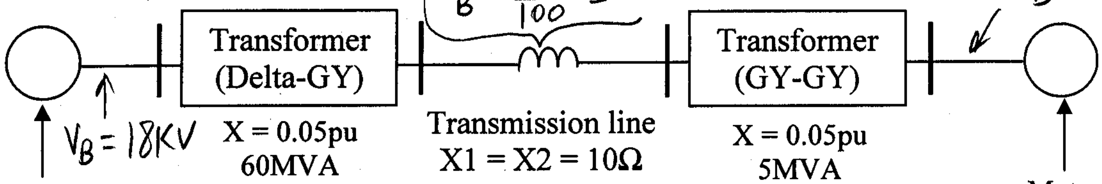
EE369, Final Exam, 2-5pm, Dec. 9, WRW102. Name: KEY

Six equally-weighted problems. Three sheets of notes permitted. Show all work.

Problem 1. Draw the positive, negative, and zero-sequence one-line diagrams for the system shown. Use 69kV, 100MVA as the base in the transmission line. Generator, transformer, and motor impedances are given in per unit on their own bases.

$Z_B = \frac{(69)^2}{100} = 47.61\Omega$ $\quad$ $V_B = 4.16KV$



$V_B = 18KV$

Generator
50MVA, 20kV
Subtransient reactances
X1 = X2 = 0.15pu
X0 = 0.12pu
Generator is connected GY through a j0.3Ω (Actual ohms) grounding reactor

Transformer (Delta-GY): X = 0.05pu, 60MVA, 18kV/69kV

$0.05\left(\frac{100}{60}\right) = 0.0833$

Transmission line: X1 = X2 = 10Ω, X0 = 30Ω

$j10\Omega \rightarrow j0.21pu$

$j30\Omega \rightarrow j0.63pu$

Transformer (GY-GY): X = 0.05pu, 5MVA, 69kV/4.16kV

$0.05\left(\frac{100}{5}\right) = 1.000$

Motor
4MVA, 4.16kV
Subtransient reactances
X1 = X2 = 0.10pu
X0 = 0.08pu
delta connection

$X1 = X2 = 0.10\left(\frac{100}{4}\right)\left(\frac{4.16}{4.16}\right)^2 = 2.50$

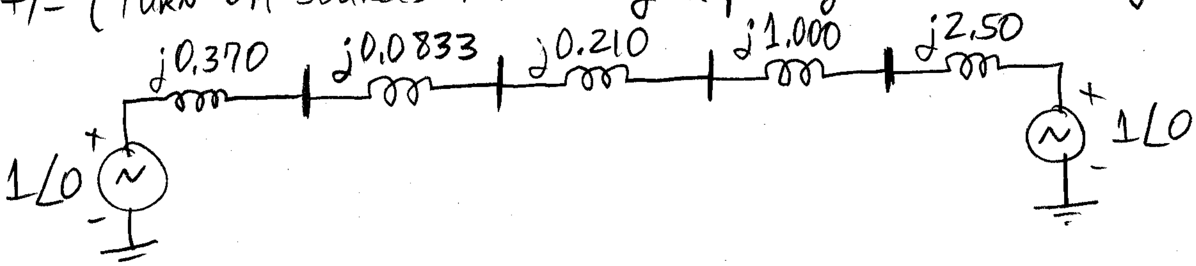
$X0 = 0.08\left(\frac{100}{4}\right) = 2.00$

For gen, $X_1 = X_2 = 0.15\left(\frac{100}{50}\right)\left(\frac{20}{18}\right)^2 = 0.370pu$

