Reactive Power Management and Voltage Control of large Transmission system using SVC (Static VAR Compensator)

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***Abstract*—The role of the transmission network in the Power System is to transmit the power generated in the power plants to the load centers and the interconnected power systems. The transmission of electric power has to take place in the most efficient way in addition to providing flexibility in the process. Flexible A.C. Transmission System (FACTS) promotes the use of static controllers to enhance the controllability and increase the power transfer capability. Providing reactive shunt compensation with shunt-connected capacitors and reactors is a well established technique to get a better voltage profile in a power system. Shunt capacitors are inexpensive but lack dynamic capabilities, thus some form of dynamically controlled reactive power compensation becomes essential. This feature is provided by Static VAR Compensator (SVC). The work presented here also compares SVC with fixed capacitor compensation and documents the superiority of SVC using Computer Simulation and its performance for reactive power management and better voltage control.**

Keywords- AC transmission, FACTS, static VAR Compensator (SVC), Power Electronics, thyristor, power converter.

I. INTRODUCTION

Transmission systems are becoming increasingly stressed because of growing demand and because of restrictions on building new lines. However, most high voltage transmission systems are operating below their thermal rating due to such constraints as stability limits. EPRI is pioneering flexible ac transmission system (FACTS) technology to make it possible to load lines at least for some contingencies up to their thermal limits without compromising system reliability.

Static VAR Compensator (SVC) was first introduced in late 1960s.These compensators used Thyristor switch capacitor (TSC) or Thyristor Controlled Reactor (TCR) with fixed power factor correcting capacitor. Such SVCs were then modified for dynamic compensation of electric power transmission system by using TCR in combination with TSCs. Until the 1990s no suitable GTO devices were available for use in high power applications. The Electric Power Research Institute (EPRI) has encouraged the use of power electronic devices in power transmission system under its Flexible AC Transmission System Program (FACTS). The present paper deals with the simulation of SVC on PSCAD/EMTDC along with the associated details of the circuit design [1]. Further the performance evaluation has been carried out to verify the accuracy and validity of the results as compared to Fixed Capacitor Compensation. The static VAR compensator is now mature technology that is widely used for transmission applications. Electric utility industry standardization of basic models is needed, and is recommended in this paper [1]. The dynamic stability improvement of a longitudinal power system using a power system stabilizer (PSS) and a static VAR (reactive volt-ampere) compensator (SVC) is reported. Results from time-domain simulations indicate that the PSS and the SVC are very effective in damping system oscillations [2]. The recent availability of Electromagnetic Transient Programs with graphical front ends now makes it possible to put together models for circuits and systems in a manner similar to the connection of components in a laboratory [5]. High speed control allows the power system operators to use the transmission system in an advantageous, steady state mode, which may normally be unacceptable from the point of view of stability/security considerations in the context of mechanical control system, and yet it can respond with high speed to deal with the stability/security threatening conditions [9]. Power electronics is a combination of power semiconductor devices called thyristors, configured in many different ways in circuits with appropriate controls, to accomplish ac to dc or dc to ac conversion, frequency conversion, switching, reactive power generators and many other potential applications. Today, thyristor switching capability changes from tens of kilowatts to thousands of megawatts [16].

II. SVC SYSTEM

In transmission line compensation, the main objectives are

1. Improvement of voltage regulation and reactive power control.
2. Improvement in system stability.

An ideal compensator must have ability to respond instantaneously in achieving all these objectives. Static VAR Systems (SVS) have emerged as VAR generation and absorption systems. The function of SVS is to provide high speed reactive power load compensation resulting in voltage stabilization and stability improvement. The specific functions of an SVS can be summarized as follows

1. Voltage Control
2. Prevention of Voltage collapse
3. Damping of Power Oscillations

SVS Configurations: Providing reactive shunt compensation with shunt- connected capacitors and reactors is a well established technique to get a better voltage profile in a power system [2]. The basic form of reactive power compensation required, to compensate reactive power loads, is the fixed shunt capacitors being well distributed across the network and located preferably closed to the loads. This would ensure reasonable voltage profile during steady state condition. However, this may not be adequate to ensure stability under overload or contingency conditions. Shunt capacitors are inexpensive but lack dynamic capabilities, thus some form of dynamically controlled reactive power compensation becomes essential. The phase angle between the end voltages, determined by the real component of the line current, is not affected by the shunt compensation. Similarly, adding a reactor instead of a capacitor in shunt will reduce the voltage. Instead of mechanical switching (using circuit breakers) of these devices, we can use thyristor valves, thereby increasing the control capability radically. This approach is called static VAR compensation (SVC).

