



Transfer Capability Enhancement of Transmission Line Using Static VAR Compenstator

Arti Pateriya and Nitin Saxena

*Department of Electrical Engineering,
Jabalpur Engineering College, Jabalpur, (MP), India*

(Received 15 October, 2012 Accepted 10 January, 2013)

ABSTRACT: Voltage stability analysis in an existing long transmission line, plays a essential role in power system area. This paper employs the shunt connected compensation (SVC) based FACTS device for the control of voltage ,active power, reactive power and power damping oscillations in long distance transmission line. Here also deals with determination of the optimal location of shunt flexible a.c. Transmission system (FACTS) devices for a long transmission line for voltage and power transfer improvement. The results also show that optimal location depends upon voltage magnitude and the line loading and system initial operating conditions. In this paper the two machine 4-bus test system is simulated using MATLAB Simulink environment.

Keywords: Stability, simulation, power transfer, SVC.

I. INTRODUCTION

In modern era the applications of the power electronics devices in power systems are very much bigger. It is an urgent need to control the power flow, in a long distance transmission line. The FACTS devices are introduced in the power system transmission for the reduction of the transmission line losses and also to increase the transfer capability[1]. The flexible AC transmission system(FACTS) are now recognized as a viable solution for controlling transmission voltage, power flow, dynamic response, etc. and represent a new era for transmission systems. It uses high current power electronic devices to control the voltage, power flow, etc. of a transmission system. FACTS devices are very effective and capable of increasing the power transfer capability of a line, if the thermal limit permits, while maintaining the same degree of stability [2]. Tan, *et al* [3] have demonstrated the effectiveness of SVC and STATCOM of same rating for the enhancement of power flow. Shunt compensation enhance the real power handling capacity of line at a much lower cost than the building a second transmission line of the same capacity. Shunt FACTS devices are recognized as smooth control of reactive power over a wide range to support transmission line [2, 6].

Today's power systems are widely interconnected to take advantage of diversity of loads, availability of resources and fuel prices, in order to supply electricity to the loads at minimum cost with a required reliability. Transmission is often an alternative to new generation and less transmission capability means a requirement for more

generation resources. The cost as well as difficulties encountered in building new transmission lines, limits the transfer of available power. In many cases economic energy or reserve sharing is constrained by the transmission capacity. Flexible AC transmission system (FACTS) technology opens up new opportunities for controlling power flow and enhancing the usable capacity of present transmission lines. FACTS device control the interrelated parameters that govern the operation of a transmission system, thus enabling the line to carry power close to its thermal rating. The analytical method is used here to find out the optimal location of FACTS devices, in which first system model simulated, and after simulation observe the voltage magnitude and reactive power consumption at all buses. Now select the lowest voltage magnitude and highest reactive power consumption bus, for considerable voltage and power transfer capability this lowest voltage magnitude and highest reactive power consumption bus is the optimal location to install FACTS devices.

It has been observed that shunt FACTS devices give maximum benefit from their stabilized voltage support when sited at the optimal location of the transmission line. The proof of maximum increase in power transfer capability is based on a simplified model of the line that neglects the resistance and capacitance, which is a reasonable assumption for short transmission lines. However, for long transmission lines, when the accurate model of the line is considered, the results may deviate significantly from those found for the simplified model especially with respect to stability improvement [5,7].

II. POWER SYSTEM STABILITY

A. Definition of Stability of a System

The stability of a system is defined as the tendency and ability of the power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium[2]. Let a system be in some equilibrium state. If upon an occurrence of a disturbance and the system is still able to achieve the equilibrium position, it is considered to be stable. The system is also considered to be stable if it converges to another equilibrium position in the proximity of initial equilibrium point. If the physical state of the system differs such that certain physical variable increases with respect to time, the system is considered to be unstable. Therefore, the system is said to remain stable when the forces tending to hold the machines in synchronism with one another are enough to overcome the disturbances. The system stability that is of most concern is the characteristic and the behavior of the power system after a disturbance [2].

