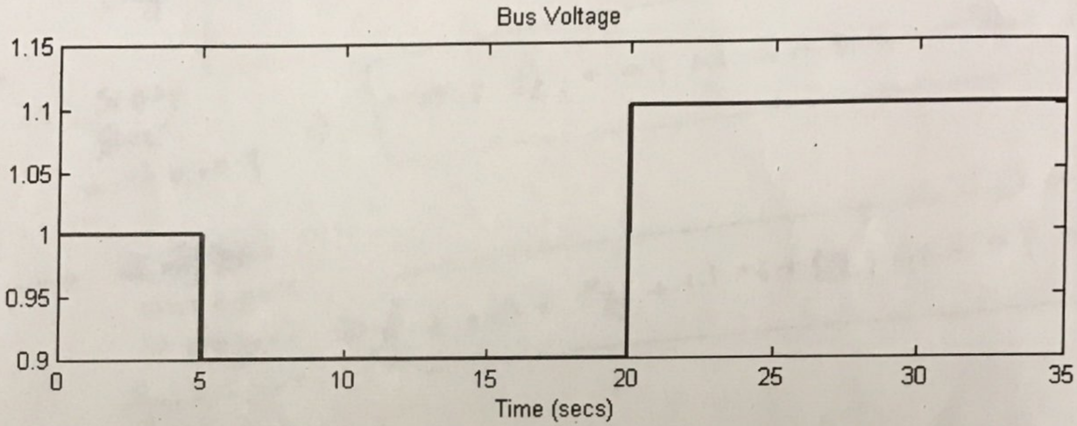
Name: Younes Sangsefidi

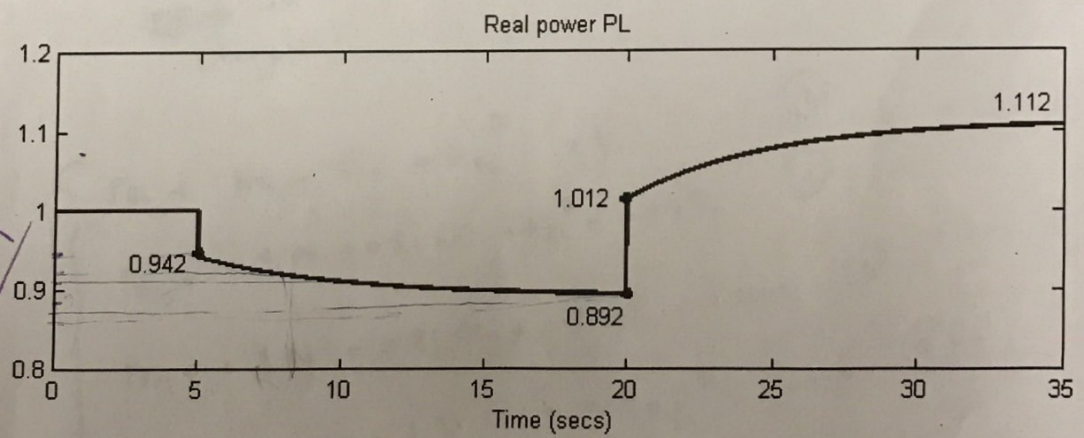
EE523 Midterm Examination

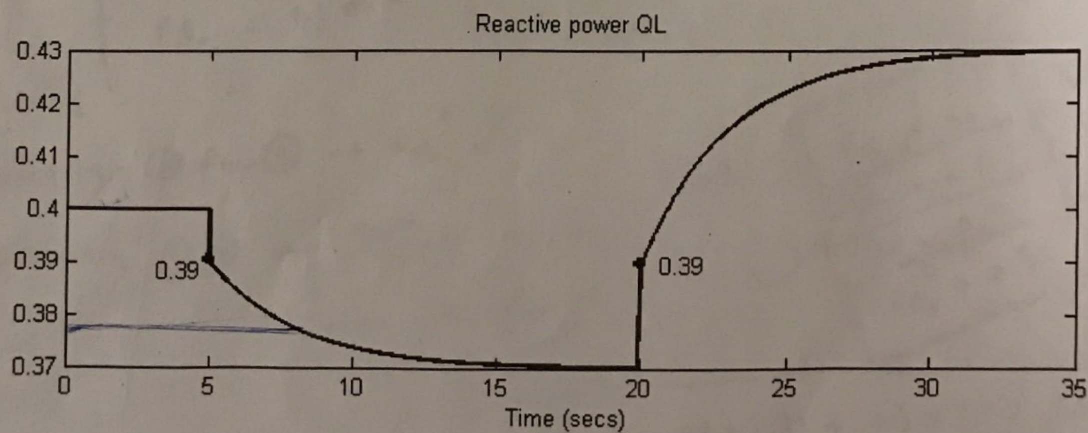
March 10, 2014 5.30 pm to 7.30 pm

1) Estimate the composite load model of a substation using the load response shown below. The static load is assumed to be a Zip model and the dynamic load is modeled by a first order transfer function. (25 points)

ZIP







$$P = P^{static} + P^{dynamic} = P^s_{lo_i} + M_i v_i + G_i v_i^2 + \frac{k^D_{p_i}}{1+sT_{lp_i}} v_i$$

$t=5^- \Rightarrow$ Steady state $v_i = 1 \Rightarrow \boxed{1 = P_{lo_i} + M_i + G_i + k^D_{p_i}}$

$t=5^+ \Rightarrow$ Static part is changed but dynamic part is not changed $\Rightarrow \boxed{0.942 = P_{lo_i} + 0.9 M_i + 0.81 G_i + k^D_{p_i}}$

$t=20^- \Rightarrow$ Steady state with $v_i = 0.9 \Rightarrow \boxed{0.892 = P_{lo_i} + 0.9 M_i + 0.81 G_i + 0.9 k^D_{p_i}}$

