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SENSITIVITY & TRANSIENT ANALYSIS OF STATCOM USING MATLAB / SIMULINK

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***ABSTRACT**— The STATCOM (Synchronous Static Compensator) is avidly used for voltage regulation in distribution and transmission systems. However, the strict modeling and STATCOM gain and losses compensation is required to improve the overall fidelity of the system. This research outlines the modeling for STATCOM system sensitivity and transient analysis incorporating the impact of shunt devices using MATLAB/Simulink software. The system analysis explains how shunt connected FACTS devices are used for voltage stability and efficient power transfer. In an interconnected system, voltage control attains higher importance in view of power dispatch; keeping the equipment loading within safe permissible limits. STATCOM dynamic responses are analyzed with varying voltage regulation and stability factors. The locations of FACTS devices were varied to analyze the sensitivity of the system against the desired system MVA ratings. Simulation results of newly modelled system were than compared with SVC and transient responses against varying MVA ratings were analyzed.*

Keywords — STATCOM, FACTS, MVA, SVC

1- INTRODUCTION

Efficient electric power supply, high availability and optimum system throughput has become one of the most vital and unparalleled quality assurance precedent over the turn of the century. This efficient system model also poses large scale concerns including environment, the installation of new power plant or transmission lines, deregulation and development of fast electronic power flow control devices.

The electrical design analysis to address these high end demands and to meet the regulatory system parameters is a knowledge intensive task which demands constant up-gradation, modeling and channeling of finding union between current system in place, their optimized models and future installation predictions. In order to address these requirements and compute the projected overall system's effect with optimum system parameters and ability to integrate with the current system in place, the power electronics based flexible AC transmission systems (FACTS) have been developed and used as economical and efficient means to control the power transfer in the interconnected AC transmission systems. The FACTS devices counters the system transients and allows forcing the power transit in the lines with higher transmission capacity [1], [2].

Voltage stability and efficient voltage transformation are major responsibilities of power system operators. It is concerned with the ability of power system to maintain acceptable voltage at all nodes in the system under normal and contingent conditions. A power system is said to have entered a state of voltage instability when cause a progressive and uncontrollable decline in voltage. Inadequate reactive power support from generators and transmission lines leads to voltage instability phenomena and designing mitigation schemes to prevent voltage instability is of great value to utilities [3].

There is important and fundamental correlation between active and reactive power transmission. As transmission of active power requires magnitude of voltages so the magnitude must be high enough to support the loads and low enough to avoid equipment breakdown. Thus, we have to control, and if necessary, to support or constrain, the voltages at all the key point of network.

Controlling and channeling the voltage to a specific system part and transmission to counter system transients is made possible using FACTS devices to compensate for reactive losses over the transmission lines using the STATCOM model. Different methods are used to control the voltages in different power systems. This research analyzes the role of shunt connected FACTS devices. We discuss how Shunt devices are used to regulate the system voltage and improve its performance. In this research, we demonstrate the effect of FACTS devices on power system through MATLAB simulation [4].

2- STATCOM

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.

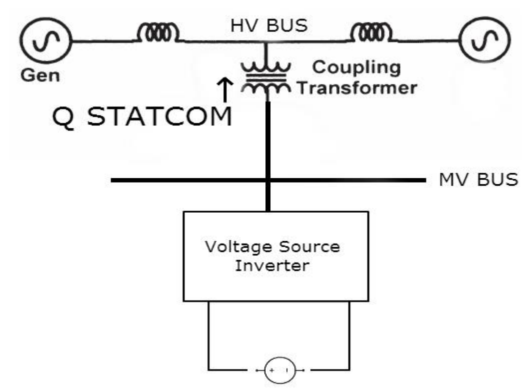

Figure 1- Schematic diagram of STATCOM

Contrary to a thyristor-based Static Var Compensator, STATCOM output current (inductive or capacitive) can be controlled independent of the AC system voltage. This isolation and ability to control the voltage transients between generation and load helps to model the transients on the bus bar and thus the overall power efficiency ratings of the system.

