



RESEARCH ARTICLE

Enhancement Of Voltage Stability And Power Oscillation Damping Using Static Synchronous Series Compensator With Smes

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ABSTRACT

The power system network is becoming more complex nowadays and it is very difficult to maintain the stability of the power system. The main purpose of this paper proposes a 12-pulse based Static Synchronous Series Compensator (SSSC) with and without Superconducting Magnetic Energy Storage (SMES) for enhancing the voltage stability and power oscillation damping in multi area system. Control scheme for the chopper circuit of SMES coil is designed. A three area system is taken as test system and the operation of SSSC with and without SMES is analysed for various transient disturbances in MATLAB / SIMULINK environment.

Keywords— Static Synchronous Series Compensator (SSSC), Superconducting Magnetic Energy Storage (SMES), multi area system, transient disturbances.

1. INTRODUCTION

Today's modern interconnected power system is highly complex in nature. In this, one of the most important requirements during the operation of the electric power system is the reliability and security. Maintaining stability of such an interconnected multi area power system has become a cumbersome task. As a counter measure against these problems, the Flexible AC Transmission System (FACTS) devices were proposed. Nowadays, the new Energy Storage System (ESS) is interface with FACTS device to increase its performance. In bulk power transmission systems, power electronics based controllers called FACTS, used to simultaneous control of real and reactive power flow control, has been proposed in the literature [1]-[2].

Presently, FACTS devices are a viable alternative as they allow controlling voltages and current of appropriate magnitude for electric power system at an increasingly lower cost [3]. However, a comparable field of knowledge on FACTS/ESS control is quite limited. Therefore, in this work a methodology is proposed to control the power flow, which uses FACTS controllers with energy storage. Using switching power converter-based FACTS controllers can carry this out. Among the different modeling of FACTS devices, SSSC is proposed as the most adequate for the present application well discussed [4]. The DC inner bus of the SSSC allows incorporating a substantial amount of energy storage in order to enlarge the degrees of freedom of the

SSSC device and also to exchange active and reactive power with utility grid. Based on a previous study of all energy storage technologies currently available, the use of SMES is proposed for the considered application has been presented in [5]-[6]. Novel reactive power controllers for STATCOM and SSSC have been reported [7].

This paper proposes a model of SSSC with and without SMES to carry out the power flow control in the electric system. The SMES coil has been connected to the Voltage Source Converter (VSC) through the dc-dc chopper. Detail on operation, control strategy of SSSC, chopper control of SMES and simulation results for SSSC with and without SMES are presented in the subsequent sections.

II. SSSC INTEGRATED WITH SMES

SSSC is a Voltage Sourced Converter (VSC) based series compensator. In this, compensation works by increasing the voltage across the impedance of the given physical line, which in turn increases the corresponding line current and the transmitted power. For normal capacitive compensation, the output voltage lags the line current by 90°. With voltage source inverters the output voltage can be reversed by simple control action to make it lead or lag the line current by 90°. The addition of energy storage device is helpful in exchanging the real power. Without energy storage device, exchanging of real power is not efficient.

A SMES containing electronic converters rapidly injects and/or absorbs the real and/or reactive power or dynamically controls the power flow in an ac system. Since the dc current in the magnet does not change rapidly, the power input or controlling the voltage across the magnet with a suitable electronics interface changes the output of the magnet. The single line diagram of the multi area test system used for the simulation study is shown in Fig. 1.

