ECE 404-TD / 504-TD

ST: T&D APPLICATIONS OF VOLTAGE SOURCE CONVERTERS

SESSION no. 35

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ECE 404/504: Homework #5

Due Session 37 (April 17)

rms

1. Implement an averaged model of a three VSC with an AC source voltage of 2.4kV (L-L), R = 0.096 Ω , L = 3,82mH (X/R = 15) and a switching frequency of 3600Hz.
   A. Determine V_{dc} if the maximum amplitude of the modulating function is 0.8 and the maximum reactive power the converter can supply is 4MVAR while transferring 0 MW (both measured at the source side of the R-L). Round up to nearest 10 V.
   C. Generate open loop modulating functions ($m_a(t)$, $m_b(t)$, and $m_c(t)$ such that P=4MW and Q=0. Verify that the converter supplies this using averaged models.

   $|m|$
   δ_m

   D. Generate open loop modulating functions such that P=3.71MW and Q=1.5MVAR. Verify that the converter supplies this.
   E. Generate open loop modulating functions such that P=3.71MW and Q=-1.5MVAR. Verify that the converver supplies this.
   F. Generate open loop modulating functions such that P=-3.71MW and Q=-1.5MVAR. Verify that the converver supplies this.
   G. ECE 504 students, implement using a switching model. Compare ac currents to those from the averaged models and the fundamental component of converter terminal voltages to averaged model results.

2. Now the VSC from problem 1 has a closed loop control scheme implemented in the synchronously rotating d-q reference frame. Assume that the source voltage is constant.
   A. Determine the i_{dref} and i_{qref} such that P=4MW and Q=0.
   B. Determine the i_{dref} and i_{qref} such that P=3.71MW and Q=1.5MVAR.
   C. Determine the i_{dref} and i_{qref} such that P=3.71MW and Q=-1.5MVAR
   D. Determine the i_{dref} and i_{qref} such that P=3.71MW and Q=-1.5MVAR
   E. ECE 504 students implement cases A-D using closed loop control in your EMT program using averaged models.

Assume PLL → $V_{sq} = 0$

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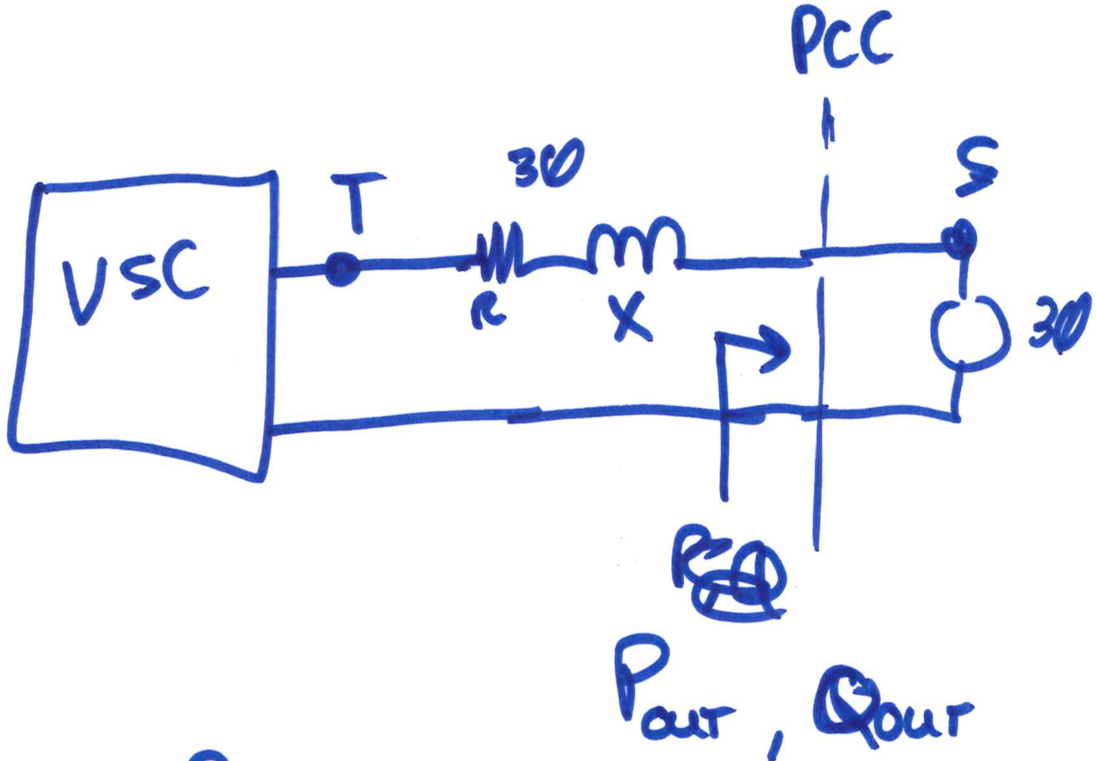

