IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

Charging Infrastructure

Lecture-27

Closed loop control of three-phase AC-DC converter-II

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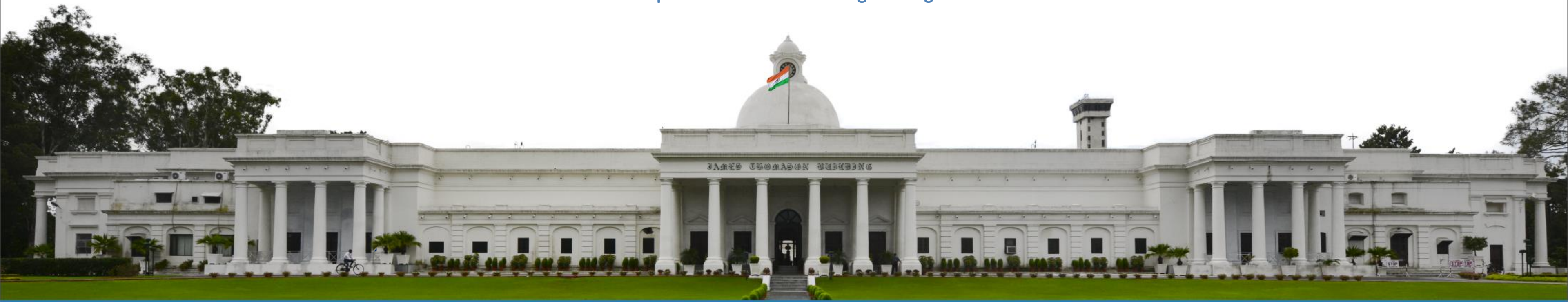
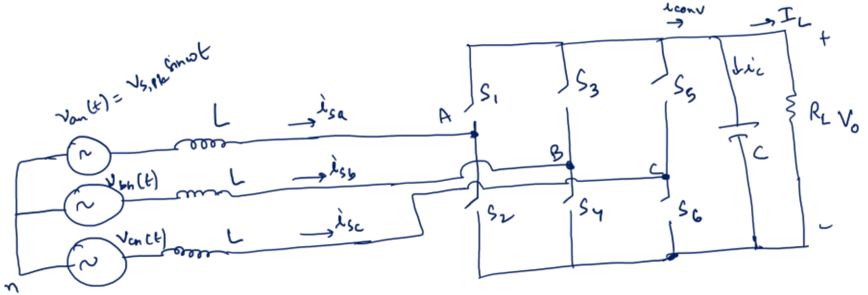


Recap

Control Objectives

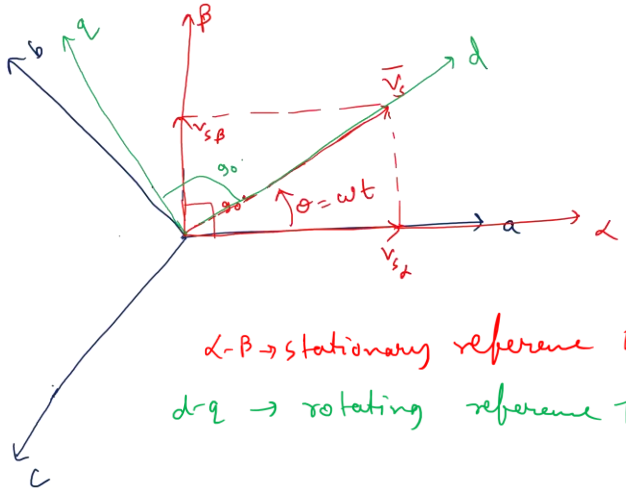
① To regulate the output voltage to a desired value. ($> \sqrt{2}\, V_{L-L}$)



