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Power System Transient Stability Improvement Using Optimal Control of Static Synchronous Compensator

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Abstract

The development and use of FACTS devices for power transmission system has led to the application of these controllers to improve the stability of power systems. This paper discusses the optimal control of static compensator (STATCOM) to improve transient stability. To demonstrate the ability of the proposed control strategy, it has been applied on a single machine and multi machine power systems. Different modes of operation of compensator regarding the modulation of active and reactive power has been considered. In multi machine system, since the control signal based on the state variable is not available at the compensator bus, the derivative of an electric quantity derived from local measurement has been utilized.

Key words: Transient stability, Optimal control, Static synchronous compensator, STATCOM, FACTS Devices.

1- Flexible AC Transmission System
2- Static Synchronous Compensator

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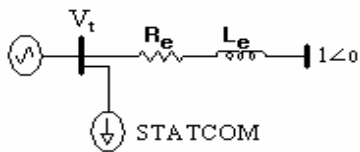
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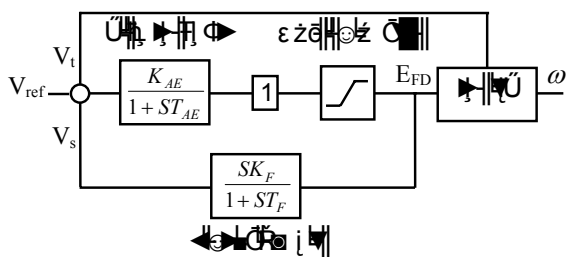
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$$\begin{cases} \dot{E}'_d = [-E'_d - (X_q - X'_d)I_q] / T'_{qo} \\ \dot{E}'_q = [-E'_{FD} - E'_q (X_d - X'_d)I_d] / T'_{do} \end{cases}$$

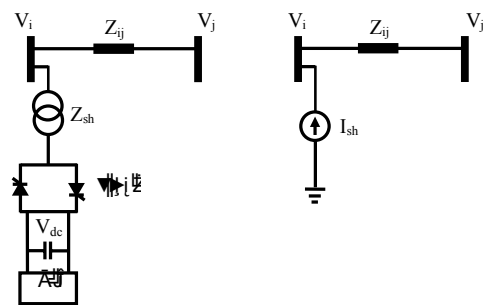
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$$\begin{matrix} T'_{qo} & T'_{do} & E_{FD} \\ & & q \quad d \end{matrix}$$

$$\begin{cases} V_d = E'_d - R_a I_d - X'_d I_q = -V_\infty \sin(\delta) + R_e I_d + \omega L_e I_q \\ V_q = E'_q - R_a I_q + X'_d I_d = -V_\infty \cos(\delta) + R_e I_q - \omega L_e I_d \\ V_t = (V_d^2 + V_q^2)^{1/2} \end{cases}$$

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$$\frac{2H}{\omega_s} \omega_{p.u}(t) \frac{d^2 \delta(t)}{dt^2} + D \omega_{p.u}(t) \frac{d \delta(t)}{dt} = P_{mp.u}(t) - P_{ep.u}(t)$$

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$V(\delta, \omega)$

$$\begin{cases} \frac{2H}{\omega_s} \frac{d\omega(t)}{dt} = P_{mp.u}(t) - P_{ep.u}(t) - D\omega(t) \\ \frac{d\delta(t)}{dt} = \omega(t) - \omega_s \end{cases} \quad (1)$$

$V(\delta, \omega)$

$$\dot{V} = \frac{dV}{dt} = \frac{\partial V}{\partial \delta} \cdot \frac{d\delta}{dt} + \frac{\partial V}{\partial \omega} \cdot \frac{d\omega}{dt} \quad (2)$$

$$\frac{\partial V}{\partial \delta} = - \left[P_m - \frac{3V^2}{X} \sin(\delta) \right] \quad (3)$$

$$\frac{\partial V}{\partial \omega} = \frac{2HP_b}{\omega_s} (\omega - \omega_s) \quad (4)$$

$$V(\delta, \omega) = \frac{HP_b}{\omega_s} (\omega - \omega_s)^2 - \left[P_m (\delta - \delta_s) + \frac{3V^2}{X} (\cos(\delta) - \cos(\delta_s)) \right] \quad (5)$$