2.1- Methodology

The system modelling and efficiency analysis is achieved by the following design & analysis methodology:

a. Study, modeling and simulation of shunt devices.

b. Application of Shunt devices to improve power system performance using MATLAB/Simulink software.

c. Study of impact of various parameters of Shunt devices on system performance.

The impact of STATCOMs on the studied power system will be shown and compared on the basis of simulation and analytical results.

2.2- System parameters

In order to realize the effect of our STATCOM model, we have chosen a close resemblance of system model parameters in proportion to the active deployments across country.

The power grid consists of four 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 is on.

The transmission line is 1116 MW from bus B1 to B3. In our model, the STATCOM is located at the midpoint of the line (bus B2) and has a rating of +/- 100MVA. This STATCOM is phasor model of a typical three-level PWM STATCOM. If we open the STATCOM dialog box and select "Display Power data", we will see that our model represents a STATCOM having a DC link nominal voltage of 40 kV with an equivalent capacitance of 375uF. 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 of an actual PWM STATCOM.

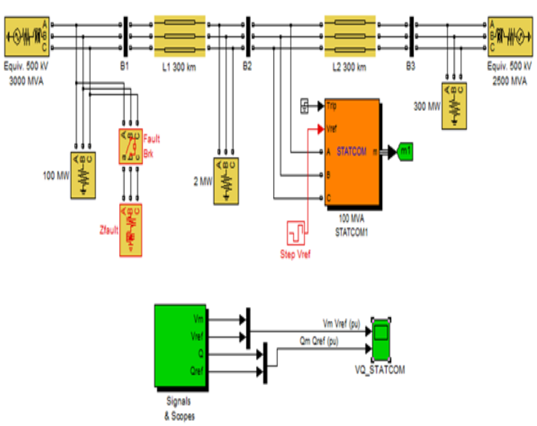

Figure 2- Power system diagram

2.3- STATCOM dynamic response

The above mentioned system parameters were modelled using MATLAB. The dynamic response of our model has been verified by simulating the bus bar with the attached FACTS devices for an overall dynamic response of complete system range. The model parameters were adjusted by opening the STATCOM dialog box and select "Display Control parameters". Verify that the "Mode of operation" is set to “Voltage regulation". Also, the "droop" parameter should be set to 0.03 and the "Vac Regulator Gains" to 5 (proportional gain Kp) and 1000 (integral gain Ki). Close the STATCOM dialog block and open the "Step Vref" block (the red timer block connected to of the STATCOM).

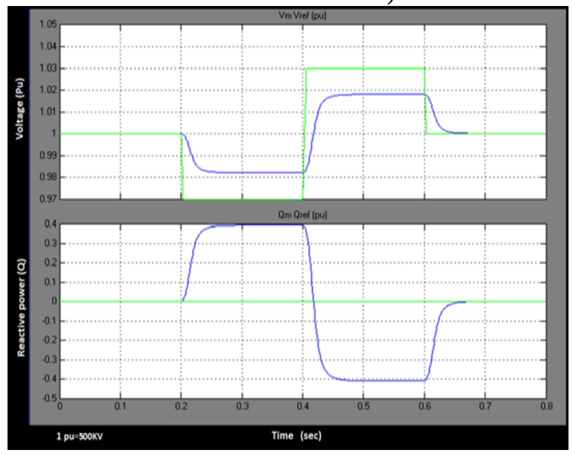

Figure 3- General System Response

This block should be programmed to modify the reference voltage Vref as: Initially Vref is set to 1 pu; at t=0.2 s, Vref is decreased to 0.97 pu; then at t=0.4 s, Vref is increased to 1.03; and finally at 0.6 s, Vref is set back to 1 pu. Run the simulation and look at the "VQ STATCOM" scope. The first graph in Figure 3 displays the Vref signal (magenta trace) along with the measured positive-sequence voltage Vm at the STATCOM bus (which is evident by yellow trace).

The second graph displays the reactive power Qm (yellow trace) absorbed (positive value) or generated (negative value) by the STATCOM. The signal Qref (magenta trace) is not relevant to our simulation because the STATCOM is in "Voltage regulation" and not in "Var Control".

