TUSHAR:

EE581 Power System Stability and Control

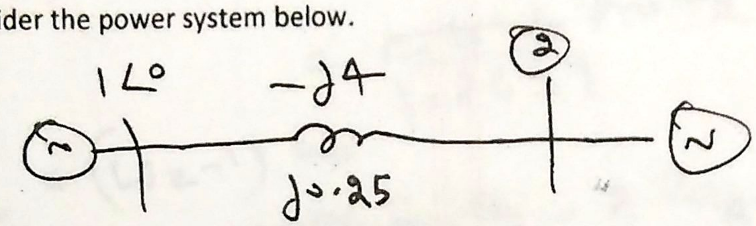
Final Examination

May 3, 2013

3 pm to 5 pm

(40 minutes)

1) Consider the power system below.



Power-flow specifications: PG2 = 1.0 and V2 = 1.0

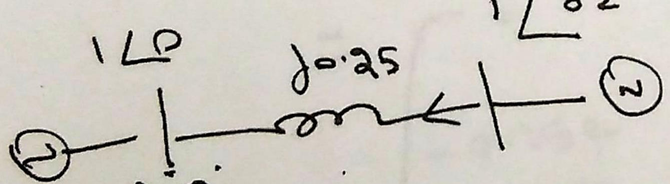
Generator parameters: $x_d = 1.5$, $x_q = 1.4$, $x_d' = 0.3$, $x_q' = 0.4$, $K_D = 2$, $H = 5$, $R_a = 0$, $T_{d0}' = 10$, $T_{q0}' = 1$

a) Find the power-flow solution. 10
b) Derive classical model for the system. 10
c) Find the equilibrium point from the power-flow solution. 10
d) Linearize the model and compute the eigenvalues. 10

(40 points)

Power flow:

$V_2 = 1.0, \quad P_{G2} = 1.0$



$\frac{1.1}{0.25} \sin\delta_2 = 1$

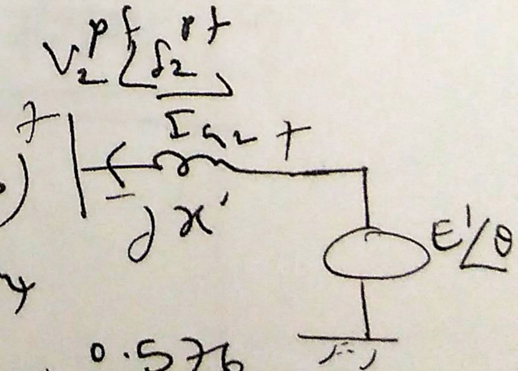
$\Rightarrow \sin\delta_2 = 0.25$

$\Rightarrow \delta_2 = \sin^{-1} 0.25 = 0.2527 \text{ rad.}$

Initialization:

$\vec{I}_{21} = \frac{1\angle 0.2527 - 1\angle 0}{j0.25}$

$= 1 + j0.127 = \vec{I}_{G2}$



$\Rightarrow E_2'\angle\theta_2 = 1\angle 0.2527 + \vec{I}_{G2}(j0.35)$

$= \cancel{1.0176}\ \cancel{\angle 0.0984}$

$\boxed{x' = 0.35}$

0.576

$E_2' = \cancel{1.0176}\ 1.015 \qquad \theta_2 = \cancel{0.0984} \qquad P_{m_2} = 1.0$

<u>Model:</u> $P_{a2} = \cancel{\frac{E_2'}{}\angle\theta_2 - 1\angle 0}$

$$= \frac{E_2' \cdot 1}{(x' + x_{line})} \sin\theta_2$$

$$= \frac{\cancel{1.0176}\ 1.015}{0.35+0.25} \sin\theta_2$$

$$= \cancel{1.696}\ 1.8359 \sin\theta_2$$

$\dot{\theta}_2 = (\omega_2 - 1)\,\omega_s$

$10\,\dot{\omega}_2 = 1 - \cancel{1.696}\ 1.8359 \sin\theta_2 - 2(\omega_2 - 1)$

$\Rightarrow$ <u>Linearization:</u>

$$J = \begin{bmatrix} 0 & \omega_s \\ \frac{-\cancel{1.696}\ 1.8359 \cos\theta_2}{10} & \frac{-2}{10} \end{bmatrix} \Bigg| \; \theta_2 = \cancel{-0.0984}\ 0.5576$$

