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Power System Stability Analysis Using Static Synchronous Series Compensator

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Abstract: The objective of this paper is to make an investigation in enhancement of voltage stability, power flow transfer capability in the transmission network using static synchronous series compensator. In our analysis we have discussed about twelve pulse static synchronous series compensator which can be operated with and without superconducting magnetic energy storage which results in enhancing the power oscillation damping, voltage stability in power system. The work was carried out using MATLAB 8.0. Simulink results show SSSC is more effective in increasing the transmission capacity and to enhance the voltage stability of power system under various transient disturbances.

Key words: Stability · SSSC · Power oscillation damping · Transmission capacity

INTRODUCTION

In recent years the development of modern interconnected power system is very high complex in nature. In this operation the important key requirements of the electric power system is the reliability and security. To maintain stability for such an interconnected multi area power systems become a huge task. To diagnosis these problems, the Flexible AC Transmission System (FACTS) devices were introduced. Today the new Energy Storage System (ESS) is interfaced with Flexible AC Transmission System device to increase its efficiency. During bulk power transmission the power electronics based controllers called FACTS, are used to simulate control of real and reactive power flow control. The static synchronous series compensator (SSSC) is a controller of FACTS family which is used to prove its efficiency in terms of stability improvement. The design consists of a solid state voltage source converter (VSC) which is used to generate a controllable AC voltage at fundamental frequency. The injected voltages are kept in quadrature with the line current, so that it can emulate as inductive or capacitive reactance. This is done to influence the power flow through the transmission line. The primary work of a SSSC is to control power flow analysis in steady state condition. In the literature survey several methods have been proposed for computing power flow equations [1-3]. The voltage sensitivity method [4-6] are the most direct approach methods for voltage sensitivity to system parameters. Energy method has been discussed for voltage security assessment [7-9], but it is seems to be highly nonlinear and complex for numerical routines. Different types of FACTS devices [10-14]. From the above review, the basic model of the SSSC which has DC capacitor has been replaced by an energy storage device such as a high energy battery installation which allows active as well as reactive power exchanges with the AC system.

The Basic Operation of SSSC: The Static Synchronous Series Compensator (SSSC) is a series device of FACTS family. The power electronics devices are used to control power flow and improve power oscillation damping on power grids. Here SSSC injects a voltage Vs in series with the transmission line where it is connected SSSC does not use any active power source; the injected voltage must stay in quadrature with line current. By varying the magnitude Vq of the injected voltage in quadrature with current, the SSSC performs the function of a variable reactance compensator, either capacitive or inductive. The variation of injected voltage is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage Vconv from a DC voltage source. A capacitor connected on the DC side of the VSC acts as a DC voltage source. A small active power is drawn from the line to keep the capacitor charged

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and to provide transformer and VSC losses, so that the injected voltage Vs is practically 90 degrees out of phase with current I. In the control system block diagram Vd_conv and Vq_conv designate the components of converter voltage V_conv which are respectively in phase and in quadrature with current shown in Fig.1. Two VSC technologies can be used for the VSC: a). VSC using GTO-based square-wave inverters and special interconnection transformers. Typically four three-level inverters are used to build a step voltage waveform. Special interconnection transformers are used to neutralize harmonics contained in the square waves generated by individual inverters. In this type of VSC, the fundamental component of voltage Vconv is proportional to the voltage Vdc. Therefore Vdc has to vary for controlling the injected voltage. b). VSC using IGBT-based PWM inverters. This type of inverter uses Pulse-Width Modulation (PWM) technique to synthesize a sinusoidal waveform from a DC voltage with a typical chopping frequency of a few kilohertz. Harmonics are cancelled by connecting filters at the AC side of the VSC. This type of VSC uses a fixed DC voltage Vdc. Voltage Vconv is varied by changing the modulation index of the PWM modulator. The SSSC (Phasor Type) block models an IGBT-based SSSC (fixed DC voltage). However, as details of the inverter and harmonics are not represented, it can be also used to model a GTO-based SSSC in transient stability studies.