3- SENSITIVITY ANALYSIS

3.1- Parameter Variation of STATCOM

3.1.1- Droop

Droop is the difference between the reference voltage of device and voltage of the bus to which device is connected. Looking at the Vm and Vref signals, you can see that the STATCOM does not operate as a perfect voltage regulator (Vm does not follow exactly as the reference voltage Vref). 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) [4]. The variations in values of Droop is adjusted in accordance with the changes in the position of the FACTS devices on the bus bar. The droop ratio slope must be close to the voltage Vref, which can be achieved by closely following the droop regulator.

The effect of different values of droop is shown in table 1.

Table 1- Transient response for different values of droop

Droop	Difference B/w *Vm* and *Vr*
0.05	0.016
0.03	0.02

0.00	0.00

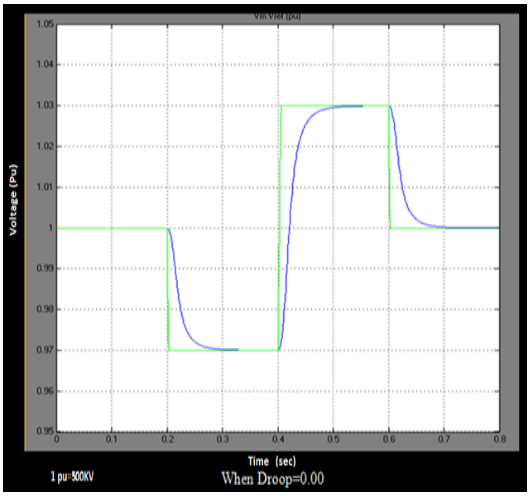

Figure 4(a)- When Droop=0.00

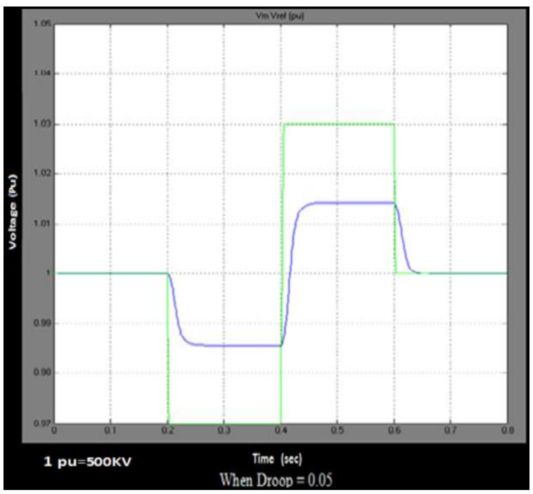

Figure 4(b)- When Droop = 0.05

As table 1 and above mentioned figures of droop shows that when we increase the droop, the difference between Vm and Vr increases. Ideally droop should be zero so that Vm exactly follows the Vr, but, this cannot be practically realized, and thus, the values for droop are adjusted to have a uniform slope and a value as close to reference voltage on system bus as possible.

3.1.2- Kp and Ki

Kp and Ki are proportional and integrated gains of STATCOM. There effect on performance of STATCOM is discussed in table 2.

