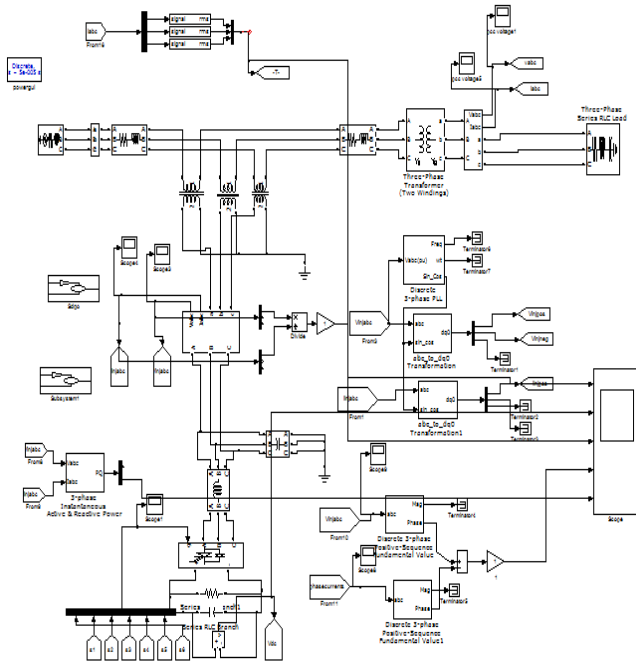


Fig.8.Matlab/Simulink Model of Static Synchronous Series Compensator operates as a Series Capacitive Compensator.

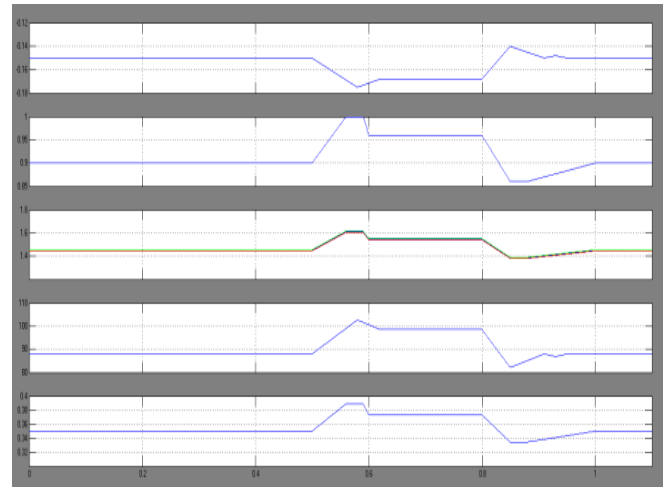


Fig.9.System response to step change in controller reference value (a) Injected reactance (b) Dc side voltage (c) Transmission line currents (d) phase angles (e) Injected reactive power.

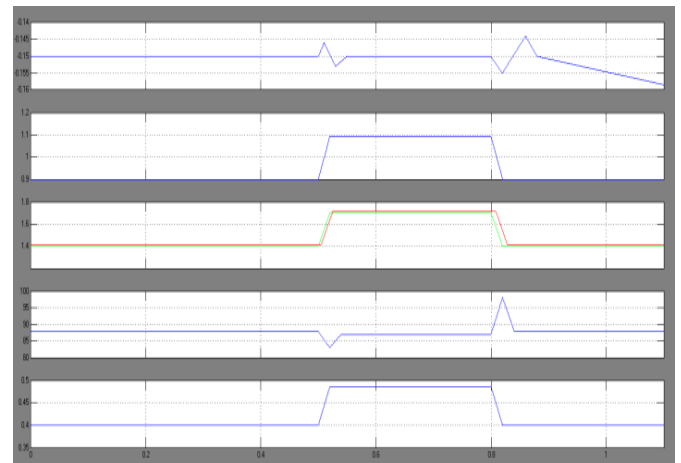


Fig.10.Impact of load variation (a) Injected reactance (b) Dc side voltage (c) Transmission line current (d) Phase angle (e) Injected reactive power.

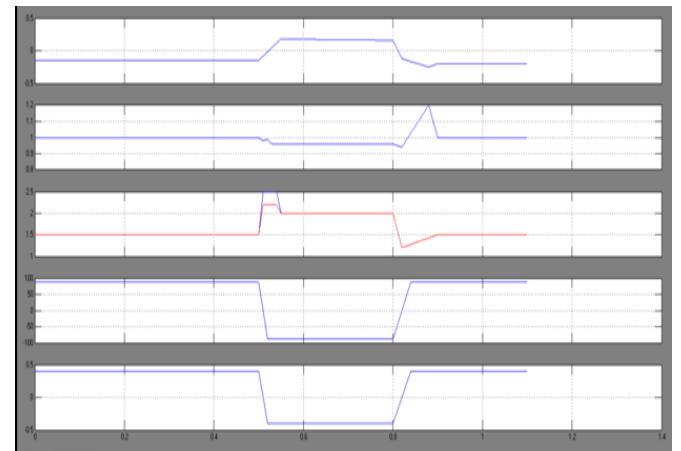


Fig.11. System Responses To 3 Lines-To-Ground Fault (a) Injected reactance (b) Dc side voltage (c) Transmission line current (d) Phase angle (e) Injected reactive power.

V. CONCLUSION

The series VSC regulates the transmission line impedance by using an indirect controller. In this paper, simulation of various aspects of Static Synchronous Series Compensator (SSSC), which are, power oscillation damping, improving transient stability done in Matlab-Power System Block set (PSB). Improvement of transient stability and dynamic stability by SSSC is explained. The simulation results reveal that the SSSC device with power oscillation damping (POD) controller are more effective and bitterly improve the active, reactive power flow and voltage control in a power system as compared to STATCOM device.

VI. REFERENCES

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