International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:8, No:5, 2014

# Dynamic Modeling and Simulation of a STATCOM/SMES Compensator in Power Systems

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***Abstract*****—**The advent of Flexible AC Transmission Systems (FACTS) is giving rise to a new family of power electronic equipment emerging for controlling and optimizing the performance of power system, e.g. STATCOM. Static synchronous Compensator (STATCOM) is a commonly used FACTS device and has been successfully applied in power systems. In this sense, superconducting magnetic energy storage (SMES) in integration with a static synchronous compensator (STATCOM) is capable of supplying power systems with both active and reactive powers simultaneously and very rapidly, and thus is able to enhance the security dramatically. In this paper the structure and characteristics of the STATCOM/SMES is proposed. In addition, using a proper control scheme, STATCOM/ SMES is tested on an IEEE 3-bus system and more effective performance of the presented STATCOM/SMES compensator is evaluated with alone STATCOM through the dynamic simulation by using PSCAD/EMTDC software.

***Keywords*****—**STATCOM/SMES, Oscillation Damping, Control, Power System.

## I. Introduction

POWER systems have been experiencing dramatic changes in electric power generation, transmission, distribution, and end-user facilities. Continuing electric load growth and higher power transfer in a largely interconnected network lead to complex and less secure power system operation. In addition, certain factors such as technical, economical, environmental, and governmental regulation constraints put a limitation on power system planning and operation. One of the most significant problems in power systems is weakly damped swings between synchronous generators and subsystems that must be controlled in appropriate way, in spite the power system will encounter a serious problem and lose the normal operation. Due to the recent advances in high power semiconductor technology, FACTS technology has been proposed to solve this problem [1], [2]. Furthermore, as a typical FACTS device, STATCOM have been developed and has been put into operation to improve of transient stability margin, power quality improvement and damping of power system oscillations by reactive power control [3], [4].Whereas the addition significant energy storage capability to STATCOM to created more reliable and more flexible, in addition to the number of degrees of freedom for STATCOM is increased, therefore an energy storage system (ESS) for integration of STATCOM is proposed.

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Recent developments and advances in energy storage and power electronics technologies are making the application of energy storage technologies a viable solution for modern power applications. Viable storage technologies include batteries, flywheels, ultra-capacitors, and superconducting energy storage systems. SMES systems for power utility applications have received considerable attention due to rapid response, high power, high efficiency and four quadrant control [5]. STATCOM and SMES are considered to cooperate and emerge as a compensator with prominent capability in power swings damping improvement. In [6] the application of SSSC-SMES for frequency stabilization is examined and in [7], [8] the experimental system integration of a battery energy storage system (BESS) into a STATCOM is discussed.

In this paper firstly, a general model and performance principles of STATCOM/SMES compensator is proposed and secondly to present control scheme, the simulation results for STATCOM/SMES in order to damping power system oscillations is shown.

## II. Proposed Model for the STATCOM/SMES Compensator

### *A. General Concepts*

In principle, STATCOM is a shunt connected device which injects reactive current into the ac system. Whereas the STATCOM can only absorb/inject reactive power, consequently is limited in the degree of freedom. The addition of SMES allows the STATCOM to inject and/or absorb active and reactive power simultaneously, and therefore provides additional benefits and improvements in the system. A functional model of a STATCOM/SMES compensator is shown in Fig. 1. This model consists mainly of the STATCOM, the SMES coil with the related filtering and protection system, and the main coupling transformer to the ac system and the interface between both devices, represented by the dc-dc converter. The Power Conversion System (PCS) acts as the power interface between the SMES and STATCOM by affecting a bidirectional energy transfer between the two. Integration of SMES with STATCOM could increase the performance of the STATCOM and reduce the cost of the power conversion unit needed for the SMES. Whereas the inclusion of a SMES in the dc bus of the STATCOM requires the use of an interface to adapt the voltage and current levels of both devices, in this case a two-quadrant three-phase dc-dc chopper is adopted as interface.

