

Reduction of Over Line Current in Power System from Short Circuit Effect Using Static Synchronous Series Compensator

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Abstract: Problem statement: One of the major problems in power system is the over line current from short circuit effect. It may cause in the electrical apparatus outages. **Approach:** Static Synchronous Series Compensator (SSSC) is a power electronic based device that has the capability of controlling the line current. This study applies the SSSC to decrease the over line current in power system during dynamic state. To verify the effect of the SSSC on over line current reduction, the mathematical model of power system equipped with a SSSC is presented. The variation curve of line current of the faulted system with without and with a SSSC is tested and compared in various cases. **Results:** The line current of the system without a SSSC is continuously oscillation and the maximum value is much more than the system with a SSSC. **Conclusion:** SSSC can decrease over line current in power system from short circuit effect.

Key words: Over line current, power system stability, FACTS devices, static synchronous, Static Synchronous Series Compensator (SSSC), Single Machine Infinite Bus (SMIB), transformer leakage, voltage injection, voltage source, short circuit, High Voltage Direct Current (HVDC), Flexible AC Transmission System (FACTS)

INTRODUCTION

The short circuit in power system is unavoidable situation and it provides the high current. It may cause in power apparatus outage. One of the major problems in power system is the over line current from short circuit effect (Barbuy *et al.*, 2009; Coe and Laosethakul, 2010; Subramanian *et al.*, 2010; Barnes *et al.*, 2009). They have proposed many methods to improve stability of power system such as load shedding, High Voltage Direct Current (HVDC), Flexible AC Transmission System (FACTS), (Matondang and Jambak, 2010; El-Shennawy *et al.*, 2010; Hannan *et al.*, 2009; Magaji and Mutafa, 2009; Wong and Lee, 2009; Metkar and Talbar, 2010; Mustafa and Magaji, 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 (Ahmad and Al-Husban, 2009; Bagher *et al.*, 2009; Hashim and Marghany, 2009; Zahim *et al.*, 2009).

This study presents the method of decreasing over line current in power system from short circuit effect by using a SSSC. The mathematical model of power system equipped with a SSSC is systematically derived. The simulation results are tested on a Single Machine Infinite bus system. The effect of SSSC on reduction of over line current is investigated in various cases.

MATERIALS AND METHODS

Mathematical Model: Figure 1a shows the single line diagram of Single Machine Infinite Bus (SMIB) system without a SSSC and the corresponding equivalent circuit is shown in Fig. 1b. Here X_1 is the equivalent reactance between the machine internal bus and the bus m and X_2 is the equivalent reactance between bus m and the infinite bus. The generator is represented by a constant voltage source (E') behind transient reactance (X_d').

Consider the system without a SSSC as shown in Fig. 1, the line current is given by:

$$\begin{aligned} I_0 &= \frac{E' - V_b}{jX} \\ &= \frac{(E' \cos \delta + jE' \sin \delta) - (V_b)}{jX} \\ &= \left(\frac{E'}{X} \sin \delta\right) + j\left(-\frac{E'}{X} \cos \delta + \frac{V_b}{X}\right) \end{aligned} \quad (1)$$

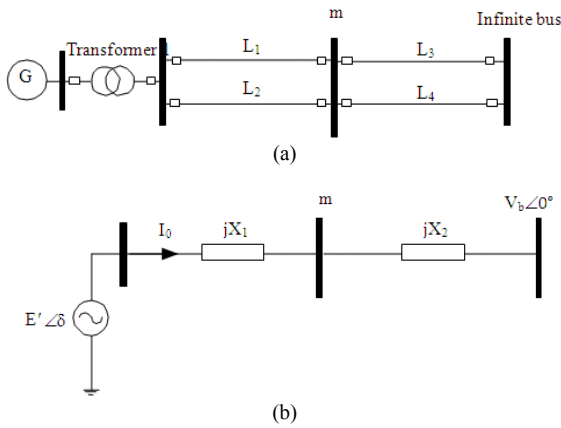


Fig. 1: Single machine infinite bus system (a) schematic diagram (b) equivalent circuit