$$\frac{d\delta(t)}{dt} = \omega(t) - \omega_s \quad (6)$$

$$\frac{d\omega}{dt} = \frac{\omega_s}{2HP_b} (P_m - P_e) \quad (7)$$

$$P_e = \frac{3V^2}{X} \sin(\delta) + \frac{3V}{2} (\text{Re}(I_{STATCOM}) \cos(\delta) - \text{Im}(I_{STATCOM}) \sin(\delta)) \quad (8)$$

$$\dot{V} = - \frac{3V}{2} (\omega - \omega_s) (I_d \cos(\delta) + I_q \sin(\delta)) \quad (9)$$

$$\psi_2 \quad \psi_1 \quad () \quad ()$$

$$\psi_1(t) = \frac{2H}{\omega_s} (\omega - \omega_s) \quad () \quad I_{STATCOM} \quad (\omega - \omega_s)(I_d \cos(\delta) + I_q \sin(\delta))$$

$$\psi_2(t) = P_m - \frac{3V^2}{X} \sin(\delta) - \frac{3V}{2} [I_d \cos(\delta) + I_q \sin(\delta)] \quad () \quad () \quad ()$$

$$H_a = \frac{\omega_s}{2H} \left[P_m - \frac{3V^2}{X} \sin(\delta) \right] \psi_1 - \frac{\omega_s}{2H} \cdot \frac{3V}{2} [I_d \cos(\delta) + I_q \sin(\delta)] \psi_1 + (\omega - \omega_s) \psi_2$$

$$\phi(\delta, \omega) = -\frac{\omega_s}{2H} \cdot \frac{3V}{2} [I_d \cos(\delta) + I_q \sin(\delta)] \psi_1 = -\frac{3V}{2} [I_d \cos(\delta) + I_q \sin(\delta)] (\omega - \omega_s)$$

$$\dot{\psi}_1 = -\frac{\partial H_a}{\partial \omega} = \psi_2$$

$$\psi_2 = -\frac{\partial H_a}{\partial \delta} = \frac{\omega_s}{2H} \left[\begin{matrix} -\frac{3V^2}{X} \cos(\delta) \\ -\frac{3V}{2} (-I_d \sin(\delta) + I_q \cos(\delta)) \end{matrix} \right] \psi_1$$

$$I_{STATCOM} = K(\omega - \omega_s) \sin \delta \quad () \quad (\delta = \delta_s \quad \omega = \omega_s \quad I_{STATCOM} = 0)$$

$$I_{STATCOM} = \begin{cases} I_{MAX} & , I_{MAX} \leq I_{STATCOM} \\ K(\omega - \omega_s) \sin(\delta), I_{MIN} \leq I_{STATCOM} \leq I_{MAX} \\ I_{MIN} & , I_{MIN} \geq I_{STATCOM} \end{cases} \quad () \quad ()$$

$$\psi_1(\omega = 0) = 0 \quad \psi_2(\delta = \delta_s, I_{STATCOM} = 0) = 0$$

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$$I_{STATCOM} = \begin{cases} I_{MAX} & , I_{MAX} \leq I_{STATCOM} \\ K(\omega - \omega_s) \cos(\delta) & , I_{MIN} \leq I_{STATCOM} \leq I_{MAX} \\ I_{MIN} & , I_{MIN} \geq I_{STATCOM} \end{cases} \quad ()$$

$$I_{STATCOM} = \begin{cases} I_{MAX} & , I_{STATCOM} \geq 0 \\ I_{MIN} & , I_{STATCOM} < 0 \end{cases} \quad ()$$

$$I_{STATCOM} = \begin{cases} I_{MAX} & , I_{STATCOM} \geq 0 \\ I_{MIN} & , I_{STATCOM} < 0 \end{cases} \quad ()$$

$(\omega_s \delta_s)$

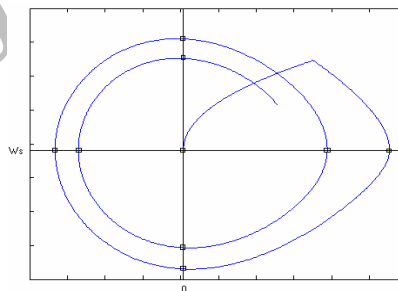
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$$(\omega - \omega_s)(I_d \cos(\delta) + I_q \sin(\delta)) \geq 0 \quad ()$$

$$\begin{cases} \omega \geq \omega_s & \Rightarrow I_d/I_q \geq -\tan(\delta) \\ \omega < \omega_s & \Rightarrow I_d/I_q < -\tan(\delta) \end{cases} \quad ()$$