② The current drawn should have unity power factor (upf) operation

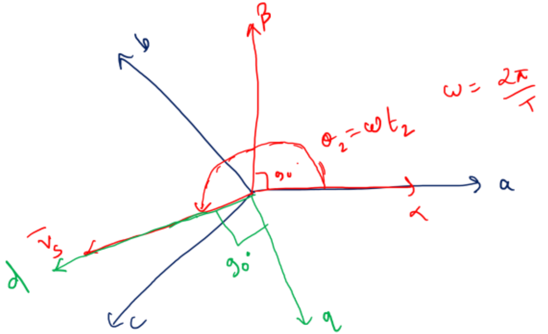
$i_{sa} + i_{sb} + i_{sc} = 0$ (for balanced 3-φ operation)

Recap



α-β → stationary reference frame

d-q → rotating reference frame



at one instant 't'

a, b, c → sampled quantity (v_s, i_s, v_{conv})

$\alpha = a - b/2 - c/2 \Rightarrow \alpha = \frac{3a}{2}$

$\beta = a\cos 90° + b\cos 30 - c\cos 30 \Rightarrow \beta = \frac{\sqrt{3}}{2}b - \frac{\sqrt{3}}{2}c$

$d = \alpha\cos\theta + \beta\sin\theta$

$q = -\alpha\sin\theta + \beta\cos\theta$

$V_{s\alpha} = \frac{3}{2}V_{sa}$

$V_{s\beta} = \frac{\sqrt{3}}{2}V_{sb} - \frac{\sqrt{3}}{2}V_{sc}$

(V_{sa}, V_{sb}, V_{sc} → sampled $v_{an}(t), v_{bn}(t), v_{cn}(t)$)

$\Rightarrow V_{sd} = V_{s\alpha}\cos\theta + V_{s\beta}\sin\theta$

$V_{sq} = -V_{s\alpha}\sin\theta + V_{s\beta}\cos\theta$

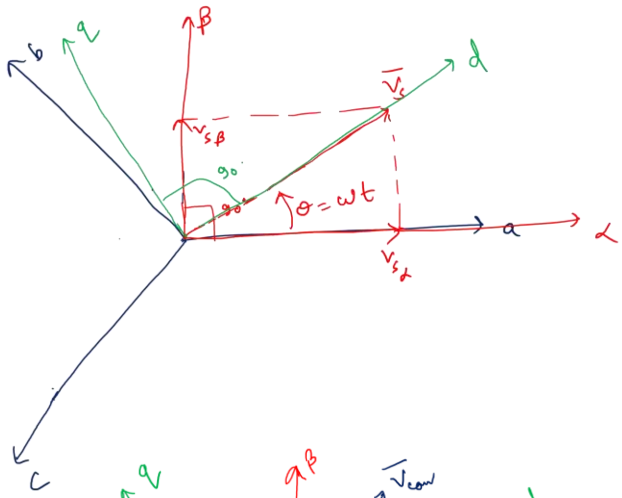
$I_{s\alpha} = 3/2\, I_{sa}$

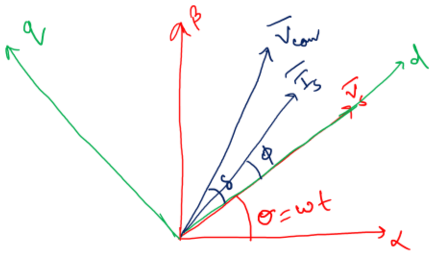
(I_{sa}, I_{sb}, I_{c} → sampled i_{sa}, i_{sb}, i_{sc})

$I_{s\beta} = \frac{\sqrt{3}}{2}I_{sb} - \frac{\sqrt{3}}{2}I_{sc}$

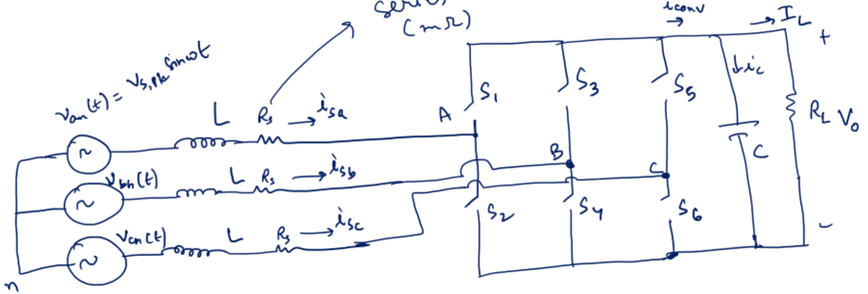
$I_{sd} = I_{s\alpha}\cos\theta + I_{s\beta}\sin\theta$