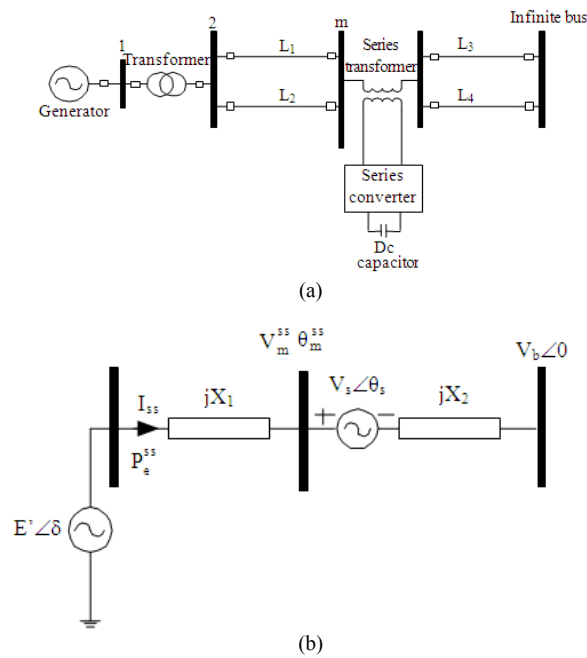


Fig. 2: Single machine infinite bus system with a SSSC (a) schematic diagram (b) equivalent circuit of system with a SSSC represented by a series voltage injection

Here $X = X_1 + X_2$:

$$\theta = \tan^{-1} \left[\frac{V_b - E' \cos \delta}{E' \sin \delta} \right] \quad (2)$$

The output electrical power of the system without a SSSC is given by:

$$P_c^0 = \frac{E' V_b}{X} \sin \delta \quad (3)$$

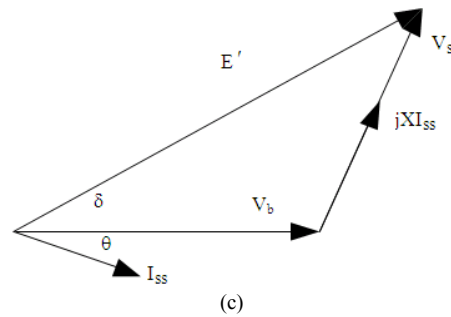
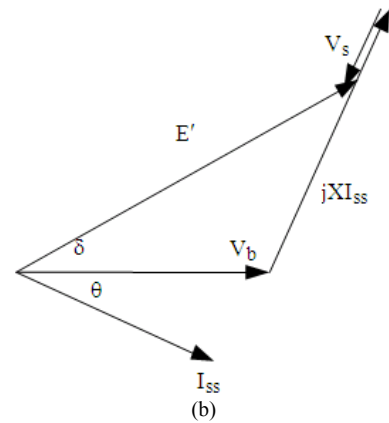
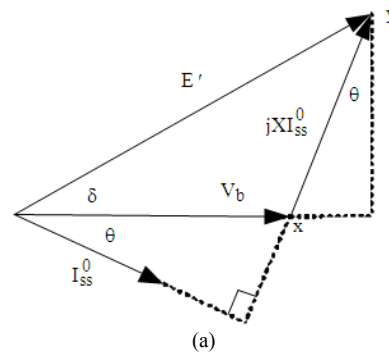


Fig. 3: Phasor diagram (a) without a SSSC (b) with a SSSC operating in capacitive mode (c) with a SSSC operating in reactive mode

Now, consider the system with a SSSC as shown in Fig. 2. The Fig. 2b represents the equivalent circuit of Fig. 2a. The SSSC is represented by a series voltage injection (V_s) and transformer leakage reactance. When V_s is positive, the SSSC supplies the reactive power to the system, it is called capacitive mode and then the series voltage angle θ_s is in lagging with the line current as shown in Fig. 3b whereas V_s is negative, the SSSC absorbs the reactive power to the system, it is called reactive mode and then the series voltage angle θ_s is in leading with the line current as shown in Fig. 3c.