B. Need for power system stability

The power system industry is a field where there are constant changes. Power industries are restructured to cater to more users at lower prices and better power efficiency. Power systems are becoming more complex as they become inter-connected. Load demand also increases linearly with the increase in users. Since stability phenomena limits the transfer capability of the system, there is a need to ensure stability and reliability of the power system due to economic reasons. Different types of power system stability have been classified into rotor angle stability, frequency stability and voltage stability. Fig. 1 shows the classification of power system stability.

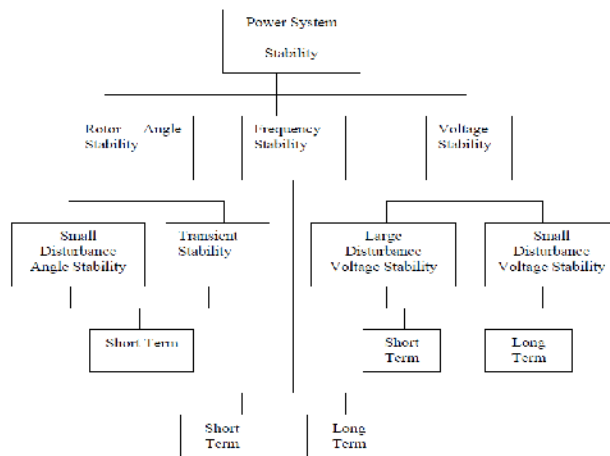


Fig. 1. Classification of power system stability.

III. PROBLEM FORMULATION

The problem formulation for total power transfer capability with FACTS devices including transmission power loss is used to determine the maximum power that can be transferred from a specific set of generators in source area to loads in sink area within real and reactive power generation limits, line flow limits, voltage limits, stability limits, and FACTS devices operation limits. SVC is used to enhance the load ability of the transmission line. SVC is used to control bus voltage, reactive power injection, stability control, oscillation damping and unbalanced compensation.

The equations for system flow and stability are given as:

$$P_{Gi} - P_{Di} + P_L + P_{FDi}(V_{FDi}) + \sum_{j=1}^N V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \quad \dots(1)$$

$$Q_{Gi} - Q_{Di} + Q_L + Q_{FDi}(V_{FDi}) + \sum_{j=1}^N V_i V_j Y_{ij} \sin(\theta_{ij} - \delta_i + \delta_j) = 0 \quad \dots(2)$$

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad \dots(3)$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \quad \dots(4)$$

$$V_i^{min} \leq V_i \leq V_i^{max} \quad \dots(5)$$

$$|S_{Li}| \leq S_{Li}^{max} \quad \dots(6)$$

$$0 \leq V_{FDi} \leq V_{FDi}^{max} \quad \dots(7)$$

$$Q_{FDi}^{min} \leq Q_{FDi} \leq Q_{FDi}^{max} \quad \dots(8)$$

Where,

P_{Gi}, Q_{Gi} : real and reactive power generations at bus i ,

P_{Di}, Q_{Di} : real and reactive loads at bus i ,

V_i, V_j : voltage magnitudes at bus i and j ,

$P_{FDi}(V_{FDi}, \alpha_{FDi})$: injected real power of FACTS device at bus i ,

$Q_{FDi}(V_{FDi}, \alpha_{FDi})$: injected reactive power of FACTS device at bus i ,

S_{Li} : i th line or transformer loading,

N : total number of buses,

δ_i, δ_j : voltage angles of bus i and j ,

Y_{ij} : magnitude of the ij th element in bus admittance matrix,

θ_{ij} : angle of the ij th element in bus admittance matrix,

And the equations for power transmission are given as:

$$P = \frac{V_s V_r}{X_L} \sin(\delta_s - \delta_r) = \frac{V^2}{X_L} \sin \delta \quad \dots(9)$$

$$Q = \frac{V_s V_r}{X_L} [1 - \sin(\delta_s - \delta_r)] = \frac{V^2}{X_L} [1 - \cos \delta]$$

... (10)

$$\delta = \delta_s - \delta_r$$

... (11)

$$|V_s| = |V_r| = |V|$$

... (12)

where, P is Active power in p.u.

Q is Reactive power in p.u.

V_s is Sending end voltage in p.u.

V_r is Receiving end voltage in p.u.

X_L is Line reactance in p.u.

s is Voltage angle at sending end.

r is Voltage angle at receiving end.

