ECE 404-TD / 504-TD

ST: T&D APPLICATIONS OF VOLTAGE SOURCE CONVERTERS

SESSION no. 33

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1. Implement a 3ϕ VSC
   - → averaged model
   - – switching model

   } open loop control

   In ATP or EMTDC

   · measure P, Q

2. Given commands for P, Q or change in V_{DC} & V_{AC}
   - → determine current set points i_a, i_α, i_β or i_d, i_q

3. ECE 504 students: closed loop control or NPC converter in ATP/EMTDC

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Three Phase Phase VSC Locked Loop (PLL)

Cases where synchronization is needed

- Non-PWM switching schemes
- Synchronous PWM switching schemes
- When control loop operates in the synchronous DQ reference frame
- Control loop for α–β may or may not need synchronizing reference
  - Frequency comes along with measured α and β terms
  - May need depending on method for determining current references

Park's Transform Based PLL

→ commonly applied scheme for tracking frequency of a measured signal

- Measured voltages

$$v_{sd} = V_s \cdot \cos\left(\omega_0 \cdot t + \theta_0 - \rho(t)\right)$$

$$v_{sq} = V_s \cdot \sin\left(\omega_0 \cdot t + \theta_0 - \rho(t)\right)$$

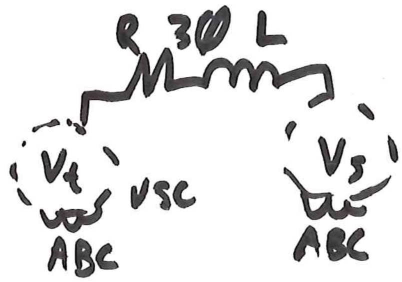
V_s is a space phasor

ρ(t): rotating ref frame

- Output current equations in transformed domain

$$L \cdot \left(\frac{d}{dt} i_d\right) = L \cdot \omega(t) \cdot i_q - \left(R + r_{on}\right) \cdot i_d + \left(v_{td} - v_{sd}\right)$$

$$L \cdot \left(\frac{d}{dt} i_q\right) = L \cdot \omega(t) \cdot i_d - \left(R + r_{on}\right) \cdot i_q + \left(v_{tq} - v_{sq}\right)$$



External system

r_{on}: switching device resistance - conduction loss

$$\frac{d}{dt} \rho(t) = \omega(t)$$

- The choice of ρ(t) makes a big difference. If it 0, stay in α–β frame (no rotation)
- In this case we want:

$$\rho(t) = \omega_0 \cdot t + \theta_0$$

or another angle

Von of the device ignored because small

- Then $\frac{d}{dt} \rho(t) = \omega_0$
- If this is the case, then

$$v_{sq} = 0 \qquad \text{and} \qquad v_{sd} = V_s$$

- Design a feedback controller to regulate v_{sq} to be 0

$$\omega(t) = H(p) \cdot v_{sq}(t) \qquad \text{where } H(p) \text{ is a linear transfer function}$$

use voltage to as synchronizing reference

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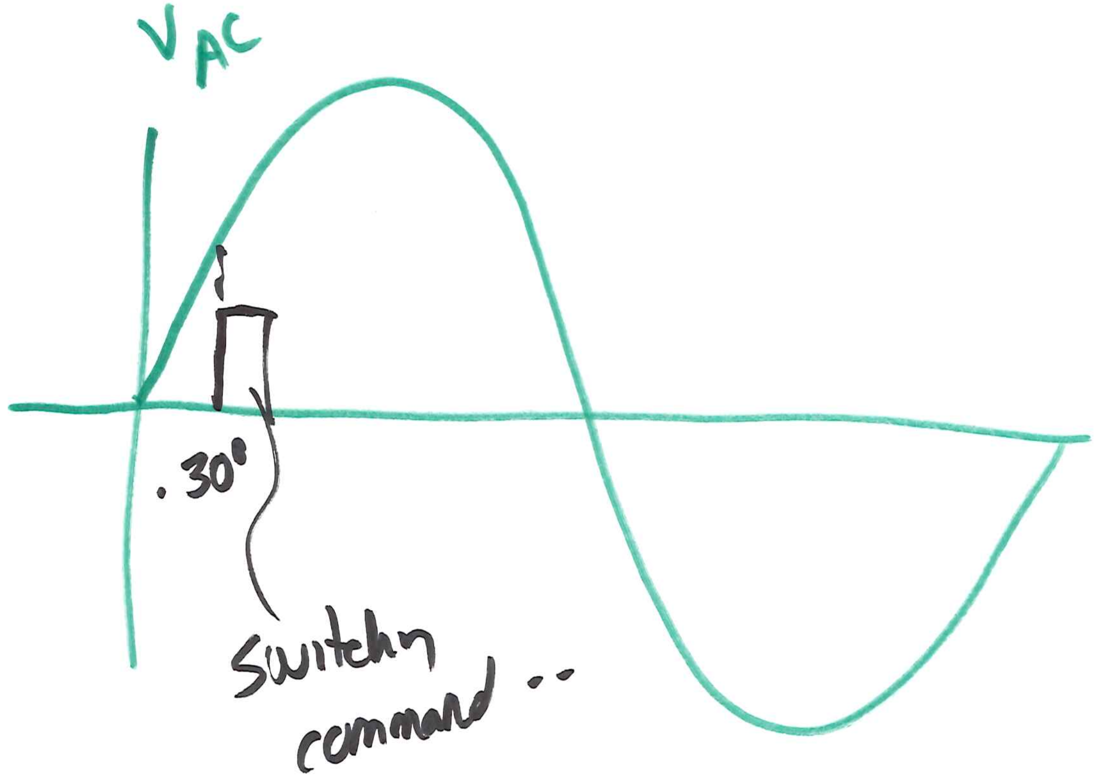