$t=20^+ \rightarrow$ ~~Steady~~ static part is changed, dynamic part not changed $\Rightarrow \boxed{1.012 = P_{l_i} + 1.1 M_i + 1.21 G_i + 0.9 k^D_{p_i}}$

$$\begin{cases} P_{lo_i} + M_i + G_i + k^D_{p_i} = 1 & (1) \\ P_{lo_i} + 0.9 M_i + 0.81 G_i + k^D_{p_i} = 0.942 & (2) \\ P_{lo_i} + 0.9 M_i + 0.81 G_i + 0.9 k^D_{p_i} = 0.892 & (3) \\ P_{lo_i} + 1.1 M_i + 1.21 G_i + 0.9 k^D_{p_i} = 1.012 & (4) \end{cases}$$

~~Or then~~ Subtracting (3) from (2) $\rightarrow k^D_{p_i}$ ✓

then Subtracting (3), (1) and (3), (4) $\rightarrow M_i, G_i$

then $\rightarrow P_{lo_i}$

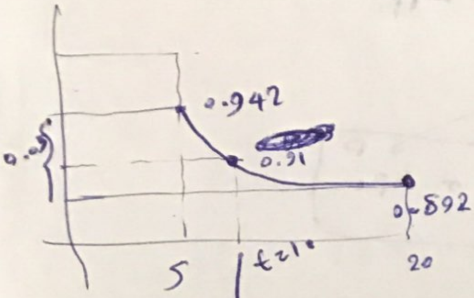
$\Rightarrow$

$$\boxed{\begin{array}{l} P_{lo_i} = 0.1 \\ M_i = 0.2 \\ G_i = 0.2 \\ k^D_{p_i} = 0.5 \end{array}}$$ ✓

test $\rightarrow \boxed{0.1 + 0.2 \times 1.1 + 0.2 \times 1.21 + 0.5 \times 1.1 = 1.112}$ ✓

Scanned by CamScanner

for determing b_{1P}^{i};



with looking at figure it will be around t=10

$0.63 \times 0.05 \simeq 0.0315$

$\Rightarrow$ $0.942 - 0.0315 \simeq 0.91$

$$\boxed{b_{1P} = 10 - 5 = 5\,\text{sec}}$$

About reactive power:

$$Q = Q^{static} + Q^{dynamic} = Q_{l0_i} + H_i V_i + B_i V_i^2 + \frac{k_{Q_i}^{D}}{1 + b_{1Q_i}} V_i$$

$\Rightarrow$ $t = 5^- \Rightarrow 0.4 = Q_{l0_i} + H_i + B_i + k_{Q_i}^{D}$ doesnot change fast!

$t = 5^+ \Rightarrow 0.39 = Q_{l0_i} + 0.9 H_i + 0.81 B_i + k_{Q_i}^{D}$

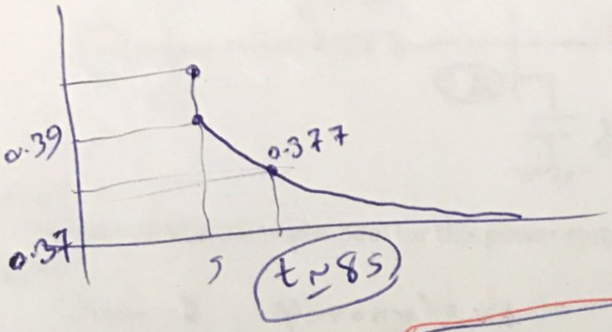
$t = 20^- \Rightarrow 0.37 = Q_{l0_i} + 0.9 H_i + 0.81 B_i + 0.9 k_{Q_i}^{D}$

$t = 20^+ \Rightarrow 0.39 = Q_{l0_i} + 1.1 H_i + 1.21 B_i + 0.9 k_{Q_i}^{D}$

$$\begin{cases} Q_{l0_i} + H_i + B_i + k_{Q_i}^{D} = 0.4 \\ Q_{l0_i} + 0.9 H_i + 0.81 B_i + k_{Q_i}^{D} = 0.39 \\ Q_{l0_i} + 0.9 H_i + 0.81 B_i + 0.9 k_{Q_i}^{D} = 0.37 \\ Q_{l0_i} + 1.1 H_i + 1.21 B_i + 0.9 k_{Q_i}^{D} = 0.39 \end{cases} \xrightarrow[\text{like previous part}]{\text{in a way}} \boxed{\begin{array}{l} Q_{l0_i} = 0.1 \\ H_i = 0.1 \\ B_i = 0 \\ k_{Q_i}^{D} = 0.2 \end{array}}$$

test $\rightarrow$ $\boxed{0.1 + 0.1 \times 1.1 + 0 \times 1.21 + 0.2 \times 1.1 = 0.43}$

For determing b_{1Qi}:



$0.39 - 0.37 = 0.02$

$0.02 \times 0.63 = 0.0126$

$\Rightarrow 0.39 - 0.0126 = \boxed{0.3774}$

$\Rightarrow \boxed{b_{1Qi} = 8 - 5 = 3 \text{ sec}}$

this is approximate based on looking at figure

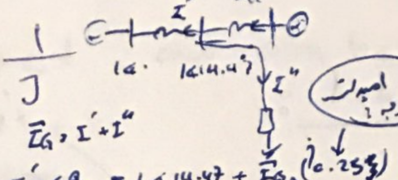
25

$E_2' \approx 1.038$

$\theta_2 \approx 28.4^{\circ}$

E.q. Solution

ارائه از روی برگه

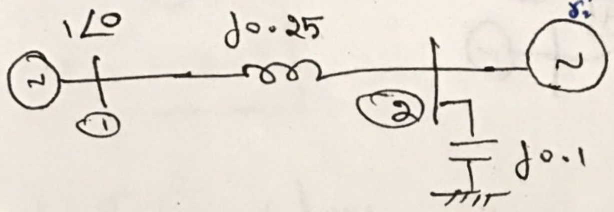


$\vec{E}_G = I' + I''$

$E_2' \angle \theta_2 = 1\angle 14.47 + \vec{E}_G (0.25j)$

$(Q_2 \approx 0.027)$?

