

ECE 404-TD / 504-TD

ST: T&D APPLICATIONS OF
VOLTAGE SOURCE CONVERTERS

SESSION no. 35

ECE 404/504: Homework #5

Due Session 37 (April 17)

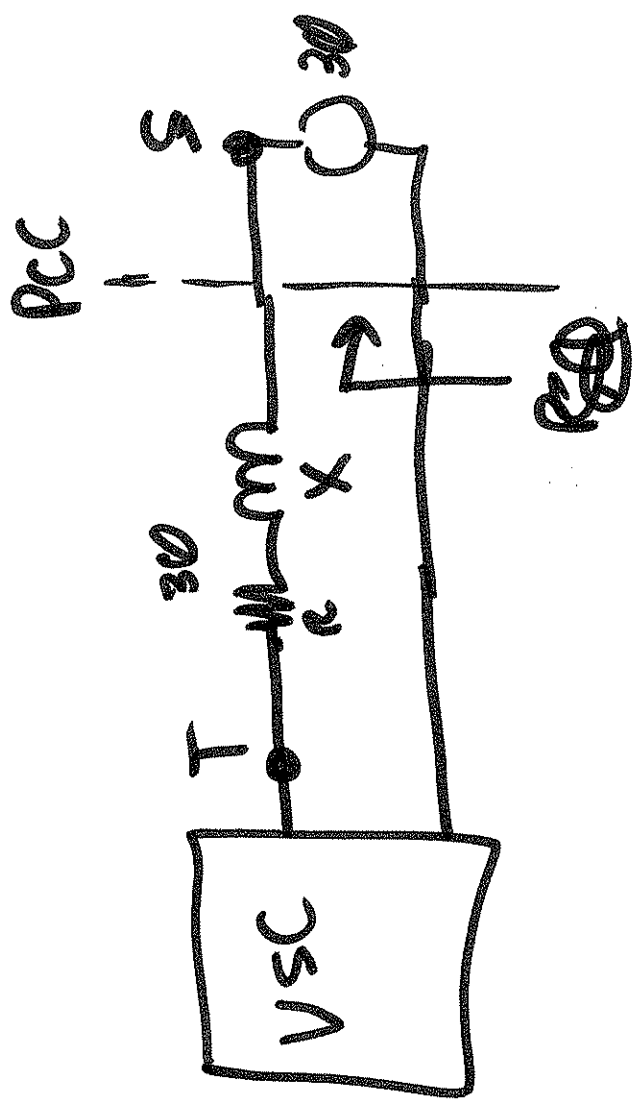
rms

1. Implement an averaged model of a three VSC with an AC source voltage of 2.4kV (L-L), $R = 0.096 \Omega$, $L = 3.82\text{mH}$ ($X/R = 15$) 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 $P=4\text{MW}$ and $Q=0$. Verify that the converter supplies this using averaged models.
 - D. Generate open loop modulating functions such that $P=3.71\text{MW}$ and $Q=1.5\text{MVAR}$. Verify that the converter supplies this.
 - E. Generate open loop modulating functions such that $P=3.71\text{MW}$ and $Q=-1.5\text{MVAR}$. Verify that the converter supplies this.
 - F. Generate open loop modulating functions such that $P=-3.71\text{MW}$ and $Q=-1.5\text{MVAR}$. Verify that the converter 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 $P=4\text{MW}$ and $Q=0$.
 - B. Determine the i_{dref} and i_{qref} such that $P=3.71\text{MW}$ and $Q=1.5\text{MVAR}$.
 - C. Determine the i_{dref} and i_{qref} such that $P=3.71\text{MW}$ and $Q=-1.5\text{MVAR}$.
 - D. Determine the i_{dref} and i_{qref} such that $P=3.71\text{MW}$ and $Q=-1.5\text{MVAR}$.
 - E. ECE 504 students implement cases A-D using closed loop control in your EMT program using averaged models.