From Fig. 2b, the line current of the system with a SSSC is given by:

$$\begin{aligned} \mathbf{I}_{ss} &= \frac{\mathbf{E}' - \mathbf{V}_s - \mathbf{V}_b}{jX} \\ &= \left[\frac{\mathbf{E}' - \mathbf{V}_b}{jX} \right] + \left[\frac{-\mathbf{V}_s}{jX} \right] \end{aligned} \quad (4)$$

From the Eq. 1 and 4, the line current of the system with a SSSC is given by:

$$\mathbf{I}_{ss} = \mathbf{I}_0 + \Delta \mathbf{I} \quad (5)$$

$$\text{Here, } \Delta \mathbf{I} = \frac{-\mathbf{V}_s}{jX}$$

From Eq. 1 and 4, $\Delta \mathbf{I}$ is the additional component of the system of a SSSC.

From the phasor diagram as shown in Fig. 3, it indicates that the SSSC doesn't change the line current angle. However, the SSSC affects on the line current magnitude. When V_s lags line current 90 degree, the line current magnitude is increased and when V_s leads line current 90 degree, the line current magnitude is decreased as can be seen in Fig. 3.

MATERIALS AND METHODS

The dynamic of power system as shown in Fig. 2a can be expressed by following equations

$$\dot{\delta} = \omega \quad (6)$$

$$\dot{\omega} = \frac{1}{M} [P_m - P_e^{ss}] \quad (7)$$

Here, δ , ω , P_m , M and P_e^{ss} are the rotor angle, speed deviation, mechanical input power, moment of inertia and electrical output power. The output electrical power equation of generator can be expressed by:

$$\begin{aligned} P_e^{ss} &= \text{Re}[\mathbf{E}'(\mathbf{I}_{ss})^*] \\ &= \text{Re}[\mathbf{E}'(\mathbf{I}_0)^*] + \text{Re}[\mathbf{E}'(\Delta \mathbf{I})^*] \end{aligned} \quad (8)$$

The first term of Eq. 8 represents the system without a SSSC. The second term is the additional component from the SSSC (ΔP_e^{ss}) rewritten by:

$$P_e^{ss} = P_e + \Delta P_e^{ss} \quad (9)$$

The ΔP_e^{ss} is written by:

$$\begin{aligned} \Delta P_e^{ss} &= \text{Re} \left[\mathbf{E}' \left(\frac{-\mathbf{V}_s}{jX} \right)^* \right] \\ &= \text{Re} \left[E' \angle \delta \left(\frac{-V_s \angle \theta_s}{jX} \right)^* \right] \\ &= \frac{E' V_s}{X} \sin(\delta - \theta_s) \end{aligned} \quad (10)$$

Here:

$$\Delta P_e^{ss} = \frac{E' V_s}{X} \cos(\delta - \theta) \quad (11)$$

From the Eq. 2, it can be written by:

$$E' \sin \delta \sin \theta = V_b \cos \theta - E' \cos \delta \cos \theta \quad (12)$$

With some mathematical manipulations of Eq. 11, it can be written by:

$$\cos(\delta - \theta) = \frac{V_b}{E'} \cos(\theta) \quad (13)$$

From the Fig. 3, the cosine of the line current angle is given by:

$$\begin{aligned} \cos(\theta) &= \frac{E' \sin(\delta)}{xy} \\ &= \frac{E' \sin(\delta)}{\sqrt{(E')^2 + (V_b)^2 - 2E'V_b \cos(\delta)}} \end{aligned} \quad (14)$$

From Eq. 10 and 13, the additional component of output electrical power is:

$$\Delta P_e^{ss} = \frac{V_s E' V_b}{X \sqrt{(E')^2 + (V_b)^2 - 2E'V_b \cos \delta}} \sin \delta \quad (15)$$

From Eq. 8 and 14, the output electrical power of system with a SSSC is given by:

$$P_e^{ss} = P_e + \frac{V_s P_e}{\sqrt{(E')^2 + (V_b)^2 - 2E'V_b \cos \delta}} \quad (16)$$

It can be seen from Eq. 15 that the output electrical power flow can be controlled by a SSSC. With positive value of V_s , the output electrical power is increased whereas with negative value of V_s , the output electrical power is reduced. Thus the control strategy of SSSC is given by:

$$V_s = k\omega \quad (17)$$

Here, k is constant gain control.