IV. FACTS DEVICES IN POWER SYSTEM

Shunt compensation is used to influence the natural electrical characteristics of the transmission lines by generating the reactive power. There are two distinctly different approaches to controllable VAR generation. The first group employs reactive impedances with thyristor switches as controlled-elements (e.g. SVC); while the second group uses self-commutated static converters as controlled voltage sources (e.g. STATCOM). Extensive elaborations on FACTS devices can be found in the literature.

A. Static VAR Compensator (SVC)

SVC is basically a shunt connected static VAR generator whose out-put is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables. Fig. 2 shows the single-line diagram of an SVC and a simplified block diagram of its control system. The control system consists of the following main components:

* A measurement system measuring the positive – sequence voltage to be controlled.

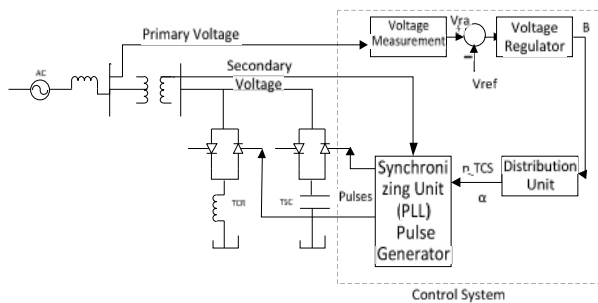


Fig.2. Single-line diagram of an svc and its control system block diagram.

* A voltage regulator that uses the voltage error (difference between the measured voltage V_m and the reference voltage V_{ref}) to determine the SVC susceptance needed to keep the system voltage constant.

* A distribution unit that determines the Thyristor Switched Capacitors (TSCs) that must be switched in and out, and computes the firing angle α of Thyristor Controlled Reactors (TCRs).

* A synchronizing system using a Phase-Locked Loop(PLL) synchronized on the secondary voltages.

* A pulse generator that sends appropriate pulses to the thyristors.

V. FOUR BUS TEST SYSTEM

The system described in this section illustrates modeling of a simple transmission system containing two hydraulic power plants. The FACTS device (SVC) and power system stabilizers (PSS) are used to improve voltages stability and power oscillation damping of the system. The power system illustrated in this paper is quite simple. However, the phasor simulation method allows simulating more complex power grids.

A. Description of Transmission System

The single line diagram shown below represents (four bus systems) a simple 400 KV transmission system. This system which has been made in ring mode consisting of buses (B1 to B4) connected to each other through three phase transmission lines L1, L2-1, L2-2 and L3 with the length of 280,150,150 and 150 km respectively. And the four loads are connected of 250MW, 100MW, 50MW and a dynamic load as shown in Fig.4 System has been supplied by two power plants with the phase-to-phase voltage equal to 11 KV. Active and reactive powers injected by power plants 1 and 2 to the power system are presented in per unit by using base parameters S_b = 2100 MVA and V_b = 400KV, the power plants 1 (M1) and plants 2 (M2) generated 2100 MVA and 1400 MVA in per unit, respectively.

To maintain system stability with respect to loading, the transmission line is shunt compensated at by FACTS device SVC. The two machines are equipped with a hydraulic turbine and governor (HTG), excitation system, and power system stabilizer (PSS). The dynamic load is connected at bus B3. We can use it to program different types of faults on the 400 KV systems and observe the impact of the FACTS on system stability and power transfer capability.

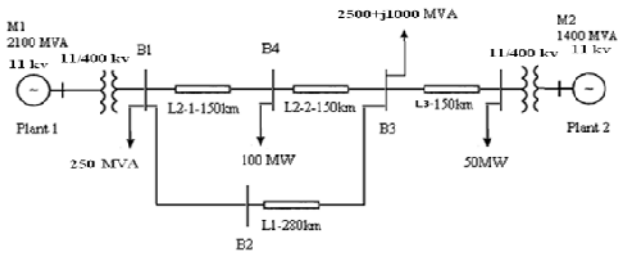
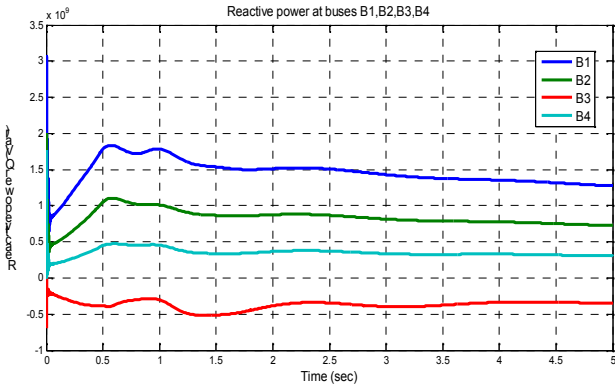