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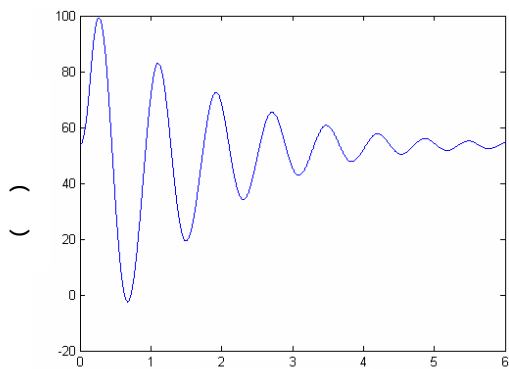
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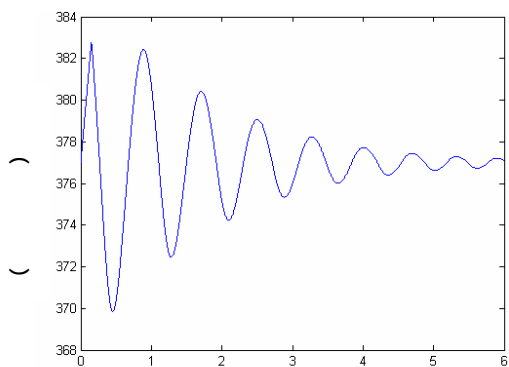
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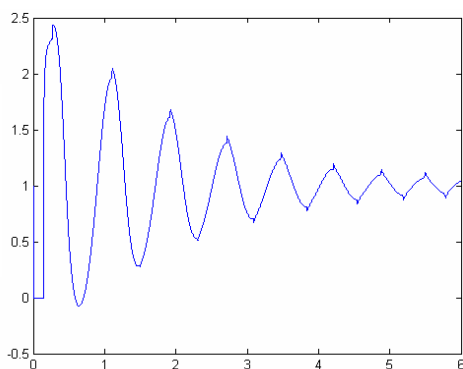
$$I_{STATCOM} = K(\omega - \omega_s) \cos \delta \quad ()$$



