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Matlab Computation For Studying Effect Of Location Of Shunt FACTS Devices In Long Transmission Line System

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Abstract

Shunt FACTS devices are used for controlling transmission voltage, power flows, and damping of power system oscillations for high power transfer levels. In this paper the effect of location of a shunt FACT device is investigated for an actual line model of a transmission line. Effect of change of location of the shunt FACTS device to get the highest possible benefit is studied. It is found that the maximum sending end power and maximum receiving end power varies with the location of the shunt FACTS device. The result of actual transmission line model is compared with the result of simplified transmission line model and it is found that in actual transmission line, shunt FACTS devices should be connected before mid-point of the line for maximum benefits. MATLAB codes have been developed in this study.

Keywords: **FACTS, SVC, STATCOM, mid-point, two area power system.**

1. INTRODUCTION

Flexible AC transmission systems (FACTS) have gained a great interest since 1970s as the development and advancement in power electronics is made. Reactive power compensation is an important issue in electrical power system. Therefore, shunt FACTS controllers are employed in power system to compensate reactive power flow and hence the system fluctuations and stability is controlled. Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) are members of FACTS family that are connected in shunt with the system and they are highly effective in improving the system stability.

Earlier it has been proved that shunt FACTS devices give maximum benefit from their stabilized voltage support when sited at the mid-point of the transmission line. The proof of maximum increase in power transfer capability is based on the simplified model of the line neglecting line resistance and capacitance. However, for long transmission lines, when the actual model of the line is considered, the results may deviate significantly from those found for the simplified model, especially with respect to transient stability improvement].

2. SHUNT FACTS DEVICE: SVC

According to definition of IEEE PES Task Force of FACTS Working Group: Static VAr Compensator (SVC): A shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage). This is a general term for a Thyristor Controlled Reactor (TCR) or Thyristor Switched Reactor (TSR) and/or Thyristor Switched Capacitor (TSC) Fig. 1. The term, “SVC” has been used for shunt connected compensators, which are based on thyristors without gate turn-off capability. It includes separate equipment for leading and lagging vars; the thyristor –controlled or thyristor – switched reactor for absorbing reactive power and thyristor – switched capacitor for supplying the reactive power.

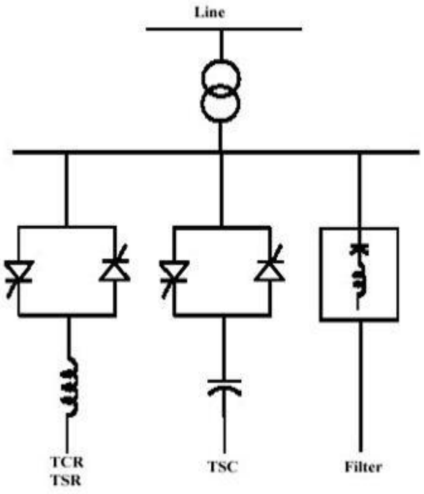

Figure 1 Static Var Compensator

V-I characteristics of SVC are shown in the figure 2.

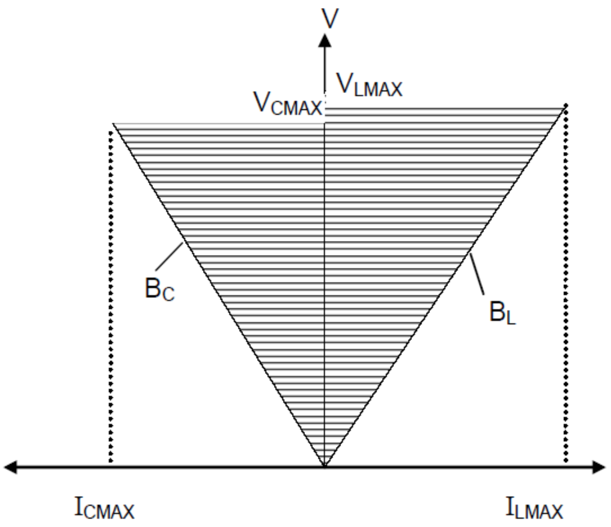

Figure 2 SVC V-I characteristics

Power modulation by SVC in transmission line

The real power flow through a transmission line with a SVC located at the middle of the line, Fig. 3 is described by:

$$P=2*(V_iV_m/X_{ij})*\sin(\delta_{im}) \qquad (1)$$

Where $\delta_{im}=\delta_i-\delta_m$. Since the SVC is located at the electrical midpoint of the line, $\delta_{im}\approx\delta_{ij/2}$ and $V_m\approx V_j$. therefore, the real power can be obtained by:

$$P=2*(V_iV_j/X_{ij})*\sin(\delta_{ij}/2) \qquad (2)$$

The equivalent susceptance of the SVC, B_{SVC}, is given by

$$B_{SVC}=(1/X_c)-B_L(\alpha) \qquad (3)$$

and

$$B_L(\alpha)=\{2\pi-2\alpha+\sin(2\alpha)\}/\ \pi*X_L\ ;\quad \pi/2\le\alpha\le\pi \qquad (4)$$

where α is the thyristor firing angle.