$P_{OUT} = -P_{ST}$

$Q_{OUT} = -Q_{ST}$

$R << X$ → approximate $R=0$ for calculations

$$\bar{S}_{ST} = \bar{V}_S \cdot \bar{I}_{ST}^{*} \qquad \theta_{V_S} = 0$$

$$\stackrel{pu}{=} \qquad\qquad \theta_{V_T} = \delta$$

$$= \bar{V}_S \left(\frac{\bar{V}_S - \bar{V}_T}{jX} \right)^{*}$$

$$= \frac{|V_S|^2 - \bar{V}_S \bar{V}_T^{*}}{-jX}$$

$$= \frac{|V_S|^2 \angle 0 - |V_S||V_T| \underbrace{\angle \theta_{VS} - \theta_{VT}}_{0 - \delta}}{-jX}$$

$$\bar{S}_{ST} = \frac{|V_S|^2 \angle 90^\circ - |V_S||V_T| \angle 0 - \delta + 90^\circ}{X}$$

$$P_{ST} = \mathrm{Re}(\bar{S}_{ST}) = \frac{|V_S||V_T|}{X} \sin(0 - \delta)$$

$$\cos(a + 90^\circ) = -\sin(a)$$

$$P_{OUT} = -P_{ST} = \frac{|V_S||V_T|}{X} \sin(\delta - 0)$$

$$-\sin(0 - \delta) = \sin(\delta - 0)$$

$P_{TS} = -P_{ST}$ since $R = 0$

$$Q_{ST} = \text{Im}(\bar{S}_{ST})$$

$$= \frac{|V_S|^2 - |V_S||V_T|\cos(0-\delta)}{X}$$

$$\sin(a+90^\circ) = \cos(a)$$

for our range of δ: $\cos(0-\delta) = \cos(\delta-0)$

$$Q_{OUT} = -Q_{ST} = \frac{-|V_S|^2}{X} + \frac{|V_S||V_T|\cos(0-\delta)}{X}$$

$$Q_{TS} = \frac{|V_T|^2 - |V_T||V_S|\cos(\delta - \theta)}{X}$$

$Q_{TS} \neq -Q_{ST}$ in general

They differ by $|I|^2 X$

$$m(t) = \underbrace{M}_{\text{peak amplitude of } m} \cos(\omega t + \delta)$$

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3ϕ P, Q with # Volts, ohm – –

$$\bar{S}_{3\phi} = 3|V_{\ell n}||I_\phi| \angle(\theta_V - \theta_I)$$

$$S_{3\phi} = 3\left(\frac{|V_{AS}|^2 \angle 90 - |V_{AS}||V_{AT}| \angle(0 - \delta + 90^\circ)}{X}\right) \quad (V_{AS} = V_{\ell n})$$

$$|V_{LL}| = \sqrt{3}\,|V_{\ell n}| \rightarrow$$

$$S_{3\phi} = \frac{|V_{ASLL}|^2 \angle 90^\circ - |V_{ASLL}||V_{ATLL}| \angle 0 - \delta + 90^\circ}{X}$$

- Easiest way to get P, Q measured in ATP

→ V_{SAG} → have Plotxy find V_1, θ_{V1}

Same for I_A → I_1, θ_{I1}

calculate P, Q off line

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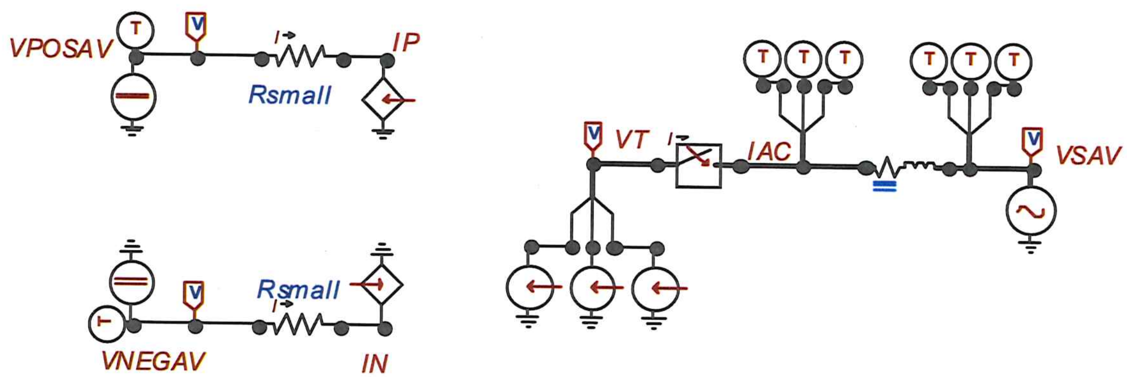
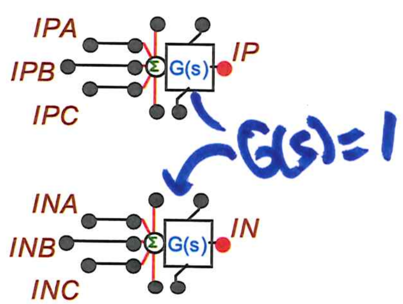
P and Q output from VSC and Applying Transformations