The basic reactive components of a static compensator are shunt reactors and shunt capacitors. These reactors are varied by means of thyristors. The capacitor banks are either a fixed amount or are varied in steps by thyristor switching. Based on these principles various static compensators have been developed. These are characterized by fast response, reliability, low operating costs and flexibility.

Basic Description of Static VAR Compensation (SVC) [1]

SVC can be of one of the following types:

1. Thyristor controlled Reactor (TCR)
2. TCR plus Fixed Capacitor (FC)
3. Thyristor switched Capacitor (TSC)
4. TSC plus TCR

Figure 1 is a one-line diagram of a typical static VAR system for the transmission application. TSC plus TCR is very popular and most effective. Figure 1 gives the general idea of realization of SVC using TSC plus TCR scheme. The idea is to sense the voltage of the line and keep it stable by introducing capacitance or inductance in the circuit, depending on the signal generated by Automatic Voltage Regulator (AVR). So obviously, the gating signals to thyristor valves will have to be changed in accordance with the AVR signal. Since control can be achieved in every cycle of the voltage waveform by (controlling the conduction time of thyristors), the control is very fast and accurate. Compensator characteristics as shown in figure 2. It shows that if the voltage decreases than the desired , capacitive current is supplied and when the voltage over shoots, inductive current is supplied. The point of steady state operation will be at the intersection of the compensator characteristics and the system load line suppose, due to a disturbance in power system (e.g. throwing off of a load from the system), the load line has shifted from B1 to B2 (refer to figure 2).

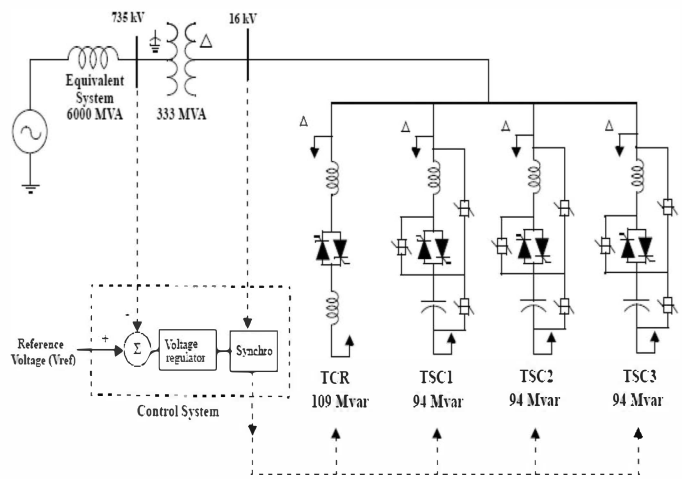


Figure 1: Typical static VAR system (SVS)

Before disturbance, the steady state point was at “a”. If the response of the TCR control were slow, the operating point would have moved straight to point “b”, but since the thyristor control is very fast, the voltage, even before overshooting to point “b”, will stabilize at point “c”. This describes the typical control action of a SVC.

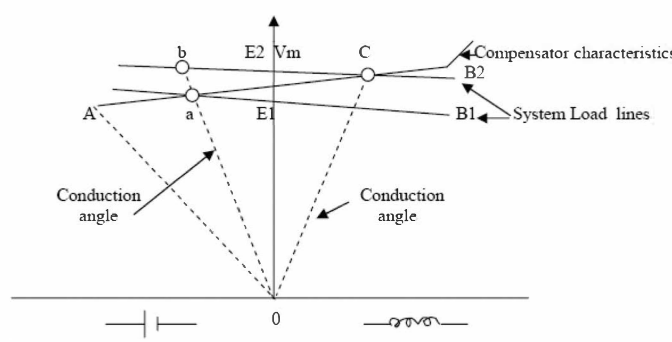


Figure 2: Effect of TCR Compensation on operating point.

SVC Characteristics: A specific SVC regulation characteristics is shown in figure 3 [3] the droop is set depending on the SVC rating and the short circuit level of the controlled bus. Under normal network conditions the SVC control should be set to zero MVAR exchange with the system. During distributed conditions the SVC susceptance is varied by the regulator to counteract the voltage oscillations.