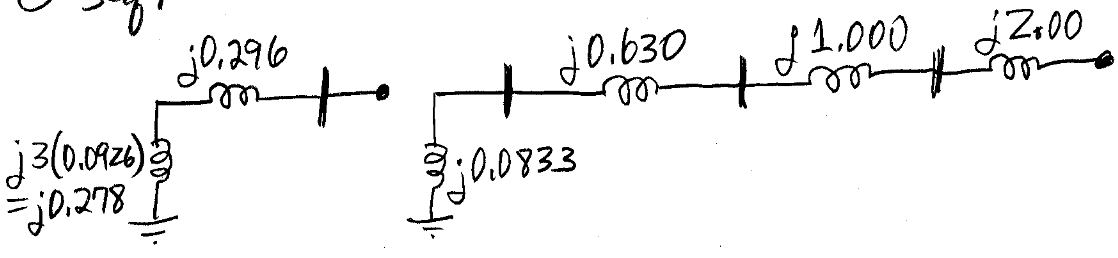
$X_0 = 0.12\left(\frac{100}{50}\right)\left(\frac{20}{18}\right)^2 = 0.296\ pu$

Reactor, $Z_B = \frac{(18)^2}{100} = 3.24$, so $j0.3\Omega$ becomes $j0.0926$ pu

+/- (Turn off sources for − by replacing the $1\angle 0$ voltage with a short)



0 seq.



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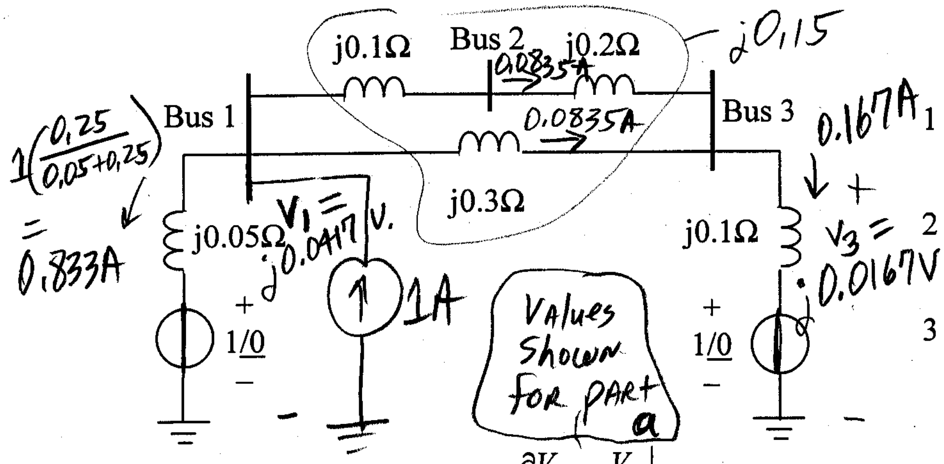
Problem 2. The positive-sequence one-line diagram for a network is shown below. ~~The ground ties at busses 1 and 4 represent the subtransient impedances of machines.~~ Prefault voltages are all 1.0pu.



	1	2	3
1	$z_{11} = j0.0417$		
2	$z_{21} = j0.0334$		
3	$z_{31} = j0.0167$		

Part a

a. Use the definition $z_{jk} = \frac{\partial V_j}{\partial I_k} = \left.\frac{V_j}{I_k}\right|_{I_m = 0, m \neq k}$ to fill in column 1 of the Z matrix.

Now, a solidly-grounded three-phase fault occurs at bus 1. Z_{11} Check, $j0.05 \| (j0.15 + j0.10) = j0.0417$ (OK)

b. Compute the fault current

c. Use the fault current and Z matrix terms to compute the voltages at busses 2 and 3.

d. Find the magnitude of the current flowing in the line connecting busses 2 and 3.

$$V_2 = V_3 + j0.2\left(\frac{0.167}{2}\right) = j0.0334$$

$$\text{b. } I_{1a}^{F} = \frac{V_{1a}^{PRE}}{Z_{11}} = \frac{1}{j0.0417}$$

$$\boxed{I_{1a}^{F} = -j24.0A}$$

$$\text{c. } V_{2a}^{F} = V_{2a}^{PRE} - Z_{21} I_{1a}^{F} = 1.0 - (j0.0334)(-j24) = 1.0 - 0.800 = \boxed{0.200V}$$

$$V_{3a}^{F} = V_{3a}^{PRE} - Z_{31} I_{1a}^{F} = 1.0 - (j0.0167)(-j24) = 1.0 - 0.401 = \boxed{0.600V}$$

$$\text{d. } I_{23}^{F} = \frac{V_2^F - V_3^F}{j0.2} = \frac{0.2 - 0.6}{j0.2} = \boxed{j2.0}$$

