

## Analysis and Simulation of a STATCOM for Midpoint Voltage Regulation of Transmission Lines

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**Abstract:** Shunt Flexible AC Transmission System (FACTS) device such as SVC and STATCOM, when placed at the midpoint of a long transmission line, play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuations and transient stability. The paper is based on analytical and simulation analysis, and conclusions can be used as power industry guidelines. In this paper. We explain the principle structures of STATCOM and the impact of this device on midpoint voltage regulation. Furthermore, the performance of the STATCOM is compared with that of conventional static var compensator (SVC) under fault condition. The study is thereby simulated using the MATLAB/SIMULINK software and simulation results show that STATCOM is effective in midpoint voltage regulation on transmission line.

**Key words:** Flexible AC Transmission System (FACTS), SVC, STATCOM, Voltage Regulation.

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### INTRODUCTION

Flexible AC Transmission System (FACTS) is one aspect of power electronics revolution that is taking place in all areas of electric energy. FACTS controllers use various power electronic circuit topologies or equipment that perform certain function such as current control, power control, etc., and has the potential use in generation, transmission and distribution of electric energy (Hingorani and Gyugyi, 1999).

Shunt controller, therefore, is a good way to control and damp voltage oscillations by injection of leading or lagging reactive current at and around the point of connection. There are various shunt connected FACTS devices; the major ones in terms of applications are the static VAR compensator (SVC) and static synchronous compensator (STATCOM).

SVCs are well known to improve power system properties such as steady state stability limits, voltage regulation and var compensation, dynamic over voltage and under voltage control, counteracting sub-synchronous resonance, and damp power oscillations (Hamad, 1986),(Hosseini and Mirshekhar, 2001). Voltage controlled SVC, as such, does not provide any damping to the power system (Oliveria, 1994),(Zhou, 1993).

STATCOM is basically a voltage source converter, VSC that converts a dc voltage at its input terminals into three-phase ac voltages at fundamental frequency of controlled magnitude and phase angle. VSCs use pulse width modulation, PWM, technology, which makes it capable of providing high quality ac output voltage to the grid or even to a passive load (Uzunovic, 2001). STATCOM provides shunt compensation in a similar way as SVC but utilizes a voltage source converter rather shunt capacitors and reactors (Machowski, 1997). The basic principle of operation of a STATCOM is the generation of a controllable AC voltage source behind a transformer leakage reactance by a voltage source converter connected to a DC capacitor. The voltage difference across the reactance produces active and reactive power exchanges between the STATCOM and the power system (Wang and Li, 2000). The effect of stabilizing controls on STATCOM controllers have been investigated also in several recent reporting (Wang and Li, 2000), (Wang, 1999).

This paper discusses about dynamic response of STATCOM and compares STATCOM and SVC under fault condition.

#### **Basic Configuration STATCOM:**

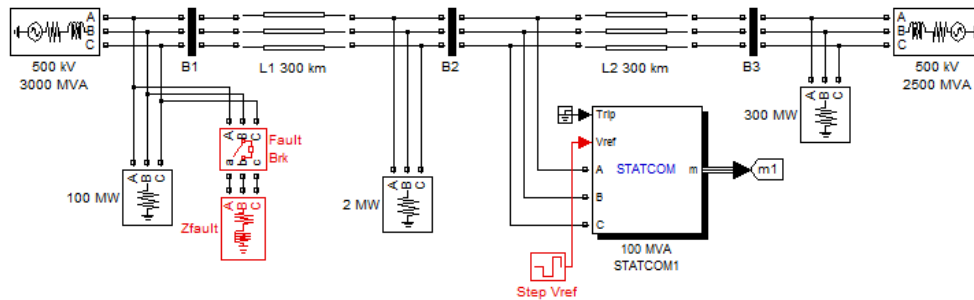
An SVC provides voltage regulation and dynamic reactive power reserve by means of thyristor-controlled reactors (TCR) and thyristor-switched capacitors (TSC) for var absorption and production respectively. A STATCOM accomplishes the same effect by using a VSC to synthesize a voltage waveform of variable magnitude with respect to the system voltage. The STATCOM branch offers both reactive power absorption and production capability whereas an SVC requires separate branches for each. The STATCOM, especially when controlled with PWM, allows faster response and thereby improves power quality. This is very useful to mitigate flicker from disturbances caused by electric arc furnaces at steel mills.

