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COMMUNICATIONS

IMPROVING POWER SYSTEM TRANSIENT STABILITY WITH AN OFF–CENTRE LOCATION OF SHUNT FACTS DEVICES

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Shunt Flexible AC Transmission System (FACTS) devices, when placed at the mid-point of a long transmission line, play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuations and transient stability. This paper deals with the location of a shunt FACTS device to improve transient stability in a long transmission line with predefined direction of real power flow. The validity of the mid-point location of shunt FACTS devices is verified, with different shunt FACTS devices, namely static var compensator (SVC) and static synchronous compensator (STATCOM) in a long transmission line using the actual line model. It has been observed that the FACTS devices, when placed slightly off-centre towards sending-end, give better performance in improving transient stability and the location depends on the amount of local/through load.

K e y w o r d s: FACTS, STATCOM, SVC, transient stability

1 INTRODUCTION

Recent development of power electronics introduces the use of FACTS devices in power systems. FACTS devices are capable of controlling the network condition in a very fast manner and this unique feature of FACTS devices can be exploited to improve the transient stability of a system. Reactive power compensation is an important issue in electrical power systems and shunt FACTS devices play an important role in controlling the reactive power flow to the power network and hence the system voltage fluctuations and transient stability [1]. SVC and STATCOM are members of FACTS family that are connected in shunt with the system. Even though the primary purpose of shunt FACTS devices is to support bus voltage by injecting (or absorbing) reactive power, they are also capable of improving the transient stability by increasing (decreasing) the power transfer capability when the machine angle increases (decreases), which is achieved by operating the shunt FACTS devices in capacitive (inductive) mode [2].

Previous works on the topic prove that shunt FACTS devices give maximum benefit from their stabilized voltage support when sited at the mid-point of the transmission line [3]. 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 [4].

This paper consists of the comparison of various results found for the different locations of shunt FACTS device in a long transmission line considering the actual models of the line for a transient stability study. Computer simulation results under a severe disturbance condition (three phase fault) for different fault clearing times and different locations of FACTS devices are analyzed. It is shown that for the actual long transmission line model with a predefined direction of real power flow, shunt FACTS device needs to be located slightly off-centre. Further the location of these devices depends on the amount of local load and through load.

The paper is organized as follows. Section 2 gives a brief introduction of the shunt FACTS devices used. A two area system with a shunt FACTS device is described in Section 3. The computer simulation results for system under study are presented and discussed in Section 4 and in Section 5 conclusions are given. The various parameters of the system are listed in Appendix.

2 SHUNT FACTS DEVICES IN POWER SYSTEM

Shunt FACTS devices are classified into two categories, namely variable impedance type (SVC) and switching converter type (STATCOM).

A. SVC

The SVC uses conventional thyristors to achieve fast control of shunt-connected capacitors and reactors. The configuration of the SVC is shown in Fig. 1 (a), which basically consists of a fixed capacitor (C) and a thyristor controlled reactor (L). The firing angle control of the

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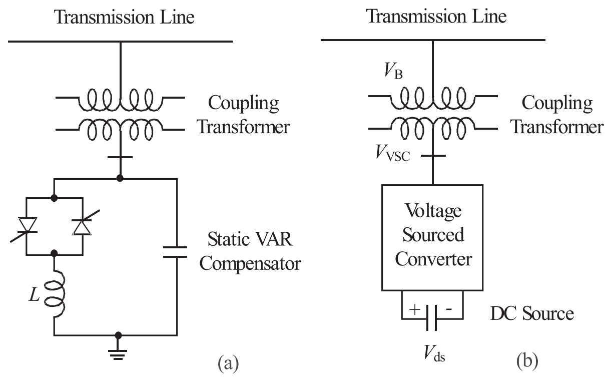

Fig. 1. (a) SVC connected to a transmission line, (b) STATCOM connected to a transmission line.

thyristor banks determines the equivalent shunt admittance presented to the power system.

