

Coordination of Series and Shunt Flexible AC Transmission System Devices Based Voltage Source Converter for Improving Power System Stability

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Abstract: Problem statement: Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC) have been individually applied to improve stability of power system. **Approach:** This study presents the coordination of a STATCOM and SSSC for improving power system stability. The swing curves of the three phase faulted power system with various cases are tested and compared. **Results:** The swing curve of system without FACTS devices has undamped oscillation. The system with a STATCOM or a SSSC can increase damping of power system whereas the system with coordination of a STATCOM and a SSSC provides the best results of stability improvement **Conclusion:** From the simulation results, the stability of power system can be much better improved by coordination control of a STATCOM and a SSSC.

Key words: Power system stability, transient stability, FACTS devices, static synchronous compensator, static synchronous series compensator, Unified Power Flow Controller (UPFC), Single Machine Infinite Bus (SMIB)

INTRODUCTION

In modern power systems, there exists a continuous challenge to improve stability of power system. The rapid advances in power electronics area have made it possible to apply it to power system. Flexible AC Transmission System (FACTS) devices based on the rapid development of power electronics technology to improve stability of power system. FACTS devices can be categorized in two groups. The first group of FACTS devices uses the Thyristor to control the reactors or capacitors. The second group of FACTS devices uses more advanced power electronic to control power flow of power system. The examples of FACTS devices are Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (STATCOM), Unified Power Flow Controller (UPFC) and Inter line Power Flow Controller (Al-Husban, 2009; Al-Abbas, 2009; Babajnejad and Keypour, 2010; Ibrahim, 2009; Magaji and Mustafa, 2009; Mustafa and Magaji, 2009; Nisar *et al.*, 2009; Kumkratug, 2010a).

The Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC) are the member of the FACTS family that are connected in shunt and in series with power system as shown in Fig. 1 and 2, respectively. They use the solid state voltage source converter with GTO thyristor switches or other high performance of semi-conductor and transformer. The STATCOM can electrically mimic reactor and capacitor by injecting a shunt current in quadrature with the line voltage

whereas the SSSC can electrically mimic reactor and capacitor by injecting a series current in quadrature with the line current (Kumkratug, 2010b; 2010c).

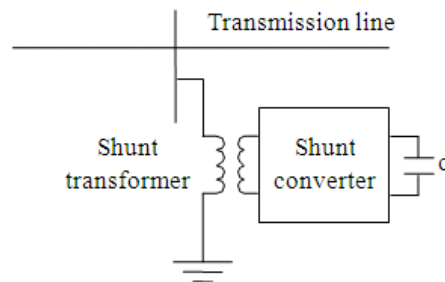


Fig. 1: Schematic diagram of STATCOM.

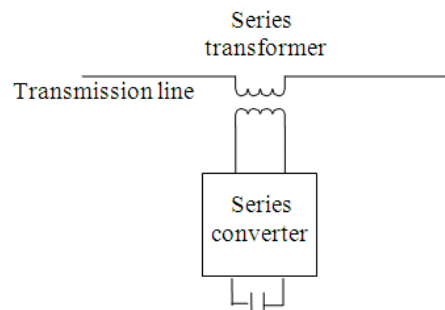


Fig. 2: Schematic diagram SSSC

This study presented the coordination of a TCSC and a SVC for improving transient stability of power system. The presented mathematical model has shown that power flow with combination of a TCSC and SVC can be controlled both series and shunt reactance. The simulation results are tested on Single Machine Infinite Bus (SMIB) system.

MATERIALS AND METHODS

Mathematical model: Figure 3a shows the single machine infinite bus stem without FACTS devices and Fig. 3b shows equivalent circuit of Fig. 1a. Here E' and V_b are the generator voltage behind transient reactance and infinite bus voltage. The X_1 is the equivalent reactance from generator to bus m and the X_2 is the equivalent reactance from m to infinite bus.

The output electrical power of the system without FACTS devices is given by:

$$P_e^0 = \frac{E'V_b}{X} \sin \delta \tag{1}$$

Here X is the sum of X_1 and X_2 .

Figure 4 shows the SMIB system with a STATCOM equipped at bus m. A STATCOM is represented by a shunt current injection as shown in Fig. 4.