2) a) Solve the power-flow problem below. (10 points)



$V_2 = 1$ pu

$P_{G2} = 1$ pu

b) Write-out the classical model for this power system. (15 points)

Gen 2 parameters:

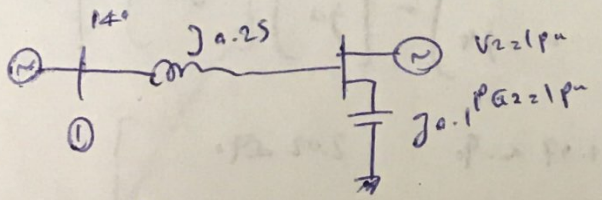
$H_2 = 5$ sec, $x'_{d2} = 0.25$, $x'_{q2} = 0.25$, $k_{D2} = 1$

$x_{d2} = 1.0$, $x_{q2} = 1.1$, $T'_{do2} = 10$, $T'_{qo2} = 4$,

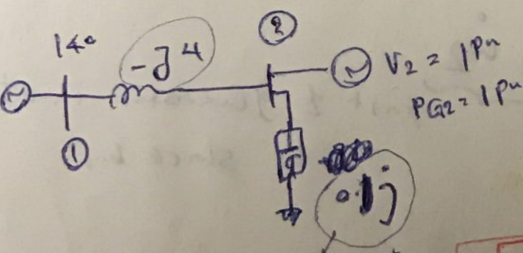
$E_{fd2} = 1.2$

$X_L > 0 \Rightarrow X_L = 0.25j \to Y_L = -4j$

$X_C < 0 \Rightarrow X_C = -10j \to Y_C = 0.1j$



$\Downarrow$



the coefficient should be 7°

δ_2 is unknown:

$$Y_{bus} = \begin{bmatrix} -j4 & +j4 \\ +j4 & -j3.9 \end{bmatrix} = \begin{bmatrix} 4\angle -90^{\circ} & 4\angle 90^{\circ} \\ 4\angle 90^{\circ} & 3.9\angle -90^{\circ} \end{bmatrix}$$

Y_{21}, θ_{21}, θ_{12}

$V_1 = 1$ pu, $V_2 = 1$ pu, $P_{L2} = 0$, $P_{G2} = 1$ pu

the input of power flow

$P_{21} = Y_{21} V_2 V_1 \cos(\delta_2 - \delta_1 - \theta_{21})$ (1)

$P_{21} = Y_{21} V_2 \cos(\delta_2 - 90^{\circ}) = 4\cos(\delta_2 - 90) = 4\sin\delta_2$

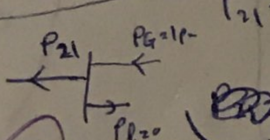
we have just 1 unknown in power flow that is δ_2

$\Downarrow$

it is not needed to use Jacobian.

$\Downarrow$

power flow can be solved directly by writing P_{21}



$P_{21} = \underbrace{P_G - P_{L2}}_{\text{Scheduled}} = 1\text{pu} - 0 = 1$ pu

$\Rightarrow P_{21} = 4\sin\delta_2 = 1$ pu $\Rightarrow$ $\sin\delta_2 = 0.25$

$\Rightarrow \delta_2 = 14.47^{\circ}$

the solution of power flow

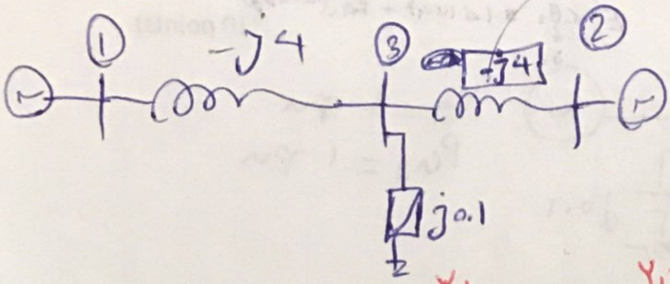
$Q_{21} = Y_{21} V_2 \sin(\delta_2 - \delta_1 - \theta_{21}) = 4\sin(-75.53)$

-5

with this angle we can calculate any variable.

classical model :

$x'_{2} = \frac{x'_{d2} + x'_{q2}}{2} = 0.25 \Rightarrow \boxed{Y_2 = -\frac{1}{0.25} j = -j4}$



Y_{bus} :

$$\vec{Y}_{bus} = \begin{array}{cc} & \begin{array}{cc} Y_{11} & Y_{12} \end{array} \\ & \begin{bmatrix} -j4 & 0 & j4 \\ 0 & -j4 & j4 \\ j4 & j4 & -j7.9 \end{bmatrix} \\ & \begin{array}{cc} Y_{21} & Y_{22} \end{array} \end{array} = \begin{bmatrix} 4\angle -90 & 0 & 4\angle 90 \\ 0 & 4\angle -90 & 4\angle 90 \\ 4\angle 90 & 4\angle 90 & 7.9\angle -90 \end{bmatrix}$$

$\boxed{NG+1 = 2}$

$$\vec{Y}_G = Y_{11} - Y_{12} Y_{22}^{-1} Y_{21} = \begin{bmatrix} -j4 & 0 \\ 0 & -j4 \end{bmatrix} - \begin{bmatrix} j4 \\ j4 \end{bmatrix} \begin{bmatrix} -j7.9 \end{bmatrix}^{-1} \begin{bmatrix} j4 & j4 \end{bmatrix}$$

$$\vec{Y}_G = \begin{bmatrix} 1.97\angle -90 & 2.02\angle 90 \\ 2.02\angle 90 & 1.97\angle -90 \end{bmatrix}$$

in classical model, state variables are $\underbrace{\dot{\theta}_2, \dot{w}_2}$ just 1 generator in addition to slack bus

$$\begin{bmatrix} \dot{\theta}_2 \\ \dot{w}_2 \end{bmatrix} = \begin{bmatrix} (w_2 - 1) w_s \\ \frac{1}{2H_i}\left[P_{m2} - P_{e2} - K_{D2}(w_2 - 1)\right] \end{bmatrix}$$