RESULTS

The proposed model of decreasing over line current in faulted power system equipped with a SSSC is investigated on sample system. Fig. 4 shows the sample system. The system parameters are:

$$M=5.6, X_t = 0.1, X'_d = 3, X_{L1}=0.4, X_{L2}=0.4, X_{L3}=0.9, X_{L4}=0.4, P_m=0.9$$

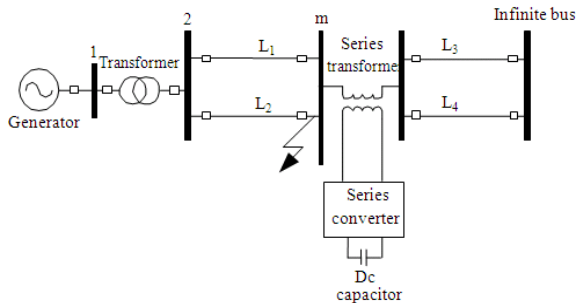


Fig. 4: Sample system

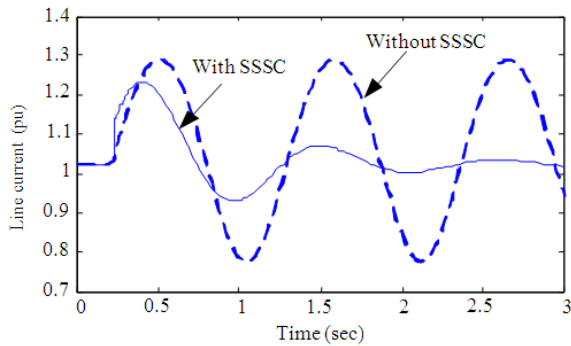


Fig. 5: Line current of the faulted system with $t_{cl} = 130$ msec

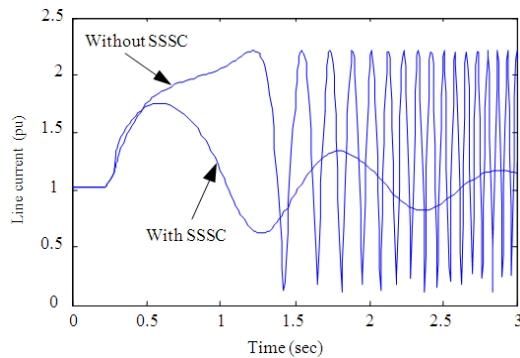


Fig. 6: Line current of the faulted system with $t_{cl} = 140$ msec

It is considered that a 3-phase fault appears on line L1 and it is cleared by opening the faulted line. Figure 5 shows the variation curve of line current of the system with clearing fault time (t_{cl}) 130 msec and Fig. 6 shows the variation curve of line current of the system with clearing fault time (t_{cl}) 138 msec.

DISCUSSION

It can be observed from the simulation results that with $t_{cl} = 130$ msec and without a SSSC ($K=0$), the line current continuously oscillation and with a SSSC, the line current can return to normal steady state at few seconds. With increasing t_{cl} to 138 msec, the over line current of the system without a SSSC is increased much more and higher frequency. However, the over line current can be significant reduced by using the SSSC.

CONCLUSION

This study presents the method of decreasing over line current in power system from short circuit effect by using a SSSC. The mathematical model of power system equipped with a SSSC is systematically derived. It was found from the proposed model that the line current can be controlled by a SSSC. The simulation results are tested on a Single Machine Infinite bus system. It was found from the simulation results that the SSSC can decrease over line current in power system from short circuit effect.

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