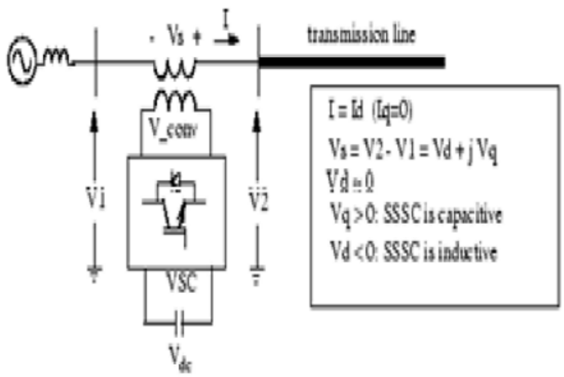

Fig: 1 Single line Diagram of SSSC

The Control System Consists of: A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the current I. The output of the PLL (angle È=ùt) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltages and currents (labeled as Vd, Vq or Id, Iq on the diagram). The Measurement systems measuring the q components of AC positive-sequence of voltages V1 and V2 (V1q and V2q) as well as the DC voltage Vdc. AC and DC voltage regulators which compute the two components of the converter voltage (Vd_conv and Vq_conv) required to obtain the desired DC voltage (Vdcref) and the injected voltage (Vqref). The Vq voltage regulator is assisted by a feed forward type regulator which predicts the V_conv voltage from the Id current measurement is shown in Fig. 2.

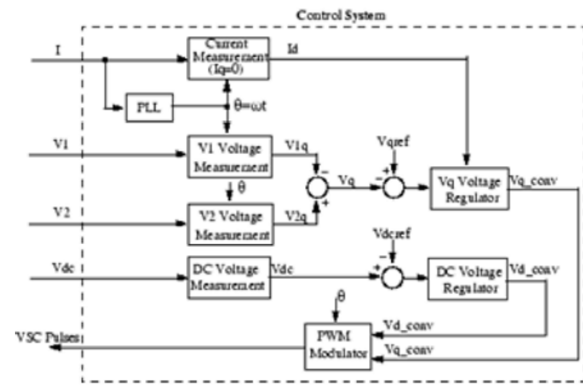

Fig. 2: Control Parameters of SSSC

Simulation Analysis:

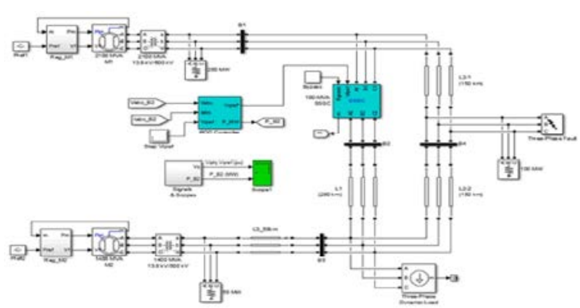

Fig. 3: MATLAB Simulation of SSSC

The simulation circuit of SSSC is shown in Fig.3. The Static Synchronous Series Compensator (SSSC), one of the important FACTS devices, consists of a voltage-sourced converter and a transformer connected in series with a transmission line. The SSSC injects a voltage of variable magnitude in quadrature with the line current, thereby emulating an inductive or capacitive reactance. This emulated variable reactance in series with the line can then influence the transmitted electric power. The SSSC is used to damp power oscillation on a power grid following a three-phase fault. The power grid consists of two power generation substations and one major load center at bus B3.