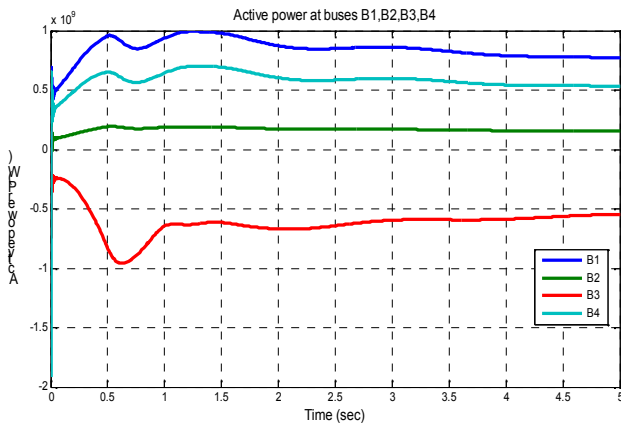
Fig. 3. The single line diagram of 4-bus 400 kV transmission test system.

VI. SIMULATION AND RESULT

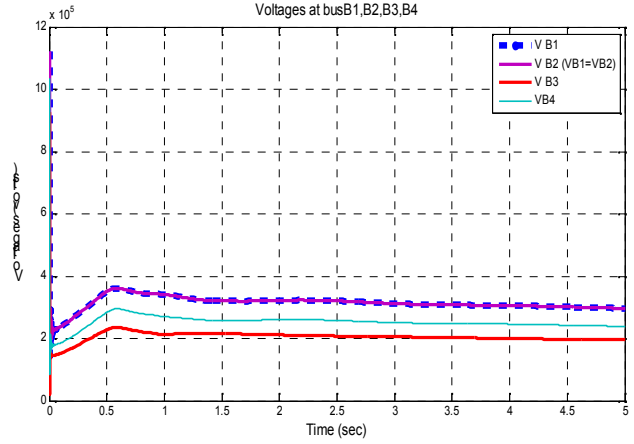
A. System analysis with-out FACTS



(a)



(b)



(c)

Fig. 4. Profiles at buses B1, B2, B3, B4 with-out FACT Device, (a) Reactive power (b) Active power (c) Voltage.

Table.1. Active, Reactive power & voltages with-out FACTS.

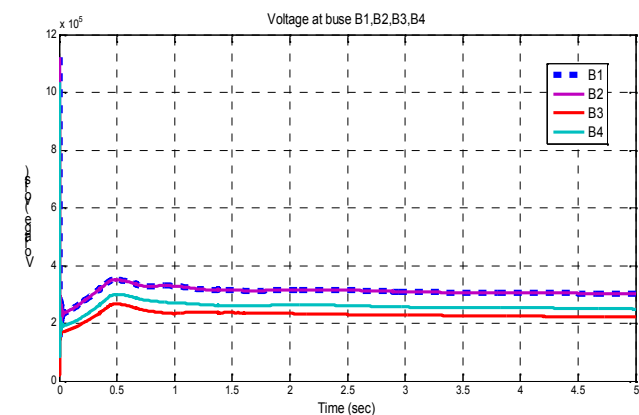
BUS	P(MW)	Q(MVar)	S(MVA)	V(KV)
B1	768.4	1274	1487.7	296.8
B2	154.6	725.2	741.4	296.8
B3	-545.4	-342.6	664.08	195.4
B4	530.8	304.4	611.8	239.1