$\boxed{r_s = 0}$

$$\Rightarrow \begin{bmatrix} \dot{\theta}_2 \\ \dot{w}_2 \end{bmatrix} = \begin{bmatrix} (w_2 - 1) w_s \\ 0.1\left[P_{m2} - P_{G2} - (w_2 - 1)\right] \end{bmatrix}$$

in type 3 $\delta_2 = \theta_2$

$$P_{G2} = \sum_{j=1}^{\boxed{NG+1} = 2} Y_{G2j} E'_2 E'_j \cos(\delta_2 - \delta_1 - \theta_{G2j}) = Y_{G21} E'_2 E'_1 \cos(\delta_2 - 0 - \theta_{G21}) + Y_{G22} E'^2_2 \cos(-\theta_{G22})$$

$$= 2.02\, E'_2 \cos(\theta_2 - 90) + 1.97\, E'^2_2 \cancel{\cos(90)} = \boxed{2.02\, E'_2 \sin\theta_2}$$

in type 3, E_2' is fixed and can be found

from power flow solution

$$\boxed{E_2' = \text{const}}$$

$$\begin{pmatrix} \dot{\theta}_2 \\ \dot{\omega}_2 \end{pmatrix} = \begin{bmatrix} (\omega_2 - 1)\,\omega_s \\ 0.1\left[P_{m_2} - 2.02\,E_2' \sin\theta_2 - (\omega_2 - 1)\right] \end{bmatrix}$$

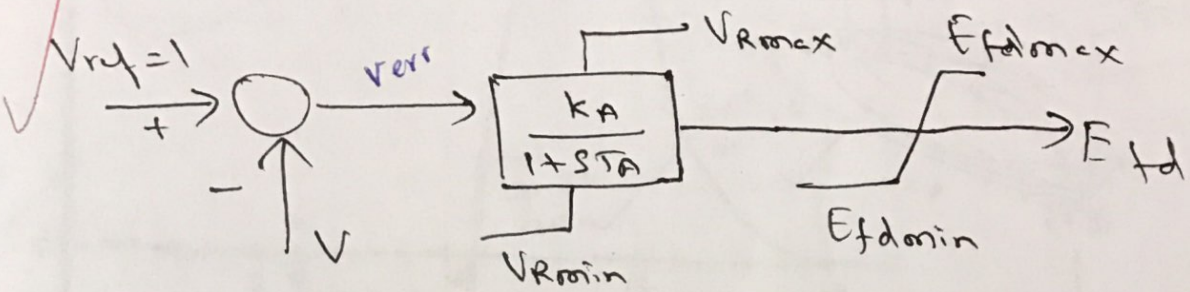
$\boxed{\text{a constant}}$

found from load flow

$$x = \begin{pmatrix} \theta_2 \\ \omega_2 \end{pmatrix} \Rightarrow \boxed{\dot{x} = f(x)}$$

20

3) Consider the Automatic Voltage Regulator (AVR) as shown below.



a) Derive and plot the time-response of the AVR first ignoring the nonwindup and windup limits. (10 points)

b) Plot the time-response of the AVR now including the nonwindup limits. (10 points)

c) Plot the time-response of the AVR including both nonwindup and windup limits. (5 points)

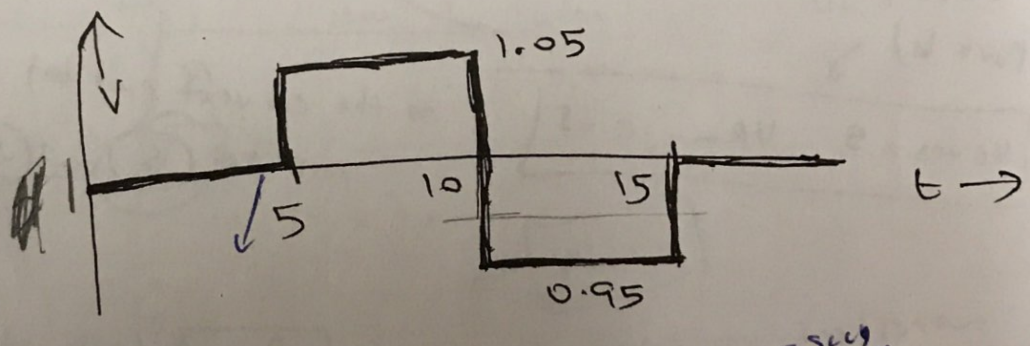
AVR parameters :

$\boxed{K_A = 200}$, $\boxed{T_A = 1 \text{ sec}}$

$E_{fdmin} = -2.0$, $E_{fdmax} = 2.0$

$V_{Rmin} = -5.0$, $V_{Rmax} = +5.0$

Voltage plot :



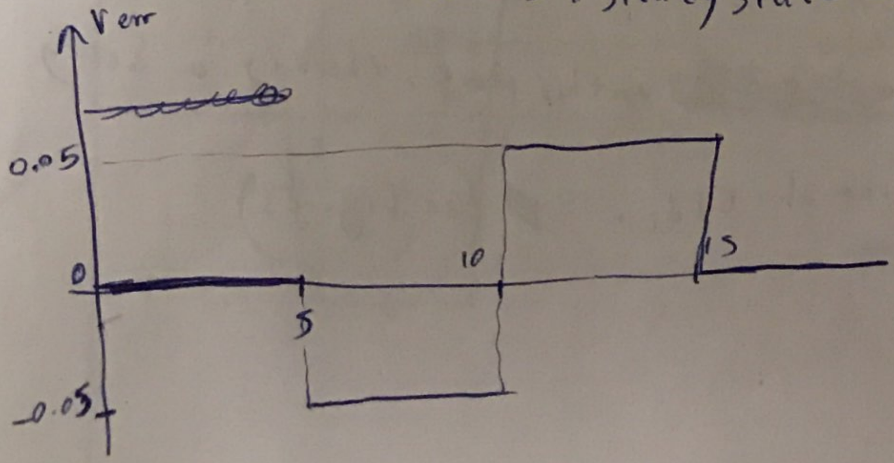
before 5 : steady state → up to t = 5 secs