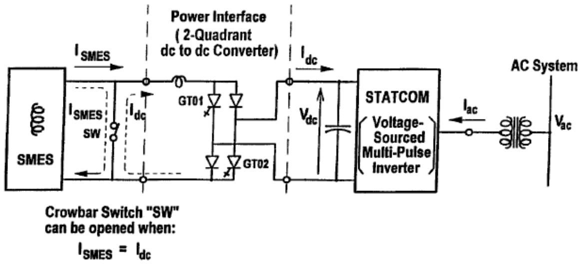



Fig. 1 General model of a STATCOM/SMES compensator

The traditional STATCOM (without SMES) has only two possible steady-state operating modes: inductive (lagging) and capacitive (leading). Although both the STATCOM output voltage magnitude and phase angle can be controlled, they cannot be independently adjusted since the STATCOM has no active power capability. In the case of a STATCOM/SMES compensator, the number of operating modes is extended to four. These modes are namely, inductive with dc charge, inductive with dc discharge, capacitive with dc charge and capacitive with dc discharge, as shown in Fig. 2.

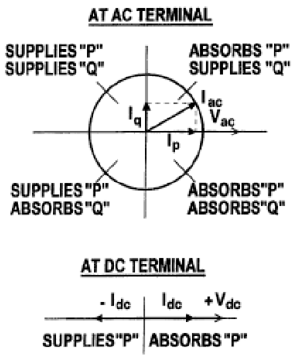



Fig. 2 STATCOM/SMES compensator P-Q plane for each operating mode

*B. The DC-DC Chopper Operation in Order to Charge/ Discharge SMES Coil*

There are two different modes of operation for SMES power conditioning systems. One is for charging of the SMES coil and the other is for discharging. Fig. 3 shows the direction of power flow for the two modes. For both of the operation modes, the dc link is assumed to have a constant $V_{DC}$ as shown in Fig. 3.

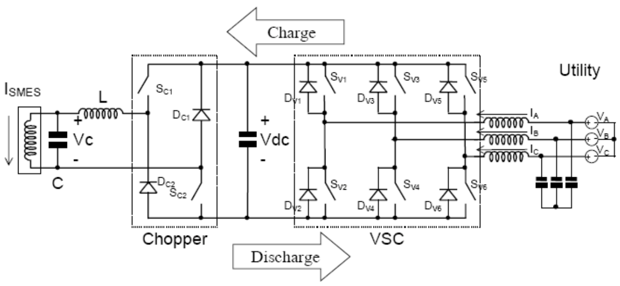



Fig. 3 The directions of the power flow for the two modes

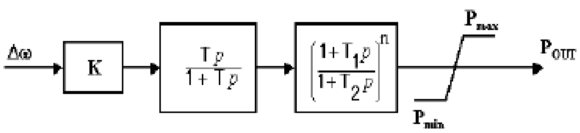
The SMES coil can be charged by providing positive voltage $V_c$ across the filter capacitor *C*. This can be done by turn-on of the two chopper switches $S_{c1}$, and $S_{c2}$. When either one of the switches is turned off; $I_{SMES}$ will flow through the opposite diode of the same leg. This will cause freewheeling of $I_{SMES}$. By changing the duty ratio of the one switch, the average value of $V_c$ can be controlled. So, the amount of charging power can be controlled. Since the dc link assumed as having constant voltage, the energy should come from the utility through Voltage Source Converter (VSC). For the charging, the VSC should be operated as a rectifier to get energy from the utility [9].

The discharging of the SMES requires the reverse process of the PCS. The SMES coil can be discharged by providing negative voltage $V_c$ across the filter capacitor *C*. This can be done by turn-off of the two chopper switches. When either one of the switches is turned on; $I_{SMES}$ will flow through the switch causing freewheeling of $I_{SMES}$. By changing the duty ratio of the one switch, the average value of $V_c$ can be controlled. So, the amount of discharging power can be controlled. During discharging mode, the energy should flow to the utility through VSC. For the discharging, the VSC should be operated as a VSI to provide energy to the utility.