The first power generation substation (M1) has a rating of 2100 MVA, representing 6 machines of 350 MVA and the other one (M2) has a rating of 1400 MVA, representing 4 machines of 350 MVA. The load center of approximately 2200 MW is modeled using a dynamic load model where the active & reactive power absorbed by the load is a function of the system voltage. The generation substation M1 is connected to this load by two transmission lines L1 and L2. L1 is 280-km long and L2 is split in two segments of 150 km in order to simulate a three-phase fault (using a fault breaker) at the midpoint of the line. The generation substation M2 is also connected to the load bya 50-km line (L3). When the SSSC is bypass, the power flow towards this major load is as follows: 664 MW flow on L1 (measured at bus B2), 563 MW flow on L2 (measured at B4) and 990 MW flow on L3 (measured at B3).The SSSC, located at bus B1, is in series with line L1.

It has a rating of 100MVA and is capable of injecting up to 10% of the nominal system voltage. This SSSC is a phasor model of a typical three-level PWM SSSC. If you open the SSSC dialog box and select "Display Power data", you will see that our model represents a SSSC having a DC link nominal voltage of 40 kV with an equivalent capacitance of 375 mF. On the AC side, its total equivalent impedance is 0.16 pu on 100 MVA. This impedance represents the transformer leakage reactance and the phase reactor of the IGBT Bridge of an actual PWM SSSC. The SSSC injected voltage reference is normally set by a POD (Power Oscillation Damping) controller whose output is connected to the Vqref input of the SSSC. The POD controller consists of an active power measurement system, a general gain, a low-pass filter, a washout high-pass filter, a lead compensator and an output limiter. The inputs to the POD controller are the bus voltage at B2 and the current flowing in L1.

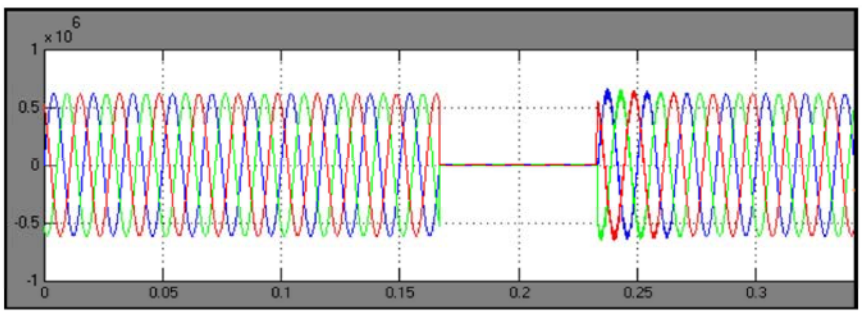

Fig. 4: Three phase voltage waveform with fault occurrence and clearance using SSSC

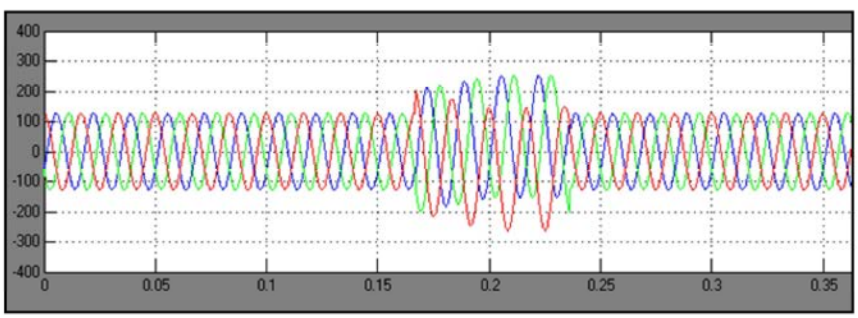

Fig. 5: Three phase current waveform with fault occurrence and clearance using SSSC