$$= \begin{bmatrix} 0 & 377 \\ -0.154\ \cancel{-0.1688} & -0.2 \end{bmatrix}$$ 5

Eigenvalues are $\underline{\underline{-0.1 \pm j\ \cancel{7.976}\ 7.618}}$ 5

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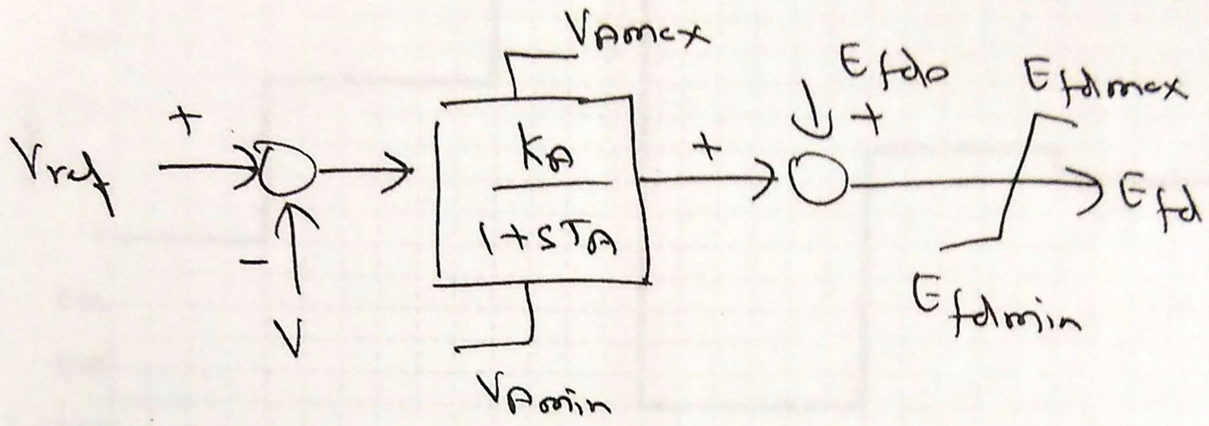
2) Consider the exciter model below. Exciter response from a step response test is shown in the plot below. Assume Vref=1.03. Estimate the exciter parameters KA, TA, Efd0, and VAmin, VAmax, Efdmin and Efdmax. (20 points)



$V_{rf} = 1.03 \Rightarrow E_{fd0} = 0.$ (4)

$\Rightarrow$ steady state:
$V_{rf} = 1.03,\ V = 1 \Rightarrow E_{fd} = K_A(V_{rf} - V)$

$\Rightarrow 3 = K_A(0.03)$

$\Rightarrow K_A = 100$ (4)

V changes from 1.~~03~~ to 1.05

$\Rightarrow V_{rf} - V = 0.02 \Rightarrow K_A(V_{rf} - V) = -2.$

Efd reaches $-2 \Rightarrow V_{Amin} < -2.$

(63%) (4)

$\Rightarrow T_A = 1$ sec.