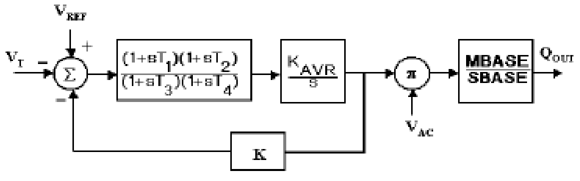
## III. Control Scheme for the STATCOM/SMES Compensator

The controller provides an active and reactive power command to achieve the desired system response. For optimal control of transmission capacity, it is desired to have a controller that can achieve independent active and reactive power responses [10]. To accomplish this goal, a proposed controller is developed that can produce the desired switching commands from independent active and reactive power commands. The control functions of the STATCOM/SMES compensator have two parallel independent parts for active power control and reactive power control. The active power control is to control the active power output of STATCOM/SMES compensator to suppress the generator rotor oscillation [11].

The reactive power control is to keep the terminal voltage at the reference value [12]. Fig. 4 is the control blocks of the two parts. In Fig. 4 (a), the K in the first block is the multiplying factor. The second block is the resetting block which makes $P_{out}$ zero when t → ∞. The third block is a phase compensation block that will make $P_{out}$ be synchronous with Δω. In Fig. 4 (b), $K_{AVR}$, $T_1$, $T_2$, $T_3$, and $T_4$ are the gain and time constants of the automatic voltage regulator. K is the negative feedback factor. In our case, there is no phase shift here with n=0.




(a)Active power control function of STATCOM/SMES compensator




(b) Reactive power control function of STATCOM/SMES compensator

Fig. 4 Control function structure of STATCOM/SMES compensator

## IV. The Effectiveness of the STATCOM/SMES Compensator in Power System

### *A. Power Oscillation Damping*

Power oscillation of a power system is a sustained dynamic event whereby an angle oscillation due to any minor disturbance in the case of an under-damped power system would result in a corresponding power oscillation around steady state power transmitted and a lack of sufficient damping would be a major problem as a limitation factor for transmittable power. Therefore it is crucial to vary the applied compensation to counteract accelerating and decelerating swings of disturbed machines. The electric power transmitted must be increased to compensate for excess mechanical input power when the rotationally oscillating generator accelerates and angle δ increases and vice versa. For small power oscillations continuously varying compensator output in sympathy with the generator angle or power is preferred, as shown in Fig. 5 [1].

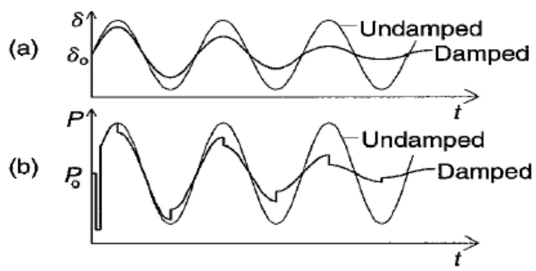



Fig. 5 Waveforms illustrating power oscillation damping by reactive shunt compensation: (a) generator angle, (b) transmitted power

### *B. Simulation Results*

The IEEE 3-bus system used to evaluation the dynamic performance of the proposed STATCOM/SMES compensator in form of a simplified single-line diagram is shown in Fig. 6. The base load used at bus 3 is a 750MW and 200Mvar load, and is modeled as a constant PQ. Each machine has a simple exciter, and a simple governor is used for the machine at bus 1. The generators are modeled in detail by means of sub-transient model.

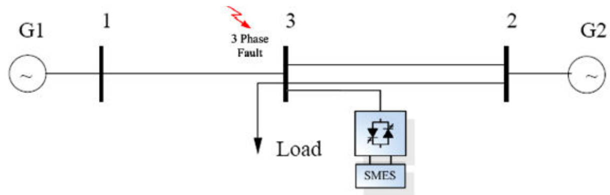



Fig. 6 IEEE 3-bus test system

In this case, a three-phase-to-ground fault at bus 3 is applied in the bulk power system (at t=0.1s) and then clearance of it. An 80Mvar STATCOM and a 250MJ/50MW were used in STATCOM/SMES compensator. The data for the STATCOM are given in Table I.