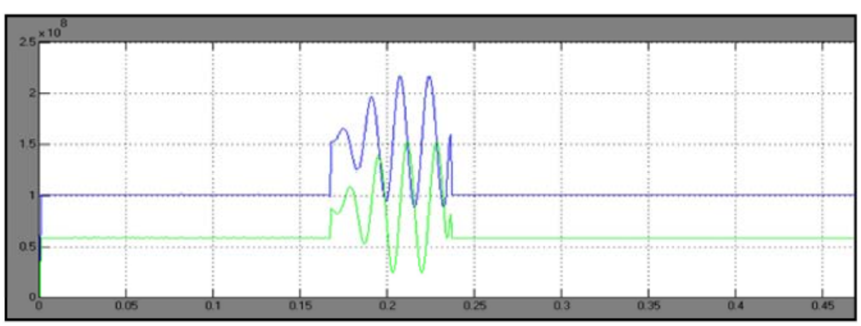

Fig. 6: Three phase Power waveform with fault occurrence and clearance using SSSC

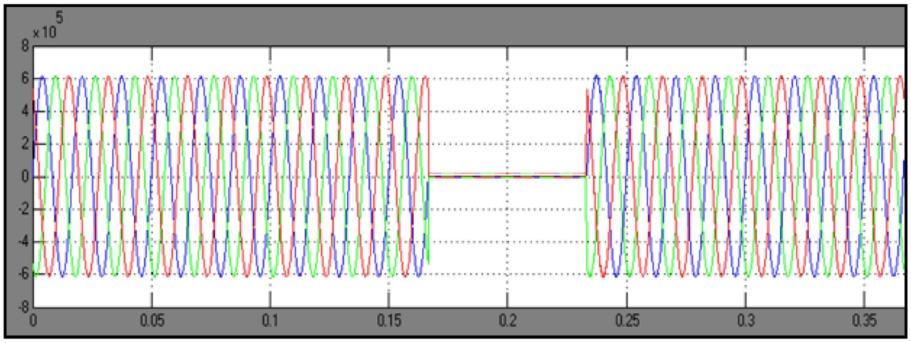

Fig. 7: Three phase voltage waveform with fault occurrence and clearance using SSSC with ESD

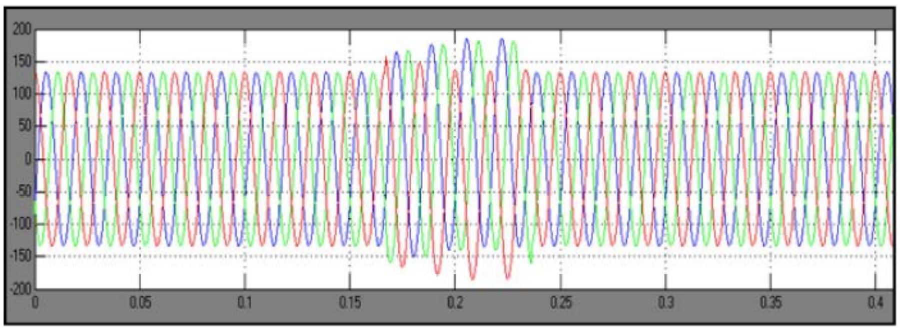

Fig. 8: Three phase current waveform with fault occurrence and clearance using SSSC with ESD

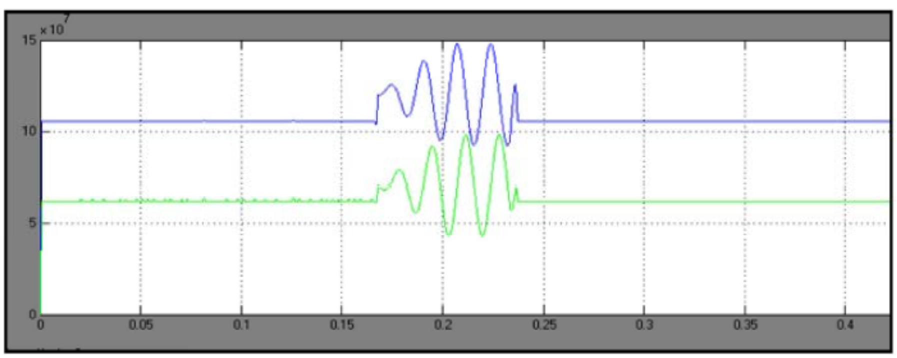

Fig. 9: Three phase Power waveform with fault occurrence and clearance using SSSC with ESD