⇓

$\boxed{V_{err} = 0}$

⇓

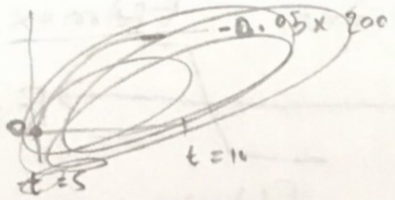
$\boxed{E_{fd} = 0}$

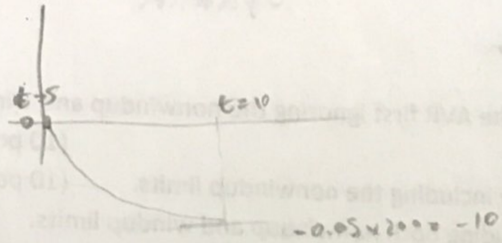


a)

$0 < t < 5 \rightarrow V_{Ri} = 0 \quad E_{fdi} = 0$

$5 < t < 10 \rightarrow$





$\tau_A = 1\,sec \Rightarrow$ at $t = 6\,sec \Rightarrow V_{Ri} = E_{fdi} = -6.3$

$10 < t < 15 \rightarrow$ constant time $= 1\,sec \Rightarrow t = 11\,sec \rightarrow V_{Ri} = E_{fdi} = -10 + 0.63 \times 20 = 2.6$ volt

$t > 15 \longrightarrow$ time constant $1\,sec \rightarrow t = 16\,sec \rightarrow V_{Ri} = E_{fd} = 10 - 6.3 = 3.7$

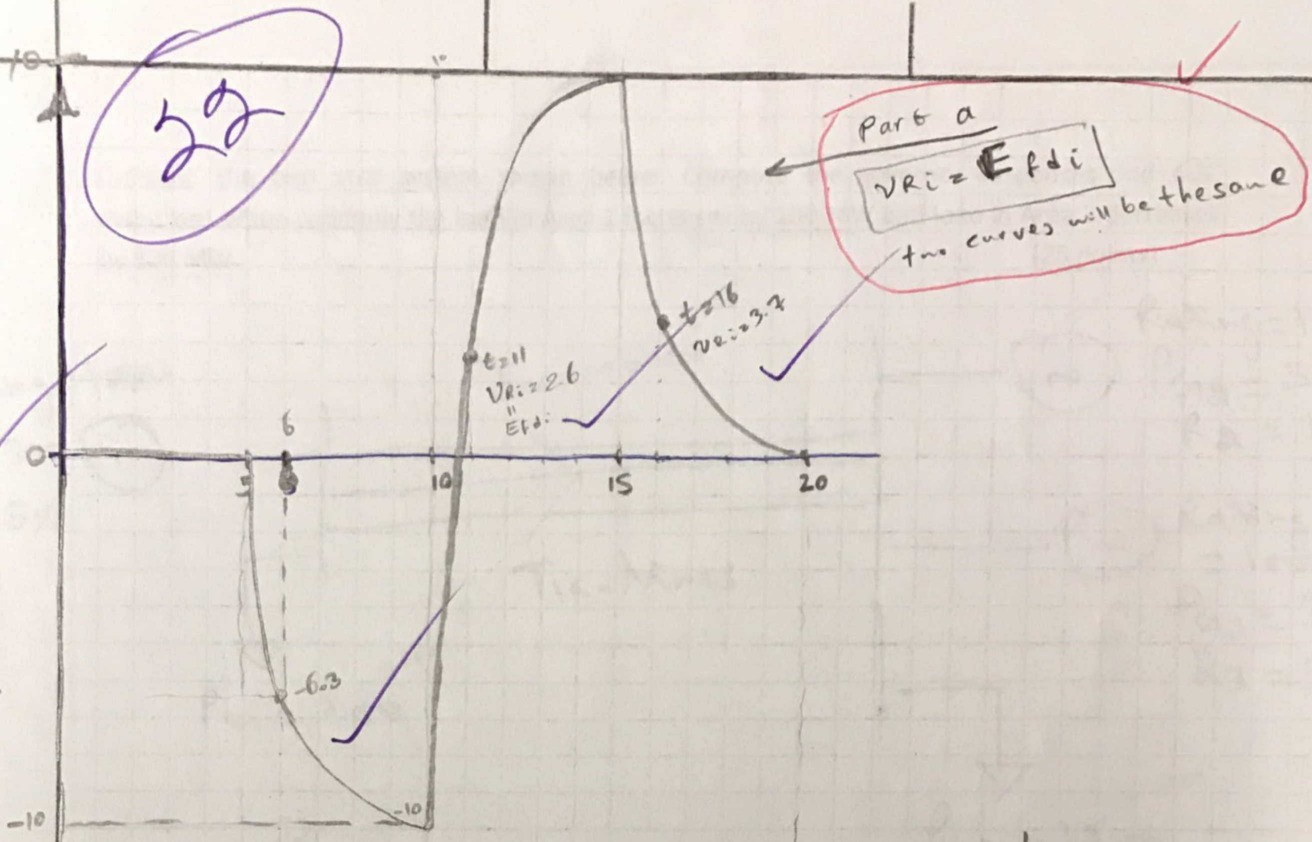
part b) ↘

$\boxed{V_{Rmax} = 5 \quad V_{Rmin} = -5}$ ⇒ the curve of part (a) will be ~~cut~~ cut at points of 5 and -5

part c) V_{Ri} is allowed to go to ± 5. But E_{fdi} is limited to ± 2.