The output electrical power of generator in the system with a STATCOM is given by (Kumkratug, 2010b):

$$P_e^{sh} = P_e^0 + \Delta P_e^{sh} \tag{2}$$

ΔP_e^{sh} is the additional component of the output electrical power from the STATCOM affect as given by:

$$\Delta P_e^{sh} = C_1 I_q \sin(\delta - \theta_m) \tag{3}$$

Here:

$$\theta_m = \tan^{-1} \left[\frac{X_2 E' \sin \delta}{X_2 E' \cos \delta + X_1 V_b} \right] \tag{4}$$

$$V_m = \left(\frac{X_2 E' \cos(\delta - \delta_m) + X_1 V_b \cos \delta_m}{X_1 + X_2} \right) + \left(\frac{X_1 X_2}{X_1 + X_2} \right) I_q \tag{5}$$

Figure 5 shows the SMIB system with a SSSC inserted between bus m and infinite bus. A SSSC is represented by a series voltage injection as shown in Fig. 5.

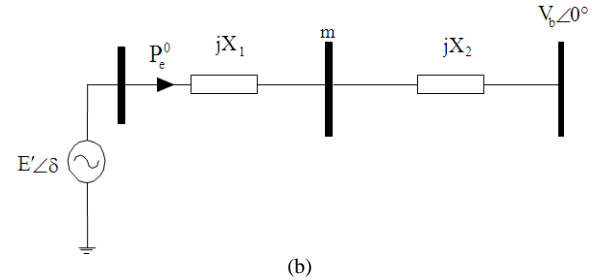
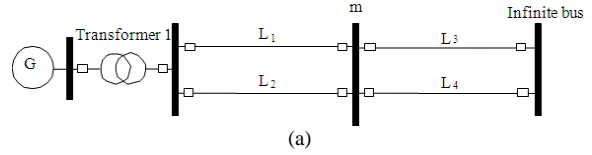


Fig. 3: Single Machine Infinite Bus (SMIB) system (a) single line diagram (b) equivalent circuit.

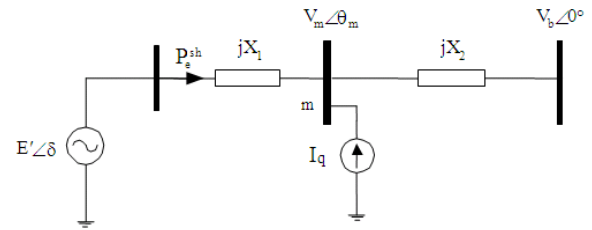


Fig. 4: Equivalent circuit of SMIB system with a STATCOM

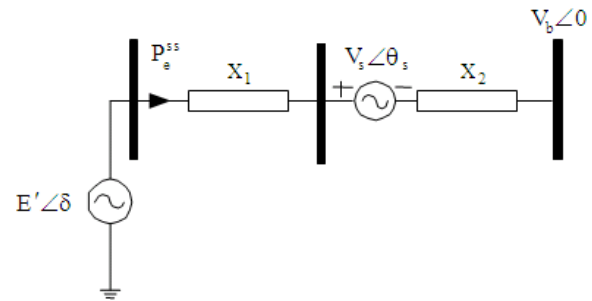


Fig. 5: Equivalent circuit of SMIB system with a SSSC

The output electrical power of generator in the system with a SSSC is given by (Kumkratug, 2010c):

$$P_e^{ss} = P_e^0 + \Delta P_e^{ss} \tag{6}$$

ΔP_e^{ss} is the additional component of the output electrical power from the SSSC affect as given by:

$$\Delta P_e^{ss} = C_2 V_s P_e^0 \tag{7}$$

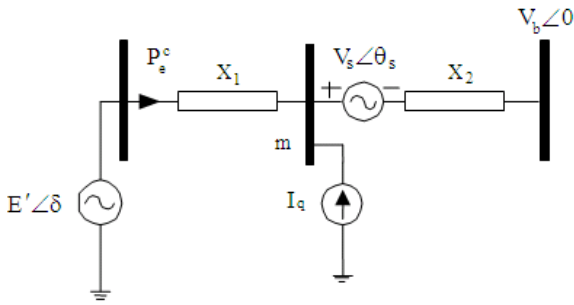


Fig. 6: Equivalent circuit of SMIB system with the combination of a STATCOM and a SSSC

Here:

$$C_2 = \frac{1}{\sqrt{(E')^2 + V^2 - 2E'V \cos \delta}}$$

This study presented the mathematical model of the system with system with coordination of STATCOM and SSSC. Figure 6 shows the equivalent circuit of the system with a STATCOM and a SSSC.