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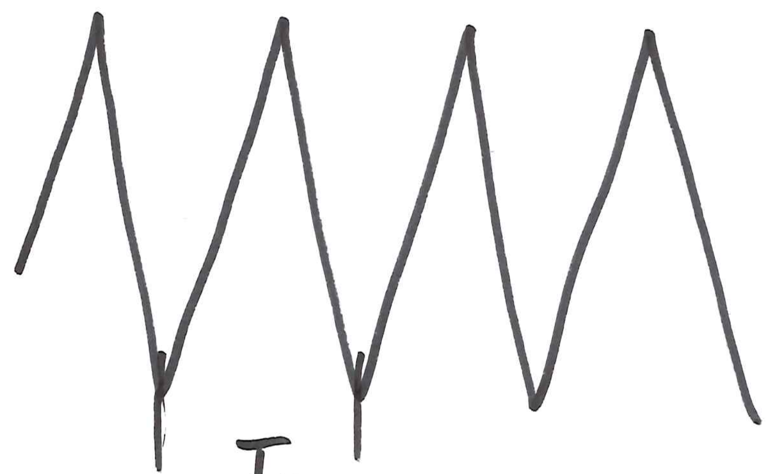


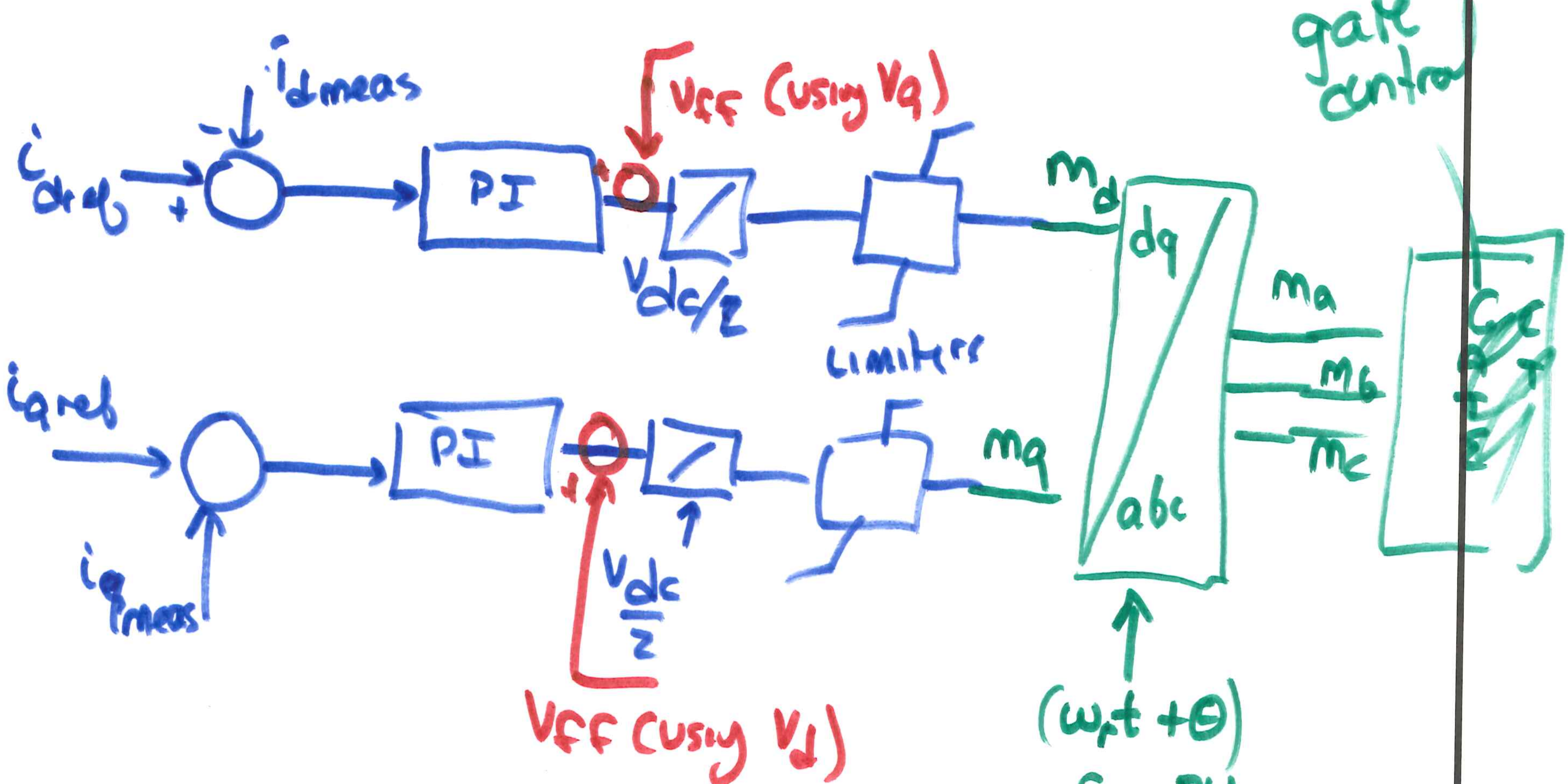