Assume PLL $\rightarrow V_{sq} = 0$

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~~P_{out}~~
P_{out}, Q_{out}

$$P_{out} = -P_{ST}$$

$$Q_{out} = -Q_{ST}$$

$R \ll X \rightarrow$ approximate $R=0$ for calculations

$$\underline{S}_{ST} = \underline{V}_s \cdot \underline{I}_{ST}^* \quad \Theta_{\delta} = 0$$

$$\underline{I}_{PM} = \underline{V}_T \quad \Theta_{\delta} = \delta$$

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

$$= \frac{|\underline{V}_s|^2 - \underline{V}_s \underline{V}_T^*}{-jX} \quad \delta = 0$$

$$= \frac{|\underline{V}_s|^2 \angle 0 - |\underline{V}_s| |\underline{V}_T| \angle \Theta_{vs} - \Theta_{vt}}{-jX}$$

$$\bar{S}_{st} = \frac{|V_s|^2 \angle 90^\circ - |V_s| |V_r| \angle 0 - \delta + 90^\circ}{X}$$

$$P_{st} = \operatorname{Re}(\bar{S}_{st}) = \frac{|V_s| |V_r| \sin(0 - \delta)}{X}$$

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

$$P_{out} = -P_{st} = \frac{|V_s| |V_r| \sin(\delta - 0)}{X}$$

$\underbrace{\sin(0 - \delta)}_{-\sin(0 - \delta) = \sin(\delta - 0)}$

$$P_{TS} = -P_{ST} \quad \text{since } R = 0$$

$$Q_{ST} = \operatorname{Im}(\tilde{S}_{ST})$$

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

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

$$\begin{aligned} \text{rank} \quad \cos(\theta - \phi) \\ \text{for } \cos \phi \\ \text{for } \cos \theta \\ = \cos(\theta - \phi) \end{aligned}$$

$$Q_{out} = -Q_{ST} = -\frac{|V_S|^2}{X} + \frac{|V_T|^2 \cos(\theta - \phi)}{X}$$

$$Q_{TS} = \frac{|V_+|^2 - |V_-|^2 |V_s| \cos(\delta - \theta)}{X}$$

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

They differ by $|I|^2 X$

$$m(\omega) = M \cos(\omega t + \delta)$$

Peak amplitude of m

30 P, Q with # volts, ohm - -

$$S_{30} = 3 |V_{en}| |I_{\theta}| \sqrt{(\theta - \theta_r)}$$

$$S_{30} = 3 \left(\frac{V_{en}^2}{|V_{AS}|^2 [90 - |V_{AS}| |V_{AT}| \sqrt{(\theta - \delta + 90^\circ)}} \right) \times$$

$$|V_{cu}| = \sqrt{3} |V_{en}| \rightarrow$$

$$S_{30} = \frac{|V_{ASU}|^2 [90 - |V_{ASU}| |V_{ATU}| \sqrt{(\theta - \delta + 90^\circ)}}{\times}$$