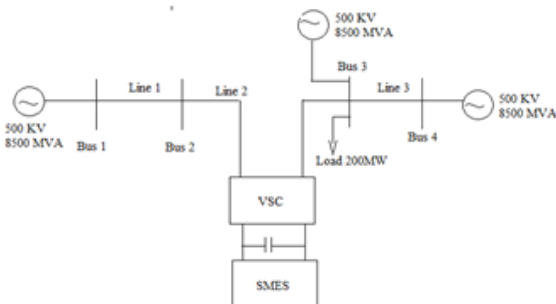


Fig. 1 Single line diagram of the test system with SSSC with SMES

III. CONTROL SCHEME FOR SSSC

The modeled SSSC circuit with its two six-pulse VSCs and their series transformers is shown in Fig 2. The converters are connected in series to the transmission line through two banks of lossless three-

phase single-phase two-winding transformers with no saturation. The dc sides of the converters are connected in parallel and share the same dc bus. The GTO valves are switched at fundamental frequency, and the dc voltage varies according to the phase control technique used to control the output voltage. The SSSC switching is synchronized with respect to the transmission line current i_{line} , and its rms magnitude I_{line} is controlled by transiently changing the phase shift α between this current and the SSSC output voltage v_{pq} .

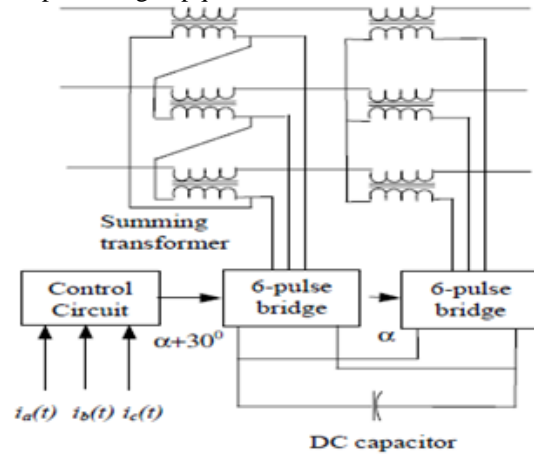


Fig. 2 Transformer configurations of 12-Pulse SSSC

The change in the phase shift between the SSSC output voltage and the line current results in the change of the dc capacitor voltage V_{dc} , which ultimately changes the magnitude of the SSSC output voltage V_{SSSC} and the magnitude of the transmission line current I_{line} . A block diagram of the SSSC controller, as implemented in the matlab simulation, is depicted in Fig 3. The SSSC output voltage V_{SSSC} is controlled by a simple closed loop ; the per unit value of the

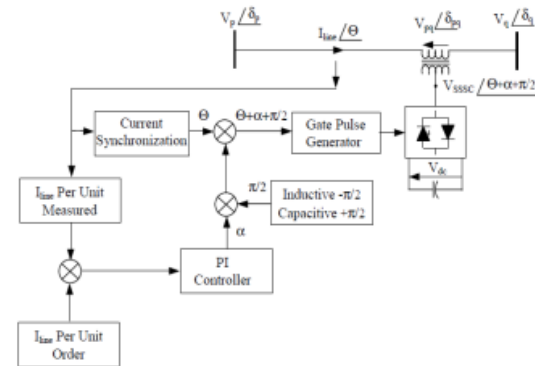


Fig. 3 Functional control diagram for phase controlled SSSC

measured line current is compared with the line current per-unit order and the error of these two values is passed to the PI controller. The output of the PI controller is the angle α , which is added to the synchronizing signal passed to the gate pulse generator by the current synchronization block. To this signal $+\alpha$, an angle of $-\pi/2$ or $+\pi/2$ has to be added since the SSSC output voltage is lagging or

leading the line current by 90° depending on the desired capacitive or inductive operation.

The phase shift of the converter output voltage VSSSC with the respect to the line current I_{line} will cause the flow of a small amount of real power from or into the converter, thereby causing a change in the dc capacitor voltage, and consequently causing a change in the converter output voltage magnitude.

IV. CHOPPER CONTROL FOR SMES

SMES consists of a coil with many windings of superconducting wire that stores and releases energy with increases or decreases in the current flowing through the wire. Although the SMES device itself is highly efficient and has no moving parts, it must be refrigerated to maintain the superconducting properties of the wire materials, and thus incurs energy and maintenance costs. SMES are used to improve power quality because they provide short bursts of energy (in less than a second).