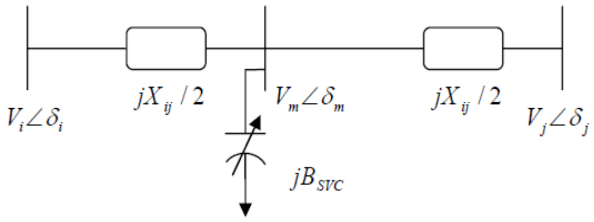

Figure 3 Transmission line with SVC

The SVC can be seen as a dynamic source of reactive current having sub-cycle reaction time. Using the thyristor valve as fast switches, capacitor banks can be switched in and out. This arrangement of switching capacitors and controlling reactors provides regular control of the reactive current output between two extremes dictated by component rating selection.

Electrical loads both generate and absorb reactive power. Since the transmitted load varies significantly from one hour to another, the reactive power equilibrium in a grid varies as well. The result can be undesirable voltage amplitude variations, a voltage depression, or even a voltage collapse.

A rapidly operating Static Var Compensator (SVC) can regularly provide the reactive power necessary to control dynamic voltage swings under different system conditions and thereby improve the power system transmission and distribution performance. Installing an SVC at one or more appropriate points in the network will enhance transfer capability through improved voltage stability, while maintaining a smooth voltage profile under different network conditions. In addition, an SVC can diminish active power oscillations through voltage amplitude modulation.

Thus the principal benefit of the SVC for transient stability enhancement is direct and rapid bus voltage control. In particular, the SVC may be used to enhance power transfer during low-voltage conditions which typically predominate during faults, decreasing the acceleration of local generators which may otherwise occur.

3. SHUNT FACTS DEVICE: STATCOM

The STATCOM is given this name because in a steady state operating regime it replicates the operating characteristics of a rotating synchronous compensator. The basic electronic block of a STATCOM is a voltage-sourced converter that converts a dc voltage at its input terminals into a three-phase set of ac voltages at fundamental frequency with controllable magnitude and phase angle.

A STATCOM can be used for voltage regulation in a power system, having as an ultimate goal the increase in transmittable power, and improvements of steady-state transmission characteristics and of the overall stability of the system. Under light load conditions, the controller is used to minimize or completely diminish line over voltage; on the other hand, it can be also used to maintain certain voltage levels under heavy loading conditions.

In its simplest form, the STATCOM is made up of a coupling transformer, a voltage source convertor (VSC), and a dc energy storage device. The energy storage device is a relatively small dc capacitor, and hence the STATCOM is capable of only reactive power exchange with the transmission system. If a dc storage battery or other dc voltage source were used to replace the dc capacitor, the controller can exchange real and reactive power with the transmission system, extending its region of operation from two to four quadrants. Figs. 4 and 5 show a functional model and the V-I characteristic of a STATCOM respectively.