Table 2- For different values of Kp and Ki

No.	Kp	Ki	Steady state response time (s)
1	1	100	∞
2	5	1000	0.68
3	10	2000	0.64

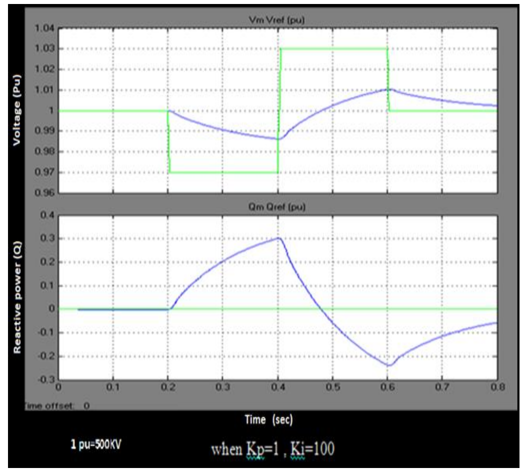

Figure 5(a)- When Kp=1, Ki=100

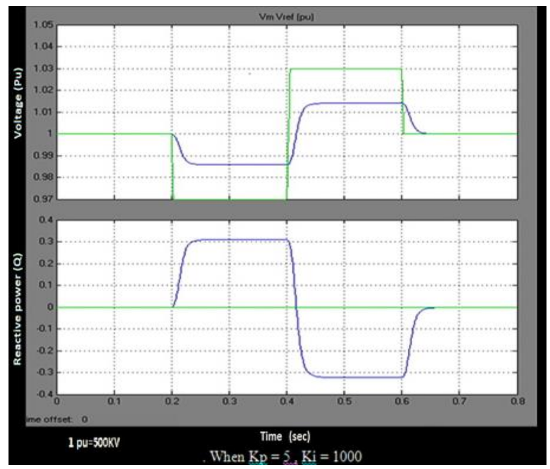

Figure 5(b)- When Kp = 5, Ki = 1000

Table 2 and above figures 5(a) and 5(b) shows that by increasing gains, the response is faster with small overshoot.

3.2- Location of Devices

In this analysis, we change the location of devices at different buses and observed the values of reactive power, absorbed and supplied power.

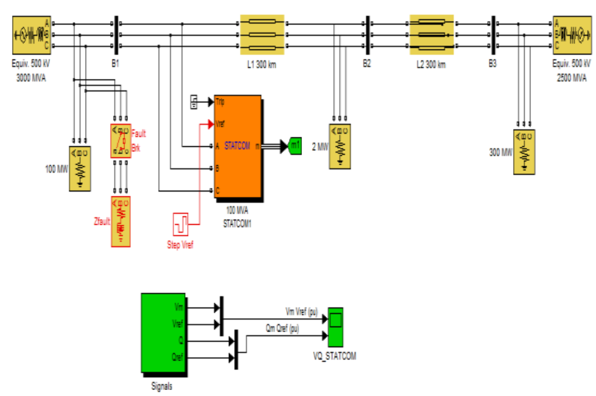

Figure 6- STATCOM connected at B1

The effect of different location is shown in table 3.

Table 3- Q supplied and absorbed

No. of bus	Q supplied (pu)	Q absorbed(pu)
1	-0.5	0.5
2	-0.4	0.4
3	-0.79	0.18

Figures 7(a) and 7(b) explain the scope of different values of Q achieved at different bus positions.

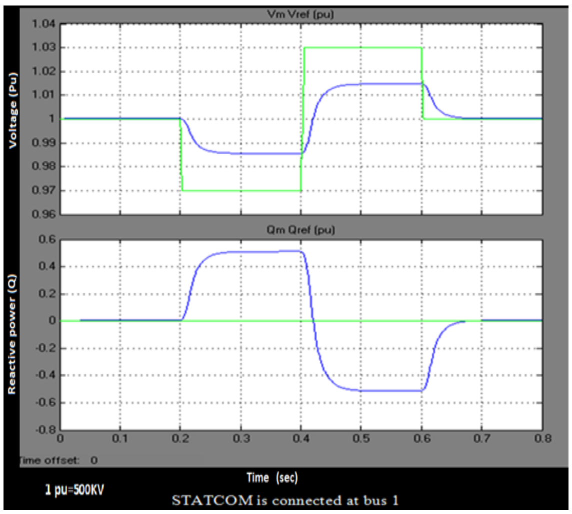

Figure 7(a)- The value of reactive power absorbed and supplied when STATCOM is connected at bus 1