$\hookrightarrow f_s = \frac{1}{T_s}$

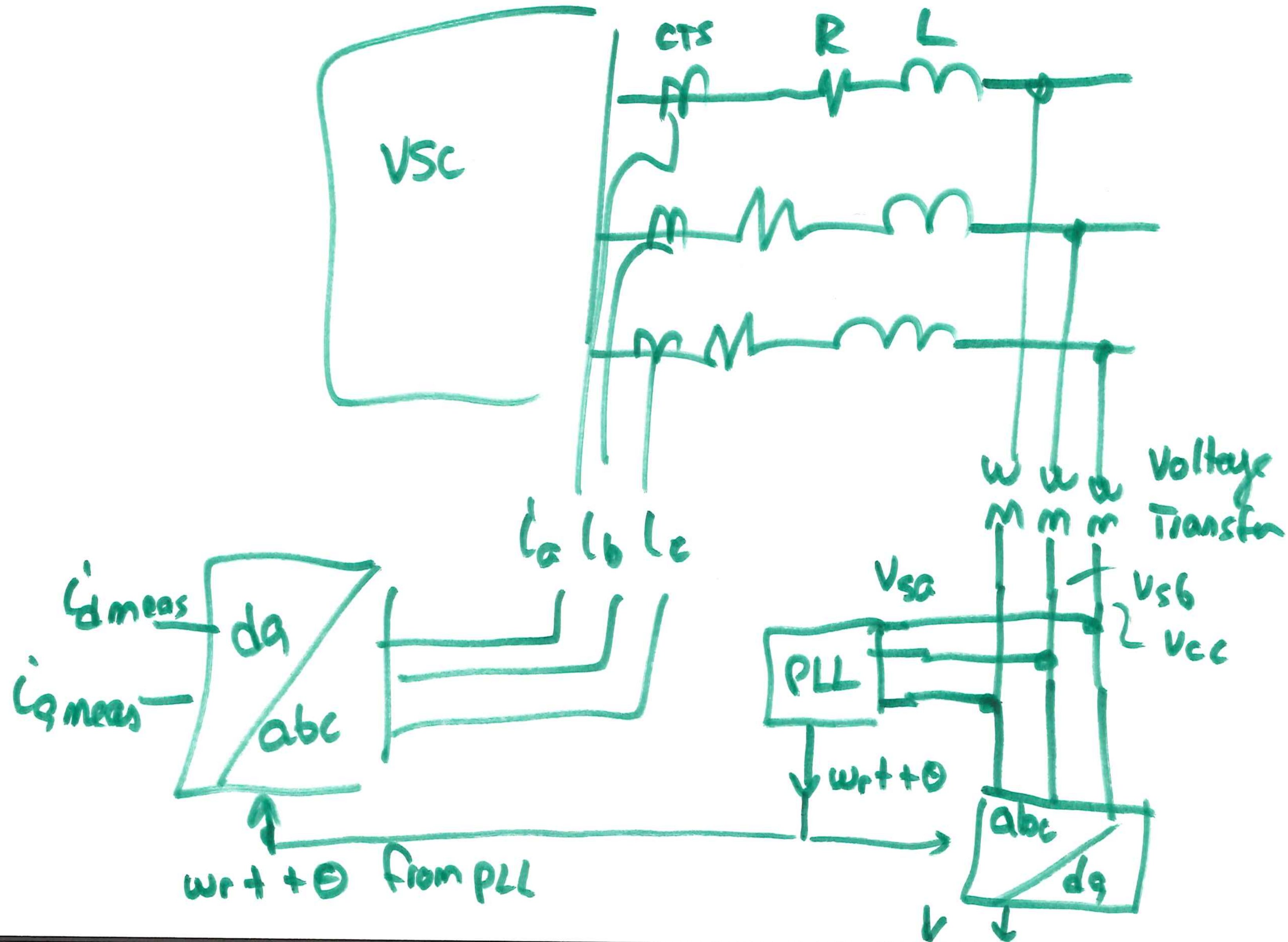
for relatively low PWM frequencies to have