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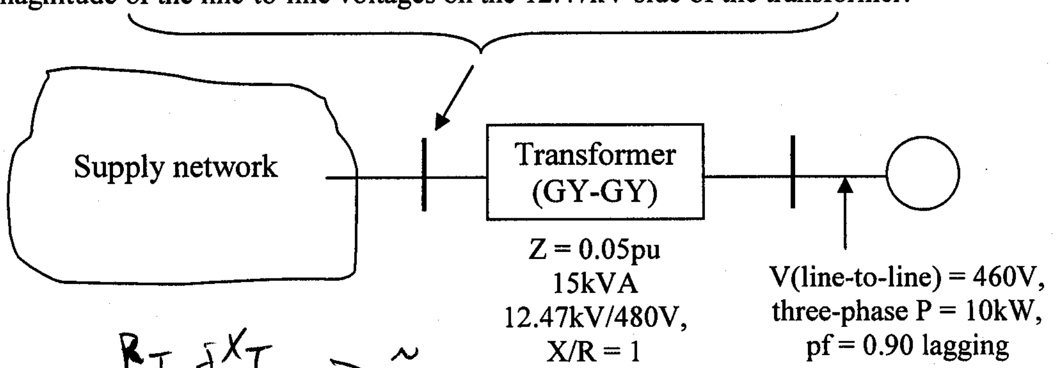
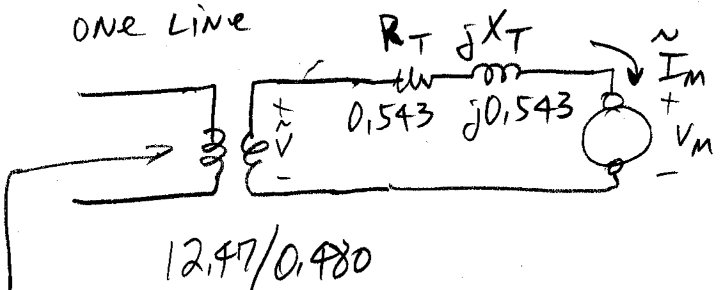
Problem 3. Find the magnitude of the line-to-line voltages on the 12.47kV side of the transformer.



ONE LINE



Want line-to-line voltage here

$R_T + jX_T$ is transformer impedance on 480V side

$$Z_B = \frac{(480)^2}{15000} = 15{,}36\Omega$$

$$Z_T = (0{,}05)(15{,}36) = 0{,}768\Omega$$

$\frac{X_T}{R_T} = 1$, so 45°, so $R_T = X_T = \frac{Z_T}{\sqrt{2}}$

$R_T = X_T = 0{,}543$

$$V_{M_{LN}} I_M^* = S_{M_{1\phi}}, \quad I_M = \frac{S_{M1\phi}^*}{V_{M_{LN}}^*}$$

$$I_M = \frac{\left[\frac{10000}{3(0{,}9)} \angle \cos^{-1}(0{,}90)\right]^*}{\frac{460}{\sqrt{3}}\angle 0} = 13{,}95\angle -25{,}8^\circ \text{ A}$$

$$\tilde{V} = \tilde{V}_M + \tilde{I}_M Z_T = \frac{460}{\sqrt{3}}\angle 0 + (13{,}95\angle -25{,}8)(0{,}768\angle 45^\circ)$$

$$= 266 + 10{,}71\angle -19{,}2 = 266 + 10{,}11 - j3{,}52 = 276 - j3{,}52$$

$\tilde{V} = 276\angle -0{,}73$, so on the 12,47kV side,

$$|\tilde{V}_{LL}| = (\sqrt{3})(276)\left(\frac{12{,}47}{0{,}480}\right) = \boxed{12419\text{ V}}$$