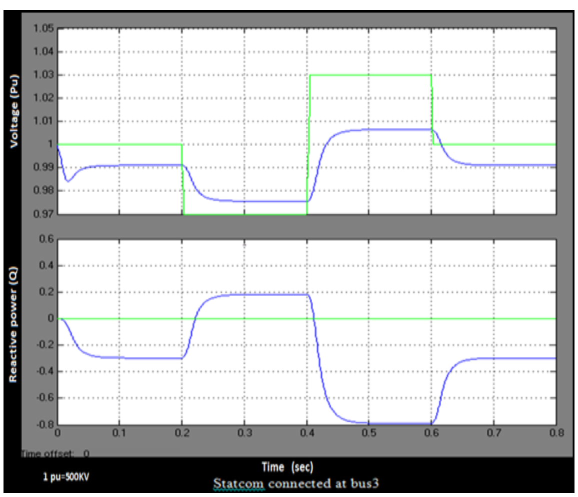

Figure 7(b)- This figure shows the response when device is connected at bus 3

As in the beginning, we calculate the value of voltage at different bus also different loads is connected at different buses. So value of the voltage varies at buses as reactive power depends upon the value of voltage difference. Voltage difference changes at every bus as a result reactive power supplied and absorbed changes at every bus.

3.3- Size Variation

In this analysis we vary the rating of STATCOM and note its effect on response following table shows its results.

The size is normally stated as by the MVA ratings of the overall system. By changing the overall bus ratings, we can analyze the system response times. An increasing steady state response time towards the load represents the overshooting of the transients, or in other words, a deviation in slope from reference voltage Vm to the actual voltage.

Table 4 covers the effects on steady state response times on the STATCOM system by varying the MVA ratings on the bar.

Table 4- For different values of STATCOM ratings

No.	MVA rating	Steady state response time(s)
1	100	0.68
2	200	0.65
3	300	0.64
4	400	0.68
5	500	0.70

Figures 8 (a) and (b) clearly explains the increasing transients for an increased MVA rating bus bar. The reactive powers along with the applied voltage shows a steep slope and changes that occur along the increasing time for the overall system response.

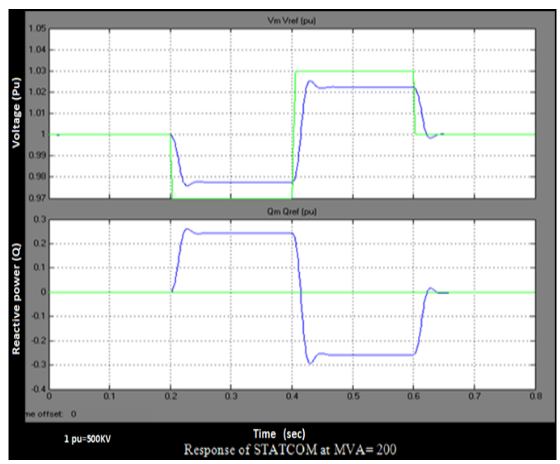

Figure 8(a)- Response of STATCOM at MVA= 200

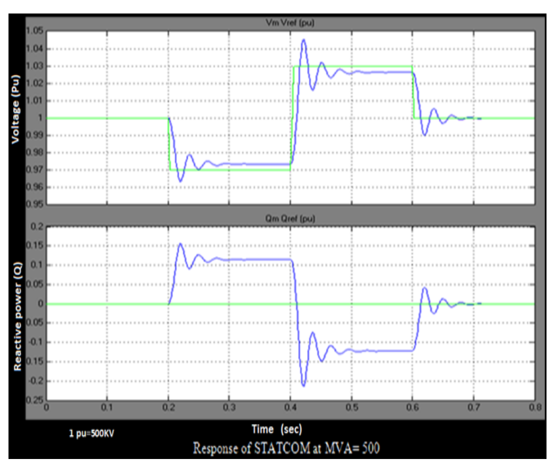

Figure 8(b)- Response of STATCOM at MVA= 500

Firstly as we increase MVA from 100 to 200, steady state response becomes faster from 0.68s to 0.65s. Similarly at 300 MVA response becomes more faster equal to 0.64s. But this decrement is up to certain limit. As we see at 400 MVA it again becomes 0.68s and at 500 MVA it is delayed up to 0.70s. Also, ripples are prominent in response. At 1000 MVA, system becomes unstable.