One of the main reasons for installing an SVC or STATCOM in transmission networks is to increase the power transfer capability where limited by post-contingency voltage criteria or under voltage loss of load probability. Determining the optimum mix of dynamic and switched compensation is a challenge. Control

systems are designed to keep the normal operating point within the middle of the SVC or STATCOM dynamic range.

The voltage-sourced converter (VSC) is the basic electronic part of a STATCOM, which converts the dc voltage into a frequency, and phase. There are different methods to realize a voltage-sourced converter for power utility application. Based on harmonics and loss considerations, pulse width modulation (PWM) or multiple converters are used.

Inherently, STATCOMs have a symmetrical rating with respect to inductive and capacitive reactive power. For example, the rating can be 100 Mvar inductive and 100 Mvar capacitive. For asymmetric rating, STATCOMs need a complementary reactive power source. Fig. 1 shows Static Synchronous Compensator (STATCOM) used for midpoint voltage regulation on a 500-kV transmission line.



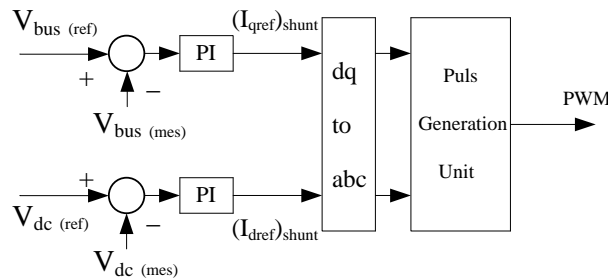
**Fig. 1:** Static Synchronous Compensator (STATCOM) Used for Midpoint Voltage Regulation on a 500-kV Transmission Line

**STATCOM Control:**

STATCOM, by injecting current in parallel with transmission line could control bus voltage and active power. Also, required active power for series section is supplied by DC-link capacitor. For this purpose, the STATCOM sampling from DC-link capacitor voltage as well as the STATCOM connected bus voltage and then by converting these values to dq0 parameters by Parks transformation and calculating voltages in per unit as follows:

$$V_{bus} = \sqrt{V_d^2 + V_q^2} \tag{1}$$

$V_{bus}$  and  $V_{dc}$  are compared by distinct values according to the block diagram depicted in Fig. 2, and generate error signals as follows:



**Fig. 2:** STATCOM control system

Generated error signals carried to PI controllers and output of PIs converted to abc parameters again and enter to the PWM pulse generating unit. By adjusting control parameters of PI and switching, finally error signals carried to zero. And accordingly  $V_{bus}$  and  $V_{dc}$  stabilized in their reference values.

**Model Description:**

The Static Synchronous Compensator (STATCOM) is one of the key FACTS devices. Based on a voltage-sourced converter, the STATCOM regulates system voltage by absorbing or generating reactive power.

Contrary to a thyristor-based Static Var Compensator (SVC), STATCOM output current (inductive or capacitive) can be controlled independent of the AC system voltage.

The power grid consists of two 500-kV equivalents (respectively 3000 MVA and 2500 MVA) connected by a 600-km transmission line. When the STATCOM is not in operation, the "natural" power flow on the transmission line is 930 MW from bus B1 to B3. In our demo, the STATCOM is located at the midpoint of the line (bus B2) and has a rating of +/- 100MVA. This STATCOM is a phasor model of a typical three-level PWM STATCOM. If you open the STATCOM dialog box and select "Display Power data", you will see that our model represents a STATCOM having a DC link nominal voltage of 40 kV with an equivalent capacitance of 375 uF. On the AC side, its total equivalent impedance is 0.22 pu on 100 MVA. This impedance represents the transformer leakage reactance and the phase reactor of the IGBT bridge.

**Table1:** The parameter values of the system

Parameters	Values
Source voltage	500kV /50Hz
Source power	3000MVA
Total Line Length	600Km
Equivalent impedance of STATCOM	0.22 pu
Equivalent capacitance of STATCOM	375μF
Modulation frequency	1.68 kHz
DC link voltage	40 kV

**Simulation Results:**

**1. STATCOM dynamic response:**

We will now verify the dynamic response of our model. Open the STATCOM dialog box and select "Display Control parameters". Verify that the "Mode of operation" is set to "Voltage regulation" and that "External control of reference voltage  $V_{ref}$ " is selected. Also, the "droop" parameter should be set to 0.03 and the " $V_{ac}$  Regulator Gains" to 5 (proportional gain  $K_p$ ) and 1000 (integral gain  $K_i$ ). Close the STATCOM dialog block and open the "Step  $V_{ref}$ " block (the red timer block connected to the " $V_{ref}$ " input of the STATCOM). This block should be programmed to modify the reference voltage  $V_{ref}$  as follows: Initially  $V_{ref}$  is set to 1 pu; at  $t=0.2$  s,  $V_{ref}$  is decreased to 0.97 pu; then at  $t=0.4$  s,  $V_{ref}$  is increased to 1.03; and finally at 0.6 s,  $V_{ref}$  is set back to 1 pu. Also, make sure that the fault breaker at bus  $B_1$  will not operate during the simulation (the parameters "Switching of phase A, B and C" should not be selected).