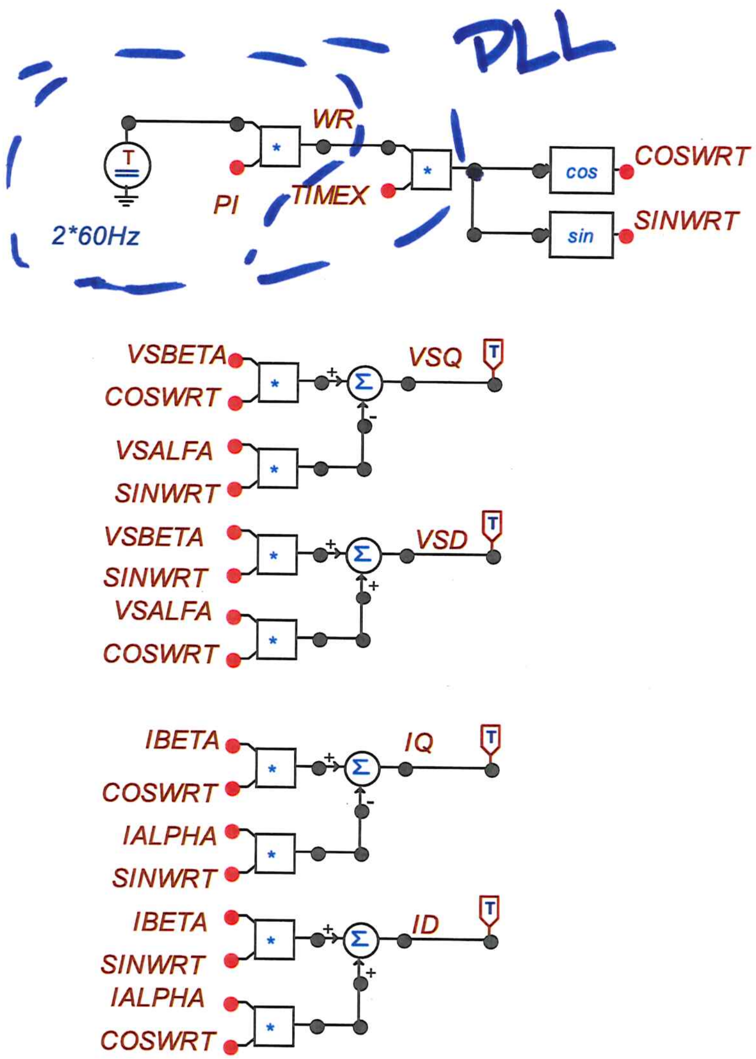
- Averaged Model Circuit



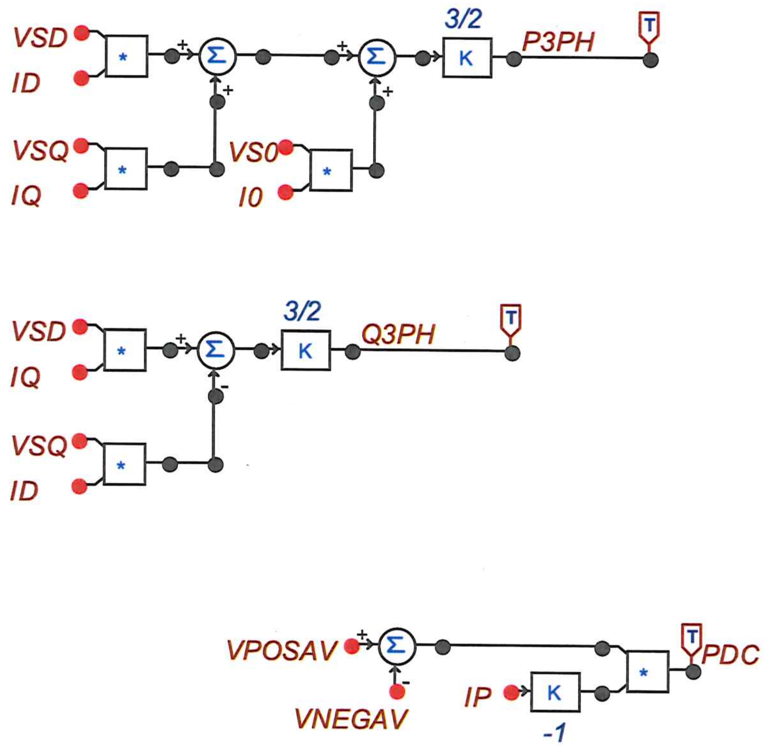
- Only a single current source on each rail in the DC bus -- take sum in TACS