So it is concluded that MVA of STATCOM should be according to the system requirement. It should not be very high so that system becomes unstable and also, not too low so that there is slow steady state response. The ideal MVA rating of STATCOM for above circuit is 300.

4- TRANSIENT ANALYSIS

Transient analysis means to see the response of system under fault condition. The following figure depicts the general transient response when switching takes place of all three phases near bus 1 at time 0.23s.

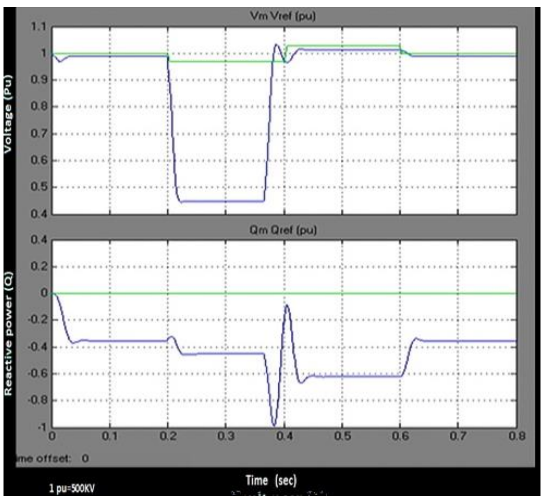

Figure 9- Fault at 0.23s

At time 0.23s three phase fault occurs near bus 1 as a result sudden decrease in voltage measured by STATCOM take place. So it supplies the maximum reactive power as shown in figure. Fault clears after 5 cycles as a result voltage again rises and reactive supplied by STATCOM decreases.

4.1- Fault location variation

Table 5 represents the impacts on V & Q at different fault locations.

Table 5- V & Q at different fault locations

Fault Location	*Vm*(pu)	*Q*(pu)
At B1	0.715	-0.72
At B2	0.45	-0.448
At B3	0.76	-0.76

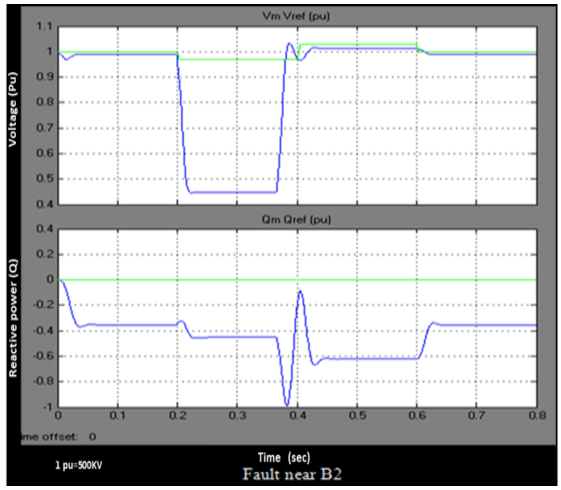

Figure 10(a)- Fault near B2

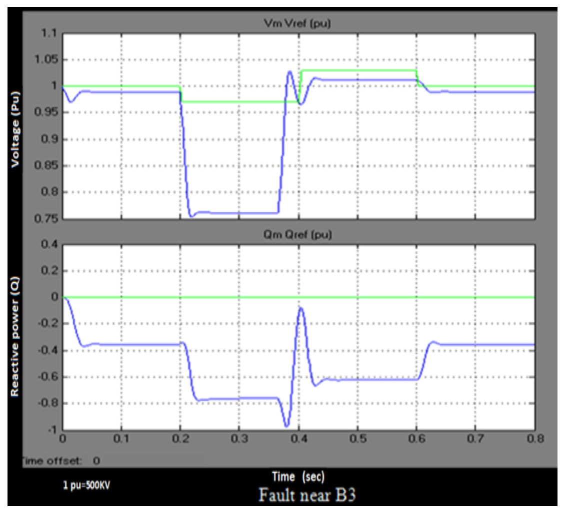

Figure 10(b)- Fault near B3

When fault at B1 occurs, it is a little bit away from STATCOM and at B2, it is very near to STATCOM. So, Vm in case 2 is very less than Vm in case 1 and therefore, STATCOM supplies the reactive power correspondingly.