TABLE I
STATCOM Data

| $R_c\,(\Omega)$ | $R_{trans}\,(\Omega)$ | $X_{trans}\,(\Omega)$ | $C\,(\mu f)$ | $K_P$ | $K_I$ |
|---|---|---|---|---|---|
| 0.64 | 0.54 | 670 | 0.121 | 0 | 150 |

The simulation results were presented for operation on STATCOM/SMES compensator and alone STATCOM compensator in PSCAD/EMTDC software [13]. The specifications for active power variations , generator rotor angle variations and angular speed variations for generator connected to bus 1 are shown in Figs. 7, 8, and 9 respectively.

This results shows that STATCOM/SMES compensator is able to stabilize the system in a very short period and provide more damping in comparison with the case where the alone STATCOM was used.

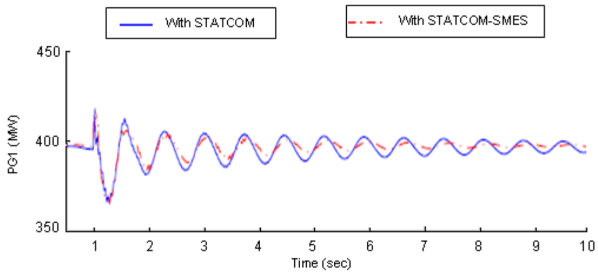



Fig. 7 Variation of generator active power

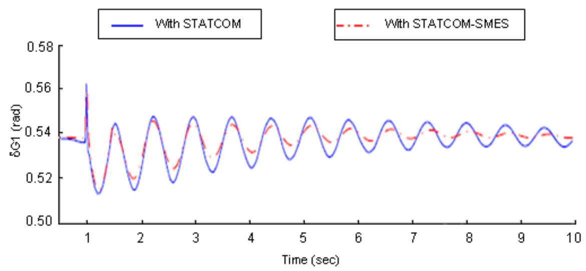



Fig. 8 Variation of rotor power angle

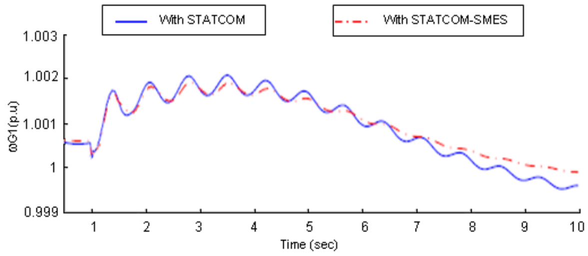



Fig. 9 Variation of angular speed

Also, characteristics of the terminal voltage $V_T$ and dc bus voltage $V_{dc}$ for compensator are shown in Figs. 10 and 11 respectively. As can be observed, the integrated compensator provides good damping to the electromechanical oscillations. The simulation results indicate that the proposed compensator is quite effective in power oscillations damping.

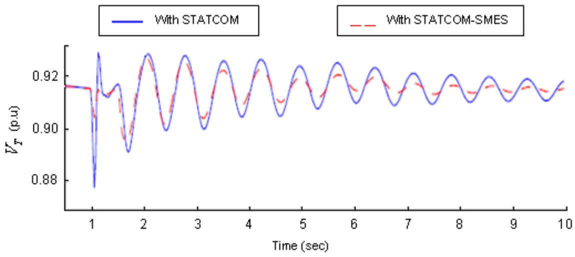



Fig. 10 Variation of compensator terminal voltage

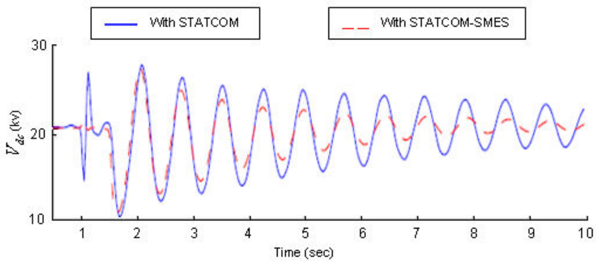



Fig. 11 Variation of compensator dc bus voltage

## V. Conclusion

This paper presents the specifications, operation and control of STATCOM/SMES compensator. The simulation results show that STATCOM/SMES compensator, which controls both reactive and active power injection/absorption, has a more significant effect on the oscillation damping compared to that alone STATCOM compensator. Also, the number of degrees of freedom for proposed compensator is increased from one to two.

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