Inter-Area Power Systems Stability Improvement by Static Synchronous Series Compensator

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Abstract: Problem statement: The inter-area power systems have special characteristic of the stability behavior. The improvement of inter-area power system is one of the important aspects in power system. **Approach:** This study applies the Static Synchronous Series Compensator (SSSC) to improve stability of inter-area systems. The SSSC is modeled and then is applied to be incorporated into the power system model for investigating stability improvement. The SSSC is modeled as the variable susceptance and is controlled during dynamic state. This presented SSSC model can be incorporated into susceptance matrix of power system model. The presented method is tested on sample inter-area power system with 3 phase fault distubrances. **Results:** The swing curve of inter-area power system without a SSSC gets increases monotonically and thus the system can be considered as unstable whereas the swing curves of system with a SSSC can be considered as stable. **Conclusion:** From the simulation results, the SSSC can enhance stability of inter-area power systems.

Key words: Power system, Static Synchronous Series Compensator (SSSC), Flexible AC Transmission System (FACTS), injected current, synchronous, thyristor controlled phase shifter, series transformer, voltage source, leakage reactance, inter-area power system

INTRODUCTION

Because of growing demand in electrical energy, Modern power system network is getting much more complicated than ever before. Some power systems are linked between two area "inter-area power systems". The inter-area power systems have special characteristic of stability behavior. The improvement of inter-area power system is one of the important aspects in power system. There are many advanced devices have been proposed during the last three decades to improve stability of power system such as High Voltage Direct Current (HVDC) system and Flexible AC Transmission System (FACTS) devices (Al-Husban, 2009; Mota and Mota, 2011; Bana Sharifian *et al.*, 2009; Chen, 2011; Jia-Liang *et al.*, 2010; Magaji and Mustafa, 2009a; Nisar *et al.*, 2009).

A Static Synchronous Series Compensator (SSSC) is a member of the FACTS family that is connected in series with power system. The SSSC consists of a solid state voltage source converter with GTO thyristor switches or other high performance of semi-conductor and transformer. The SSSC can electrically mimic reactor and capacitor by injecting a shunt current in quadrature with the line voltage. The reactive power (or current) of the SSSC can be adjusted by controlling the magnitude and phase angle of the output voltage of the

shunt converter (Magaji and Mustafa, 2009b; Kumkratug, 2011a; 2011b; El-Shennawy *et al.* 2010). This study applies the Static Synchronous Series Compensator (SSSC) to improve stability of inter-area systems. This study presents the method to incorporate SSSC model into the inter-area power system for investigating stability improvement. The simulation results are tested on a sample inter-area power system.

MATERIALS AND METHODS

Mathematical model: Consider power system consisting n_g generators and equipped a SSSC between bus m and bus n as shown in Fig. 1. Figure 2 shows the equivalent circuit diagram of Fig. 1. The E' is the transient voltage of generator and the Y^{int} is the reduced admittance matrix of power system. The SSSC can be represented by the series voltage injection $\mathbf{V}_s$ and X_2 is the reactance equivalent of a series transformer and line between bus m and n.

The voltage source and the reactance can be transformed into the current source as shown in Fig. 3 and given by:

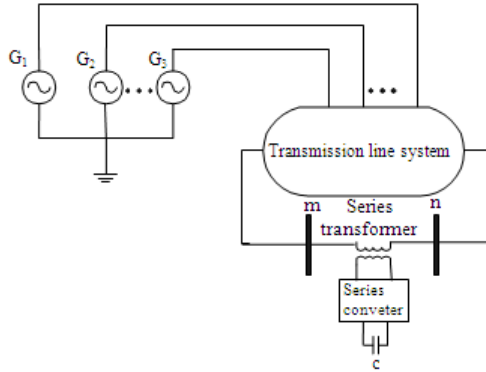$$I_{ss} = \frac{V_s}{jX_2} = -jabe^{j\alpha}V_m \qquad (1)$$
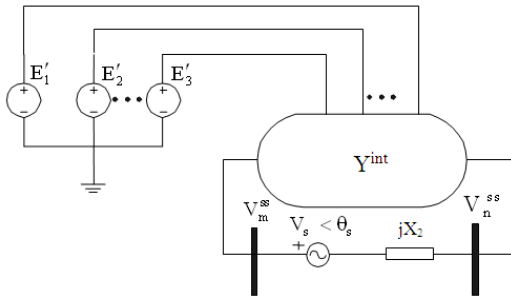
Fig. 1: Power system with a SSSC

Fig. 2: The equivalent circuit of the power system with a SSSC represented by a series voltage source and leakage reactance
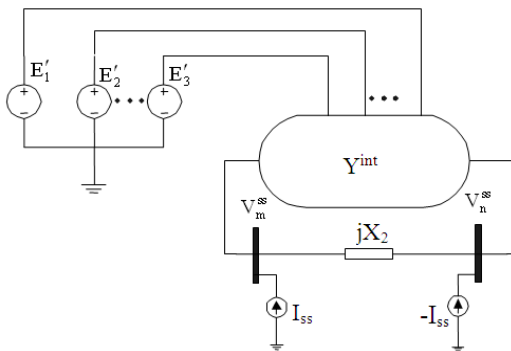