EE369, Final Exam, 2-5pm, Dec. 9, WRW102. Name: KEY

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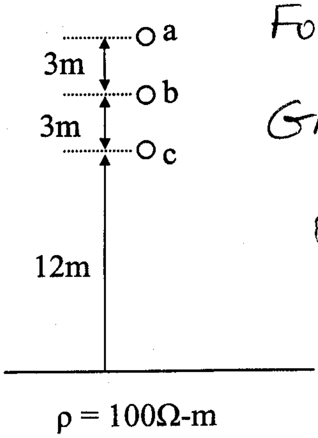
Problem 4. Consider the 69kV 60Hz transmission line shown below. The phases have single conductors.

a. Find the positive sequence R, L, and C per meter for the transmission line shown.

b. Convert the above values to series (R + jX), and shunt MVAr, per km, using a base of 69kV, 100MVA.

Conductors have outer radius 1cm, and resistance 0.06 Ω per km



For cap, $r = 1\text{cm}$. For ind, $r_{eff} = re^{-1/4} = 0.7788\text{cm}$

$$GMD_{+/-} = (3 \cdot 6 \cdot 3 \cdot 3 \cdot 3 \cdot 6)^{1/6} = 3.78\text{m}$$

$$C_{+/-} = \frac{2\pi\epsilon_0}{\ln\frac{GMD_{+/-}}{r}} = \frac{2\pi(8.854)}{\ln\frac{3.78}{0.01}}\ \text{pF/m} = 9.37\text{pF/m}$$

$$L_{+/-} = \frac{\mu_0}{2\pi}\ln\frac{GMD_{+/-}}{r_{eff}} = \frac{4\pi\times10^{-7}}{2\pi}\ln\frac{3.78}{0.007788} = 1.237\ \mu\text{H/m}$$

$$R_{+/-} = 0.06\,\Omega/\text{km}$$

(a) So, $R_{+/-} = 6\times10^{-5}\,\Omega/\text{m}$

$C_{+/-} = 9.37\text{pF/m}$

$L_{+/-} = 1.237\,\mu\text{H/m}$

(b) $Z_B = \frac{(69)^2}{100} = 47.61\,\Omega$. $R = \frac{0.06\,\Omega/\text{km}}{47.61} = 0.001260\ \text{pu/km}$

$$j\omega L = j(120\pi)(1.237\times10^{-6})(1000) = j0.466\,\Omega/\text{km} = \underbrace{j0.00980\ \text{pu/km}}_{j\omega L}$$

$$Q_{CAP\,3\phi} = 3V_{LN}^2\,\omega C = (3)\left(\frac{69000}{\sqrt{3}}\right)^2(120\pi)(9.37\times10^{-12})(1000) = 16.82\ \text{KVAr/km}$$

$$Q_{CAP\,pu} = \frac{16.82\times10^3}{100\times10^6} = 0.000168\ \text{VAr/km}$$

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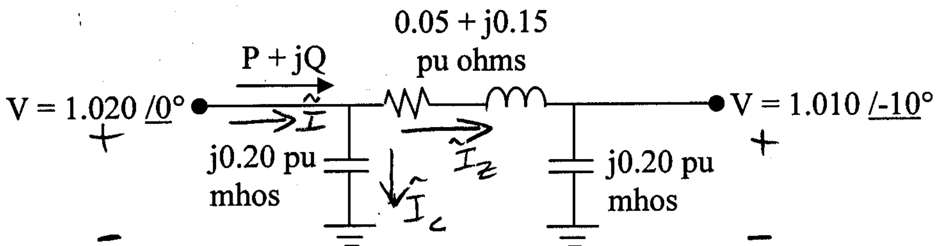
Problem 5. Calculate the P and Q flows (in per unit) for the loadflow situation shown below.