Synchronous DQ Transform



Calculate P and Q at PCC



↑ correct polarity on ~~measurement~~ calculation

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$$P = \frac{3}{2}\left(V_{sd} i_d + V_{sq} i_q\right)$$

measure volt at PCC

$V_{sq} = 0$ from PLL

$$Q = -\frac{3}{2}\left(V_{sq} i_d - V_{sd} i_q\right)$$

$V_{sq} = 0$

$$i_q = \frac{-Q_{ref}}{V_{sd}} \frac{2}{3}$$

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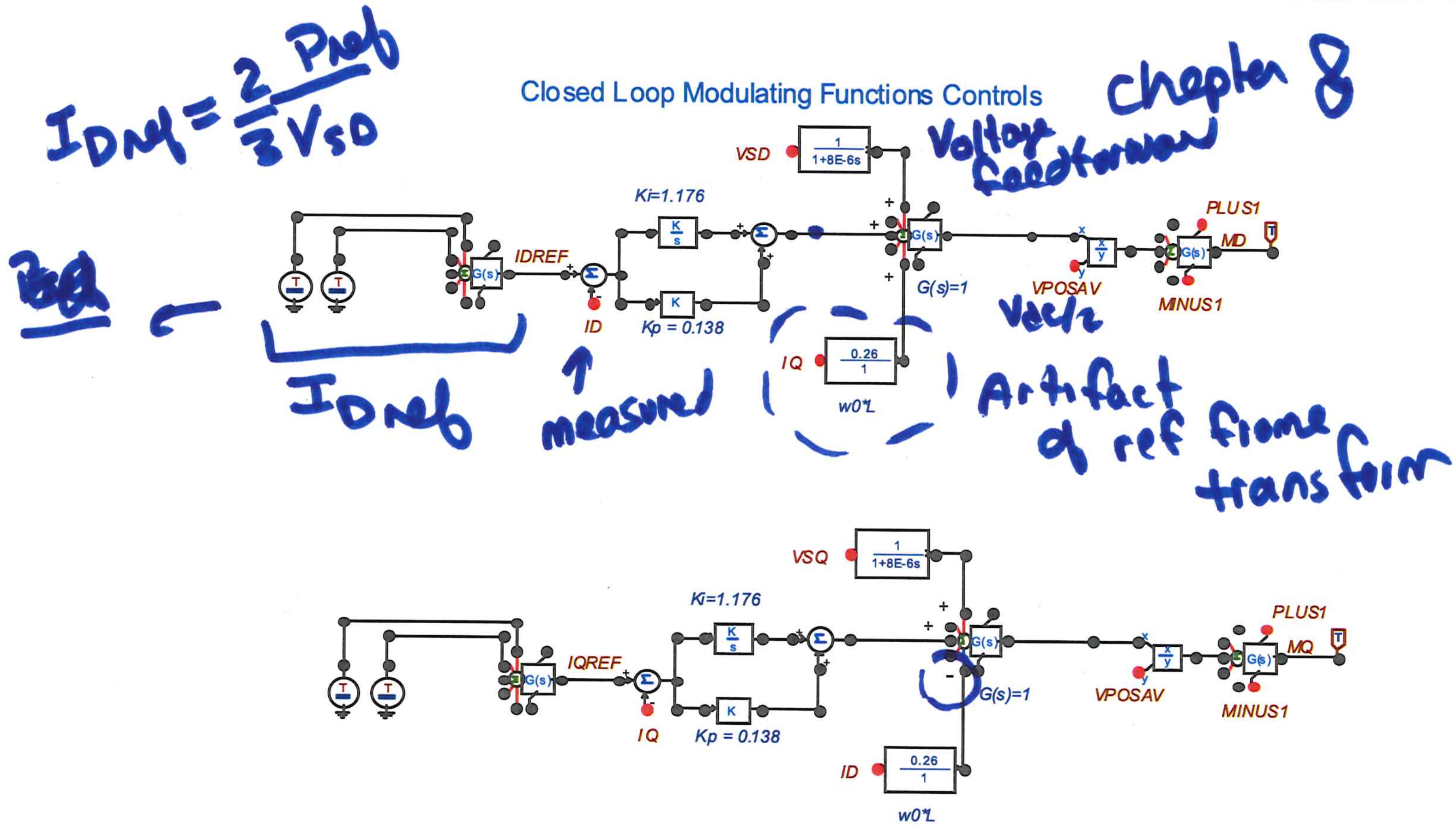
Closed Loop Modulating Functions Controls



Convert MD and MQ alpha-beta
and then to ABC domain