Improvement of Power System Transient Stability using Static Synchronous Series Compensator (SSSC)

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Abstract

This paper describes improvement of power transfer capability in IEEE 4 bus 2 machine system using Static Synchronous Series Compensator (SSSC). It is known that series controller is always contributing a better performance for power transfer capability through transmission line. Here Static synchronous series compensator (SSSC) has been used as a switching converter type series compensation. Power oscillation damping (POD) has been incorporated as a controller to damp out the oscillation. Simulation result shows after installing SSSC between bus no. 1 & 2, the power flow has been improved. The work has simulated in MATLAB Simulink 2010 and output has been compared with and without Static synchronous series compensator (SSSC).

Keywords: Static Synchronous Series Compensator (SSSC), POD Controller, Stability, Transient Stability, 4-Bus 2 Machine Systems

I. INTRODUCTION

Series compensation always plays a big role to improve power transfer capability through transmission line. Series controller can be applied variable Impedance type and switching converter type. SSSC comes under the family of switching converter type. The primary purpose of a SSSC is to control power flow in steady state, while it can also improve transient stability of a power system. The main interest is to use the SSSC for controlling power flow (active and/or reactive) in transmission lines. SSSC is connected at 4 buses 2 machine power systems. It is simulated using MATLAB and SSSC has been included with Power Oscillation Damping (POD) Controller.

Series capacitive compensation was introduced decades ago to cancel a portion of the reactive line impedance and thereby increase the transmittable power. Power flow increased by inserting an additional capacitive reactance in series with the transmission line, thereby decreasing the effective reactance of the transmission line between its two ends. Rather than shunt controller series controller controls the complex power so smoothly.

II. STATIC SYNCHRONOUS SERIES COMPENSATOR

The SSSC is generally connected in series with the transmission line. SSSC comprises voltage source converters.
And a DC capacitor. The injected voltage of the coupling transformer $V_s$ is perpendicular to the line current. SSSC is used for controlling active and reactive power in transmission line one side of the converter. It is connected to AC system and other side is connected to a capacitor and battery. It assumes DC source as battery installation to allow active as well as reactive power exchanges with the AC system. The voltage with $V_{pq}$ with respect to the transmission line $I_{line}$ determines exchange of real and reactive power with the AC system [1]. The active and reactive power exchange between the SSSC and the transmission line can be calculated as follows. [9]

$$P_{pq} = V_{pq} \cdot I_{line} \cos \phi$$
$$Q_{pq} = V_{pq} \cdot I_{line} \sin \phi$$

Where $\phi$ represents the angle between the injected SSSC. The angle between the output voltage of SSSC and line current is approximately 90. It shows that SSSC real power is small compared to reactive power. The real power going in SSSC is used only to cover for the losses and charging of the dc capacitor [9]

$$P_{pq} = P_{dc} + P_{losses}$$

Basic Operating Principle of The SSSC.

**Fig. 2**: SSSC phasor diagram

Fig 2. shows that SSSC where DC capacitor exchange by an high energy battery installation to allow active as well as reactive power exchanges with AC system. Phase displacement of the inserted voltage $V_{pq}$ with respect to line current determines exchange of active and reactive power with the AC system. Fig 2. show that line current phasor is used as reference phasor while injected SSSC voltage phasor is rotate around the center of the circle defined by the maximum inserted voltage $V_{pqmax}$. In capacitive mode, injected SSSC voltage is made to lag the transmission line current by 90 degree. In this case, the SSSC operation similar to the operation of series capacitor with variable capacitance $K*Xc$. where $K$ is a variable $V_{pq} = -jK*Xc*I_{line}$. [9] Also possible to reverse the injected SSSC voltage by 180, i.e., $V = jK*Xc*I_{line}$. Causing an increase in the transmission line reactance, which result in decrease of the line current [9]

**III. MULTI-MACHINE POWER SYSTEM WITH SSSC**

**Fig. 2**: Multi-Machine Power System with SSSC
The power grid consists of three power generation substations and one major load Centre at bus B1. The first power generation substation M1 has a rating of 2100 MVA, and the other one M2 has a rating of 1400 MVA. This system which has been made in ring mode consisting of 4 buses (B1 to B4) connected to each other through three phase transmission lines L1, L2-1, L2-2, and L3 with the length of 280, 150, 150 and 5 km. The phase to phase voltage equal to 13.8 kv.