$$P + jQ = V\tilde{I}^* = V(\hat{I}_c + \hat{I}_z)^*$$

$$\hat{I}_z = \frac{1.020\angle 0 - 1.010\angle{-10^\circ}}{0.05 + j0.15} = \frac{1.02 - (0.995 - j0.1754)}{0.1581\angle 71.6^\circ}$$

$$\hat{I}_z = \frac{0.0250 + j0.1754}{0.1581\angle 71.6} = \frac{0.1772\angle 81.9}{0.1581\angle 71.6} = 1.121\angle 10.3^\circ$$

$$\tilde{I}_z = 1.103 + j0.200$$

$$\hat{I}_c = \tilde{V} Y_c = (1.02\angle 0)(0.20\angle 90) = 0.204\angle 90^\circ = j0.204$$

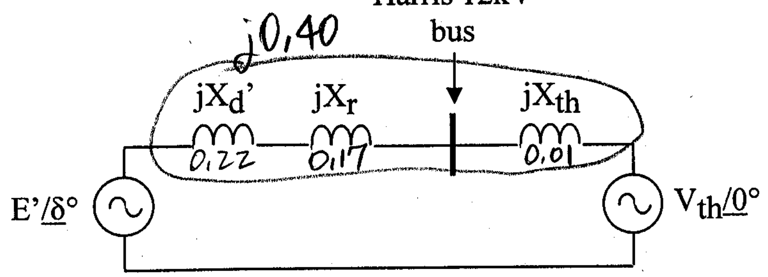
$$\hat{\tilde{I}} = \hat{I}_z + \hat{I}_c = 1.103 + j0.404 = 1.175\angle 20.1^\circ$$

$$P + jQ = (1.020\angle 0)(1.175\angle 20.1)^* = 1.199\angle{-20.1}$$

$$P + jQ = \underbrace{1.126}_{P} - j\underbrace{0.412}_{Q = -0.412}$$

Problem 6. A new 32MVA, 60Hz steam generator was recently installed at the UT power plant. The generator is connected through a large reactor to ERCOT at the Harris 12kV bus.

The electrical diagram and internal voltage (for the transient condition) that exists when the generator is producing (25MW + j12.4MVAr) is shown below. Suddenly, at t = 0, a three-phase fault with zero impedance occurs at the Harris 12kV bus. ~~The fault is successfully removed in 6 cycles (of 60Hz).~~ Assuming that E', V_{th}, and P_{mech} are constant, ~~use the equal area criterion to find the maximum value that δ achieves~~ determine the critical clearing time (in cycles). Use the attached graph to show important P and δ points and lines on the power curve, and show clearly which areas are being set equal.



Machine E' = 1.100pu
Machine δ = 16.5°
Machine P = 25MW (i.e., 0.781pu)
Machine jX_d' = j0.22pu
Machine H = 1.4seconds
Reactor jX_r = j0.17pu
Thevenin jX_{th} = j0.01pu
Thevenin V_{th} = (1.0 + j0)pu
Values given on the generator base

Remember that during the fault, the electrical power output is zero, and thus the rotor accelerates according to $\delta(t) = \frac{\omega_s P_{mech}}{4H} t^2 + \delta(t=0)$. Also, note that ω_s = 377rad/sec, δ is in radians in the above formula, and P_{mech} is in pu.

$$\delta_{CRIT} = \cos^{-1}\left[(\pi - 2\delta_0)\sin(\delta_0) - \cos(\delta_0)\right]$$

$$\delta_0 = 16.5^\circ = 0.288 \text{ rad}, \text{ so } \delta_{CRIT} = \cos^{-1}\left[\underbrace{(\pi - 2(0.288))\sin(16.5^\circ)}_{0.729} - \underbrace{\cos(16.5^\circ)}_{0.959}\right]$$