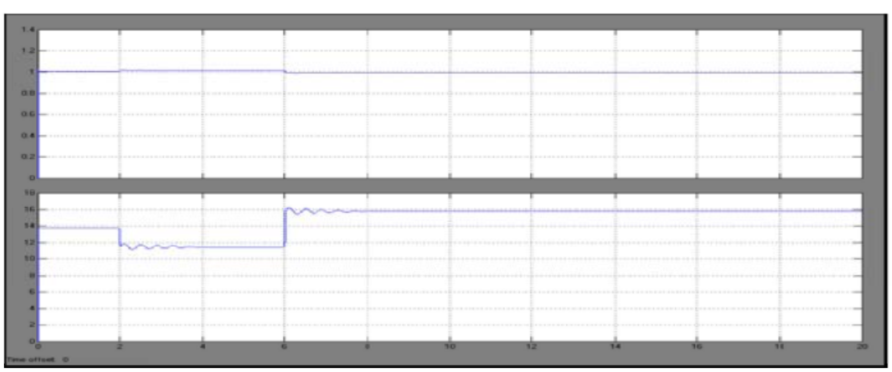

Fig. 10: Voltage and Current at bus-2 with SSSC

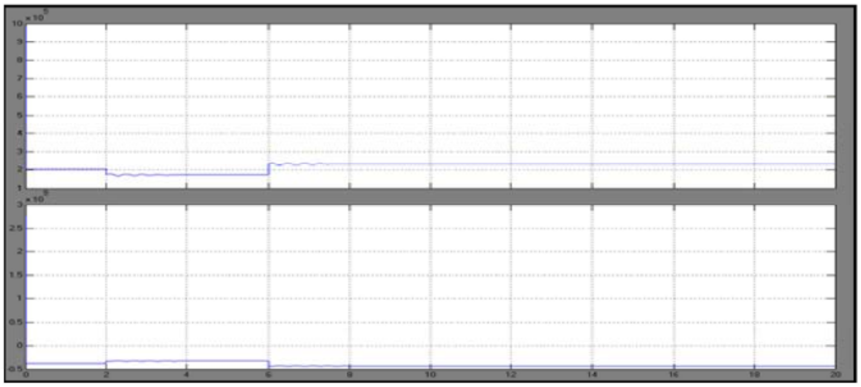

Fig. 11: Real and Reactive Power at bus-2 with SSSC

In our work the simulink network is tested with SSSC. From Fig.4 the voltage waveform results clearly infer the fault occurrence time 0.1667 seconds and clearance of fault is 0.2333 seconds. Similarly Fig.5 and Fig.6 clearly discuss about the current and power waveform. Here energy storage device is used with SSSC to improve the performance. In this paper, SMES with chopper control type ESD is used to plays an important role in real power exchange. The corresponding voltage, current and power waveforms are shown in Fig.7, Fig.8 and Fig. 9 respectively. The Power oscillation clearing time for SSSC is 0.2380 seconds and for SSSC with ESD is 0.2315 seconds.

In order to evaluate the stability, the fault case near the bus 2 is considered. In this work the post-fault analysis is also done to determine the corresponding voltage, current and power waveform. From the Fig.10 and Fig.11 it is also observed that the SSSC injects voltage in series with the line irrespective of the magnitude and phase of the line current. After the installation of SSSC the bus-2maintains constant voltage value in 1per unit.

CONCLUSION

In this paper the continuous performance of the Static Synchronous Series Compensator with and without storage element for a system is analyzed with MATLAB-simulink. The simulation results infer that the SSSC with MES is very effective in transient stability enhancement and damping power oscillations. This is maintaining throughout the transmission lines after the disturbance in power flow. The response time seems to be better when comparing to conventional systems. However, the major drawback of the present system is the total cost of a SSSC installation which is higher than the cost of other FACTS devices.

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