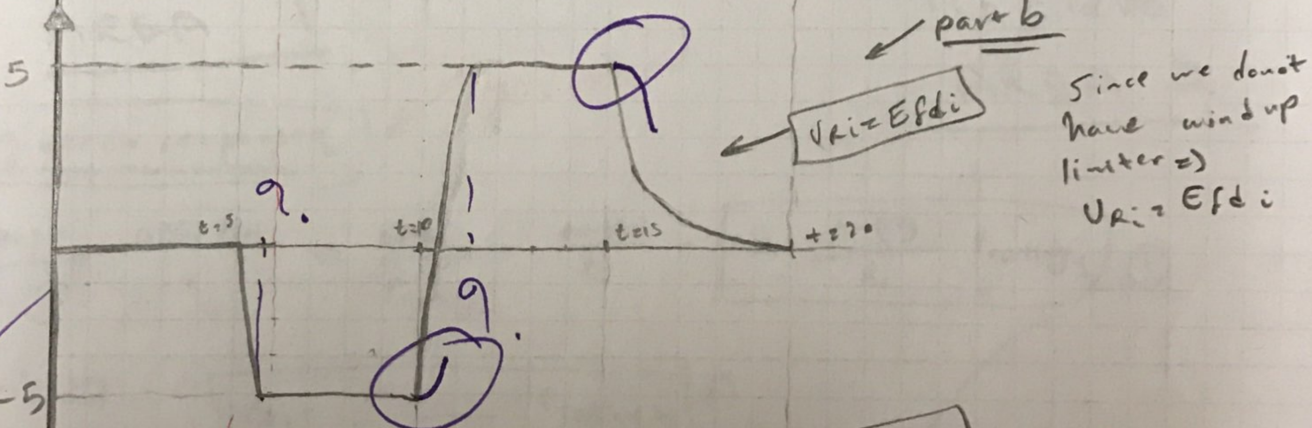
⇒ i[crossed out] in this part, there is a delay in the response of E_{fdi}. (see figures)

22



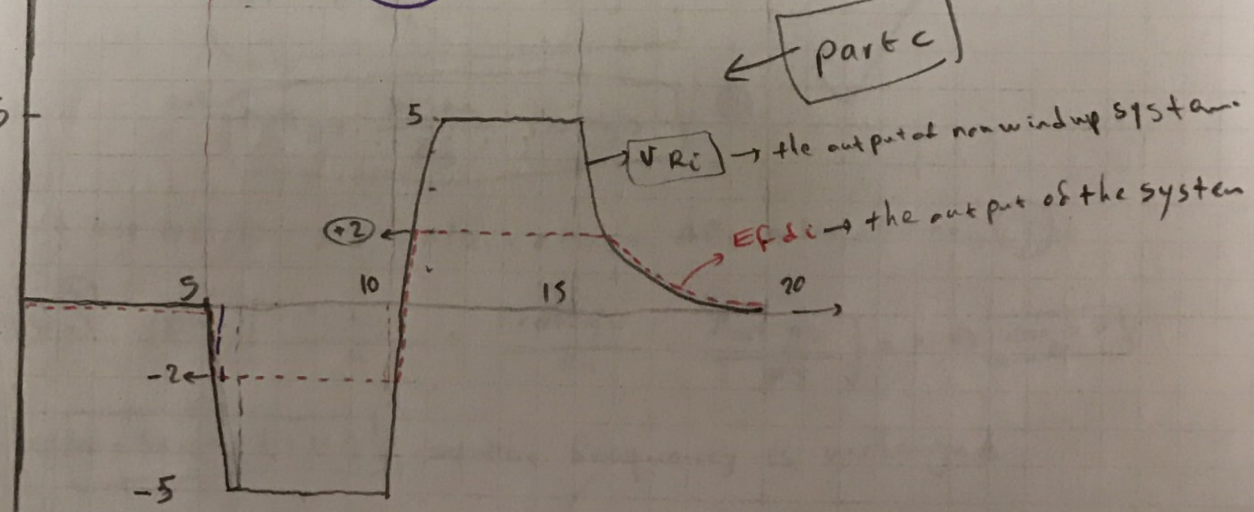
Part a
VRi = Efdi
two curves will be the same
t=11
VRi=2.6
= Efdi
t=16
VRi=3.7
-6.3
-10
10
0
5
6
10
15
20
-10

10



part b
VRi = Efdi
Since we donot have windup limiter => VRi = Efdi
t=5
t=10
t=15
t=20
5
-5