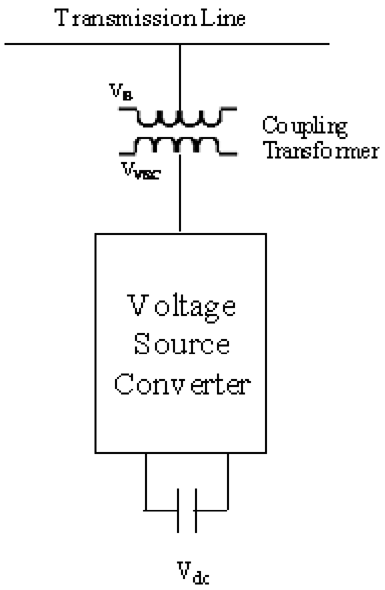

Figure 4 STATCOM configuration

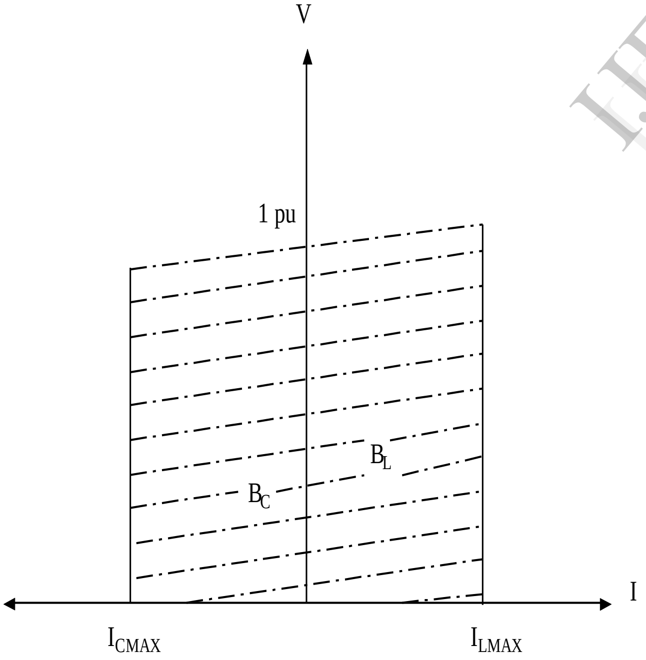

Figure 5 V-I characteristic of STATCOM

4. TWO AREA SYSTEM WITH SHUNT FACTS DEVICES

When it comes to connect a shunt FACTS device in the transmission line then the main problem is to find the best location to connect the device. In order to determine the effect of location of shunt FACTS device a two area power system is taken for the study as shown in Fig. 6. In this system two machines are connected with a 400 km long transmission line.

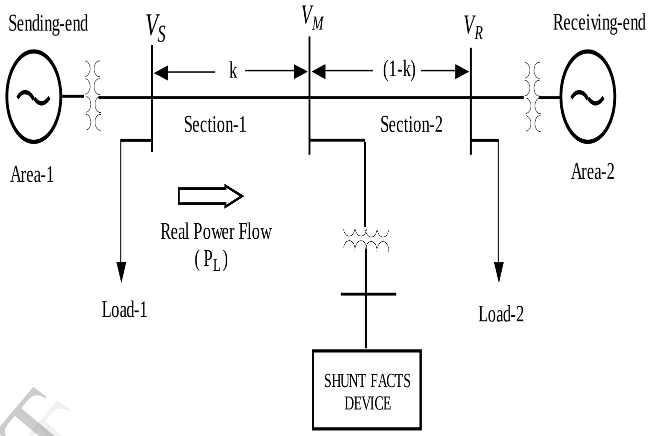

Figure 6 Single line diagram of two area power system with shunt FACTS device

The direction of real power flow is from area-1 to area-2. The shunt FACTS controller in the study is a SVC or a STATCOM and is usually connected to the line through a step down transformer, as in the Fig. 6.

If the rating of the shunt FACTS device is assumed to be large enough to supply the reactive power required to maintain constant voltage magnitude at the point of connection, the shunt FACTS device effectively divides the transmission line into two sections (section-1 and section-2) and ‘k’ is the fraction of the line length at which the FACTS device is placed. For example, if the value of ‘k’ is 0.5 that represent that FACTS device is placed at mid-point.

For the study a 400 Km long transmission line has been taken. Sending end and receiving end voltages are 400 KV. Frequency of the system is 50 Hz. Line reactance per unit length of the transmission line is 0.3205 H/km.

To see the effect of location of shunt FACTS device, MATLAB programs are written. In the first case a simplified transmission line has been taken. In this type of line, line resistance and line admittance are assumed negligible.

Power flow in shunt compensated simplified transmission line is given by the following equations,

$$P_s=P_{sm}*\sin\delta_s \qquad (5)$$

$$P_r=P_{rm}*\sin\delta_r \qquad (6)$$

where,

$P_{sm}= (V_s*V_r)/(k*X)$ = max. sending end power

$P_{rm}=(V_s*V_r)/((1-k)*X)$ = max. receiving end power

& $P_s=P_r$; because line is lossless.

P_{sm} and P_{rm} are shown below in Fig. 7,

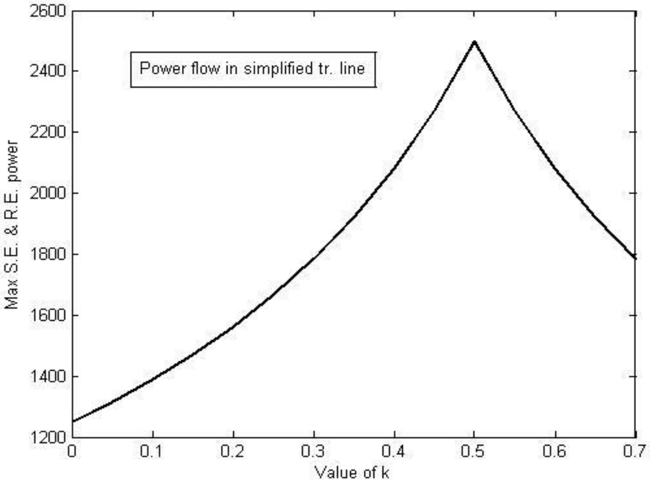

Figure 7 Variation in maximum S.E. & R.E. power of simplified tr. line with length of tr. Line

In second case an actual transmission line with resistance per unit length 0.02986 ohm/km, admittance per unit length $3.989*10^{-6}$ F/km has been taken. All other parameters are same as are the in simplified transmission line.