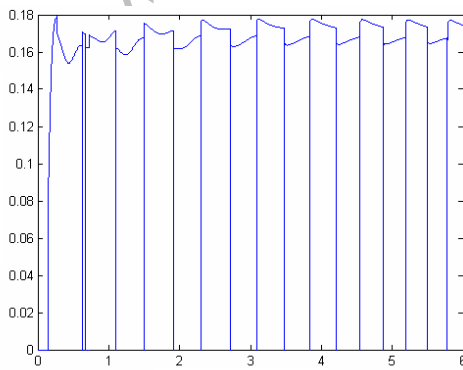
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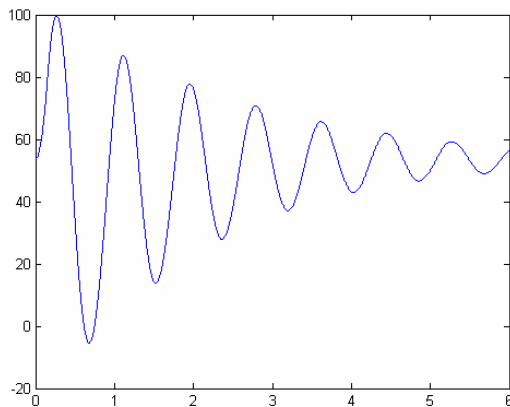
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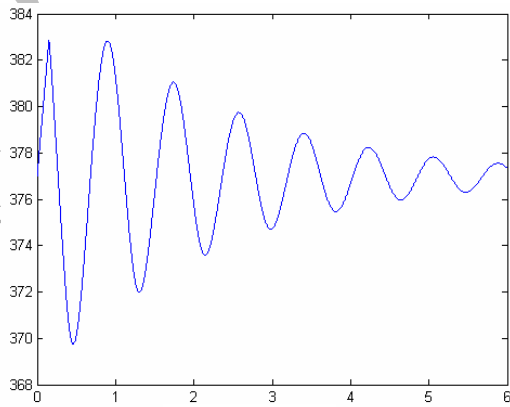
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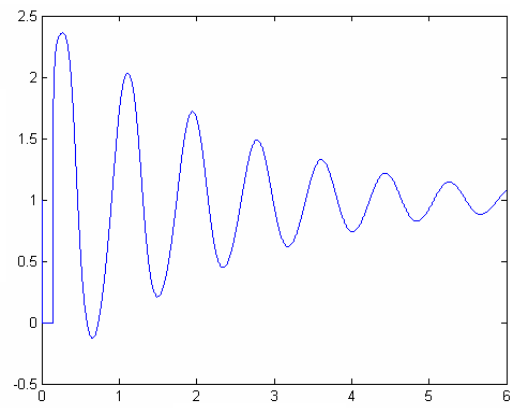
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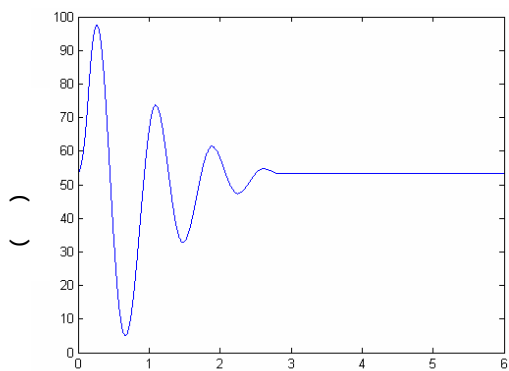
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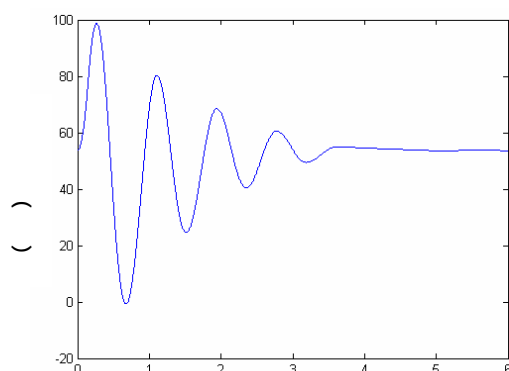
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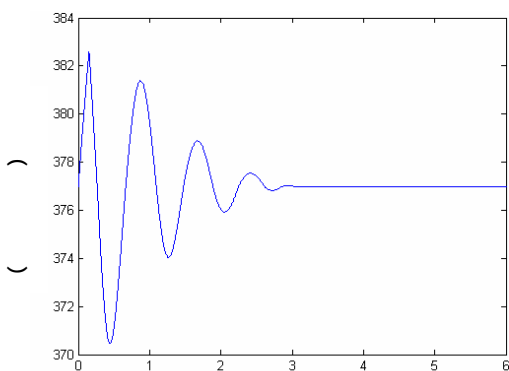
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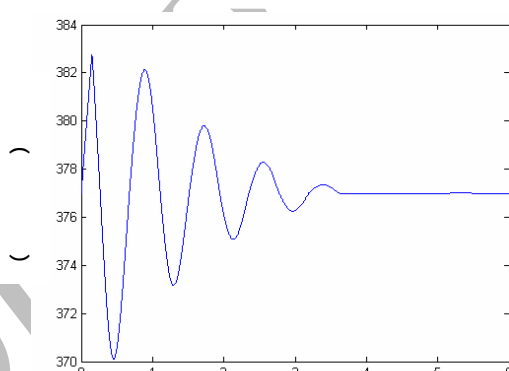
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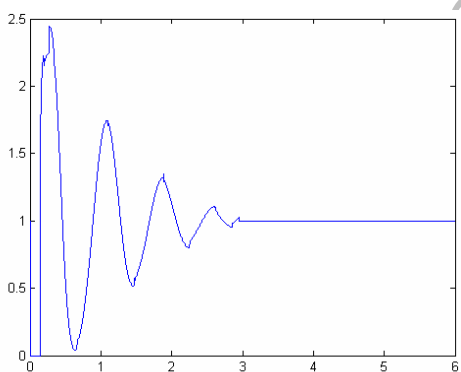
