Voltage Stability Improvement Using Static Var Compensator in Power Systems

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Abstract- **This paper investigates the effects of Static Var Compensator (SVC) on voltage stability of a power system before and after installing SVC due to the load (reactive power) variation. SVC is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. SVC is basically a shunt connected static var generator whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power variable like the control variable is the SVC bus voltage. MATLAB is used to carry out simulations of the system under study and detailed results are shown to access the performance of SVC on the voltage stability of the system.**

Keywords- Static Var Compensator (SVC), Thyristor Controller Reactor (TSR), Fixed Capacitor (FC)

I. INTRODUCTION

The main objective of this paper and research is the application of static var compensator to solve voltage regulation and system dynamic performance. SVC is thyristor based controller that provides rapid voltage control to support electric power transmission voltages during immediately after major disturbances. When voltage security or congestion problems are observed during the planning study process, cost effective solution must be considered for such problems. The main function of SVC is:

- Voltage support and regulation.
- Transient stability improvement.
- Power system oscillation damping,
- Reactive power compensation.

Reactive power change produced by load variations and line switching can cause adverse effects on voltage stability and the interconnected system security. Static var compensators (SVC) are utilized to enhance the integrated AC system voltage stability. SVC can be classified into four categories [1-2]:

- Thyristor switched capacitor banks (TSC).
- Thyristor controlled reactor banks (TCR).
- Combinations of TSC and TCR with the switched or fixed capacitor, thyristor controller reactor as the most cost effective solution to voltage instability and reactive compensation of high voltage and extra high voltage transmission networks.
- FACTS based on current injection (CSI) or voltage injection (VCI) line committed voltage source or current source inverter interface schemes.

II. MODELLING AND SIMULATION OF THE SVC

A. Thyristor Controller Reactor (TSR) and Fixed Capacitor (FC) of SVC

In order to investigate the impact of SVC on power systems, suitable of the SVC model is very important. SVC is built up with reactors and capacitors, controlled by thyristor valves which are in parallel with a fixed capacitor bank. It is connected in shunt with the transmission line through a shunt transformer. The SVC provides an excellent source of fast controllable reactive shunt compensation for dynamic voltage control through its utilization of high-speed thyristor switching/controlled reactive devices. The main components of the SVC are:

- Coupling transformer
- Thyristor valves
- Reactors
- Capacitors

Functional diagram and equivalent circuit of SVC is shown in figure 1 [3] and figure 2 [4, 5].

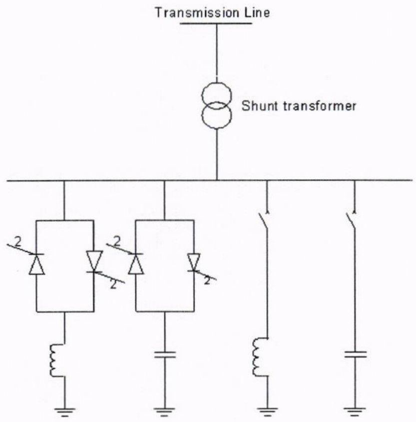


Figure 1: Functional Diagram of SVC

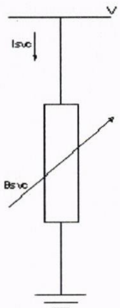


Figure 2: Equivalent Circuit of SVC

B. Basic Arrangement

The main component of one line diagram of SVC is source, transformer, capacitor bank, reactor bank and thyristor switch. It's compensated by a thyristor-controlled reactor (TCR) with the fixed capacitor. Figure 3 is a simplified one line diagram of the main components. The compensator is connected to the system through step-up transformer. On the secondary side, a three-phase wye-connected capacitor bank is paralleled with the delta-connected TCR. The rating of the reactor bank may be variable. By simulating the SVC V-I characteristic curve is obtained. Then, the actual SVC positive-sequence voltage (V1) and susceptance (B1) can be measured [6-12].