Fig. 3: The equivalent circuit of the power system with a SSSC represented by a series current source

Here:

$$a\angle\alpha = \frac{V_s\angle\theta_s}{V_m^{ss}\angle\theta_m^{ss}} \tag{2}$$

The complex power injection at bus m as shown Fig. 4 is given by:

$$S_{mi}^{ss} = P_{mi}^{ss} + jQ_{mi}^{ss} = V_m^{ss}(-I_{ss})^*$$
$$= V_m^{ss}\angle\theta_m^{ss}(-abV_m^{ss}\angle(\alpha-90+\theta_m^{ss}))^*$$
$$= -ab(V_m^{ss})^2\angle(90-\alpha) \tag{3}$$
$$= -ab(V_m^{ss})^2\sin\alpha - jab(V_m^{ss})^2\cos(\alpha)$$

The real power injection at bus m is given by:

$$P_{mi}^{ss} = -ab(V_m^{ss})^2\sin\alpha \tag{4}$$

And the reactive power injection at bus m is given by:

$$Q_{mi}^{ss} = -ab(V_m^{ss})^2\cos(\alpha) \tag{5}$$

Similarly, the complex power injection at bus n as shown Fig. 5 is given by:

$$S_{ni}^{ss} = P_{ni}^{ss} + jQ_{ni}^{ss} = V_n^{ss}(I_{ss})^*$$
$$= V_n^{ss}\angle\theta_n^{ss}(abV_m^{ss}\angle(\alpha-90+\theta_m^{ss}))^*$$
$$= abV_m^{ss}V_n^{ss}\angle(90-(\theta_m^{ss}-\theta_n^{ss}+\alpha)) \tag{6}$$
$$= abV_m^{ss}V_n^{ss}\sin(\theta_{mn}^{ss}) + jabV_n^{ss}V_m^{ss}\cos(\theta_{mn}^{ss}+\alpha)$$

The real power injection at bus n is given by:

$$P_{ni}^{ss} = abV_m^{ss}V_n^{ss}\sin(\theta_{mn}^{ss}) \tag{7}$$

and the reactive power injection at bus n is given by:

$$Q_{ni}^{ss} = abV_n^{ss}V_m^{ss}\cos(\theta_{mn}^{ss}+\alpha) \tag{8}$$

From the complex power injections as given in (4), (5), (7) and (8) associated with line voltages, they can be represented by the admittance at bus m as bus n as shown in Fig. 6 and given by:

$$Y_{mi}^{ss} = \frac{P_{mi}^{ss} - jQ_{mi}^{ss}}{(V_m^{ss})^2} \tag{9}$$

$$Y_{ni}^{ss} = \frac{P_{ni}^{ss} - jQ_{ni}^{ss}}{(V_n^{ss})^2} \tag{10}$$

Dynamic equation: The dynamic equations of power system are written by:

$$\dot{\delta}_i = \omega_i \tag{11}$$

$$\dot{\omega}_i = \frac{1}{M_i}[P_{mi} - P_{ei}^{ss}]i = 1,2....n_g \tag{12}$$

Here:

δ_i = Generator rotor angle of the i-th generator
ω_i = Generator speed of the i-th generator
P_{mi} = Input mechanical power of the i-th generator
P_{ei} = Output electrical power of the i-th generator

The output electrical power of i-th generator with can be written by:

$$P_{ei} = Re\left[E_i' I_{Gi}\right] \qquad (13)$$

Here the generator current injection (I_G) as given in (13) can be obtained by multiplying the E_G with the Y_{ss}^{int}.
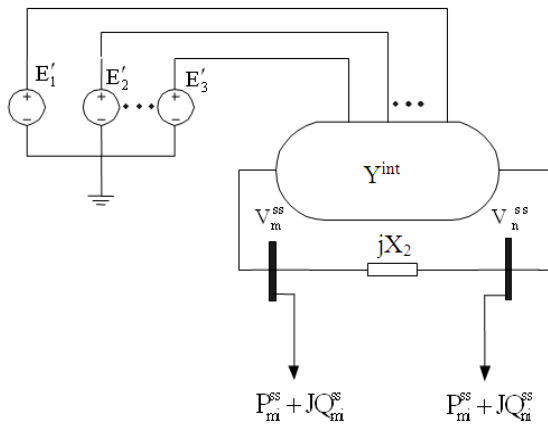