$I_{sq} = -I_{s\alpha}\sin\theta + I_{s\beta}\cos\theta$

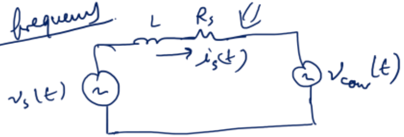


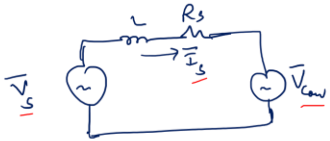


series resistance of inductance (winding resistance) (mΩ)



fundamental frequency





d-q frame

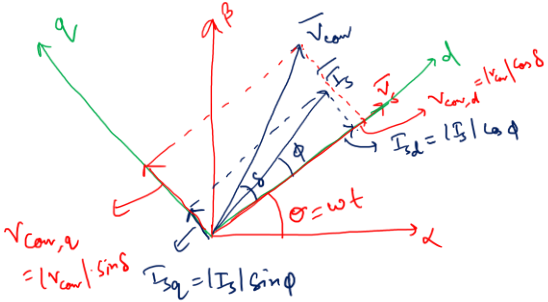
$\bar{V}_s = V_{sd} + j0$ ($v_{sq} = 0$, as the $\bar{V}_s$ is aligned along d-axis)

$(|V_s| = \sqrt{V_{sd}^2 + 0^2})$

$\Rightarrow \bar{V}_s = |V_s| \cdot e^{j0}$

$\bar{I}_s = |I_s| \cdot e^{j\phi}$

$\bar{V}_{con} = |V_{con}| \cdot e^{j\delta}$



α-β frame

$\bar{V}_s = |V_s| e^{j\theta}$

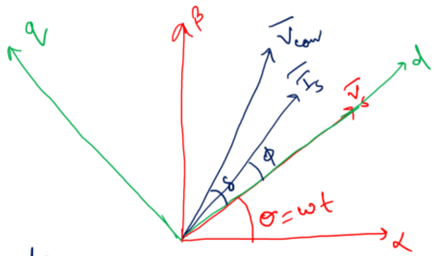
$\bar{I}_s = |I_s| \cdot e^{j(\theta+\phi)}$ $\Rightarrow$ $I_{s\alpha} = |I_s| \cdot \cos(\theta+\phi)$; $I_{s\beta} = |I_s| \sin(\theta+\phi)$

$\bar{V}_{con} = |V_{con}| e^{j(\theta+\delta)}$

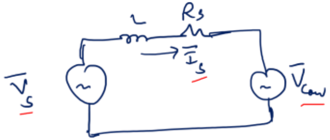
α-β stationary frame

$$\bar{V}_s = L\frac{d\bar{I}_s}{dt} + R\bar{I}_s + \bar{V}_{conv}$$

$$|V_s|e^{j\theta} = L\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi)}\right) + R_s\left(|I_s|\cdot e^{j(\theta+\varphi)}\right) + |V_{conv}|\cdot e^{j(\theta+\delta)} \longrightarrow (1)$$



$$\Rightarrow \frac{d\theta}{dt} = \omega$$



d-q (synchronous rotating) frame

By multiplying eq. (1) by $e^{-j\theta}$

$$\Rightarrow |V_s|\cdot e^{j\theta}\cdot e^{-j\theta} = L\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi)}\right)\cdot e^{-j\theta} + R_s\left(|I_s| e^{j(\theta+\varphi)}\right)\cdot e^{-j\theta} + |V_{conv}|\cdot e^{j(\theta+\delta)}\cdot e^{-j\theta}$$

$$\Rightarrow |V_s|\cdot e^{j0} = \underbrace{L\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi)}\right)\cdot e^{-j\theta}} + R_s\left(|I_s|\cdot e^{j\varphi}\right) + |V_{conv}|\cdot e^{j\delta} \longrightarrow (2)$$