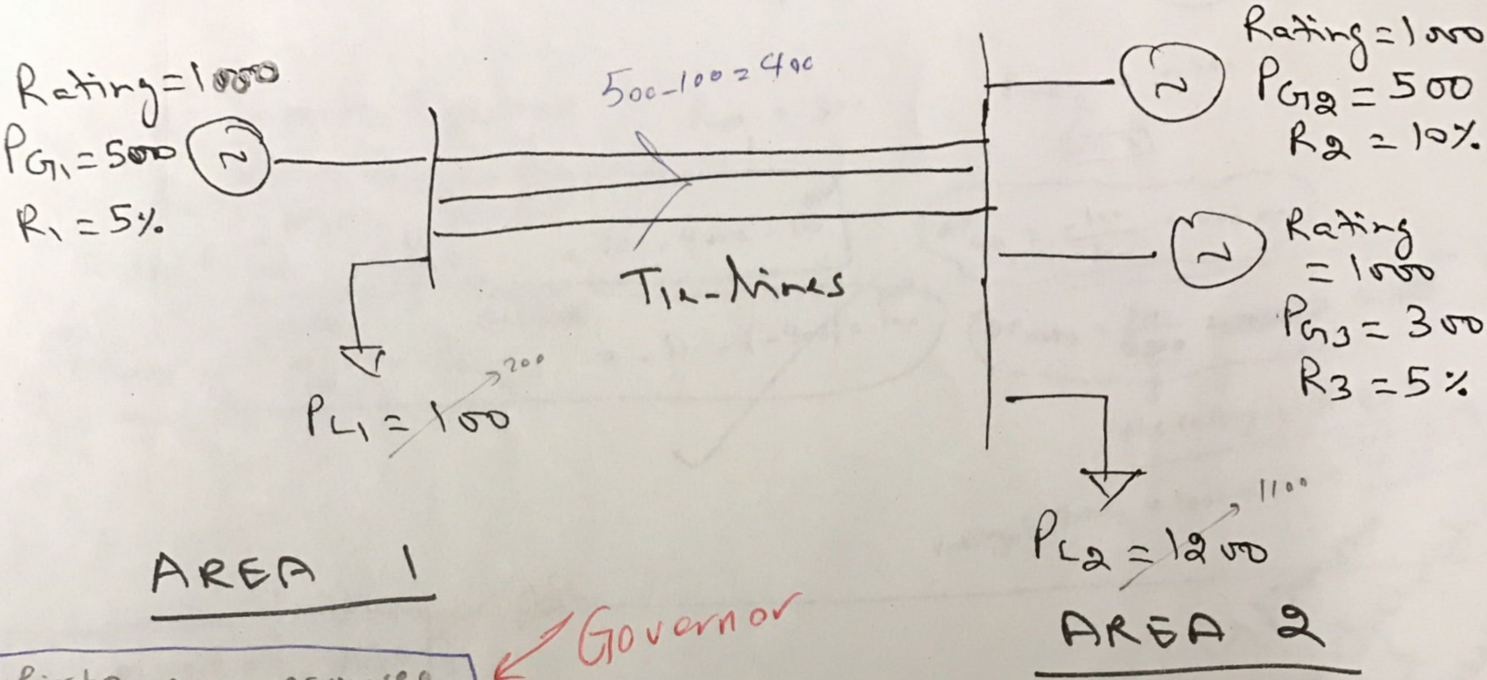
7



part c
5
VRi → the output of nonwindup system
Efdi → the output of the system
+2
-2
5
10
15
20
-5

5

4) Consider the two area system shown below. Compute the governor responses and AGC responses when suddenly the load in Area 1 increases by 100 MW and load in Area 2 decreases by 100 MW. (25 points)



Governor

* **First governor response:**

$$\frac{\Delta\omega(pu)}{R_1} = \Delta P_{G1}(pu) \Rightarrow \frac{\Delta P_{G1}}{P_{rating_1}} = \frac{\Delta\omega(pu)}{R_1} \Rightarrow \boxed{\Delta P_{G1} = \frac{\Delta\omega(pu)}{R_1} P_{rating_1}} \quad (1)$$

in similar way

$$\boxed{\Delta P_{G2} = \frac{\Delta\omega_{pu}}{R_2} P_{rating_2}} \quad (2)$$

and

$$\boxed{\Delta P_{G3} = \frac{\Delta\omega_{pu}}{R_3} P_{rating_3}} \quad (3)$$

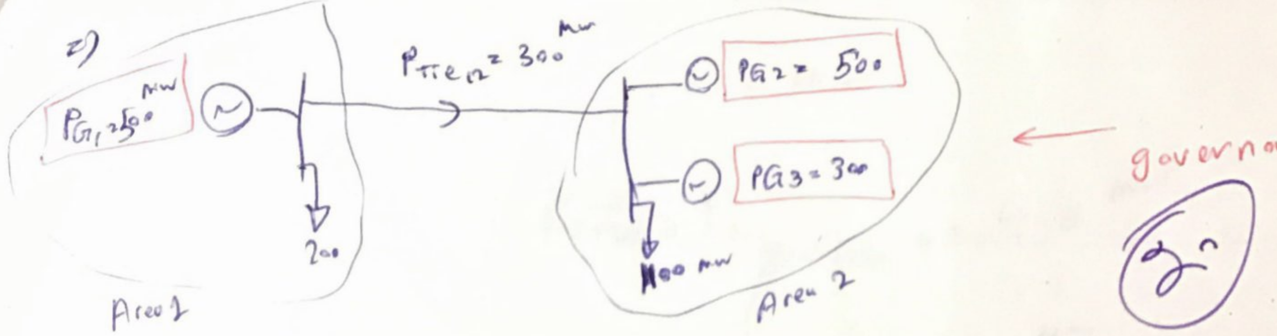
the system is loss less $\Rightarrow$ $\Delta P_{G1} + \Delta P_{G2} + \Delta P_{G3} = \Delta P_L = 100 - 100 = 0$ (4)

(1), (2), (3) (4) $\Rightarrow$ $\Delta\omega_{pu}\left[\frac{P_{rating1}}{R_1} + \frac{P_{rating2}}{R_2} + \frac{P_{rating3}}{R_3}\right] = 0 \Rightarrow \boxed{\Delta\omega_{pu} = 0}$

$\Rightarrow \boxed{W = 60 - 0 = 60\ HZ}$ $\Rightarrow$ the frequency is unchanged.

$\Delta\omega = 0 \Rightarrow \Delta P_{G1} = 0,\ \Delta P_{G2} = 0,\ \Delta P_{G3} = 0 \Rightarrow$ $\boxed{\begin{array}{l} P_{G1} = 500 \\ P_{G2} = 500 \\ P_{G3} = 300 \end{array}}$ $\rightarrow$ with the response of governor, the generation of generators are unchanged.