V changes to 1.1 $\Rightarrow$ Abruptly stops at −5

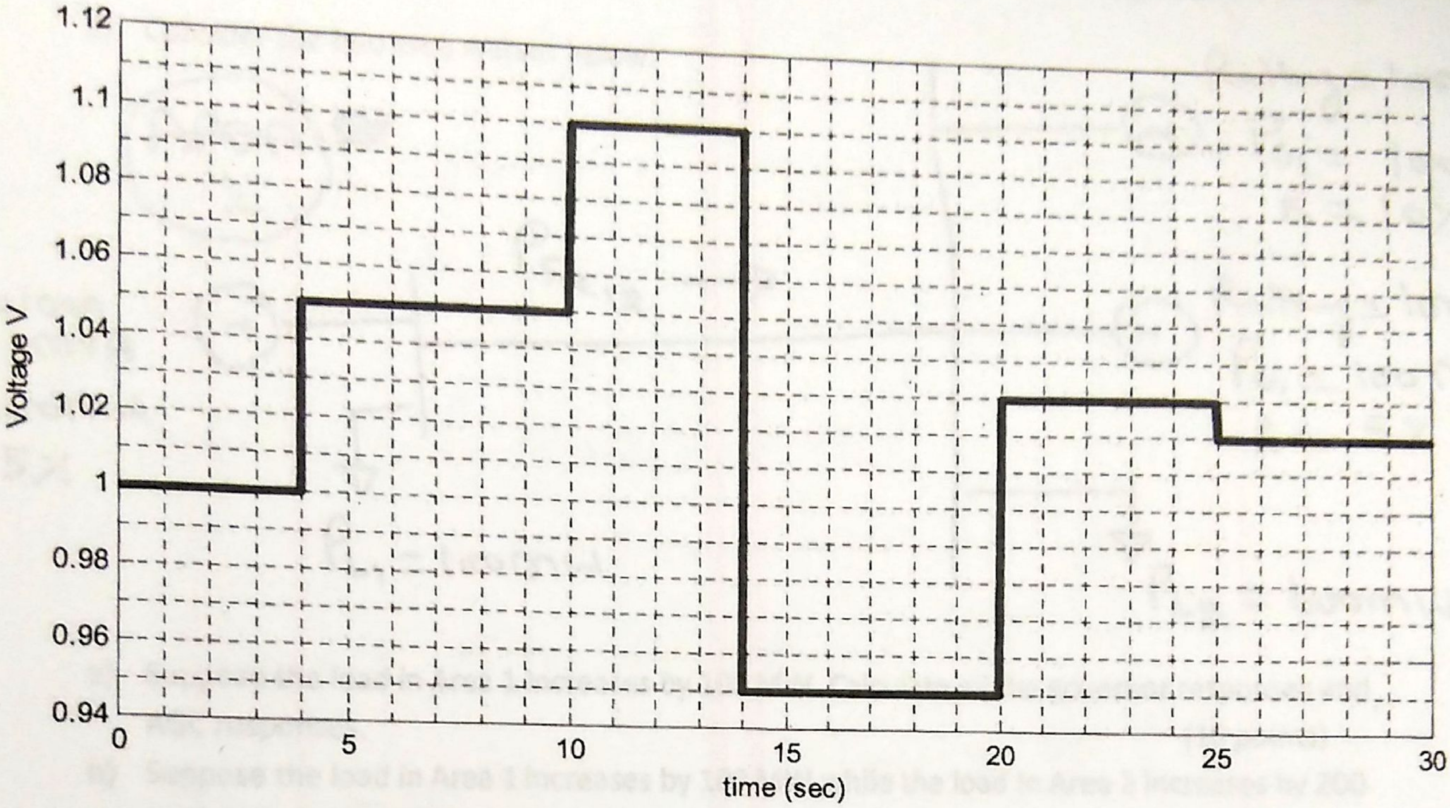
$\Rightarrow E_{fdmin} = -5$ (4)

V changes to 0.93 $\Rightarrow$ Efd abruptly ends at +5

$\Rightarrow E_{fdmax} = +5$ (4)

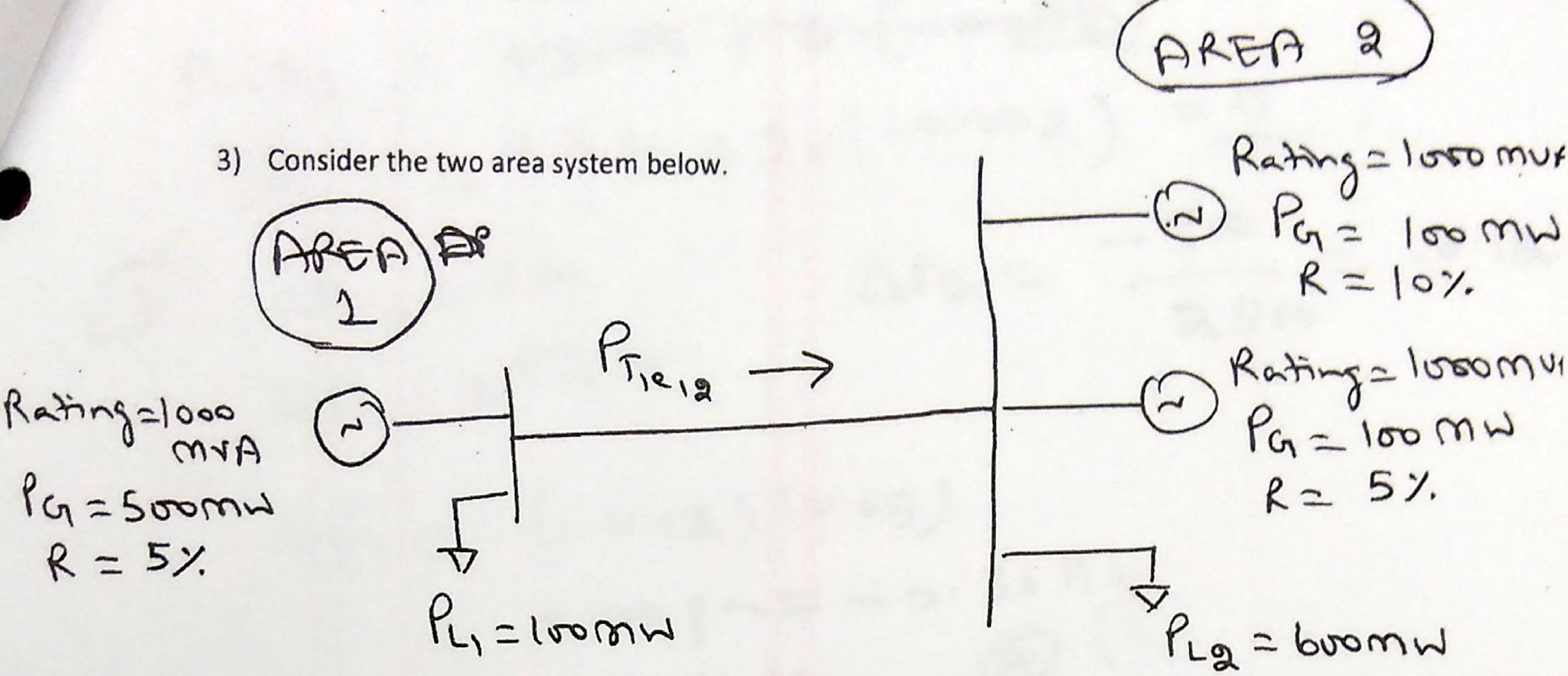
$\Rightarrow V_{Amin} < -5,\ V_{Amax} > 5$ (don't know)