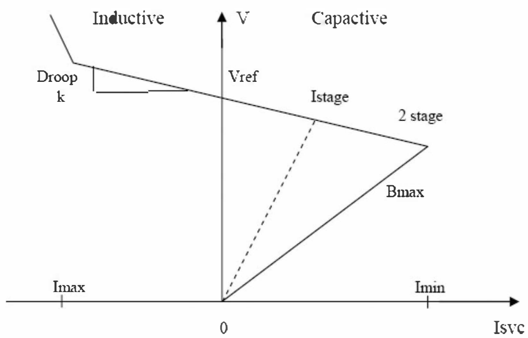


Figure 3: Typical SVC Characteristics.

Reactive Power Compensation by SVC: SVC's can supply and/or absorb reactive power depending on the design. Normally Thyristor switched capacitors (TSC) are employed for the former and Thyristor controlled reactor (TCR) for the latter function. TSC's bring about harmonic free step control of reactive power while the TCR's enable continuous control of reactive power. Generation of harmonics is inherent to any phase angle control application. The SVC's are provided with a voltage regulator whose gain and other parameters are selected to meet the required performance when SVC's placed at key locations in the network the controlled reactive power sources ensure a good voltage profile under all operating conditions. When these devices can perform with sufficient speed of response they serve to enhance the transient stability and could help to prevent voltage collapse. The well-established Static VAR Compensator (SVC) and new development when judiciously applied, becomes an attractive tool for transmission system enhancements.

III. SVC SIMULATION

Digital Simulation of SVC: For simulating SVC in power system, simple two-bus system connected by transmission line is used for simulation. The system data and line data is given in Appendix. The system consists of two 230 kV, 50 Hz generators. Sending end operated at 63 degrees and receiving end generator operated at 0 degrees power angle. The measuring and plotting icons are connected at various sections with suitable time constants and scaled for smooth measurement.

Above two bus system with fixed capacitor compensation (block diagram) is shown in figure 4. (Simulated diagram PSCAD/EMTDC CN.1). The system with SVC connected to transmission line is shown (block diagram) in figure 5 (Simulated diagram PSCAD/EMTDC CN.2). The SVC is simulated in PSCAD/EMTDC CN.2.

This SVC 400 model [4, 5] consists of a general static VAR Compensator (SVC) model SVC 400 is available which is based on state variable techniques. A state variable formulative solves the differential equations of the system for capacitor voltages and inductor currents.

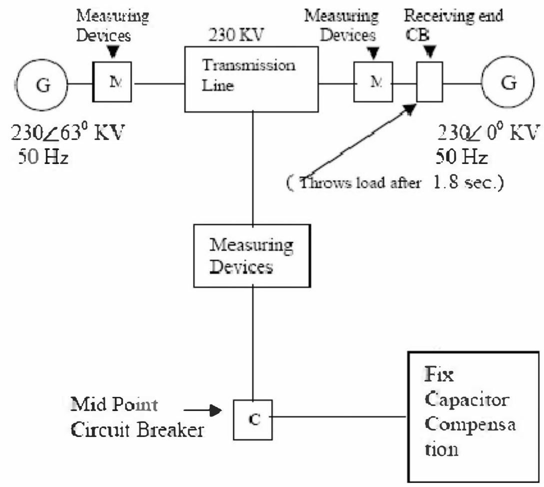


Figure 4: System with fix capacitor compensation
(Simulated diagram is shown PSCAD /EMTDC CN 1)

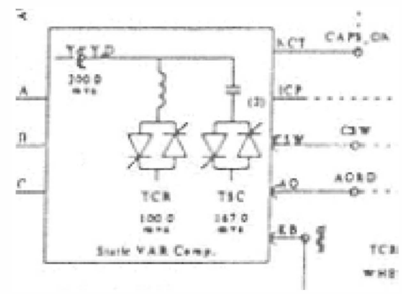


Figure 5: SVC 400 Model ICON.