• Easiest way to get P, Q measured

in ATP

$\Rightarrow V_{SAG} \rightarrow$ have Plotxy find

V_i, θ_{vi}

Same for IA $\rightarrow I_i, \theta_{fi}$



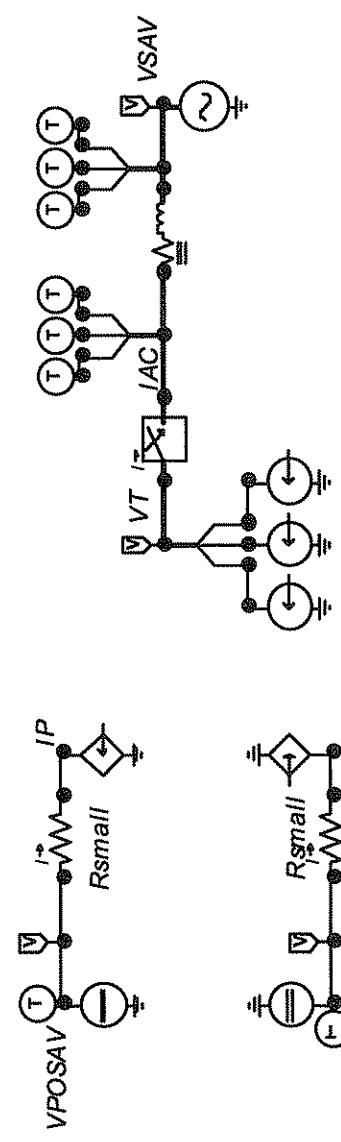
calculate P, Q

off line

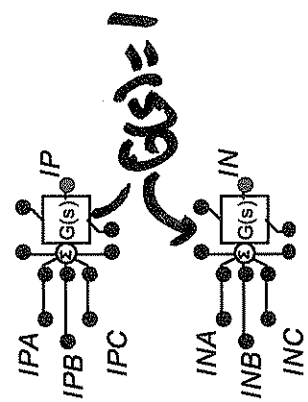
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P and Q output from VSC and Applying Transformations

- Averaged Model Circuit



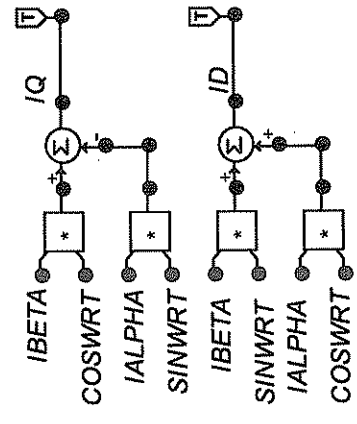
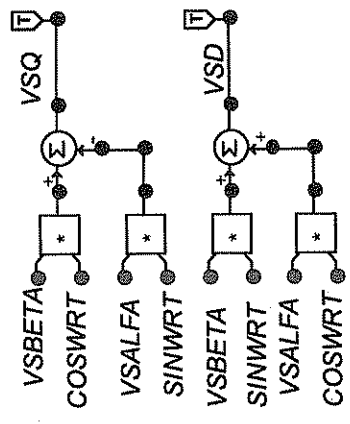
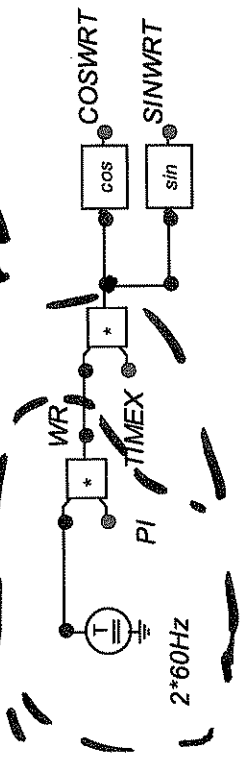
- Only a single current source on each rail in the DC bus -- take sum in TACS



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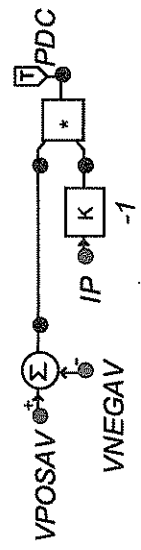
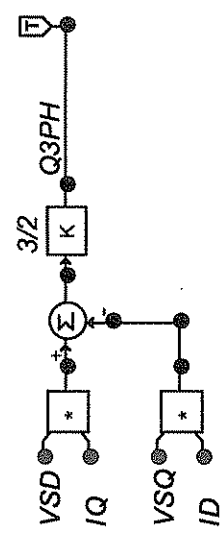
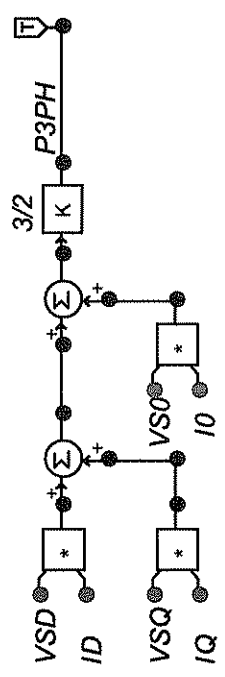
Synchronous DQ Transform