$$\boxed{\delta_{CRIT} = 103.3^\circ} = 1.803 \text{ rad}$$

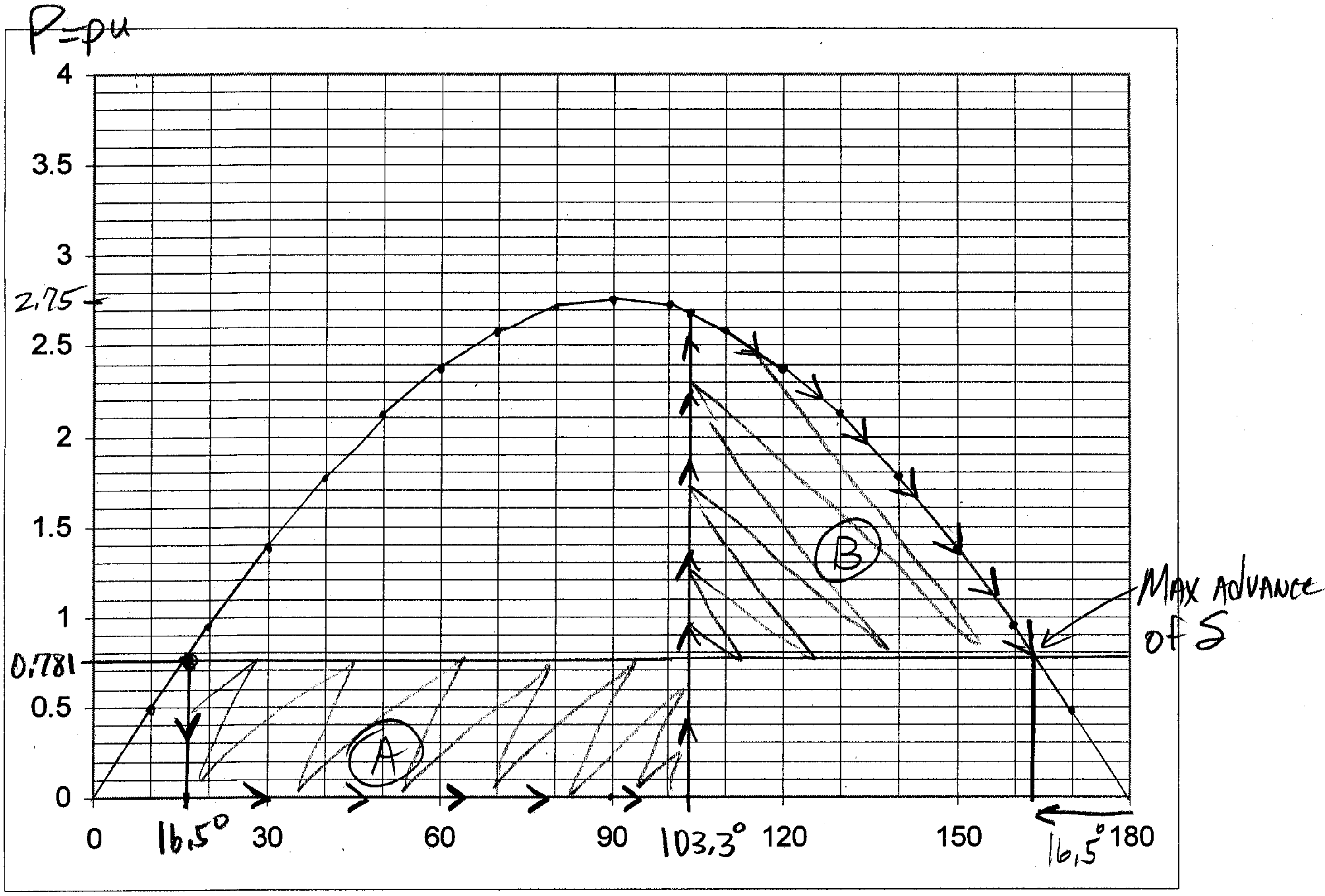
$$\text{Use } \delta(t) = \frac{\omega_s P_{MECH}}{4H} t^2 + \delta_0 \text{ to get } t^2 = \frac{4H}{\omega_s P_{MECH}}(\overset{1.803}{\delta_{CRIT}} - \overset{0.288}{\delta_0})$$

$$t^2 = \frac{4(1.4)}{(377)(0.781)}(1.803 - 0.288)$$

$$\boxed{t = 0.1697 \text{ sec} = 10.18 \text{ cycles of } 60\text{Hz}}$$

On curve,

$$P_{MAX} = \frac{E' V_{TH}}{j0.40} \sin 90^\circ = 2.75$$



δ movement

Areas A = B

δ accelerating

δ decelerating