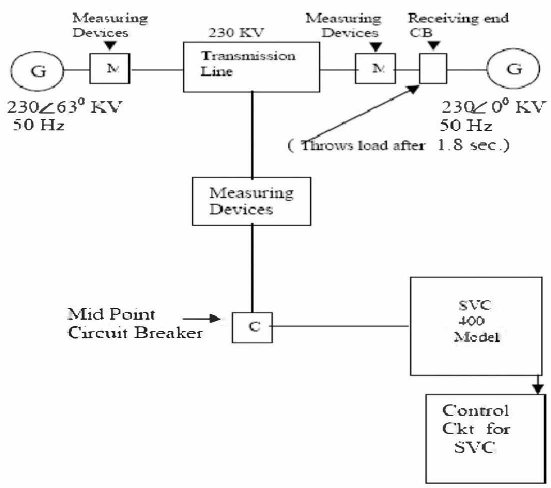


Figure 6: System with SVC Compensation

(Simulated diagram is shown PSCAD /EMTDC CN2, CN3)

The dependence of the system matrices on the value of the time-step is directly proportional, and thus the time-step can be readily changed during run as it is required for the switching elements to be modeled adequately. The SVC 400 compensator model interfaces with EMTDC program as a Norton current source Figure 5 shows the SVC 400 model (ICON use in Simulation with PSCAD)

Circuit used for Simulation: PSCAD/EMTDC software is used for simulation. It has a model for SVC comprising of TCR and TSC. Following consideration are made while using this model [PSCAD/EMTDC CN-2]

1. A suitable voltage measurement technique is necessary to reduce ac harmonics and dc ripples to obtain clean measurement for the controller.
2. A droop of the measured voltage should be derived to obtain a specific SVC regulation characteristic, such as shown in figure 3.
3. An allocator should be used to split a reactive power requirement into on/off signal for the TSC and a reactive power demand for the TCR.

A practical system is simulated [4] comprising of two sources connected through a transmission line and the SVC placed at the midpoint of the line as is usually the case. [6]. The circuit is shown in figure 5. It shows two sources marked “sending end” and “receiving end” connected through 230 kV 50 Hz. transmission lines “line1” and “line2”. The data for the transmission line model is given in Appendix and consists of physical dimensions of towers and conductors along with spacing between the conductors and their configuration voltage, active power and reactive power are measured at both ends. Between the two transmission line models i.e. practically at the middle of a long transmission line, fixed shunt capacitors of 120 MVAR rating are connected in delta through a circuit breaker (MPBrks). This circuit is analyzed to compare the performance when a SVC replaces the Fixed Capacitors (FC). The voltage and power of the FC branch are also measured. Another breaker (Rebrks) is used to connect the receiving end source to transmission line. This breaker is opened after 1.8 seconds during the simulation to create a disturbance. This will be the same as “through off” of load from the system. Obviously, the voltage at the mid-point is bound to shoot up. To reduce this voltage, capacitive power injection at the midpoint has to decrease. Here, on the contrary, with an increase in the voltage, the FC will draw more reactive power. So, the only way to pull down the voltage is to switch off the capacitors. This is achieved by switching off MPBrks at 2.1 seconds. Here, 3 milliseconds time is considered for sending, relaying and breaker operation (this can be the worst case).

Control and Firing Circuit for SVC: Now the same circuit is provided with SVC instead of FC. This is shown in figure PSCAD/EMTDC CN-3. The circuit breaker MPBrks is removed now as it is not required. The SVC is connected to the system through a 200 MVA 230/11 KV transformer. The SVC comprises of a 100 MV TCR in parallel with a 167 MVAR capacitor bank which is divided in two equal stages. Control circuit of SVC is shown in figure PSCAD/EMTDC CN-3.

IV. PERFORMANCE EVALUTION

Simulation Results with Fixed Compensator: The simulation results with FC compensation are shown in figure 7. We can observe from (d), as soon as the load is thrown off (at 1.8 seconds), the voltage shoots up to around 1.5 pu from 1 pu. After the FC are cut off, the voltage comes down to around 1.1. pu which is still higher than the required 1 pu. From (c), we observe that the capacitive power drawn by the FC rises with the voltage. The real power remains zero throughout as the capacitors are considered ideal. From (a), we can observe the reactive power at the sending and the receiving end, whereas (b) shows the real powers. Thus, we can increase the maximum power transfer capability of line with FC, but the voltage control is not satisfactory.