$V_{ref} = 1.03$.



$T_A = 1$ sec.

3) Consider the two area system below.



a) Suppose the load in Area 1 increases by 100 MW. Calculate all the governor responses and AGC responses. (10 points)

b) Suppose the load in Area 1 increases by 100 MW while the load in Area 2 increases by 200 MW. Calculate all the governor responses and AGC responses. (10 points)

c) For part a), show the typical response of system frequency and generator MW outputs in time-plots clearly indicating approximate time instants when different actions take place. (10 points)

4+2+2+2

(a) Area 2 Gen 1.

Rating = 1000 MVA R = 10%.

Equivalent rating = 500 MVA for R = 5%.

$\Delta P_{L_1} = +100 \Rightarrow \Delta P = \frac{-100}{2500} = -0.04$

$\Rightarrow \Delta f = (0.04)(0.05) = -0.002 \text{ pu} = -0.12 \text{ Hz}$ 4

$f_{new} = 59.88 \text{ Hz}$

$\Rightarrow \Delta P_{G_1} = 40 \text{ MW}$ $\Delta P_{G_2} = 20 \text{ MW}$ 3 $\Delta P_{G_3} = 40 \text{ MW}$

$\Rightarrow P_{Tie_{12}} = 340 \text{ MW} \Rightarrow \Delta P_{Tie_{12}} = -60 \text{ MW}.$

$ACE_1 = -0.06 + \frac{1}{\text{[illegible]}}(-0.002)\frac{1}{0.05}$ 2 3

$= -0.06 - 0.04 = -0.1 \text{ pu}$

$\Rightarrow \Delta P_{G_1} = +0.1 \text{ pu} = \underline{100} \text{ MW}$ ✓ 2

$\Delta P_{Tie21} = 0.1520 = +0.04\ pu$

$ACE_2 = \cancel{+0.06 + 20(-0.002)}$

$= 0.04 + 20(-0.002) = \underline{0}$.

2

(b) $\Delta P_{L1} = +100$ $\Delta P_G = \frac{-300}{2500} = -0.12$

$\Delta P_{L2} = +200$

$\Delta f = (-0.12)(0.05)$

$= -0.006\ pu = -0.36\ Hz$

3

$f_{new} = 59.64\ Hz$.

$\Delta P_{G1} = \frac{+0.006}{0.05} = +0.12\ pu$
$= 120\ MW$

$\Delta P_{G2} = 60\ MW$

$\Delta P_{G3} = 120\ MW$.

3

$= 420\ MW$.

$P_{T\,1e12}^{new} = 0.02\ pu$.

$= 20\ MW = $

$\Delta P_{Tie\,12} = 0.02 - (0.006)\,20$

2

$\Rightarrow ACE_1 = -0.1\ pu \Rightarrow \Delta P_{G1} = 100\ MW$.