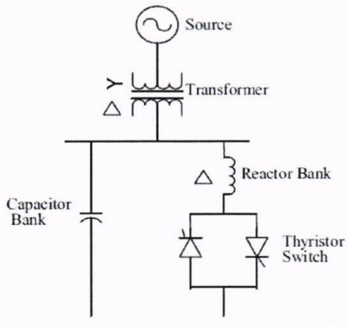


Figure 3: One Line Diagram of Main Components of SVC

C. Dynamic Response of the SVC

The three-phase programmable voltage source is used to vary the system voltage and observe the SVC performance. Initially, the source is generating nominal voltage. Then, voltage is successively decreased (0.97 pu at t = 0.1 s), increased (1.03 pu at t = 0.4 s) and finally returned to nominal voltage (1 pu at t = 0.7 s). Start the simulation and observe the SVC dynamic response to voltage steps on the Scope. The SVC response speed depends on the voltage regulator integral gain Ki (Proportional gain KP is set to zero), system strength (reactance Xn) and droop (reactance Xs). If the voltage measurement time constant and average time delays Td due to valve firing are neglected, the system can be approximated by a first order system having a closed loop time constant [6-12].

D. Description of Static Var Compensator

The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR) [6-12].

E. Single-Line Diagram of the SVC and Control System

The control system consists of:

- A measurement system measuring the positive-sequence voltage to be controlled. A Fourier-based measurement system using a one-cycle running average is used.
- A voltage regulator that uses the voltage error (difference between the measured voltage Vm and the reference voltage Vref) to determine the SVC susceptance B needed to keep them system voltage constant.
- A distribution unit that determines the TSCs (and eventually TSRs) that must be switched in and out, and computes the firing angle M of TCRs.

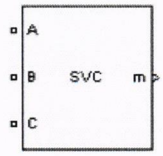


Figure 4: SVC Block

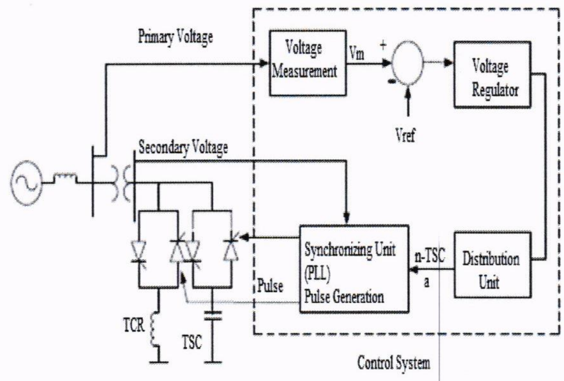


Figure 5: The Control System of SVC

- A synchronizing system using a phase-locked loop (PLL) synchronized on the secondary voltages and a pulse generator that send appropriate pulses to the thyristors..

F. *SVC V-I Characteristic*

The SVC can be operated in two different modes:

- In voltage regulation mode (the voltage is regulated within limits as explained below)
- In var control mode (the SVC susceptance is kept constant)

When the SVC is operated in voltage regulation mode, it implements the following V-I characteristic. As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (Bcmax) and reactor banks (Blmax), the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output). The V-I characteristic is described by the following three equations [6-12]:

Svc is in regulation range ($-Bc_{max} < B < BI_{max}$)

$$V = Vref + Xs.I \quad (1)$$

SVC is fully capacitive ($B = Bc_{max}$)

$$V = -\frac{I}{Bc\max} \quad (2)$$

SVC is fully inductive ($B = BI_{max}$)