B. Impact of SVC

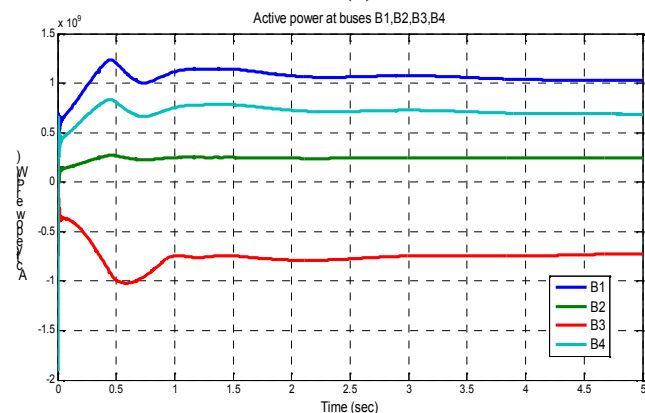
The impact of the SVC for stabilizing the network during a severe contingency. First put the two PSS in service. Verify that the SVC is in fixed susceptance mode with $B_{ref} = 0$. The rating of the SVC is ± 1000 MVA, Start simulation. The SVC will now try to support the voltage by injecting reactive power on the line when the voltage is lower than the reference voltage (1.0 pu). The chosen SVC reference voltage corresponds to the bus voltage with the SVC out of service. In steady state the SVC will therefore be floating and waiting for voltage compensation when voltage departs from its reference set point. We installed SVC at bus 3, because the voltage at bus-3 is lower as seen with-out FACT analysis. The simulation results for test system with SVC are given below. The data for different parameters are given in table 2.

The simulation study has been divided into various sections for the sake of clarity. At first the optimal location of shunt FACTS devices was determined for a given operating condition. Unlike previous works in this area, we have considered the actual line model, which affects the optimal location for a long line. The next section discusses how the optimal location changes with the different power generation by the two generators while keeping the line flow for test system. Finally, the effect of different line flows for test system is studied, while keeping the generator loadings in for test system constant and dynamically changes.

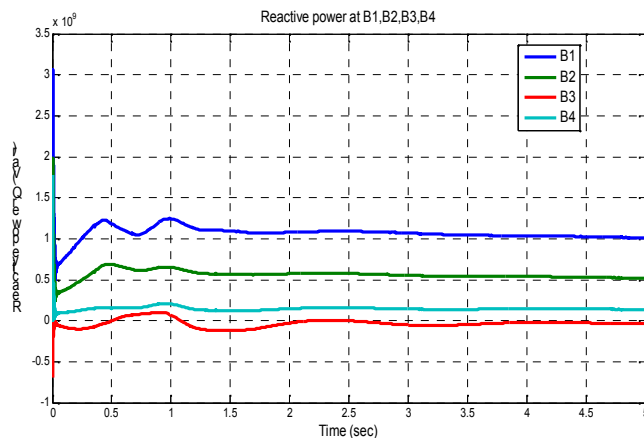
C. System Analysis with SVC



(a)



(b)



(c)

Fig. 5. Profiles at buses B1, B2, B3, B4 with SVC, (a) Voltage, (b) Active Power, (c) Reactive Power.

Table 2. Active, Reactive power & voltages with SVC.

Bus	P (MW)	Q (MVar)	S (MVA)	V (k volts)	SVC data	
					V (pu)	Q (pu)
B1	1028	1010	1441.14	301.5	-	-
B2	243	518.7	572.799	301.5	-	-
B3	-723.7	-37.3	724.66	221.8	0.6792	0.2416
B4	685.8	137.2	699.39	249.5	-	-

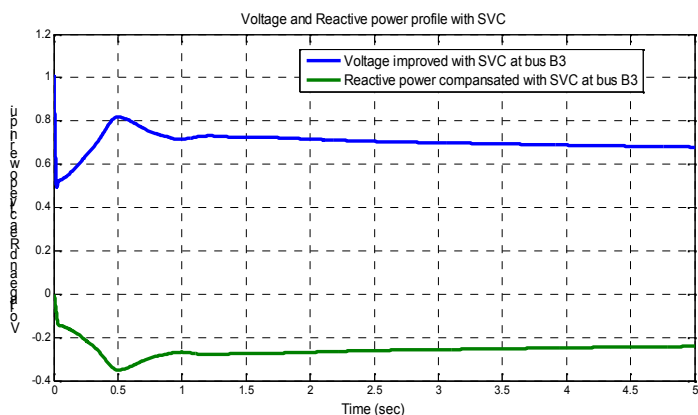


Fig. 6. SVC voltage and reactive power profiles at bus B3.