B. STATCOM

The STATCOM is based on a solid state synchronous voltage source which generates a balanced set of three sinusoidal voltages at the fundamental frequency with rapidly controllable amplitude and phase angle. The configuration of a STATCOM is shown in Fig. 1 (b). Basically it consists of a voltage source converter (VSC), a coupling transformer and a dc capacitor. Control of reactive current and hence the susceptance presented to power system is possible by variation of the magnitude of output voltage (V_{VSC}) with respect to bus voltage (V_{B}) and thus operating the STATCOM in inductive region or capacitive region

3 TWO AREA SYSTEM WITH SHUNT FACTS DEVICES

Consider a two area system (area 1 & area 2), connected by a single circuit long transmission line as shown in Fig. 2 (a). The direction of real power flow is from area 1 to area 2. The transmission line is divided in two sections (section 1 and section 2) and 's' is the fraction of line length at which the FACTS device is placed.

For a long transmission line of length l, having a series impedance of z ohm/km and shunt admittance of y mho/km, the relationship between the sending-end and receiving-end quantities with A, B, C, D constants of the line can be written as:

$$V_S = AV_R + BI_R\,, \tag{1}$$

$$I_S = CV_R + DI_R\,. \tag{2}$$

For the simplified model, where the line resistance and capacitance are neglected, both sending end power (P_S) and receiving end power (P_R) become maximum at power angle $\delta = 90°$. When a shunt FACTS device is connected to a long line to increase the power transfer capability, the above simplifications may provide erroneous results.

The active power flows at the sending end and receiving end for a long transmission line with distributed parameters can be written as [5]:

$$P_S = K_1\cos(\theta_B - \theta_A) - K_2\cos(\theta_B + \delta)\,, \tag{3}$$

$$P_R = K_2\cos\{\theta_B - \delta) - K_3\cos(\theta_B - \theta_A)\,, \tag{4}$$

where, $K_1 = AV_S^2/B$, $K_2 = AV_SV_R/B$, $K_3 = AV_R/B$, $A = |A|\angle\theta_A$, $B = |B|\angle\theta_B$, $V_R = |V_R|\angle 0$, $V_S = |V_S|\angle\delta$.

It is clear from Eqn. 4 that the receiving end power P_R reaches the maximum value when the angle δ becomes θ_B. However, the sending end power P_S of Eqn. 3 becomes maximum at $\delta = (180 - \theta_B)$.

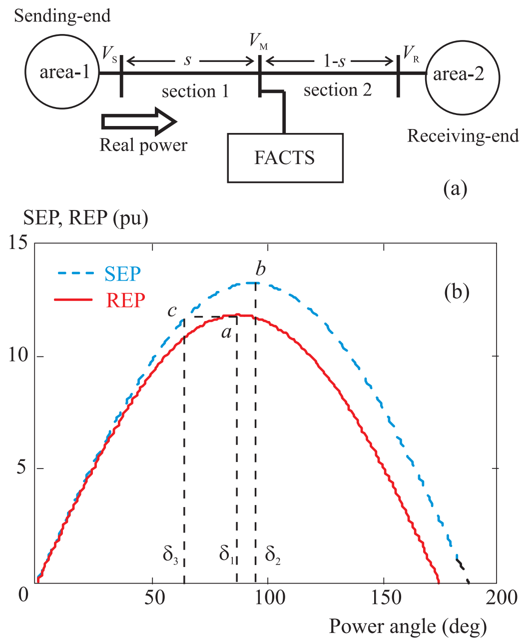

Fig. 2. (a) Two area system with shunt FACTS device, (b) Sending-end and receiving-end power angle characteristics using actual line model.

The power-angle characteristic of the line using the actual line model without FACTS device is shown in Fig. 2 (b). It also represents the power angle characteristics of both line sections, if a large rating shunt FACTS device capable of maintaining the voltage constant is placed at the centre. Assuming that the FACTS device does not absorb or deliver any active power, the receiving end power of section 1 must be equal to the sending end power of section 2. If section 1 delivers the maximum power at its receiving end (point a), the corresponding sending end power of section 2 can be represented by the same power level (point c) and the total transmission angle at the maximum power point is $\delta = \delta_1 + \delta_3$. Thus, the maximum power transfer capability of the system is limited by the maximum receiving end power of section 1.