$$V = \frac{I}{BI\max} \quad (3)$$

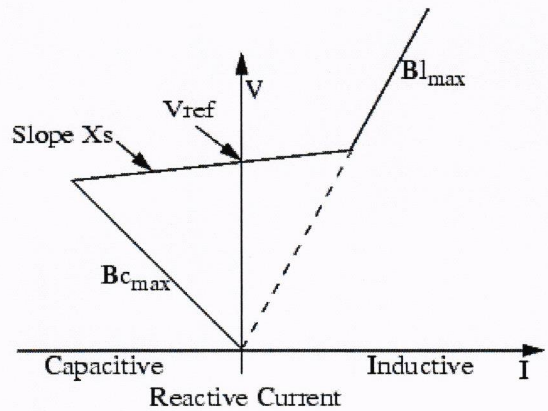
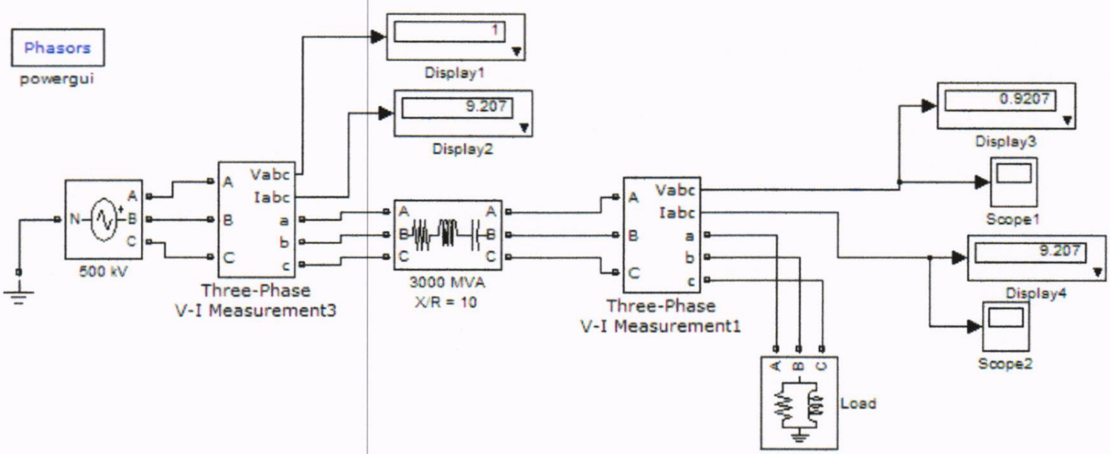