An electronic interface known as chopper is needed between the energy source and the VSI. For VSI the energy source compensates the capacitor charge through the electronic interface and maintains the required capacitor voltage. Two-quadrant n-phase DC-DC converter as shown in Fig. 4 is adopted as interface. Here ‘n’ is related to the maximum current driven by the superconducting device. The DC-DC chopper solves the problems of the high power rating requirements imposed by the superconducting coil to the SSSC. The DC-DC chopper allows to reduce the ratings of the overall power devices by regulating the current flowing from the superconducting coil to the inverter of the SSSC [8].

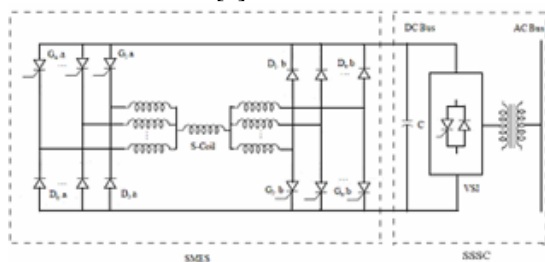


Fig. 4 Circuit diagram for Chopper

The two quadrant multi-phase chopper is composed of many shunt connected diode-thyristor legs that permit the driving of the high current ratings stored in the superconducting coil. The chopper has three modes of operation to perform the charge, the discharge and the storage in the SMES device. The chopper is operated in a step down configuration in the charge mode of the superconducting coil. Here, the set of thyristors ‘a’ are operated with the duty cycle ‘D’ while the set of thyristors ‘b’ are kept on at all times. The relationship between the coil voltage and the DC bus voltage is given by the equation

$$V_{SMES} = D * V_{DC} \tag{1}$$

Once the charging of the superconducting coil is completed, the operating mode of the DC-DC

converter is changed to the stand-by mode for which the set of thyristors ‘a’ are kept off all the time while the set of thyristors ‘b’ are kept on constantly.

In the discharge mode, the chopper is operated in a step up configuration. The set of thyristors ‘b’ is operated with duty cycle D while the set of thyristors ‘a’ is kept off at all times. The relationship between the coil voltage and the DC bus voltage is given by the equation $-V_{SMES} = (1-D) * V_{DC}$ (2)

The duty cycle ranges from 0 to 1. The relationship between the DC bus voltage and the output voltage of the inverter is given by the Eq. (3)

$$V_{DC} = K_a |V_{inv}| \tag{3}$$

Where,

$$K_a = K * a$$

k = Pulse number

a = Ratio of the coupling transformer

A) Internal control scheme for SSSC with SMES

For generating the gating pulses for VSI and the DC-DC chopper, internal control block is designed. Fig. 5 shows the internal control scheme for proposed system. The control scheme includes the decoupled control for the real and reactive power. The two independent reference signals are the reactive current and the active current. From these reference signals the amplitude and phase ratings of the voltage at the VSI is determined.

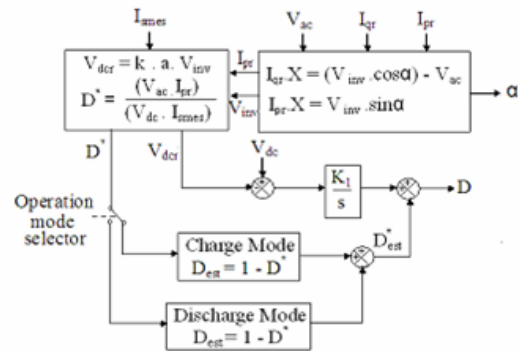


Fig. 5 Internal control scheme for SSSC with SMES

The duty cycle D is estimated from the active power ratings that the SSSC should inject from the voltage at the DC bus and from the current stored into the SMES coil. This estimated value of D_{est} is adjusted through a closed loop control whose function is eliminating the voltage error between the calculated and the real voltage ratings at the DC bus.