Power flow in shunt compensated actual transmission line is given by the following equations,

$$Ps=C1*\cos(\beta-\alpha)-C2*\cos(\beta+\delta s) \qquad (7)$$

$$Pr=C2*\cos(\beta-\delta r)-C3*\cos(\beta-\alpha) \qquad (8)$$

where,

$C1=(D/B)*Vs*Vs,$

$C2=(Vs*Vr)/B,$

$C3=(A/B)*Vr*Vr.$

Here,

$Z=r+j*X*K$ for section-1 of line;

and

$Z=r+j*X*(1-K)$ for section-2 of line;

This Z is used to calculate A,B,C,D.

Maximum S.E. & R.E. power are given by following equations and shown in Fig. 8,

$$Psm=C1*\cos(\beta-\alpha)+C2; \quad \text{at } \delta s=\pi-\beta \qquad (9)$$

$$Prm=C2-C3*\cos(\beta-\alpha); \quad \text{at } \delta r= \beta \qquad (10)$$

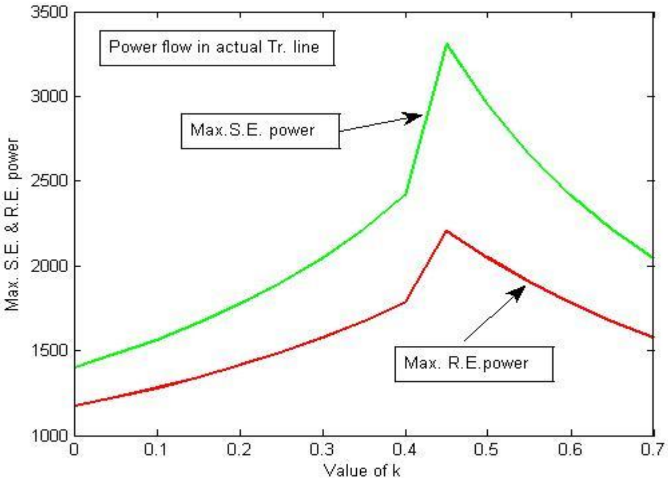

Figure 8 Variation in maximum S.E. & R.E. power of actual tr. line with length of tr. line

From Fig. 7, it is observed that the maximum S.E. power is equal to the max R.E. power because the line is lossless. The maximum power increases from 1250 MW (for k=0) to double the value i.e. 2500 MW (for k=0.5) and then decreases. And from Fig. 8, it is observed that the maximum S.E. and R.E. powers are not same due to power lose in transmission line. The maximum S.E. power increases from 1400 MW (for k=0) to the value 3300 MW (for k=0.45) and then decreases. Similarly, the maximum R.E. power increases from 1100 MW (for k=0) to the value 2275 MW (for k=0.45) and then decreases. A relative difference between Fig. 7 & Fig. 8 can be seen in Fig. 9.

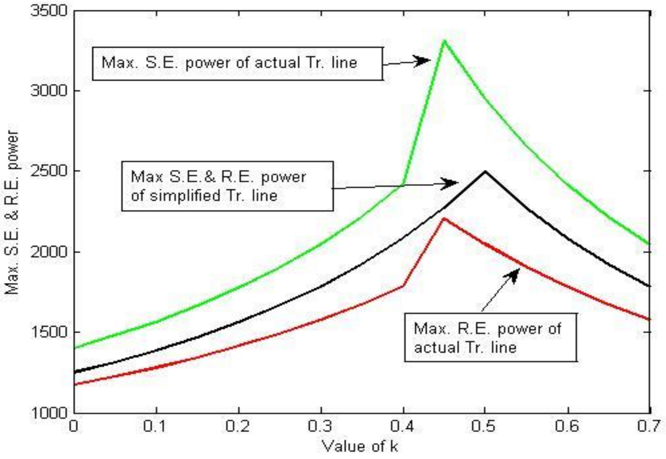

Figure 9 Comparison between Max. S.E. & R.E. powers of simplified tr. line and actual tr. line

5. CONCLUSION

In this paper, effect of location of shunt FACTS devices in two area power system network is studied. For this, a simplified transmission line (lossless line) and an actual transmission line are studied. In study, it is found that in simplified transmission line max. S.E. and R.E. power are equal and max. S.E. and R.E. power transfer capability get nearly double when SVC is connected at mid-point of the transmission line. But in actual transmission line max. S.E. and R.E. power are different with each other due to transmission line losses and max. S.E. and R.E. power transfer capability get more than double, when SVC is connected before mid-point of the transmission line. Thus it can be conclude that in actual transmission line system, stability of system is significantly improved by connecting SVC before mid-point of transmission line.

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