Figure 6: The V-I Characteristic Curve of SVC

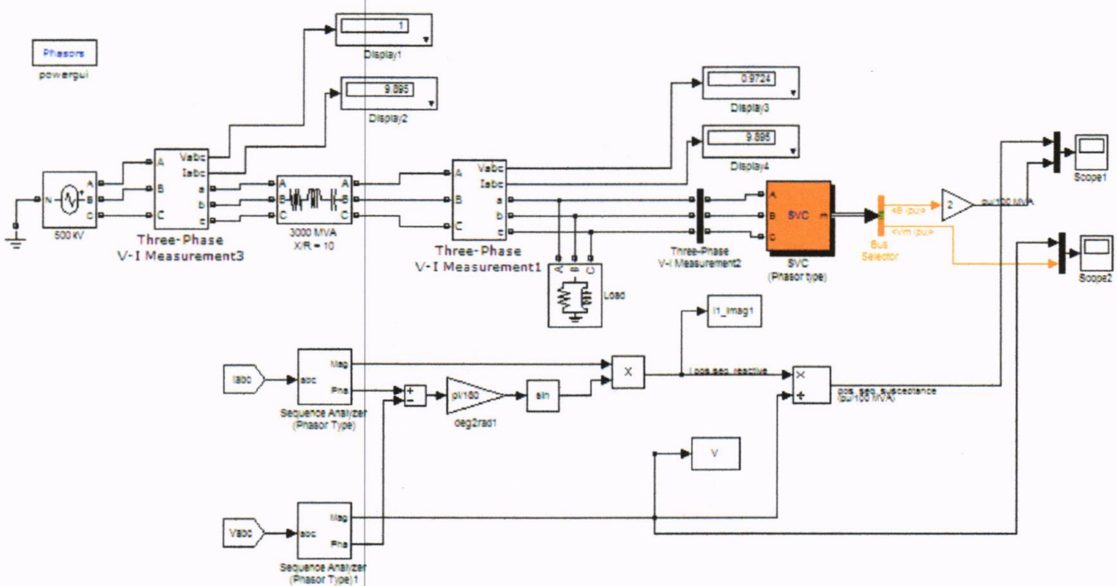
G. *Simulation Model of The SVC*

Figure 7(a) shows the simulation model of transmission line without SVC. The three-phase programmable voltage source is used in this circuit to vary the system voltage. Initially, the source is generating nominal voltage. Then, voltage is decreased to 0.97 pu at t = 0.1s. After that, it's increased to 1.03 pu at t = 0.4 s and finally returned to nominal voltage 1 pu at t = 0.7s. The voltage source is connected with three-phase series RLC branch and three-phase parallel RLC load. Initial load is set at active power, P = 1000MW and reactive power, Q = 1MVAR.

Before installing the SVC block, the value of voltage at Display1 before three-phase series RLC branch is 1pu. For initial load, the value of voltage at load bus is 0.9207pu.



(a)



(b)

Figure 7. (a) Simulation Model without SVC; (b) Simulation Model with SVC

Figure 7(b) shows the simulation model after installing the SVC block. It is a circuit that has same parameter as Figure 7(a) except the additional of the SVC block. The type of additional block is Phasor Type.

The signal processing has been used to compute the actual positive-sequence susceptance B1 and the actual system positive-sequence voltage V1. After installing the SVC block, the value of voltage at load bus increase to 0.9724pu.

III. RESULT AND DISCUSSION

A. The SVC Dynamic Response to Voltage Steps Waveforms

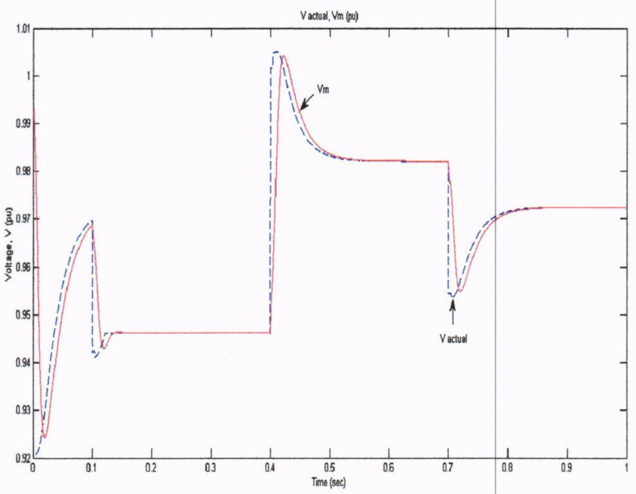


Figure 8: Waveform of V actual and Vm (pu)

From Figure 8, the waveform that obtained from Scope2 of simulation model SVC is shows the actual system positive-sequence voltage V1 and output Vm of the SVC measurement system. Actually, V actual is used to control the output voltage of the SVC measurement. The SVC is set to Voltage regulation mode with a reference voltage Vref = 1.0 pu.

Initially, from t = 0s to t = 0.1, the voltage is not in steady state voltage. Then, from t = 0.1s to t = 0.4s, the voltage is decrease due to change of voltage at three-phase programmable voltage source. After that, from t = 0.4s to t = 0.7s, the voltage is increase and change of voltage when the SVC goes from fully capacitive to fully inductive. Finally, the voltage at t = 0.7s is returned to nominal voltage and its approaching to Vref = 1 pu.