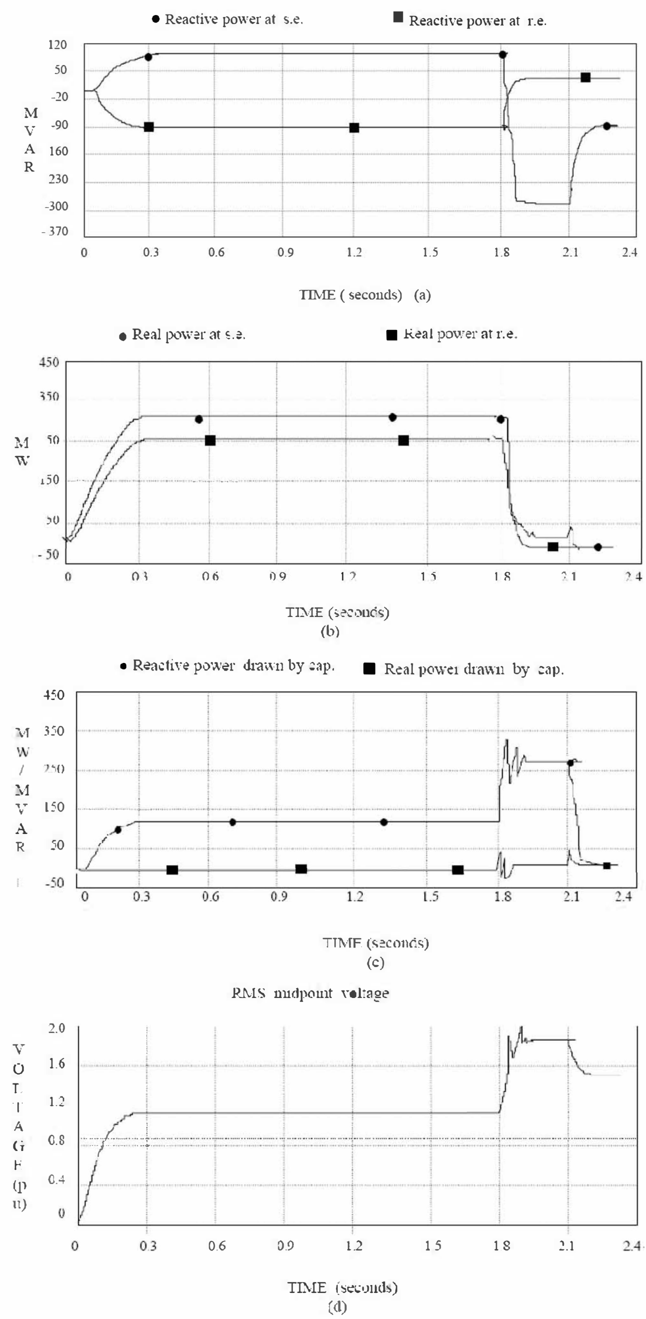
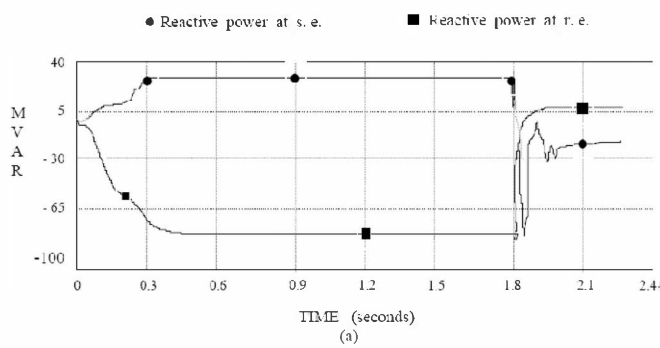


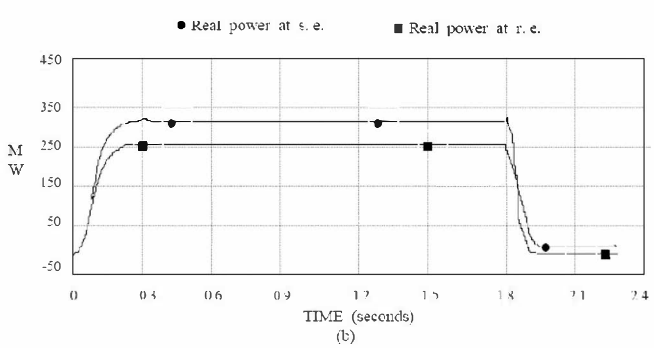
Figure 7: Performance of the system with Fix Capacitor Compensation (a, b, c & d)