It can be seen from (1), (2) and (6) that the output electrical power of generator in the system with a STATCOM and a SSSC (P_e^c) is given by:

$$P_e^c = P_e^0 + \Delta P_e^{sh} + \Delta P_e^{ss} \quad (8)$$

The dynamic equation of the system with the combination of a STATCOM and a SSSC is given by:

$$\dot{\delta} = \omega \quad (9)$$

$$\dot{\omega} = \frac{1}{M} [P_m - P_e^c] \quad (10)$$

Here δ , ω , P_m , P_e^{com} and M are the rotor angle, speed, input mechanical power, output electrical power and inertia, respectively, of the generator. Solving the Eq. 9 and 10 yields the variation of δ and ω that can be used to study the dynamic behavior of the generator. Equation 9 clearly indicates that the output electrical power (P_e^c) of the generator is the main factor that dictates the dynamic behavior of the generator because both P_m and H are usually considered as constant.

Control strategy: This study uses the machine speed to control both a TCPST and a SVC. When the speed deviation is positive ($\omega > 0$), the P_e^c is increased; When the speed deviation is negative ($\omega < 0$), the P_e^{com} is decreased.

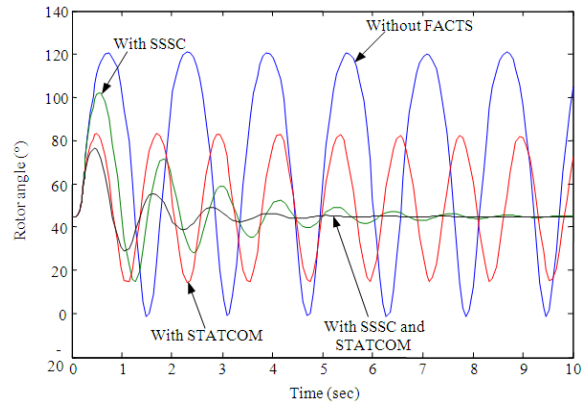


Fig. 7: Rotor angle of the system with various cases of FACTS devices

RESULTS

The presented mathematical model and control strategy is used to study the effect of coordination of a STATCOM and SSSC on transient stability improvement of the system. In all cases, it is considered that a three phase self clearing fault appears at bus m and the fault is cleared without changing the network configuration. Figure 5 shows the swing curve of the system with various cases for clearing time (t_{cl}) = 150 msec.

DISCUSSION

From the results in Fig. 7, it is found that power system without FACTS devices has undamped oscillation. The maximum and minimum rotor angles are around 120 and 0°, respectively. However, the damping of the system improves as the number of FACTS devices based voltage source converter is increased. With a SSSC, the maximum and minimum rotor angles are around 100 and 17°, respectively whereas with a STATCOM, the maximum and minimum rotor angles are around 83 and 18°, respectively. With the coordination of a SSSC and STATCOM, the maximum and minimum rotor angles are improved to 78 and 31°, respectively.

CONCLUSION

This study presented the coordination of series and shunt FACTS devices based voltage source converter for improving transient stability of power system. The Static Synchronous Series Compensator (SSSC) is series FACTS devices and it is represented by series voltage injection. The Static Synchronous Compensator

(STATCOM) is shunt FACTS devices and it is represented by shunt current injection. They are combined and modeled into power equation. The presented mathematical model has shown that power flow with combination of a SSSC and STATCOM can be controlled both series voltage and shunt current injection. The simulation results are tested on Single Machine Infinite Bus (SMIB) system. From the simulation results, it indicates that with the coordination of a SSSC and STATCOM provides the best results of transient stability improvement.

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