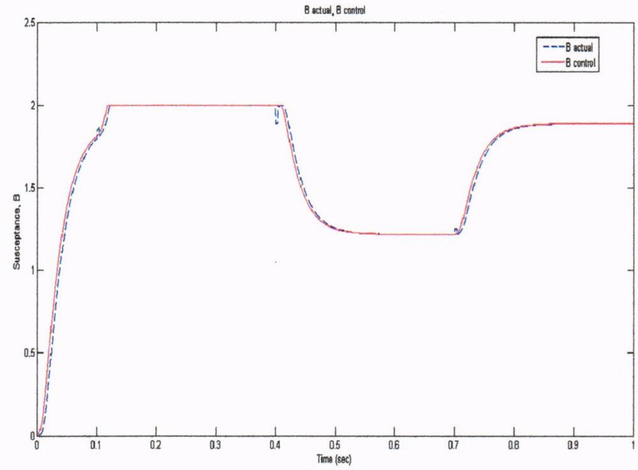


Figure 9: Waveform of B actual and B control

From Figure 9 shows the actual positive-sequence susceptance B1 and control signal output of the voltage regulator and it are obtained from Scope1. If the SVC susceptance B in range of the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks and reactor banks, the voltage is regulated at the reference voltage Vref.

From Figure 8 and 9, its can be conclude that when the voltage decrease, the susceptance B will increase due to how much the total reactive power of capacitor bank and reactor bank and while voltage increase indicates otherwise.

B. The Effect of Variation Load With and Without The SVC

The load that being used in this circuit with different value at the end of transmission line is to investigate the effect of variation load before and after installing the SVC. For this simulation model, the active power is set constant value but the reactive power with different value.

i. The Comparison of the Voltage Between Without and With SVC Due Varied Load

TABLE I. Measurement Voltage With and Without the SVC

No.	Load		Voltage, V (pu)	
	MW	MVAR	Without SVC	With SVC
1	1000	1	0.9207	0.9724
2	1000	2	0.9205	0.9723
3	1000	3	0.9202	0.9722
4	1000	4	0.92	0.9721
5	1000	5	0.9197	0.972
6	1000	6	0.9194	0.972
7	1000	7	0.9192	0.9719
8	1000	8	0.9189	0.9718
9	1000	9	0.9187	0.9717
10	1000	10	0.9184	0.9716

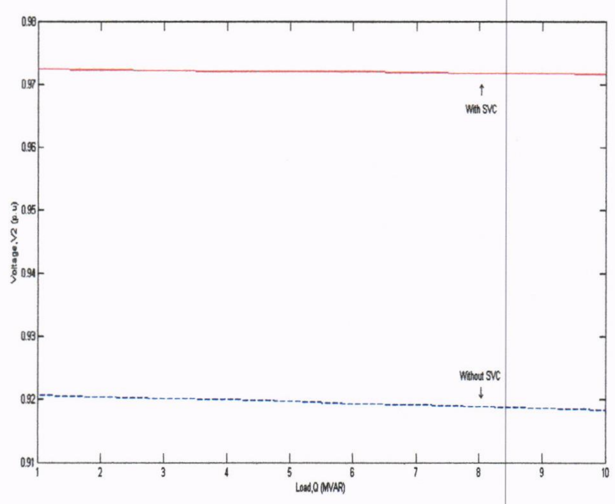


Figure10: Graph of Comparison Voltage between Without and With the SVC

Figure 10 shows the comparison of the voltage at the end of transmission line before and after installing the SVC. The main function of SVC is to maintain voltage stability at the transmission line. From graph, when load at 1000MW and 1MVAR, it was shown a different value of voltage after installing the SVC. Improvement value of voltage from 0.9207 pu to 0.9724 pu prove that with installing the SVC is better, its value approaching the reference voltage (1pu). But when the load is increased to 1000MW and 2MVAR, the voltage dropped to 0.9723 pu. From this result, its can be conclude that when increase of load would affect in voltage at the transmission line.

ii. The Reduction in Voltage Due to Load Varied

Figure 11 and 12 shows the reduction in voltage due to the increasing load.