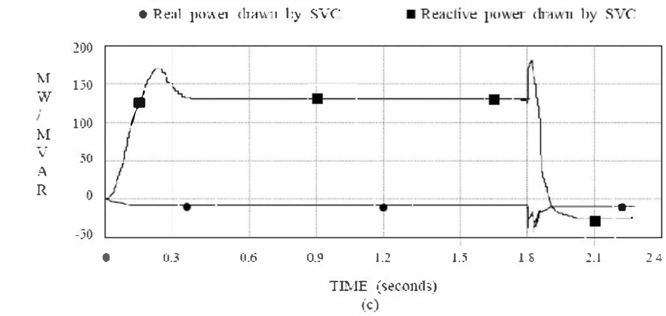
The Simulation results of the power profile with SVC are shown in figure 8 (a) to figure 8 (e). The same power profile as with FC is achieved by SVC also. It maintains the same steady state voltage of 1 pu (refer figure 8 (e) and provides the same mid-point compensation of 110 MVAR leading in steady state as FC. The reactive power at sending end and receiving end are also same (refer figures 7(a), 7(b), 8(a), 8(b)), but SVC draws real power of 10 MVAR from the system to compensate for its internal losses (refer figure 8(c))

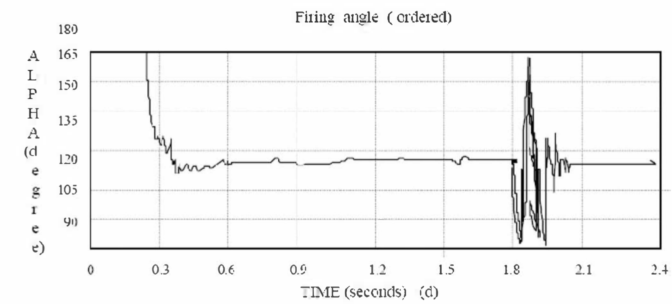
During disturbance, the reactive power supplied by SVC goes from 110 MVAR leading to 35 MVAR lagging (Refer figure 8(c)) to effectively control the over voltage within 2 cycles and make it perfectly stable in about 15 milliseconds (refer figure 8(e)). Figure 8(d) shows the firing angle to the TCR and the number of capacitor stages switched on (maximum 2) respectively. To maintain voltage during steady state, both the capacitor stages are switched on (167 MVAR leading) but as seen before a leading reactive power of 110 MVAR only is required to maintain the steady state voltage profile. So, the TCR conducts with a firing angle of about 130^0 to ensure this. After the disturbance, the voltage is controlled by cutting out both capacitor stages and adjusting the firing angle to about 125^o.

Figure 9 shows comparison between performances with FC and SVC. The vastly superior capability of SVC to control over voltage is clearly established. The only drawback with SVC seems to be that the voltage transiently shoots up to about 1.71 pu. whereas it rises to a maximum of about 1.6 pu with FC.









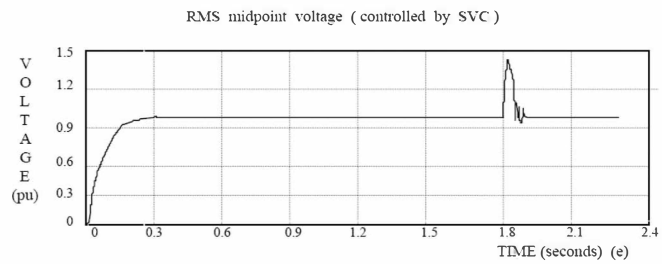


Figure 8: Performance of the system with SVC (a, b, c, d & e)

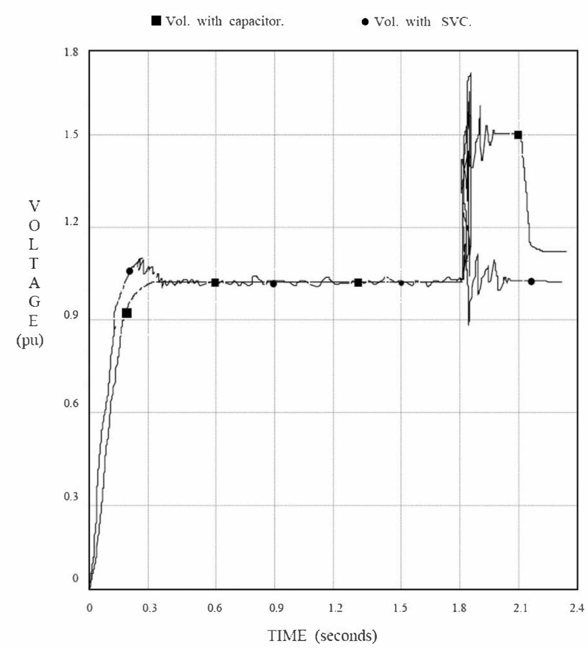


Figure 9: Comparison of voltage control capabilities of Fixed Capacitor (FC) and Static VAR Compensator (SVC).