$f_s = n f_o$ ← integer - odd

↑ power system freq

3φ VSC controller (inner)




VSC
CTS
R
L
i_a i_b i_c
Voltage Transfm
v_{sa}
v_{sb}
v_{sc}
PLL
$\omega_r t + \theta$
abc
dq
$i_{d\,meas}$
$i_{q\,meas}$
$\omega_r t + \theta$ from PLL

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- Start it out from

  $\omega(0) = \omega_0$

- Limit frequency range to narrow variation from

  $$\omega_{min} < \omega < \omega_{max}$$

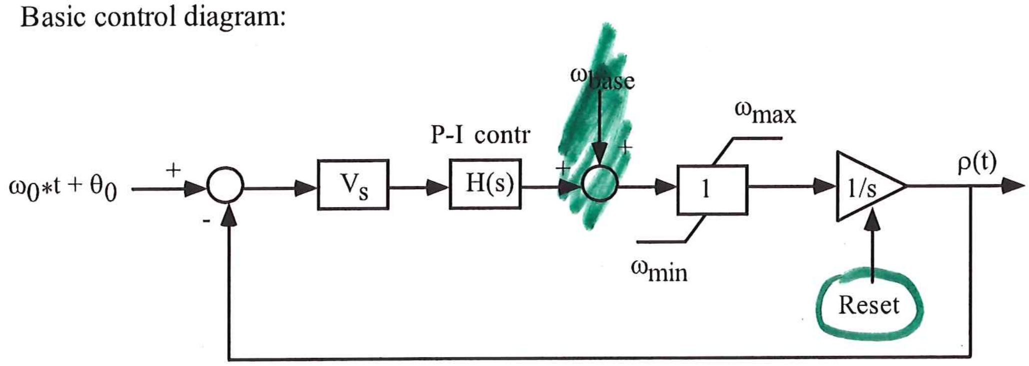
- Small frequency variations imply

  $\sin\left(\omega_0 \cdot t + \theta_0 - \rho(t)\right)$ approximately $\left(\omega_0 \cdot t + \theta_0 - \rho(t)\right)$