Table 3. Transfer capacity.

Device	Transmitted Power (MVA)	Transmission Capacity Increased (MVA)	Transmission Capacity Increased at B3 (MVA)
NO FACT	3437.99
SVC	3505.26	67.27	60.58

VII CONCLUSION

This paper deals with applications of the SVC. The detailed models of the SVC was implemented and tested in MATLAB/simulink environment. The model are applicable for voltage stability analysis, and cover broader range of power transfer capability.

The effects of SVC installed in power transmission path are analyzed in this paper, and the conclusions are as follow:

(1) The FACTS can improve voltage stability limit observably, and FACTS give better performance for power transfer capability for 4-bus system transmission capacity increased 67.27 MVA.

(2) The power losses in system without FACT is more as compared when used FACTS devices. The loading capacity with SVC is increased, the reactive power compensated form -342.6 MVAR (no FACTS) to -37.3 MVAR (SVC) and voltage injected from 195.4 (no FACTS) to 221.8 KV (SVC) at bus-3 for 4-bus system.

(3) As has been discussed above it has been observed system performance improved by introducing the FACTS Devices, the best performance has been obtained by introducing FACTS devices such as SVC and STATCOM which compensate reactive power (MVAR), voltage injected (KV) and increased power transfer capability (MVA). It's concluded that by introducing FACTS device system performance, voltage stability and transmission capability improves considerably.

REFERENCES

- [1]. M. Karthikeyan, P. Ajay-D-Vimalraj "Optimal location of shunt FACTS devices for power flow control" *IEEE proceeding of ICETEECT 2011*, pp 154-159.
- [2]. M. Kowsalya, K.K. Ray, and D.P. Kothari, 'Positioning of SVC and STATCOM in a Long Transmission Line' *International Journal of Recent Trends in Engineering*, Vol 2, No. 5, November 2009.
- [3]. Tan, Y.L., "Analysis of line compensation by shunt-connected FACTS controllers: a comparison between SVC and STATCOM", *IEEE Transactions on Power Engineering Review*, Vol.19, pp 57-58, Aug 1999.
- [4]. Lin tan and Yowgi Wang " Design of series and shunt FACTS controller using adaptive nonlinear shunt FACTS controller using adaptive nonlinear coordinated design technique,' *IEEE Tran. On power system* Vol. 12, No. 3, Aug. 1997.
- [5]. A.A Edris "Enhancement of first swing stability using a high speed phase shifter" *IEEE Tran. on power system*, Vol.6, L991, pp I II:LI 118.
- [6]. Kimbark E W "How to improve system stability without risking sub synchronous resonance " *IEEE Tran.* 1977, PAS-96(s), pp 1608-1619.
- [7]. M H Haque "Optimal location of shunt FACTS devices in long transmission line" *IEEE Proceeding. Generation. Transmission & Distribution*. Vol. 147, No.4, July 2000.
- [8]. Schauder, C, Gernhardt M. Staev E, Lemark, T. Gyugyl, L. Cease T W and Edris, A " Development of a +100MVAR static condenser for voltage control of transmission system" *IEEE Tran.* 1995, PD-IO (3), pp 1486-1496
- [9]. Chandrakar, V.K. Kothari, A.G. "Optimal location for line compensation by shunt connected FACTS controller", *The Fifth International IEEE Conference on Power Electronics and Drive Systems*", Vol 1, pp 151-156, Nov 2003.
- [10]. Nimit Boonpirom, Kitti Paitoonwattanakitj, 'Static Voltage Stability Enhancement using FACTS' *IEEE/PES transmission and distribution Conference and Exhibition Asia Pacific.*, pp.1– 5, 2007.
- [11]. P. Kundur, J. Paserba, V. Ajarapu, G. Andersson, A. Bose, C. Canizares, N. Hatzargyriou, D. Hill, A. Stankovic, C. Taylor, T. V. Cutsem and V. Vittal, 'Definition and classification of power system stability', *IEEE Trans. Power Systems*, 19(2) (2004), 1387-1401.