$$L\frac{d}{dt}\left(\underbrace{|I_s|\cdot e^{j(\theta+\varphi)}}_{u}\cdot \underbrace{e^{-j\theta}}_{v}\right) = L\left[\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi)}\right)\cdot e^{-j\theta} + |I_s|\cdot e^{j(\theta+\varphi)}\cdot\frac{d}{dt}\left(e^{-j\theta}\right)\right]$$

$$L\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi)}\cdot e^{-j\theta}\right) = L\left[\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi)}\right)\cdot e^{-j\theta} + |I_s|\cdot e^{j(\theta+\varphi)}\cdot\frac{d}{dt}e^{(-j\theta)}\right]$$

$$\frac{d}{dt}\left(e^{-j\theta}\right) = e^{-j\theta}\cdot\left(-\frac{d\theta}{dt}\right)$$
$$= j e^{-j\theta}(-\omega)$$

$$= L\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi)}\right)\cdot e^{-j\theta} - jL|I_s|\cdot e^{j(\theta+\varphi)}\cdot e^{-j\theta}\omega$$

$$\Rightarrow L\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi)}\right)\cdot e^{-j\theta} = L\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi-\theta)}\right) + jL\left(|I_s|\cdot e^{j(\theta+\varphi-\theta)}\right)\cdot\omega$$

$$L\frac{d}{dt}\left(|I_s|\cdot e^{j(\theta+\varphi)}\right)\cdot e^{-j\theta} = L\frac{d}{dt}\left(|I_s|\cdot e^{j\varphi}\right) + jL\omega\cdot|I_s|\cdot e^{j\varphi} \longrightarrow (3)$$

Put eq. (3) in (2)

$$|V_s|\cdot e^{j\theta} = L\frac{d}{dt}\left(|I_s|\cdot e^{j\varphi}\right) + jL\omega|I_s|\cdot e^{j\varphi} + R_s\left(|I_s|\cdot e^{j\varphi}\right) + |v_{conv}|e^{j\delta} \longrightarrow (4)$$

$$|I_s|\cdot e^{j\varphi} = |I_s|\cdot\cos\varphi + j|I_s|\cdot\sin\varphi$$
$$= I_{sd} + jI_{sq}$$

$$|v_s|\cdot e^{j\theta} = v_{sd} + j0 \qquad \left(v_{sd} = |v_s|\cdot\cos\theta\right)$$

$$|V_{conv}| \cdot e^{j\delta} = |V_{conv}| \cdot \cos\delta + j\,|V_{conv}| \cdot \sin\delta$$
$$= V_{conv,d} + j\,V_{conv,q}$$

$$V_{sd} + j0 = L\frac{d}{dt}(I_{sd} + jI_{sq}) + R_s(I_{sd} + jI_{sq}) + jL\omega(I_{sd} + jI_{sq}) + (V_{conv,d} + jV_{conv,q})$$

$$\Rightarrow V_{sd} + j0 = L\frac{d}{dt}I_{sd} + jL\frac{d}{dt}I_{sq} + R_s I_{sd} + jR_s I_{sq} + V_{conv,d} + jV_{conv,q} + j\omega L I_{sd} - \omega L I_{sq}$$

Seperate out Real & Imaginary part

Real part, $V_{sd} = L\frac{d}{dt}I_{sd} + R_s I_{sd} + V_{conv,d} - \omega L I_{sq}$

Imaginary part, $0 = L\frac{d}{dt}I_{sq} + R_s I_{sq} + V_{conv,q} + \omega L I_{sd}$

Rearrange the term

d-axis model, $L\frac{d}{dt}I_{sd} + R_s I_{sd} = -V_{conv,d} + \omega L I_{sq} + V_{sd}$ → cross-coupling term

q-axis model, $L\frac{d}{dt}I_{sq} + R_s I_{sq} = -V_{conv,q} - \omega L I_{sd}$ → cross-coupling term

Thank You