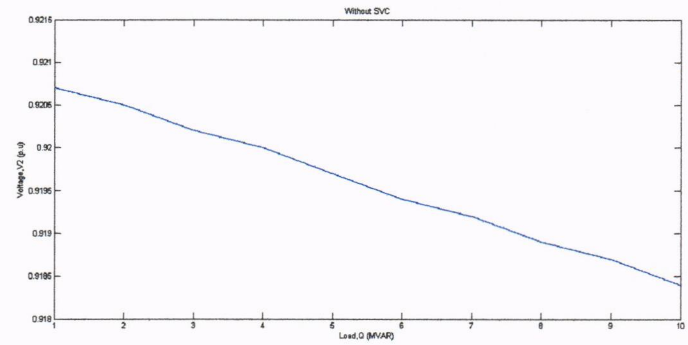


Figure 11: The Reduction in Voltage without SVC

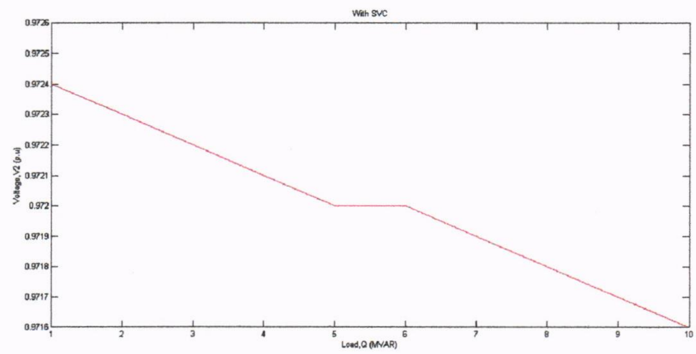


Figure 12: The Reduction in Voltage with SVC

iii. The Percentage of Voltage Improvement Due to Increase of Load

TABLE II. Percentage of Voltage Improvement Due to Increase of Load

No.	Load		% of Voltage Improvement
	MW	MVAR	
1	1000	1	5.62
2	1000	2	5.63
3	1000	3	5.65
4	1000	4	5.66
5	1000	5	5.69
6	1000	6	5.72
7	1000	7	5.73
8	1000	8	5.76
9	1000	9	5.77
10	1000	10	5.79

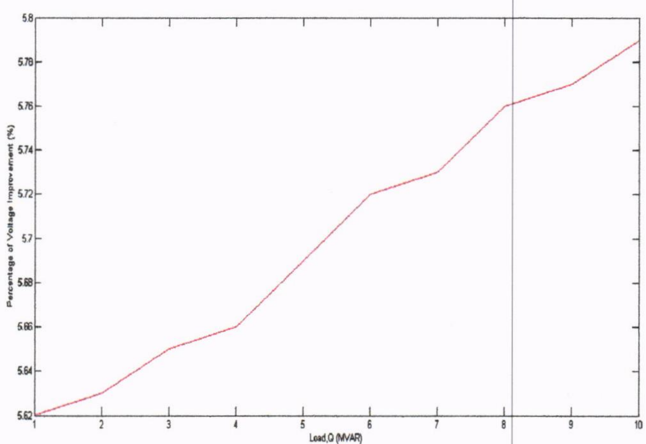


Figure13: Graph of Percentage of Voltage Improvement Due to Increase of Load

From Figure 13, it's shown the percentage of voltage improvement is proportional to the increase of load. When load is increased, the percentage of voltage improvement also increases. It should be noted that the increase of load significantly influence voltage drop at transmission line.

IV. CONCLUSION

This paper presents the effects of Static Var Compensator (SVC) on voltage stability of a power system before and after installing SVC. SVC is used primarily in power system for voltage system stabilization. In order to see whether the mitigation technique can mitigate the voltage instability, another 10 variable value of load at the end of transmission line are used for testing to investigate the effect of varying the load can influence the voltage at load bus system .It also explains about a detailed overview of the voltage-control characteristics of SVC and the principles of design of the SVC voltage regulator. The performance of SVC voltage control is depending on several factors, including the influence of network resonances, transformer saturation, geomagnetic effects, load variation and voltage distortion. When SVCs are applied in series-compensated networks, a different kind of resonance between series capacitors and shunt inductors becomes important in the selection of control parameters and filters used in measurement circuits. This will also demonstrate the advantages of using MATLAB Simulink system for analyzing steady state power system stability including control behavior.

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