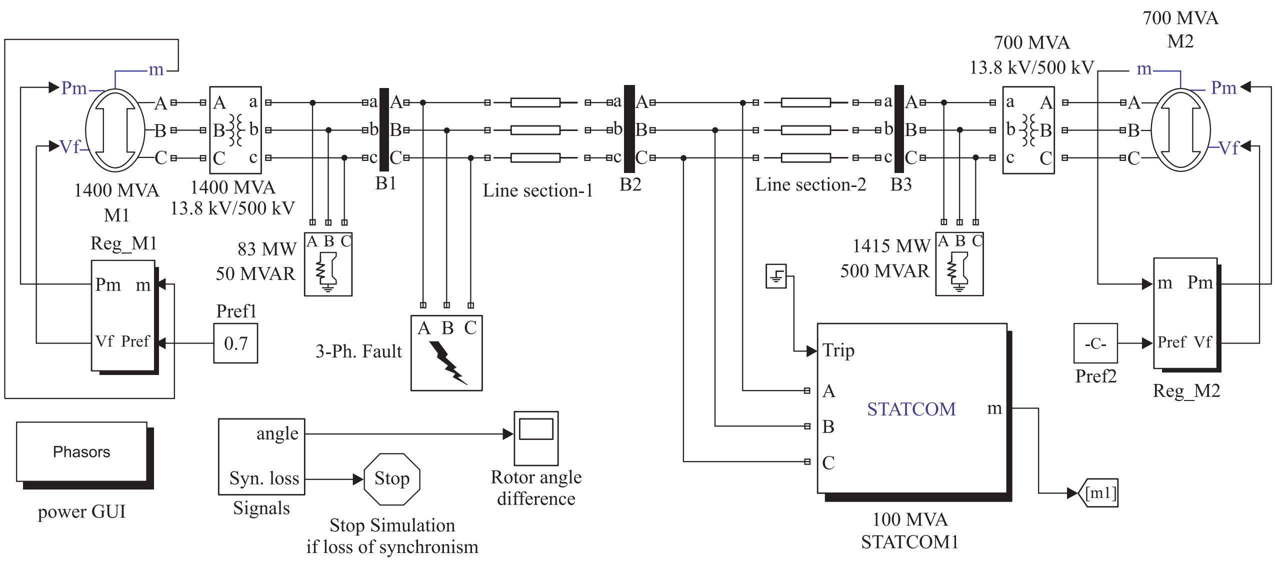

Fig. 3. MATLAB simulation model of two machine system for transient stability study with shunt FACTS devices.

The shape of the power angle curve depends on the line length or fraction 's'. For lower values of s, the maximum receiving end power of section 1 increases, while the maximum sending end power of section 2 decreases. Thus point a in Fig. 2 (b) moves upwards and point b goes downwards. Both of the powers will be equal at a value $s < 0.5$ because of the losses in the line.

4 SIMULATION STUDIES

The two area system as proposed in Section 3 is modelled with two hydraulic generating units of 1400 MVA and 700 MVA, respectively, in each area, connected via a 500 km long transmission line as shown in Fig. 3 for our study [6]. The two machines are equipped with a hydraulic turbine and governor (HTG), excitation system and power system stabilizer (PSS).These components are included in 'Reg_M1' and 'Reg_M2' subsystem blocks, respectively, as shown in Fig. 3. Both SVC and STATCOM used for this model have the same rating of ±100 MVA and the reference voltage is set to 1 pu for both SVC and STATCOM. Initial power outputs of the generators are $P_1 = 0.7$ pu and $P_2 = 0.5$ pu and the SEP and REP with out the FACTS device are 894 MW and 864 MW respectively. A three phase fault occurs at sending end bus at time $t = 0.1$ s. The original system is restored upon the clearance of the fault.

Figure 4 (a) shows the variation of the rotor angle difference of the two machines with respect to time, for a fault clearing time (FCT) of 0.218 s. It is clear from the figure that STATCOM is more effective in improving stability, and if the location of the SVC is changed, the system is stable for the same fault clearing time. To show the effectiveness of off-centre located STATCOM for transient stability improvement, FCT is increased to 0.22 s and the response is shown in Fig. 4 (b).