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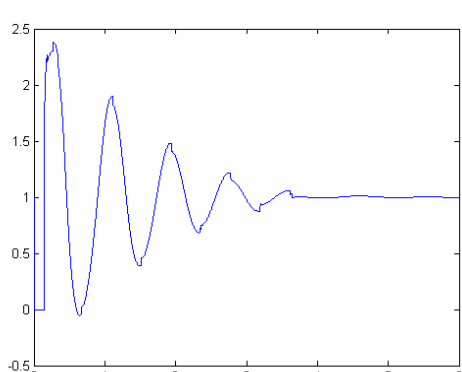
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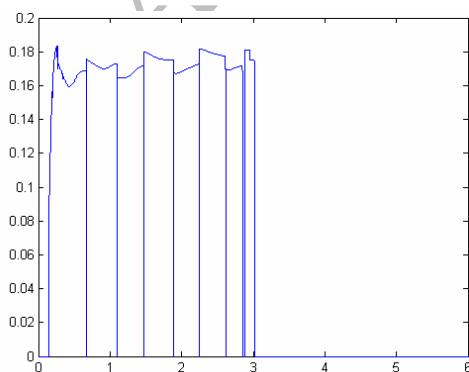
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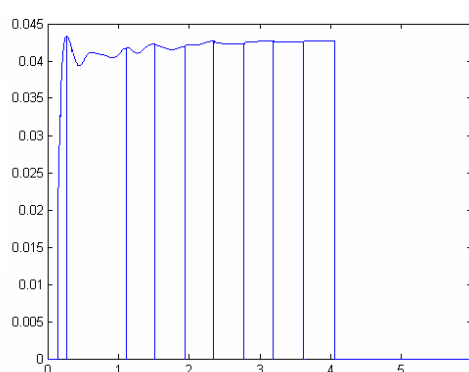
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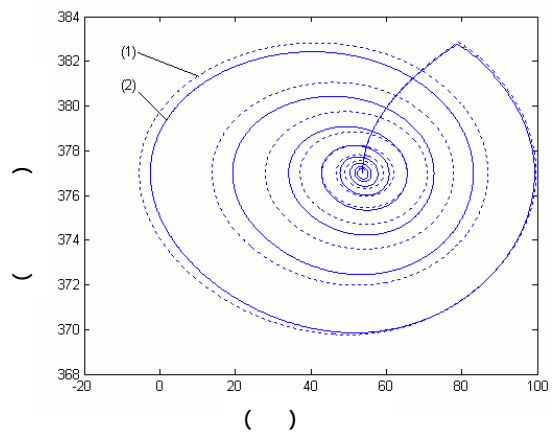
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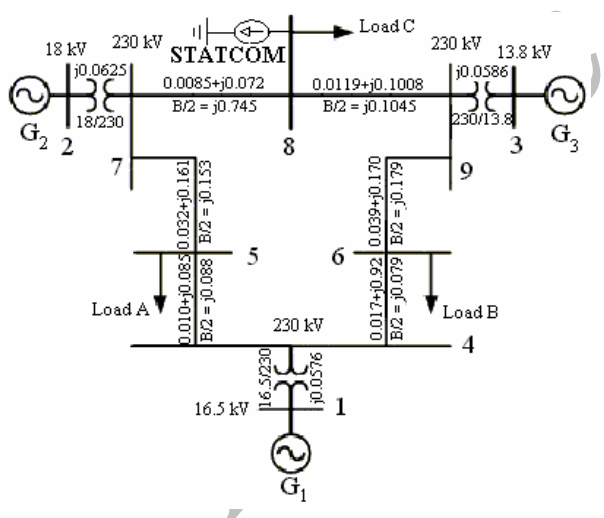
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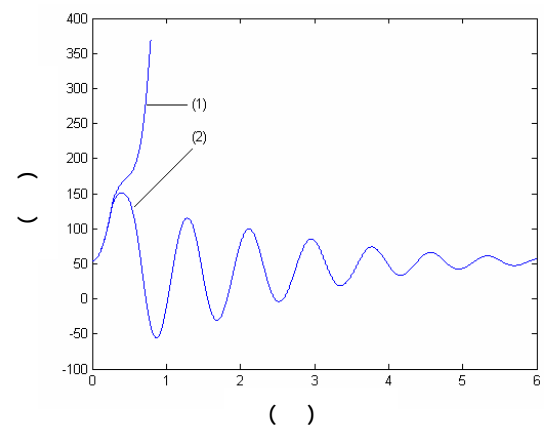
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$$\frac{dq}{dt} \cong \frac{\partial q}{\partial \delta} \cdot \frac{d\delta}{dt} = \frac{\partial q}{\partial \delta} \cdot \omega \quad ()$$