IV. SSSC POWER OSCILLATION DAMPING CONTROLLER (POD)

SSSC can be used for damping power oscillation and so enhance the overall dynamic performance of the system. In Fig 3 POD consists of the three blocks. 1) wash out filter blocks 2) phase compensator block 3) gain block. The washout filter block is used to avoid a POD response to the steady-state changes of the input signal. Phase compensator block provides the appropriate phase lag/lead characteristics and stabilizer gain Ks determine the amount of damping introduced by POD.

The selection of an appropriate input signal is a fundamental issue in the design of an effective and robust POD controller. Locally measurable signals are always preferred as input signal.

Signal such line active power, line reactive power, line current magnitude, bus voltage magnitude and angles are considered in the selection of input signals for the POD controller in this paper bus voltage and bus current are considered for input signal.

POD design method

A number of design methods may be used for POD parameter tuning. The most popular ones are based on frequency response [19, 20], eigenvalue sensitivities [21] as well as a combination of these methodologies.

The phase parameters of the phase compensator block are computed as [18]

\[ T = \frac{1}{\omega_n \sqrt{\alpha}} \]

\[ \alpha = \frac{1 - \sin(\varphi/n)}{1 + \sin(\varphi/n)} \]

Where \( \varphi \) the phase to be compensated, \( \omega_n \) is the frequency of the mode to damp and \( n \) the number of lead-lag networks usually 10% damping ratio is considered to be enough. [18]

V. SIMULATION AND RESULT

First power system with two machines and four buses has been simulated in MATLAB environment and then powers and voltages in all buses have been obtained. The results have been given in Table 1. Using obtained result bus 2 has been selected as a candidate bus to which the SSSC be installed. Therefore the simulation results have been focused on bus 2.

<table>
<thead>
<tr>
<th>Bus NO</th>
<th>V PU</th>
<th>I PU</th>
<th>P PU</th>
<th>Q PU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>13.5</td>
<td>20.6</td>
<td>-3.76</td>
</tr>
<tr>
<td>2</td>
<td>1.007</td>
<td>6.7</td>
<td>9.95</td>
<td>-1.82</td>
</tr>
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<td>3</td>
<td>1.002</td>
<td>9.8</td>
<td>14.85</td>
<td>-0.48</td>
</tr>
<tr>
<td>4</td>
<td>1.015</td>
<td>5.5</td>
<td>8.45</td>
<td>-0.59</td>
</tr>
</tbody>
</table>
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Fig. 4: Reactive power of bus-2 without SSSC

Fig. 5: Voltage bus-2 without SSSC

Fig. 6: Active power of bus-2 without SSSC
Change in current, voltage, active and reactive powers of bus-2 have been obtained in real time. The controlling systems in power plants 1,2 such as governor, PSS and other stabilizing devices are used for damping these oscillations. Oscillations amplitude for active power is more than reactive power, and this is because the ohmic parts of loads of system are much more.

Fig. 7: Active power of bus-2 with SSSC

Fig. 8: Reactive power of bus-2 with SSSC

Fig. 5: Voltage bus-2 with SSSC
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Fig. 9: Matlab/Simulink Result with SSSC

Fig. 10: Pod controller sub system
VI. CONCLUSION

It has been found that the SSSC is capable of controlling the flow of power at a desired point on the transmission line. It is also observed that the SSSC injects a fast changing voltage in series with the line irrespective of the magnitude and phase of the line current. Based on obtained simulation results the performance of the SSSC has been examined in a multimachine system, and applications of the SSSC will be extended in future to a complex system to investigate the problems related to the various modes of power oscillation in the power system.

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