To illustrate the effect of local load and through load on the optimal location of STATCOM, the loads in each area are changed keeping individual power generation constant at $P_1 = 0.8$ pu and $P_2 = 0.4$ pu with different line flows and the results are shown in Table 1.

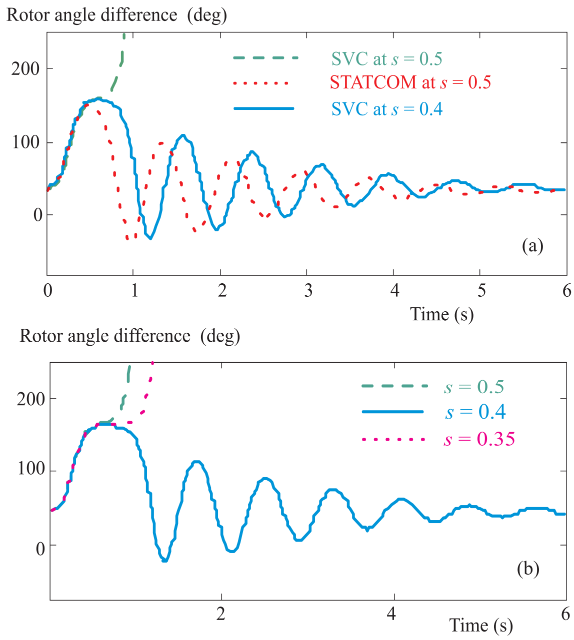

Fig. 4. (a) — Variation of rotor angle difference with shunt different locations of FACTS devices for FCT = 0.218 s; (b) Variation of rotor angle difference with STATCOM for FCT = 0.22 s.

In this work, the effectiveness of shunt FACTS devices has been studied in improving the transient stability of a sample two-area power system with different locations of these devices in the transmission line. It also shows that when there is a pre-defined direction of real power flow, the shunt FACTS devices need to be placed slightly off-centre towards the sending end for maximum benefit from the stability point of view. The optimal location of these devices also depends on the amount of local load and through load and it is seen that as the amount of local load increases the optimal location, from the transient stability point of view, moves towards the sending-end.

Table 1. Optimal location of STATCOM for different local and through loads.

Load at Receiving-end MW	MVAR	Load at Sending-end MW	MVAR	Optimal value of s
143	200	1485	500	0.45
195	200	1400	500	0.44
245	200	1322	500	0.434
296	200	1250	500	0.428

Appendix

The data for various components used in the MATLAB model of Fig. 3. (All data are in pu unless specified otherwise; the notations used are as in Sim-Power-System toolbox):

Generator parameters: $M_1 = 1400$ MVA, $M_2 = 700$ MVA, $V = 13.8$ KV, $f = 60$ Hz, $X_d = 1.305$, $X_d^1 = 0.296$, $X_d'' = 0.255$, $X_q = 0.474$, $X_q'' = 0.243$, $X1 = 0.18$

Transformer parameters: $T_1 = 1400$ MVA, $T_2 = 700$ MVA, 13.8/500 KV, $R_2 = 0.002$, $L_2 = 0.12$, $R_m = 500\,\Omega$, $X_m = 500\,\Omega$.

Transmission line parameters per km: $R_1 = 0.1755\,\Omega$, $R_0 = 0.2758\,\Omega$, $L_1 = 0.8737$ mH, $L_0 = 3.22$ mH, $C_1 = 13.33$ nF, $C_0 = 8.297$ nF.

SVC parameters: 500 KV, ± 100 MVAR, $T_d = 4$ ms, $V_{\text{ref}} = 1.0$, $X_s = 0.03$, $K_p = 3$, $K_i = 500$.

STATCOM parameters: 500 KV, ± 100 MVAR, $R = 0.071$, $L = 0.22$, $V_{dc} = 40$ KV, $C_{dc} = 375 \pm \mu$ F, $V_{\text{ref}} = 1.0$, $K_p = 50$, $K_i = 1000$.

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