V. SIMULATION RESULTS AND DISCUSSION

A three area system is taken as the test system as shown in Fig. 6 and it is analysed with two cases (a) and (b). Case (a) is discussed with SSSC without SMES and case (b) is analysed with SSSC with SMES.

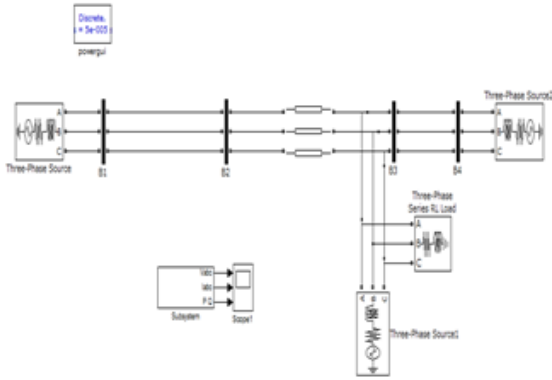


Fig. 6 Test system

A three phase fault is simulated in line 2 near the SSSC and near to bus 2 at 0.1667 sec and the fault is cleared at 0.2333 sec and the results are analysed. Voltage, Current and power output for the test system is shown in Fig. 7.

Figure 8 shows that the power output for test system for both cases, case (a) and case (b). It can be seen that the active power is increase in case (b) than in case (a).

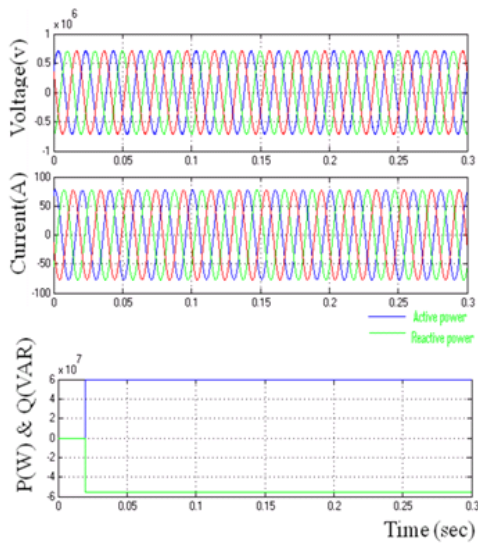


Fig. 7 Simulation result of test system

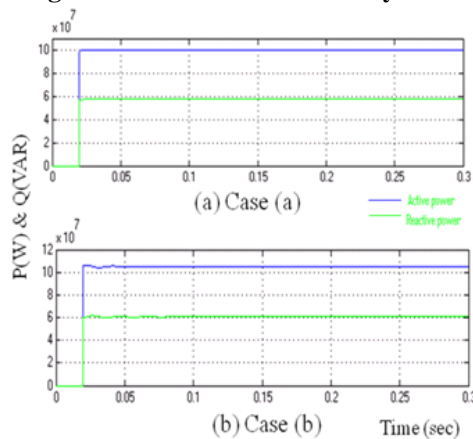


Fig. 8 Power output for Case (a) and (b)

A three phase fault is simulated in the test system in line and the variations occur in the voltage, current,

real power and reactive power are observed. Similarly, case (a) and case (b) is analysed in the test system with three phase fault.

Fig. 9 shows the simulation result for voltage in test system with fault and for both cases. It can be seen that the voltage stability increase in case (b) compare with case (a). settling time for test system with fault, case (a) and case (b) are 0.125sec, 0.045sec and 0.035sec respectively. From this, we observe settling time for case (b) is minimum.