PLL



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Calculate P and Q at PCC



~~power calculation~~
 correct calculation

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

Measure
of
power

0 from PLL

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

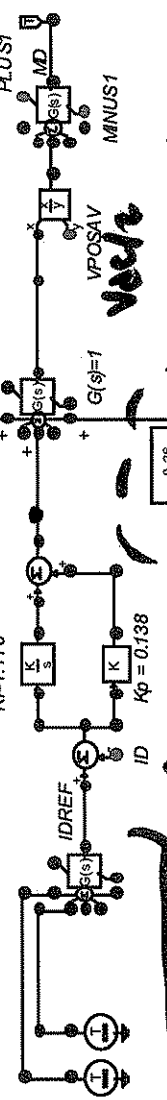
$$i_q = -Q_{ref} \frac{2}{V_{sd}}$$

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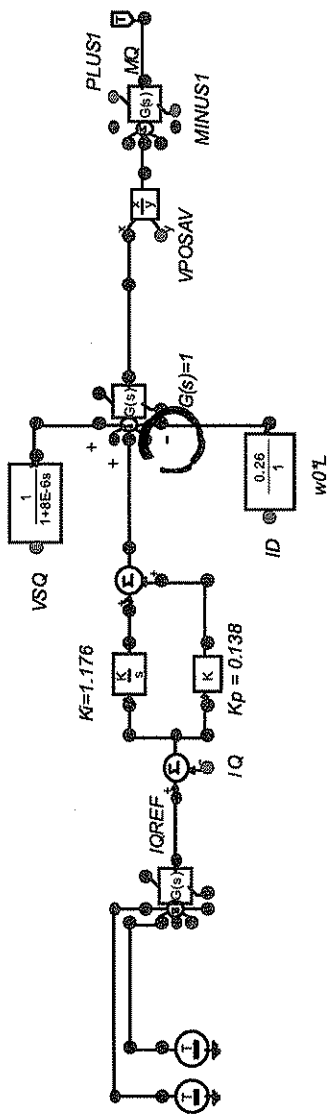
Prob
 $I_{DNM} = \frac{2}{3} V_{SD}$

Chapter 8
Voltage Feedforward

Closed Loop Modulating Functions Controls

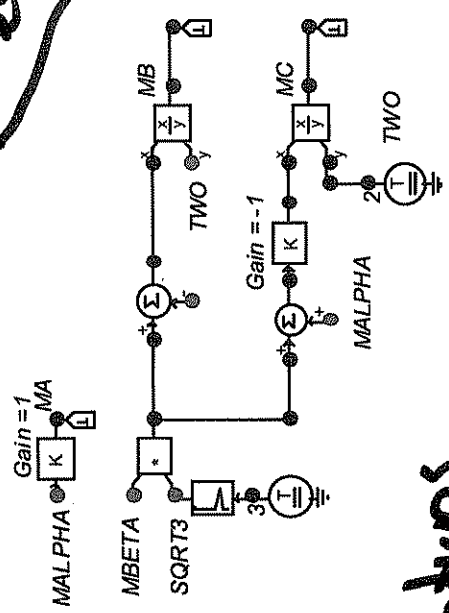
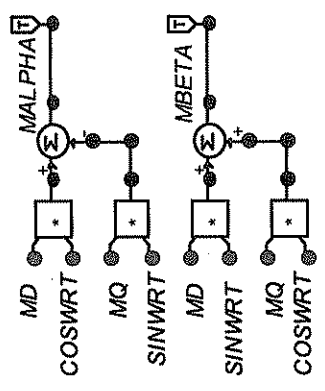


↑ measured
Artifact from transform



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



equation
4.47

inverse transformers

4.70