Run the simulation and look at the "VQ\_STATCOM" scope. The Fig. 3 displays the  $V_{ref}$  signal (magenta trace) along with the measured positive-sequence voltage  $V_m$  at the STATCOM bus. The Fig. 4 displays the reactive power  $Q_m$  absorbed (positive value) or generated (negative value) by the STATCOM. The signal  $Q_{ref}$  (magenta trace) is not relevant to our simulation because the STATCOM is in "Voltage regulation" and not in "Var Control".

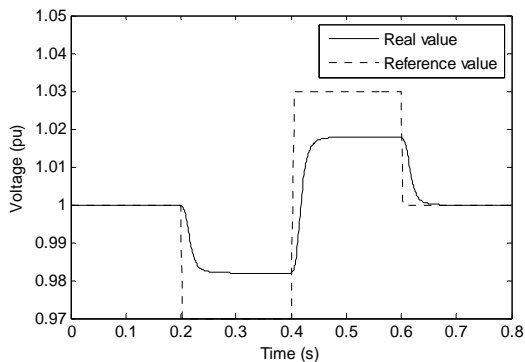
Looking at the  $Q_m$  signal we can determine that the closed-loop time constant of the system is about 20 ms. This time constant depends primarily on the power system strength at bus B2 and on the programmed  $V_{ac}$  Regulator gains of the STATCOM. To see the impact of the regulator gains, multiply the two gains of the  $V_{ac}$  Regulator Gains by two and rerun the simulation. You should observe a much faster response with a small overshoot.

Looking at the  $V_m$  and  $V_{ref}$  signals, you can see that the STATCOM does not operate as a perfect voltage regulator ( $V_m$  does not follow exactly the reference voltage  $V_{ref}$ ). This is due to the regulator droop (regulating slope) of 0.03 pu. For a given maximum capacitive/inductive range, this droop is used to extend the linear operating range of the STATCOM and also to ensure automatic load sharing with other voltage compensators (if any). Set the droop parameter to 0 and the voltage regulator gains back to 5 ( $K_p$ ) and 1000 ( $K_i$ ). If you then run a simulation, you will see that the measured voltage  $V_m$  now follows perfectly the reference voltage  $V_{ref}$ .

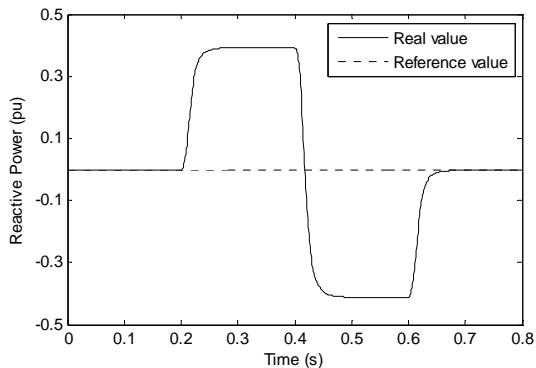
**2. STATCOM compared to a SVC under fault condition:**

We will now compare our STATCOM model with a SVC model having the same rating (+/- 100 MVA). If you double-click on the "SVC Power System" (the magenta block), you will see a SVC connected to a power grid similar to the power grid on which our STATCOM is connected. A remote fault will be simulated on both systems using a fault breaker in series with a fault impedance. The value of the fault impedance has been programmed to produce a 30% voltage sag at bus  $B_2$ . Before running the simulation, you will first disable the "Step  $V_{ref}$ " block by multiplying the time vector by 100. You will then program the fault breaker by selecting the parameters "Switching of phase A, B and C" and verify that the breaker is programmed (look at the "Transition times" parameter) to operate at  $t=0.2$  s for a duration of 10 cycles. Check also that the fault breaker inside the "SVC Power System" has the same parameters. Finally, set the STATCOM droop back to its original value (0.03 pu).