$\Delta P_{Tie21} = -20\ MW = \frac{-20}{1500}\ pu$

$= -0.0133$

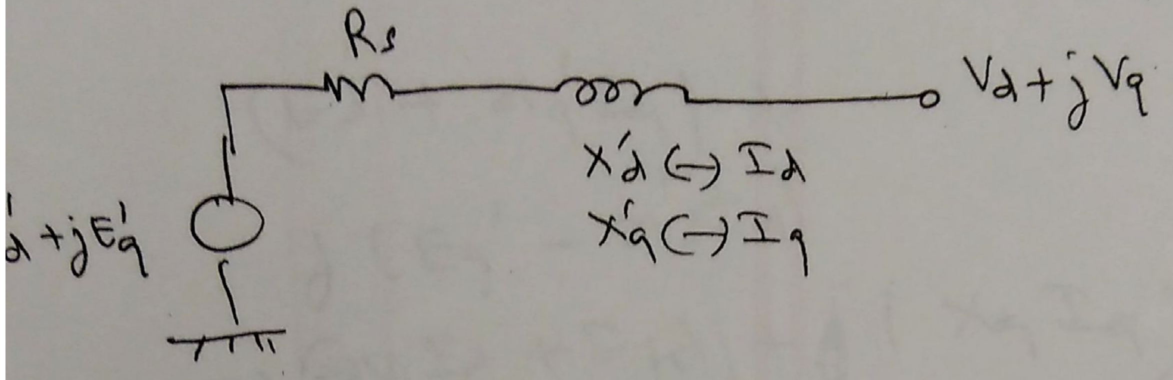
<u>Area 2</u>: $ACE_2 = -0.0133 - (0.006)20$

$= -0.1333$

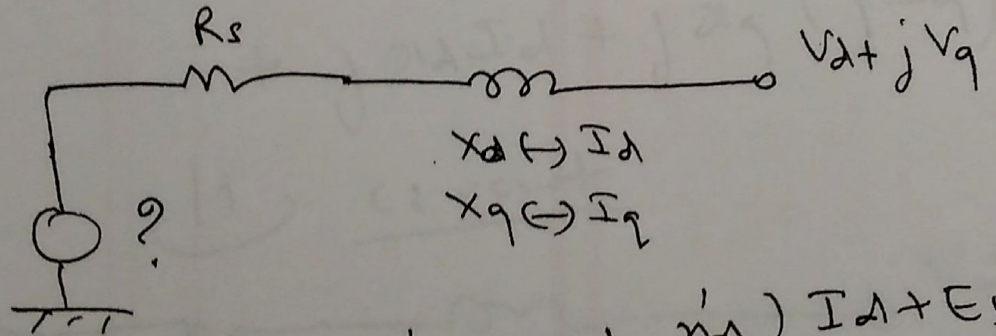
2

$\Rightarrow \Delta P_{Area2} = +200\ MW$. how to apply to (not specified P_{G2} and P_{G3}).

4) Consider the two axis power generator model. We know that the electromagnetics of the generator flux decay equations can be represented during dynamic analysis by the equivalent circuit below that was discussed in class:



Suppose we assume the machine is in steady state. Simplify the equations to show that the equivalent circuit changes to the form as shown below where the reactances change to x_d in place of x_d' and x_q in place of x_q' respectively. Solve for the voltage behind the generator impedance. (10 points)



$0 = T_{d0}'\dot{E}_q' = -E_q' - (x_d - x_d')I_d + E_{fd}$ — ①

$0 = T_{q0}'\dot{E}_d' = -E_d' + (x_q - x_q')I_q$ — ②

$\Rightarrow E_d' + jE_q' = (V_d + jV_q) + R_s(I_d + jI_q) + jx_d' I_d + jx_q' jI_q$ — ⑤

from ①, $E_q' - x_d' I_d = -x_d I_d + E_{fd}$ — ③

$E_d' + x_q' I_q = x_q I_q$ — ④

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Putting ③, ④ into ⑤,
we get

$$(E_d' + x_q' I_q) +$$
$$j(E_q' - x_d' I_d)$$
$$= j(x_d I_d + E_{fd}) + j(x_q I_q)$$
$$= V_d + jV_q + R_s(I_d + jI_q)$$

$$E_{fd} = (V_d + jV_q) + R_s(I_d + jI_q)$$
$$+ j x_d I_d + j x_q (jI_q)$$

11, circuit