V. Conclusions

From the simulation results of SVC (obtained from PSCAD/EMTDC) it is found that SVC can effectively use to control voltage and reactive power compensation. Thus the superiority of SVC over fixed capacitor compensation is proved. In addition to this we have following observations about SVC. SVC has much superior voltage control capabilities both, in steady and transient state than the conventional switched shunt capacitor and reactor compensation.

1. Due to above, SVC improves the transient stability of the system.
2. Presence of a fixed series capacitor in the circuit introduces undesirable oscillations in voltage control profile of SVC in case of disturbance, whereas the presence of TSCs tends to increase the amplitude of such oscillations.
3. Performance of SVC is satisfactory in case the system voltage reduces.

APPENDIX-I

For running Simulation on PSCAD following data selected while running the SVC case.

PI Controller Sliders:Kp:4.0,T1:0.01, Deblocked control slider at KB .V_{ref} slider :1pu,Mid-point breaker switch kept closed. At the sending end voltage of the source:230 KV and phase angle of source : 63 degrees. At receiving end voltage of the source: 230 KV, phase angle of the source : 0 degree.

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References

[1] IEEE Special stability controls working Group, “Static VAR Compensator Models for Power Flow and Dynamic Performance Simulation,” IEEE Transactions on power systems, vol. 9, no.1 February 1994. pp. 229-240.

[2] Aboytes F., Arroyo.G. and Villa G., “Application of Static VAR Compensators in Longitudinal Power Systems”, IEEE Trans on PAS, Vol.PAS-102, PP.3460-3466, Oct.1983.

[3] M.Prasad, R.S. Moni, P.Halvarsson, “Systems Aspects on Enhanced Stability using Static VAR Compensation (SVC) and Thyristor controlled series capacitor (TCSC)”, Transmission & Distribution in 2000 Technical conference February 1996, pp. 15-19.

[4] PSCAD/EMTDC working group, “Static VAR Compensator”, PSCAD/EMTDC User manual pp. 75 - 91.

[5] A.M. Gole, O.B. Nayak, T.S. Sidhu, “A Graphical Electromagnetic Simulation laboratory for Power Engineering Programs”, IEEE Transactions on Power Systems, Vol. 11, No. 2, May 1996, pp. 599-606.

[6] N. Rostamkolai, et. al., “Subsynchronous Torsional Interactions with static VAR compensators concept and practical Implications “, IEEE Transactions on Power Systems, Vol. 5, No.4, Nov. 1990, pp. 1324 - 1332.

[7] K.R. Padiyar, “Novel FACTS controllers for system improvement”, Transmission & Distribution in 2000 Technical Conferences February 1996. pp. 6 - 8.

[8] H. Schweickarat and G. Romegialli, Badenm “The static VAR Source in EHV Transmission Systems and its control “, Brown Boveri Review 9-78, pp. 585-589.

[9] N.G. Hingorani, EPRI, “Flexible AC Transmission System,” IEEE Spectrum power systems, April 1993, pp. 40-45

[10] A.M.Gole, V.K. Sood, “A static Compensator model for use with Electromagnetic Transients simulation Programs, “ IEEE Transactions on Power Delivery, vol. 5, No.3, July 1990, pp. 1398 - 1407.

[11] Cigre international conference on large high voltage Electric systems, “FACTS OVERVIEW”, IEEE Power Engineering Society April, 1995.

[12] Dr. S.A. Khaparde, Mr. S.M. Brahma, “Flexible AC Transmission System (FACTS): An Overview”, Transmission and Distribution in 2000 Technical Conferences February 1996. pp. 1-5

[13] A. M.Gole, T.L. Maguire, “Digital Simulation of Flexible Topology Power Electronic Apparatus in Power Systems”, IEEE Transactions on Power Delivery, Vol. 6, No.4. Oct. 1991 pp. 1831-1839.

[14] Dr. D.P. Kothari, “Flexible AC Transmission”, Technical conference VRCE, Nagpur 1998.

[15] PSCAD/EMTDC Users manual - Transmission line data Available: http://www.hvdc.ca.

[16] N.G. Hingorani, “High Power Electronics and Flexible AC Transmission system “ IEEE Power Engineering Review, July 1988 pp. 3-4.