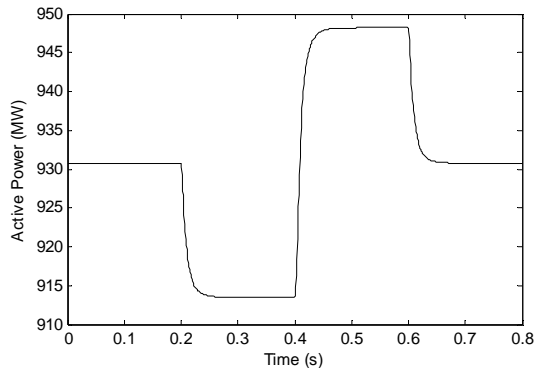
Run the simulation and look at results. Fig. 5 and Fig. 6 show active and reactive power changes. Fig. 7 shows three phase voltage changes and Fig. 8 shows three phase current changes. Changes of  $I_d$  and  $I_q$  are shown in Fig. 9 and Fig. 10. The Fig. 12 displays the measured voltage  $V_m$  on both systems (magenta trace for the SVC). The Fig. 13 displays the measured reactive power  $Q_m$  generated by the SVC (magenta trace) and the STATCOM. During the 10-cycle fault, a key difference between the SVC and the STATCOM can be observed. The reactive power generated by the SVC is -0.48 pu and the reactive power generated by the STATCOM is -0.71 pu. We can then see that the maximum capacitive power generated by a SVC is proportional to the square of the system voltage while the maximum capacitive power generated by a STATCOM decreases linearly with voltage decrease (constant current). This ability to provide more capacitive power during a fault is one important advantage of the STATCOM over the SVC. In addition, the STATCOM will normally exhibit a faster response than the SVC because with the voltage-sourced converter, the STATCOM has no delay associated with the thyristor firing (in the order of 4 ms for a SVC).



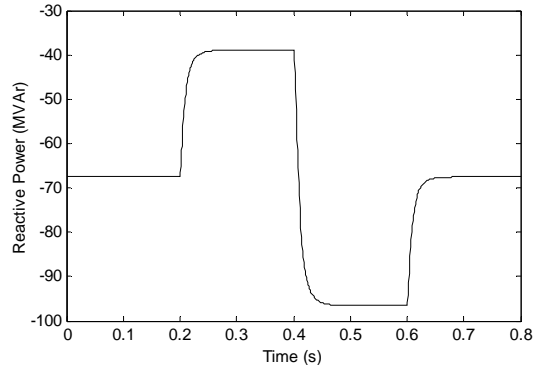
**Fig. 3:**  $V_{ref}$  signal (dotted trace) along with the measured positive-sequence voltage  $V_m$  at the STATCOM bus



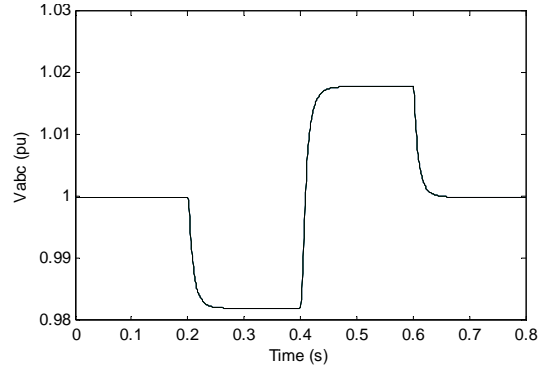
**Fig. 4:** The reactive power  $Q_m$  absorbed (positive value) or generated (negative value) by the STATCOM