5- RESULTS

5.1- Comparison between STATCOM and SVC

The basic operational difference (voltage source versus reactive admittance) accounts for the STATCOM's overall superior functional characteristics, better performance, and greater application flexibility than those attainable with the SVC.

STATCOMs and SVCs each possess characteristics that differentiate one from the other during normal operation. The main operating characteristic differences between STATCOMs and SVCs are summarized in the table 6.

Table 6- Differences in the operating characteristics of STATCOMs and SVCs

Characteristic	STATCOM	SVC

E/I characteristic	Good performance in under voltage conditions	Limited performance in under voltage conditions
Response time	1 to 2 sine wave cycles	2 to 3 sine wave cycles
Installation size	About 40% to 50% the size of an SVC installation	About 200% to 250% the size of a STATCOM installation
Installation cost	About 120% to 150% the cost of an SVC installation	About 66% to 83% the cost of a STATCOM installation

We will now compare our STATCOM model with a SVC model having the same rating (+/- 100 MVA). We will see a SVC connected to a power grid alike to the power grid on which our STATCOM is connected as we double -click on the “SVC Power System" (the magenta block).

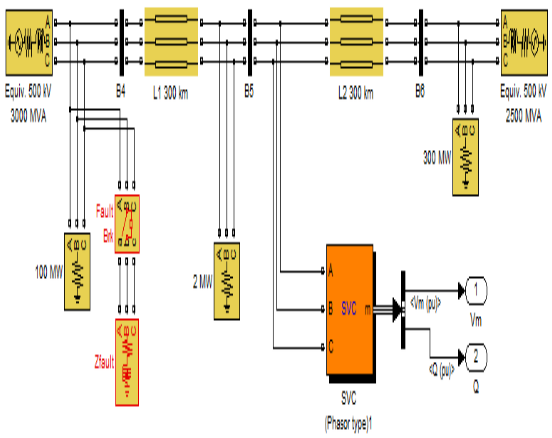

Figure 11- SVC model

The value of the fault impedance is programmed so as to create 30% voltage lag at bus B2. By selecting the parameters "Switching of phase A, B and C”, we will program the fault breaker and confirm that the breaker is programmed to activate at to operate at t=0.2s for a duration of 10 cycles. Finally, set the STATCOM droop back to its original value (0.03 Pu).

Table 7- Reactive power at different bus location under fault condition

STATCOM / SVC location	Q(pu) STATCOM	Q (pu) SVC
At B1	-0.55	-0.3
At B2	-0.71	-0.4
At B3	-0.86	-0.73

Figure 12 shows the measured voltage Vm on both systems (magenta trace for the SVC) and the measured reactive power Qm generated by the SVC (magenta trace) and the STATCOM. A key difference between the SVC and the STATCOM can be observed during the 10-cycle fault.