2)



$\Rightarrow$ with the response of governor ; $P_{net_1} = 300$ $\quad P_{net_2} = -300$ (area 2)

$$\boxed{\Delta P_{net_1} = P^{actual}_{net_1} - P^{contract}_{net_1} = 300 - 400 = -100 \text{ MW}}$$

$$\boxed{\Delta P_{net_2} = P^{actual}_{net_2} - P^{contract}_{net_2} = -300 - (-400) = 100 \text{ MW}}$$

$$\Delta P_{net_1} = \frac{-100}{1000} = -0.1 \text{ pu}$$

$$\Delta P_{net_2} = \frac{100}{2000} = 0.05 \text{ pu}$$

2000 ↓ the rating of Area 2

rating of Area 2 = 1000 + 1000 = 2000 MW

AGC

the response of AGC :

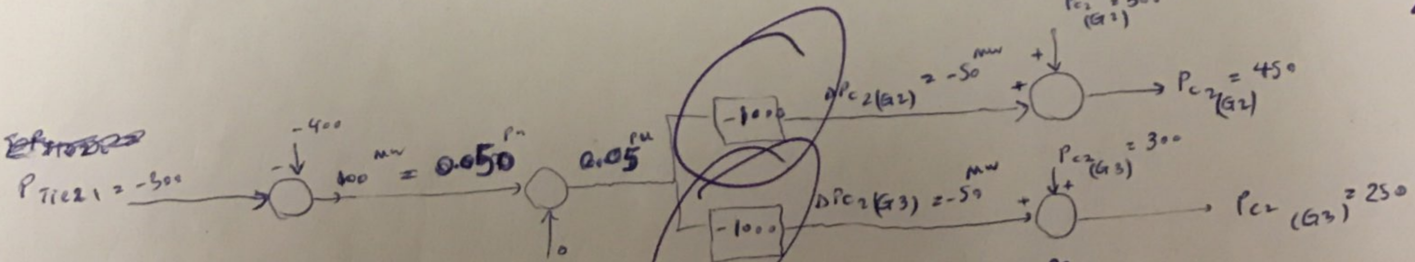
$$ACE_1 = \Delta P_{net_1} + \frac{1}{R_1} \Delta w = -0.1 \text{ pu}$$

$$\Delta P_{C_1} = -ACE_1 = +0.1 \text{ pu} = 0.1 \times 1000 = \boxed{100 \text{ MW}}$$

area 1 = generator 1

$$\Rightarrow P_{C_1} = P^{scheduled}_{C_1} + \Delta P_{C_1} = 500 + 100 = 600 \text{ MW}$$

$$\Rightarrow \boxed{P_{C_1} = 600 \text{ MW}}$$



$$ACE_2 = \Delta P_{net_2} + \frac{1}{R_{area_2}} \Delta w = +0.05 \text{ pu}$$

Area 2 ↓ including both generator 2 and generator 3

$$\Delta P_{C_{area2}} = -ACE_2 = -0.05 \text{ pu} = \boxed{-100 \text{ MW}}$$

generators 2 and 3 have the same rating

$$\Delta P_{C_{generator2}} = -50$$

$$\Delta P_{C_{generator3}} = -50$$

$$\boxed{P_{C_{generator2}} = 500 - 50 = 450 \text{ MW}}$$

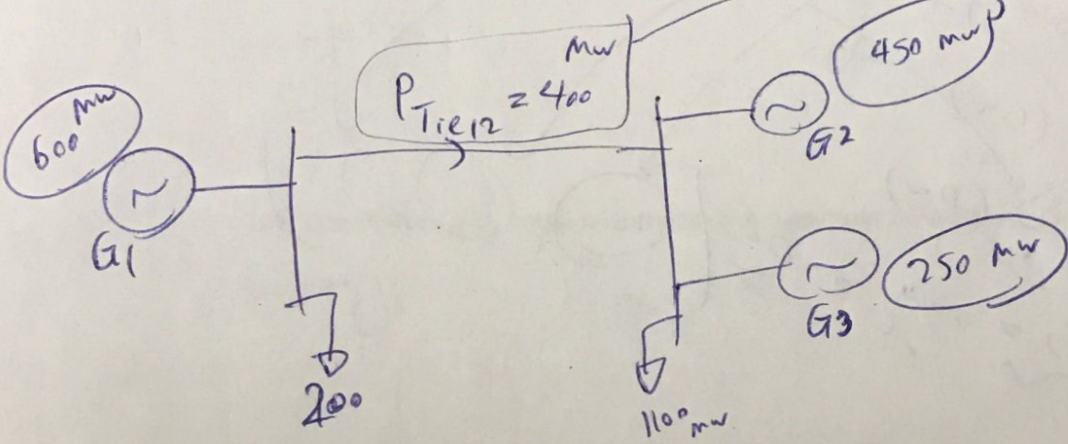
$$\boxed{P_{C_{generator3}} = 300 - 50 = 250 \text{ MW}}$$

AGC $\longrightarrow$ $P_{c_1} = 600$ MW

$P_{c_{\text{generator } 2}} = 450$ MW

$P_{c_{\text{gendrator } 3}} = 250$ MW

like the contract



$\frac{DP_1}{Rat_1}$

$DP_1 \; pu = \frac{1}{R_1}(DW)$

$\frac{DP_2}{Rat_2}$ $DP_2 \; pu = \frac{1}{R_2}(DW)$

$DP_3 \; pu = \frac{1}{R_3}(DW)$

$\frac{DP_3}{Rat3}$

$DP_1 = \frac{Rat_1}{R_1}(DW)$

$DP_2 = \frac{Rat_2}{R_2}(DW)$

$DP_3 = \frac{Rat_3}{R_3}(DW)$

$DP_1 + DP_2 + DP_3 = \frac{DW}{} \left[\;\; + \;\; + \;\; \right]$

100

Bonus questions (one point each):

1) On what day, month and year did the famous big Northeastern blackout occur?

2012 → I am not ~~s~~ sure about exact date

2) Who was the first US President who talked about smart grid in his inaugural address?

3) As of December 2012, which country has the maximum wind power installed capacity?

Germany

4) Tie-lines connecting Oregon and California consist of how many AC lines and how many DC lines and at what voltage levels?

500 kV $\xrightarrow{\text{HVAC}}$ 3 lines

500 kV $\xrightarrow{\text{HVDC}}$ 1 line → PDCI → Intertie

5) Which generator serves as the slack bus for Montana control area?

hydro generators are good for slack bus.

0