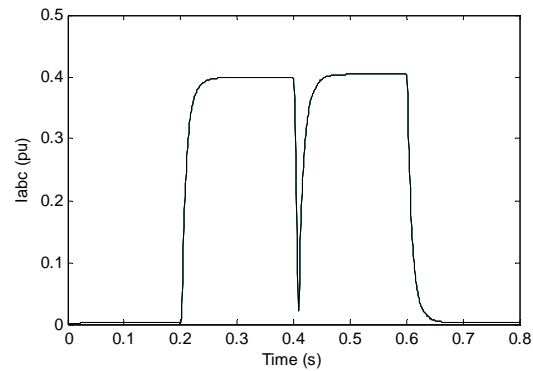
**Fig. 5:** Changes of active power



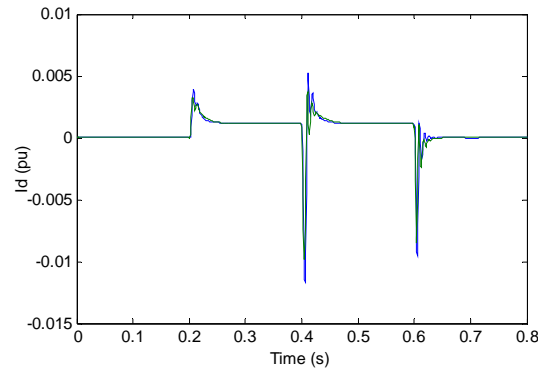
**Fig. 6:** Changes of reactive power



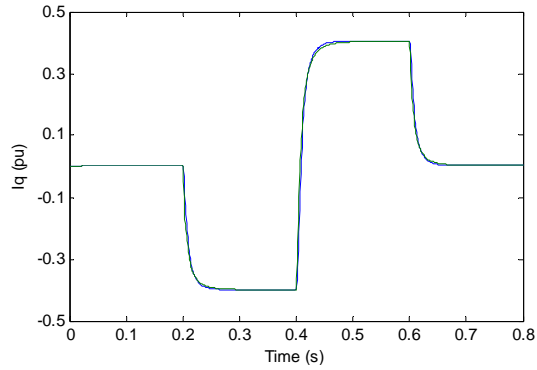
**Fig. 7:** Three phase voltage changes



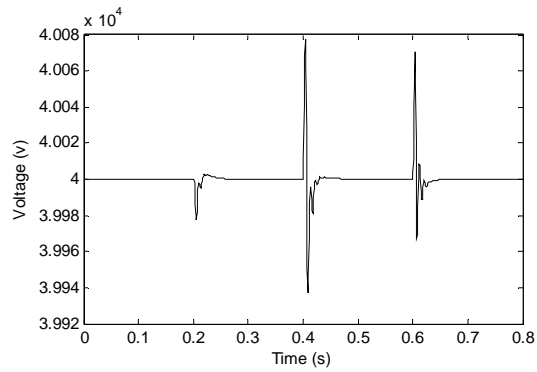
**Fig. 8:** Three phase current changes



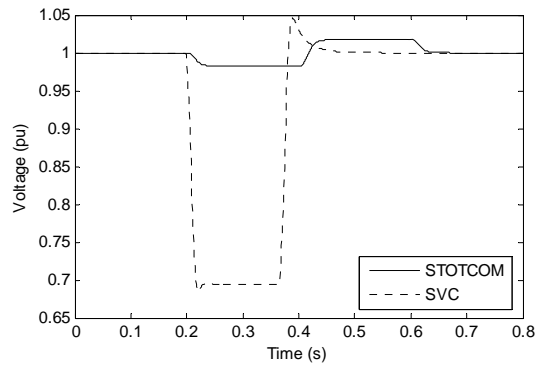
**Fig. 9:** Reference and real values of  $I_d$



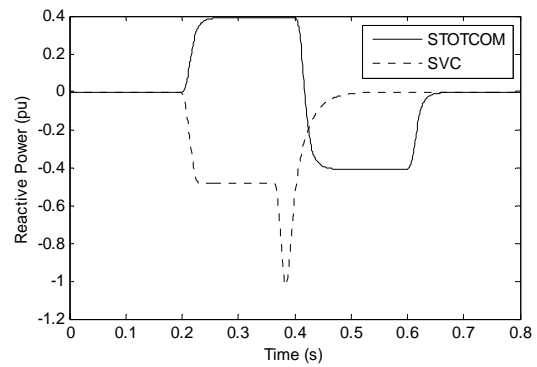
**Fig. 10:** Reference and real values of  $I_q$



**Fig. 11:** DC link voltage



**Fig. 12:** Measured voltage  $V_m$  on both systems



**Fig. 13:** The measured reactive power  $Q_m$  generated by the SVC and the STATCOM

**Conclusion:**

This paper illustrates in detail the principle characteristics of STATCOM. STATCOM system can be used for reactive power compensation in the industrial network grid and under distorted mains voltage conditions, it is more reliable than shunt capacitor reactive power compensator. We have examined the performance of SVCs and STATCOMs in electric power systems too. Based on the analytical and simulation studies, the impact of SVCs and STATCOMs on the studied power system is presented. It was shown that both devices significantly improve the transient voltage behavior of power systems. Though SVCs and STATCOMs work on different principles, their impact on increasing power system transmission capacity can be comparable.

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