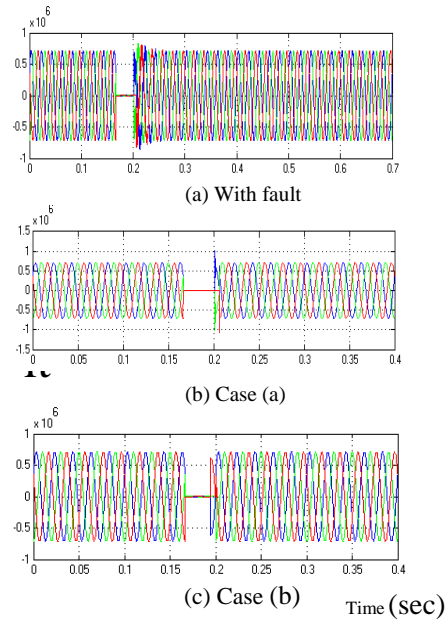


Fig. 9 Simulation result of Voltage with fault

Simulation output of current for the test system with fault and both cases output is shown in Fig. 10. Settling time of current for test system with fault is 0.385sec, for case (a) 0.105sec, for case (b) 0.04sec correspondingly.

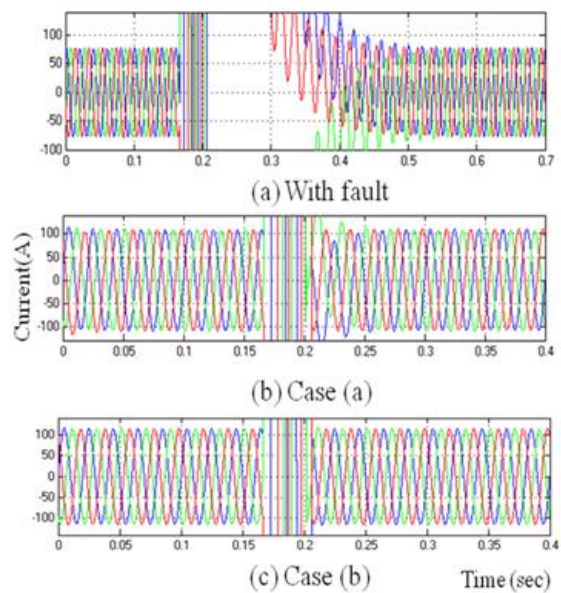


Fig. 10 Simulation result for current with fault

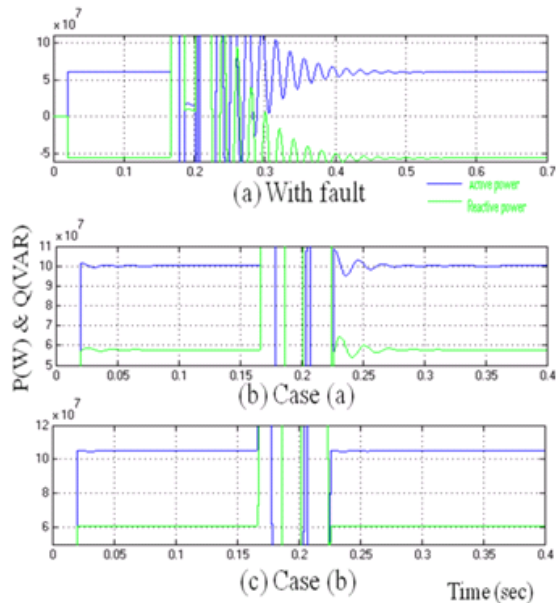


Fig. 11 Simulation result for P & Q with fault

Fig. 11 shows that the simulation result for active power (P) and reactive power (Q) for test system with fault and for both cases. In this, power oscillation is damped quickly in case (b) than case (a). Settling time for real power and reactive power is 0.355sec and 0.365sec for test system with fault and 0.135sec and 0.135sec for case (a) and 0.07sec and 0.065sec for case (b).

VI. CONCLUSION

The dynamic performance of the SSSC with and without SMES for the test system are analysed with Matlab/simulink. In this paper SMES with two quadrant chopper control plays an important role in real power exchange. SSSC with and without has been developed to improve transient stability performance of the power system. It is inferred from the results that the SSSC with SMES is very efficient in transient stability enhancement and effective in damping power oscillations and to maintain power flow through transmission lines after the disturbances.

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