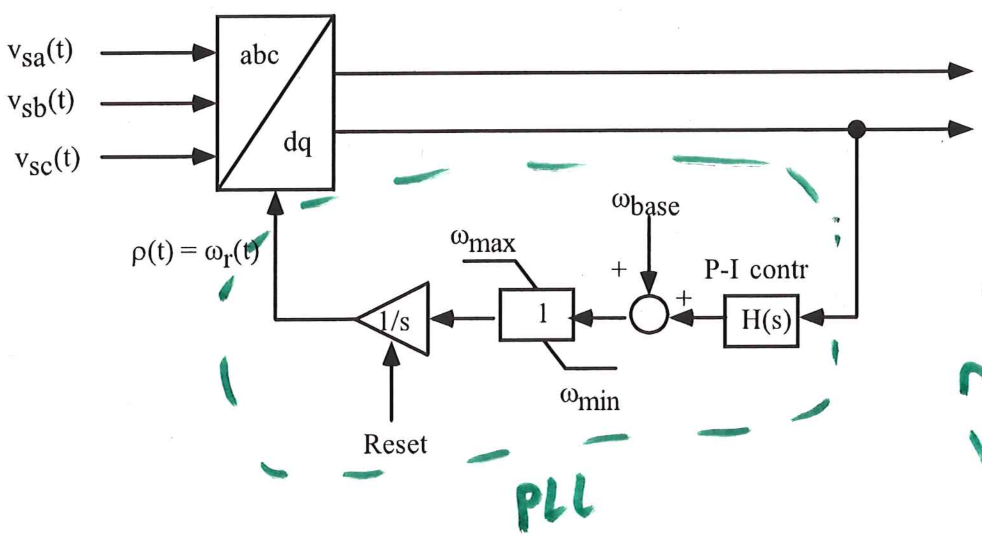
  which simplifies control loop design

  $$\frac{d}{df}\rho(t) = V_s \cdot H(p) \cdot \left(\omega_0 \cdot t + \theta_0 - \rho(t)\right)$$

- Basic control diagram:



- Three phase implementation:



vsq - regulate to 0 for the reference voltage

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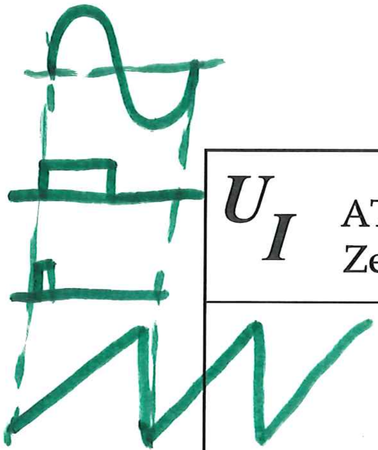
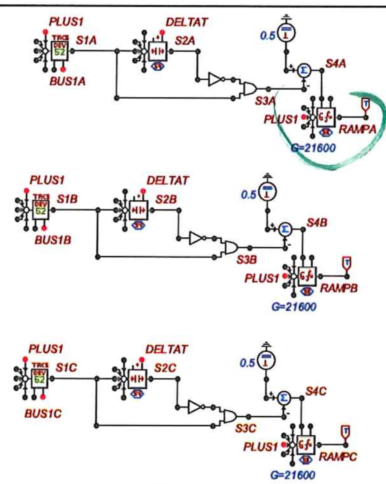


ATPDraw Implementation: Simple Zero Crossing Based : Three Phase



1/s

Phase Correction

- Create an orthogonal pair of vectors
  - » Park's transformation if three phase measurement
  - » Phase rotation (delay) if single phase input
- Need instantaneous angle reference ($\omega_r t = \theta_r$)
- Phase Error = $-V_d \sin(\theta_r) + V_q \cos(\theta_r)$

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U_I ATPDraw Implementation: Phase Locked Loop: Phase A

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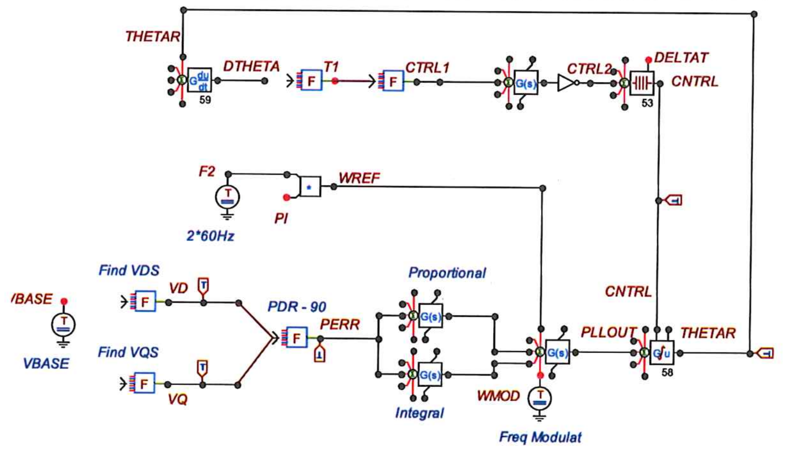