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$$signal = K_R \omega \frac{\partial q}{\partial \delta} \quad ()$$

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$$\frac{\partial q}{\partial \delta} = C_q \sin(\delta) \quad ()$$

: q

C_q

$$signal = K_R \frac{dq}{dt} \quad ()$$

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q

$$q_I(t) = +|I_A|^2 + |I_B|^2 \quad ()$$

$$\begin{aligned} \frac{dq}{dt} &= \frac{\partial q}{\partial \delta} \cdot \frac{d\delta}{dt} + \frac{\partial q}{\partial I_{STATCOM}} \cdot \frac{dI_{STATCOM}}{dt} \\ &= \frac{\partial q}{\partial \delta} \cdot \omega + \frac{\partial q}{\partial I_{STATCOM}} \cdot \frac{dI_{STATCOM}}{dt} \quad () \end{aligned}$$

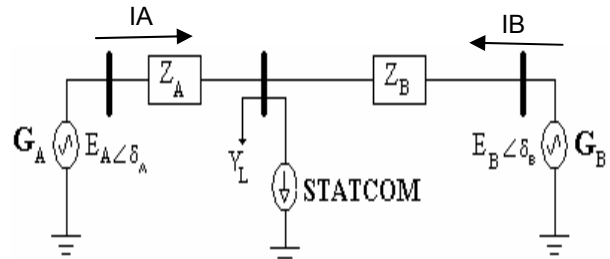
$$signal_I = K_R \frac{d}{dt} [+|I_A|^2] \quad ()$$

$$\left| \frac{\partial q}{\partial \delta} \right| \gg \left| \frac{\partial q}{\partial I_{STATCOM}} \right| \quad ()$$

$$q_I(t) = +|I_A|^2 = I_A I_A^* = B_{AA}^2 |E_A|^2 + B_{AB}^2 |E_B|^2 + 2B_{AA} B_{AB} |E_A| |E_B| \cos(\delta) \quad ()$$

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$$B_{BB} \quad B_{AA} \quad ()$$



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$$\begin{aligned} \frac{\partial q_I}{\partial \delta} &= + \frac{\partial |I_A|^2}{\partial \delta} \\ &= -2B_{AA} B_{AB} |E_A| |E_B| \sin(\delta) \quad () \end{aligned}$$