Fig. 4: The equivalent circuit of the power system with a SSSC represented by complex power injections
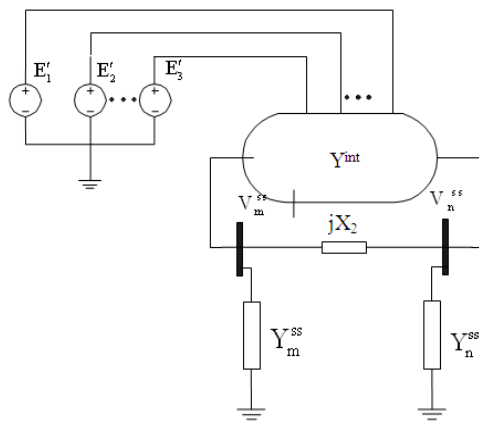

Fig. 5: The equivalent circuit of the power system with a SSSC represented by the reactances

RESULTS

The presented method of improving stability of inter-area power system by a SSSC is tested on a sample system as shown in Fig. 7. The system consists of 4 generators, 4 transformers and 11 buses. A SSSC is equipped between area 1(generator 1 and generator 2) and area 2 (generator 3 and generator 4). It is considered that a three phase fault appears at bus 8 at 100 msec and it is cleared at 180 msec. Figure 8 shows the swing curve of the system without a SSSC and Fig. 9 shows the swing curve of the system with a SSSC.
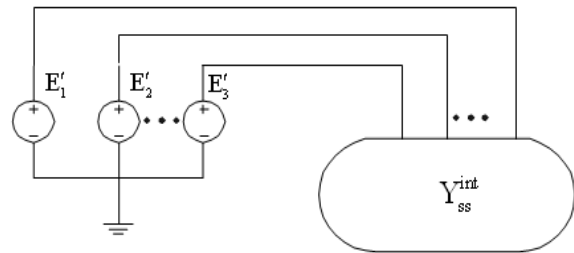

Fig. 6: The successive equivalent circuit of the power system with a SSSC represented by reduced admittance
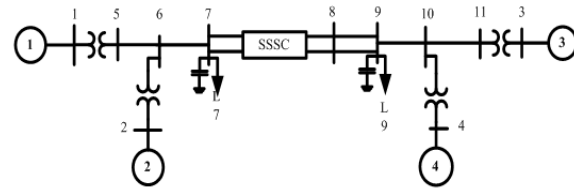

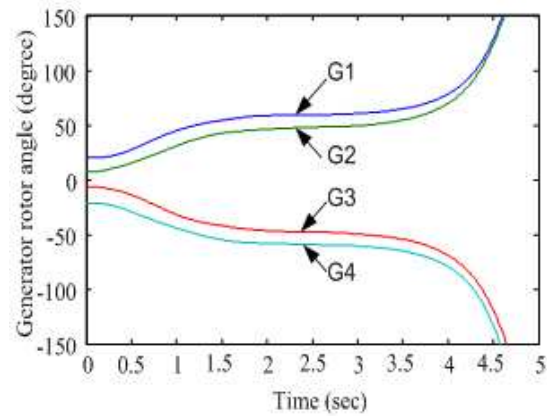Fig. 7: Inter-area power system with a SSSC

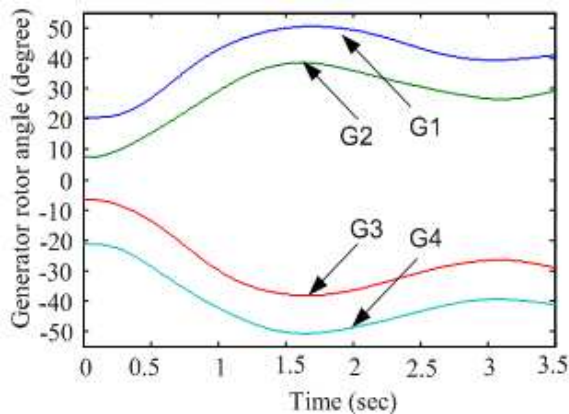Fig. 8: Swing curve of Inter-area power system without a SSSC

Fig. 9: Swing curve of Inter-area power system with a SSSC

DISCUSSION

It can be observed from the simulation results as shown in Fig. 8-9 that without a SSSSC the different angles of generator in area 1 and area 2 increases significantly and thus the system is considered as unstable. However, with a SSSC, the system is considered as stable. It indicates that a SSSC can enhance stability of the inter-area power system.

CONCLUSION

This study investigates the capability of the Static Synchronous Series Compensator (SSSC) on stability enhancement of the inter-area power system. The mathematical model is systematically derived. The SSSC is modeled and then is applied to be incorporated into the power system model for investigating stability improvement. The SSSC is modeled as the variable susceptance and is controlled during dynamic state. This presented SSSC model can be incorporated into susceptance matrix of power system model.

The presented method is tested on sample inter-area power system with 3 phase fault disturbances. The swing curve of inter-area power system without a SSSC gets increases monotonically and thus the system can be considered as unstable whereas the swing curves of system with a SSSC can be considered as stable. It indicates that a SSSC can enhance stability of the inter-area power system.

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