Synchronization 9 Spring 2013

U_I PERR and THETAR with phase jump due to load change

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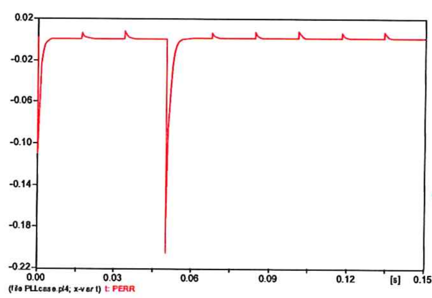

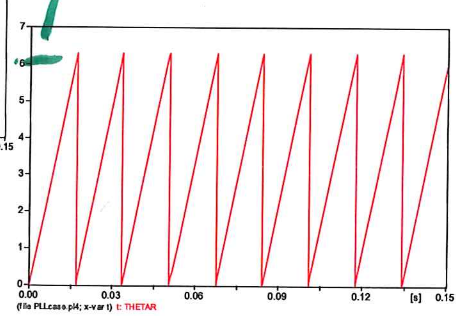

Synchronization 10 Spring 2013

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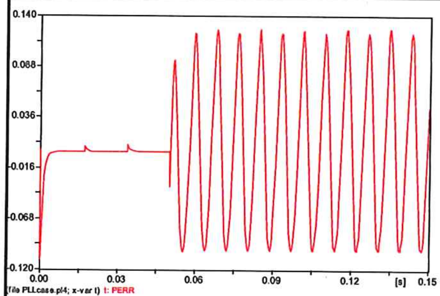
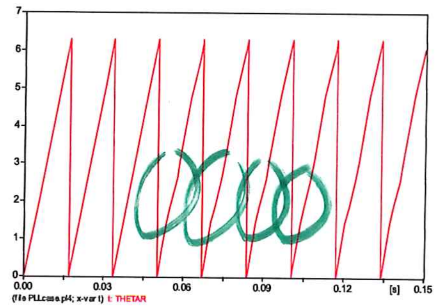
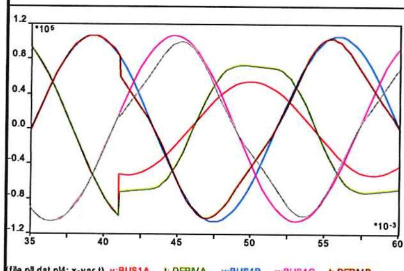
PERR and THETAR with sustained SLG Fault

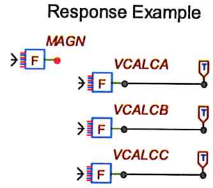




Results with PLL--SLG Fault

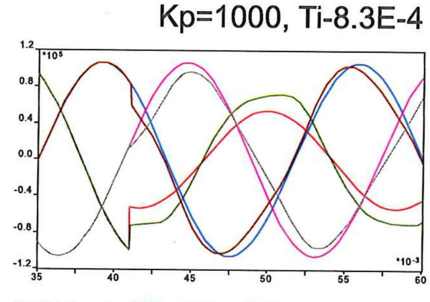


Response Example



Kp=100, Ti=8.3E-3 — 1/Ki

Kp=1000, Ti-8.3E-4



U_I Results with PLL-- Three Phase Fault

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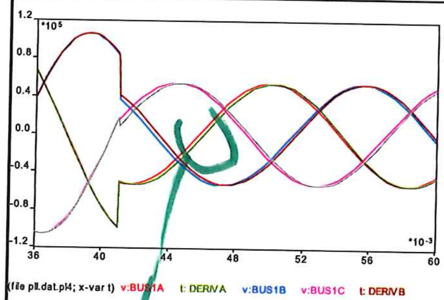
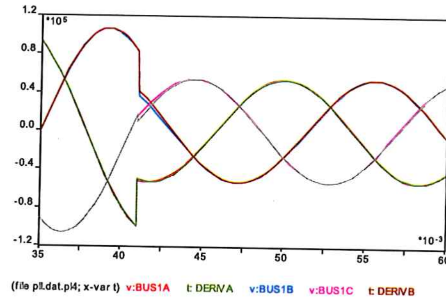
Kp=100, Ti=8.3E-3



phase error

Kp=1000, Ti-8.3E-4



U_I Compare ωt with PLL THETAR (phase jump case)

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