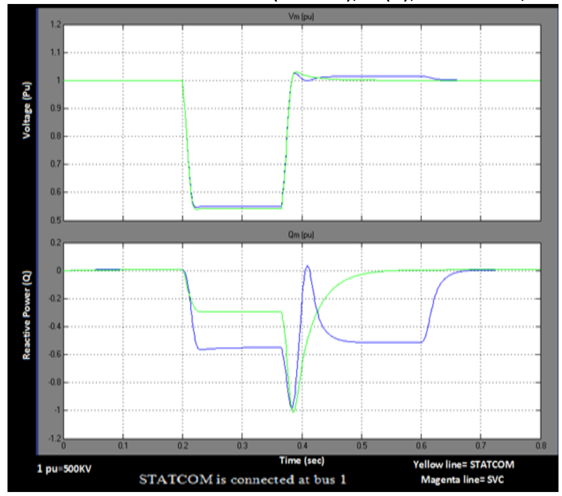

Figure 12(a)- STATCOM & SVC at B1

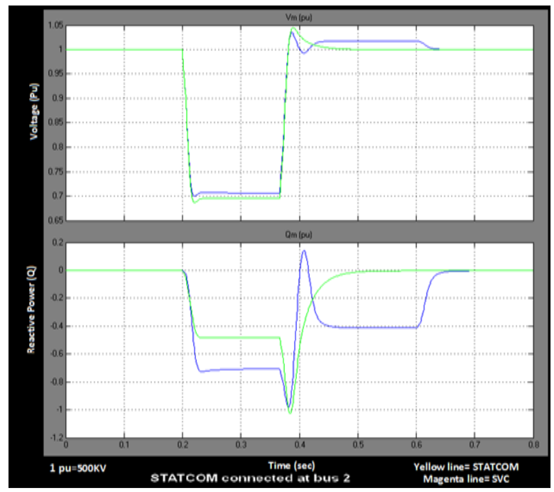

Figure 12(b): STATCOM and SVC at B2

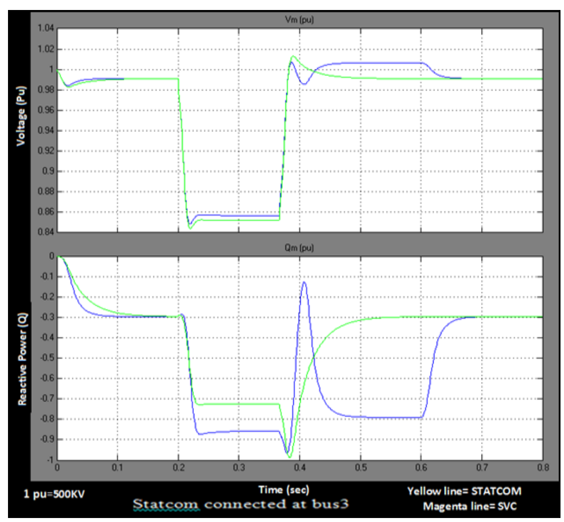

Figure 12(c)- STATCOM and SVC at B3

The reactive power generated by the SVC is -0.48 pu and the reactive power generated by the STATCOM is -0.71 pu at bus 2. 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. 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 summation, STATCOMs are capable of operating at lower voltages, are able to operate at faster speeds, and can be smaller in size than SVCs, but are also more expensive. The cost of STATCOMs can be a restrictive factor when the installation of an SVC yields acceptable results. As STATCOM technology becomes more and more widespread and installation prices for STATCOMs drop, it is expected that STATCOM technology will gradually replace SVC technology in most applications due to its superior performance.

6- CONCLUSION

The characteristic of a given power system evolve with time, as load grows and generation added. If transmission facilities are not upgraded sufficiently, the power system becomes vulnerable to steady state and transient stability problems as stability margins become narrower. The ability of transmission system to transmit power becomes impaired by angular stability voltage magnitude limit and dynamic stability limits. These limits define the maximum electrical power to be transmitted without causing damage to transmission line and electrical equipment.

In principle, limitation on power transfer can always be received by the condition of new transmission and generation facilities, FACTS controller can enable the same objectives to be met with no major alternation to system layout. The potential benefits brought about by FACTS controllers include reduction of operation and transmission investment cost, increase system security and reliability, increase power transfer capability and an overall enhancement of the equality of electrical equality of electrical energy delivered to customers.

Shunt control FACTS devices have been discussed for voltage control and for efficient power transformation.

Sensitivity analysis and stability analysis of shunt connected FACTS devices have been performed and important results about best rating and other parameters have been concluded.

7- APPLICATION OF RESEARCH

Today, the operation of power system has become very complex because the requirements for different control action at different levels. The power system operator is required to make rapid decision for adjusting these controls. These decisions are presently made by operators simply on the basis of previous experience on the selection of control strategy to develop some automated method for making such a decisions to minimize the occurrence of errors by human operators and thereby reducing the risk of unstable operation. The expert system provides the strategy to achieve a pre-determine voltage profile and to retrieve overload devices. This thesis briefly tells us how shunt connected FACTS devices measure these changes in system automatically and then operate and what effects or change in power system quantities takes place after the operation of these devices.

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