$$\sin \delta \quad []$$

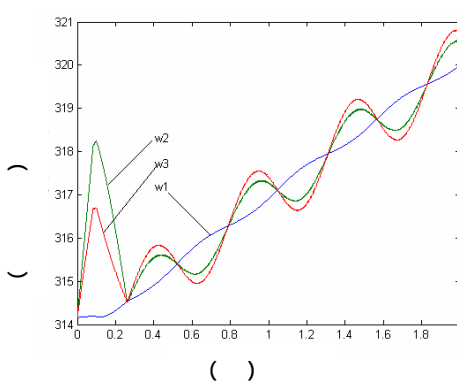
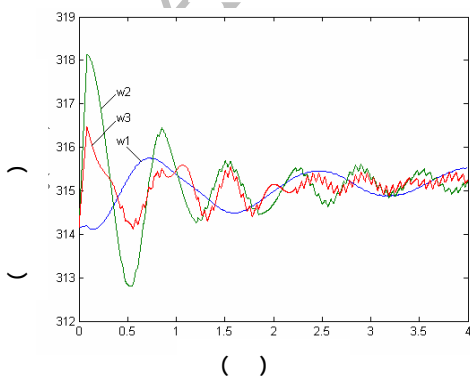
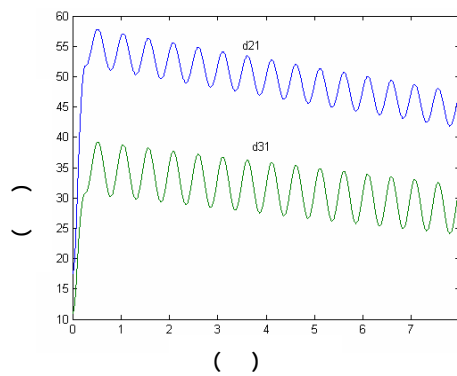
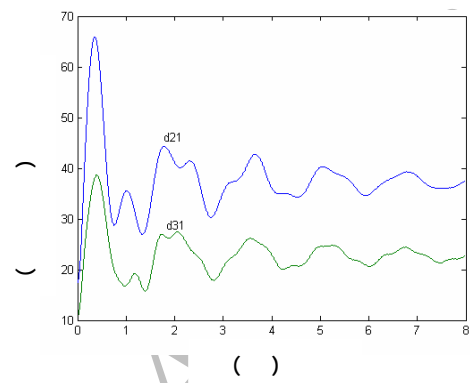
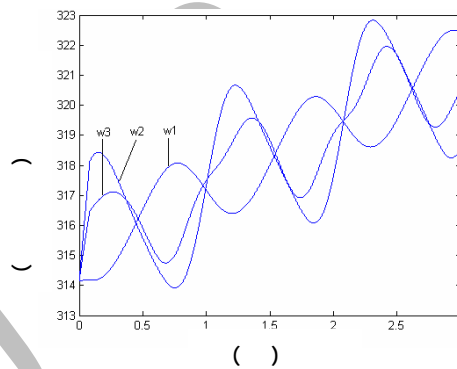
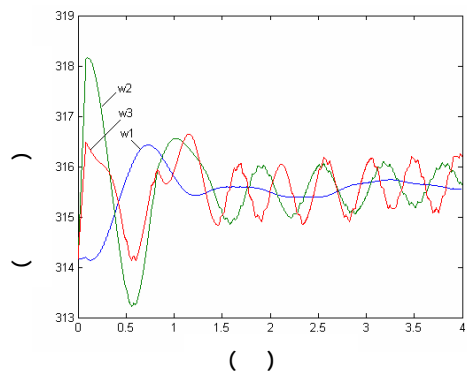
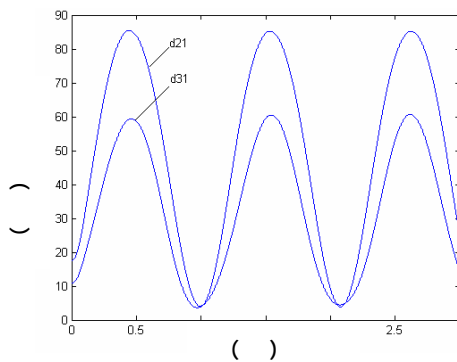
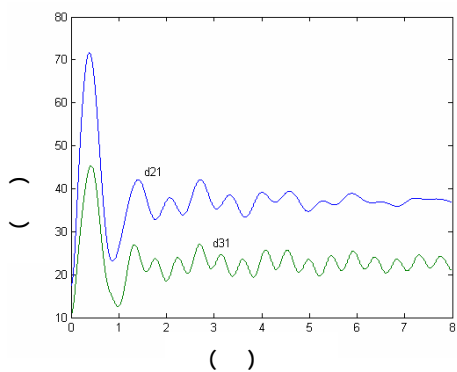
$$signal = K_R \frac{d}{dt} [|I_A|^2 + |I_B|^2] \quad ()$$

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$$K_R \frac{d}{dt} [|I_A|^2 + |I_B|^2]$$

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$$I_{STATCOM} = \begin{cases} I_{MAX} , & K_R \frac{d}{dt} [|I_A|^2 + |I_B|^2] \geq 0 \\ I_{MIN} , & K_R \frac{d}{dt} [|I_A|^2 + |I_B|^2] < 0 \end{cases}$$



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= 100 MVA

	V	
/	X'_d	d
/	R_a	
/	X_d	d
/	X_q	q
/	T'_{d0}	d
/	T'_{q0}	q
/	R_e	
/	L_e	
/	H	
π	ω_s	
	P_m	
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/	T_{AE}	
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	T_F	
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/	PSTATCOM	STATCOM

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MVA	/		
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X_d	/	/	/
X'_d	/	/	/
X_q	/	/	/
$X'q$	/	/	/
X_l	/	/	/
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