Zadatak 1

Sinkroni sustav kontinentalne Europe sastoji se od nekog udjela termoelektrana i nekog udjela hidroelektrana koje sudjeluju u regulaciji frekvencije (Slika 1). Parametri sustava su sljedeći: bazna snaga sustava iznosi 500 GW; regulacijska energija potrošnje iznosi 0.5 p.u.; $T_{gT} = 0.2$ s, $F_h = 0.3$ p.u., $T_r = 6$ s; $T_1 = 5$ s, $T_2 = 0.4$ s, $T_3 = 48$ s, $T_w = 0.8$ s; $T_b = 0.02$ s. **[Napomena: U podzadacima a) i b) Zanemarite iscrtkanu granu (baterijski spremnici) na slici 1.]**

a) Ako za ispad elektrane od 3000 MW odstupanje frekvencije u ustaljenom stanju mora biti > -200 mHz, koliko iznosi minimalna regulacijska energija proizvodnje?

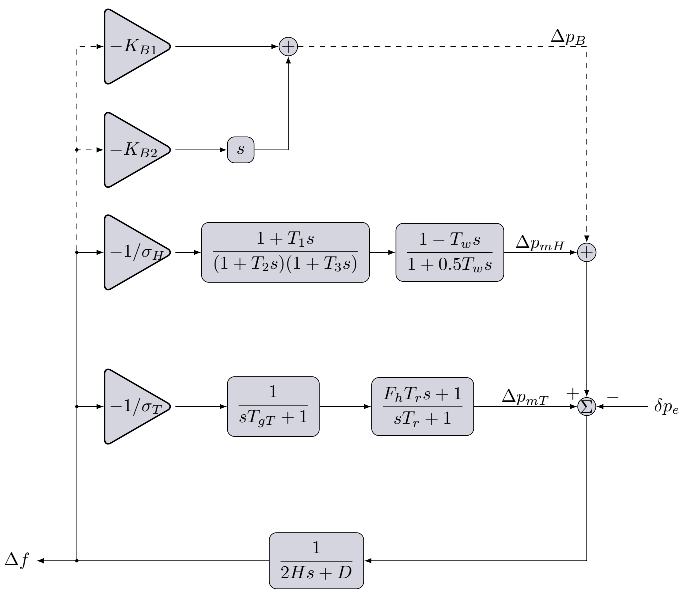
b) Ako je za poremećaj snage od 5% maksimalni dozvoljeni početni RoCoF 0.5 Hz/s, kolika je minimalna konstanta tromosti sustava?

c) Ako je zbog velikog udjela obnovljivih izvora energije spojenih preko energetske elektronike trenutna konstanta tromosti sustava 1 s, koliko mora iznositi pojačanje K_{B2} baterijskih spremnika (iscrtkana grana na slici 1) u sustavu da bi početni RoCoF bio <2 Hz/s za poremećaj snage od 10%?.

d) Koliko iznosi minimalna statičnost baterijskih spremnika ako je dozvoljeno odstupanje frekvencije u stacionarnom stanju ± 0.15 Hz za poremećaj od 20% uz $\sigma_H = 0.04$ p.u. i $\sigma_T = 0.08$ p.u.?

(Dodatna pomoć: teorem početne vrijednosti glasi $y(0) = \lim_{s\to\infty} sY(s)$**)**

(8 bodova)



Slika 1: Pojednostavljeni model sinkronog sustava kontinentalne Europe

Zadatak 2

Nacrtajte blok dijagram dinamičkog sustava opisanog jednadžbama (1)–(2), gdje su T, K, P_m, E' ,U, X i D_1, D_2 konstante, a δ i ω varijable stanja.

$$\frac{1}{K}\frac{d\delta}{dt} = (\omega - 1) \tag{1}$$

$$T\omega\frac{d\omega}{dt} + (D_1 + D_2)(\omega - 1) = P_m - \frac{E'U}{X}\sin\delta \tag{2}$$

(2 boda)

Zadatak 3

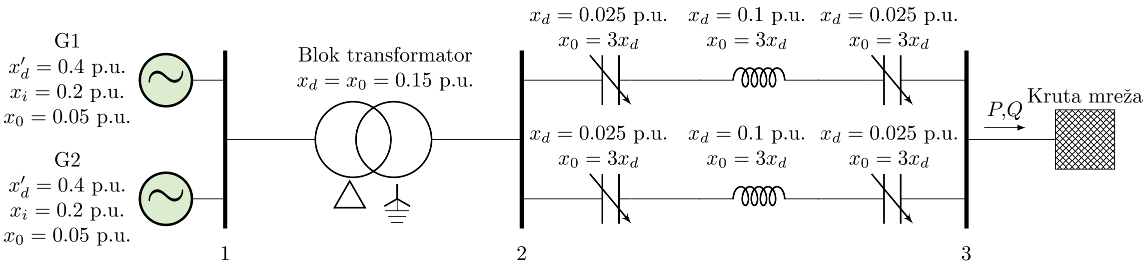
Dva identična agregata neke elektrane spojena su na krutu mrežu preko blok-transformatora i dvostrukog dalekovoda kompenziranog s oba kraja preko tiristorski upravljanih serijskih kondenzatora (TCSC) koji su podešeni prema slici 2. Agregati u poduzbuđenom režimu rada u mrežu predaju snagu $P = 0.9$ p.u. pri $\cos\varphi = 0.95$ kap. Napon krute mreže iznosi $1\angle 0^{\circ}$ p.u. Na jednom od dva paralelna voda nastaje dvopolni kratki spoj na 50% duljine voda. Potrebno je 1) odrediti kritični kut uklanjanja kvara i 2) nacrtati nadomjesnu shemu sustava sa slike 2 te odrediti izraz i skicirati krivulje za prijenos električne snage između elektrane i krute mreže za slučajeve:

a) prije nastanka kratkog spoja;

b) tijekom kratkog spoja;

c) nakon isključenja voda u kvaru.

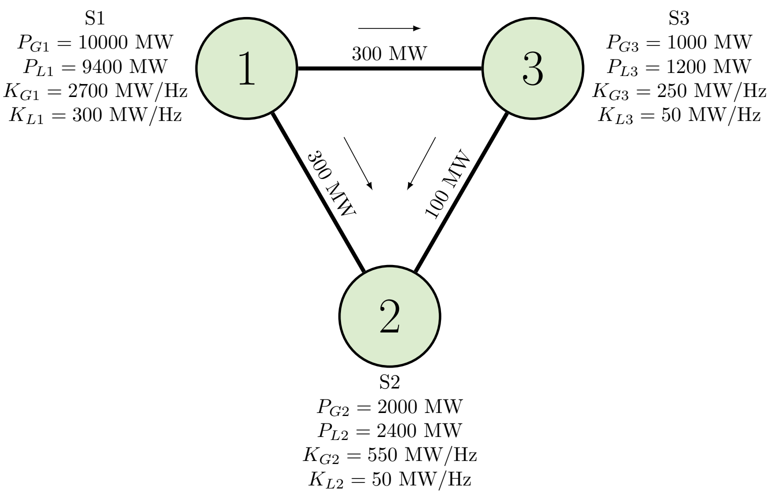
(15 bodova)



Slika 2: Spoj elektrane s dva agregata s krutom mrežom

Zadatak 4

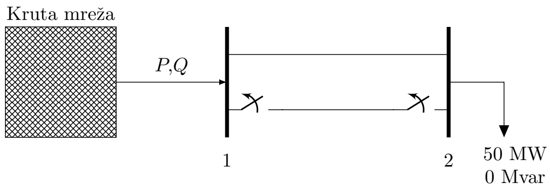
Tri sustava rade u interkonekciji (Slika 3). Joža je dispečer u operatoru sustava 1. Joži je ispao tanjur s grahom na tipkovnicu i slučajno je isključio vod između sustava 1 i 3. Sekvencijalno opišite što će se dogoditi od tog trenutka pa sve do konačnog stacionarnog stanja. Navedite i naznačite sva međustanja. Potrebno je izračunati konačno stanje u svim sustavima te sva međustanja kroz koja sustavi prolaze. Maksimalno dozvoljeno opterećenje svih vodova iznosi 500 MW. Preopterećeni vod prekostrujna zaštita automatski isključuje. Svi sustavi jednako sudjeluju u sekundarnoj regulaciji.
(10 bodova)



Slika 3: Tri sustava u interkonekciji

Zadatak 5

U slabo opterećenim visokonaponskim mrežama regulacija napona može se vršiti isključivanjem dalekovoda. Za koliko se promjeni napon sabirnice 2 ako se isključi jedan dalekovod (Slika 4)? Pri oba dalekovoda uključena, kruta mreža u dvostruki dalekovod injektira $P = 50.4$ MW i apsorbira $Q = 63.5$ Mvar. Ako se jedan dalekovod isključi, kruta mreža u dalekovod injektira $P = 50.6$ MW i apsorbira $Q = 27.8$ Mvar. Napon krute mreže iznosi 220 kV. Parametri voda su sljedeći: $R = 0.05$ Ω/km, $L = 1.553$ mH/km, $C = 10.73$ nF/km. Parametri su izraženi po fazi za jedan dalekovod. Napon krute mreže iznosi 220 kV. Duljina dalekovoda je 200 km. Frekvencija sustava je 50 Hz.
(5 bodova)



Slika 4: Prijenos snage preko dalekovoda

Zadatak 6

Objasnite princip rada primarne regulacije frekvencije. Koji sve faktori utječu na dinamičko vladanje frekvencije nakon nastanka poremećaja i kako?
(3 boda)

Zadatak 7

Što je kritični kut uklanjanja kvara i kako se može odrediti? Skicirati krivulje za prijenos snage za različite vrste kvarova.
(2 boda)

Zadatak 8

Koji element je najveći potrošač jalove snage u EES-u? Kako se regulira proizvodnja/potrošnja jalove snage sinkronog generatora? Nacrtati sustav regulacije jalove snage sinkronog generatora.
(2 boda)

Zadatak 9

Što je slom napona i koji element EES-a je najčešći uzrok sloma napona? Skicirajte pojavu sloma napona u vremenskoj domeni.
(1 bod)

Zadatak 10

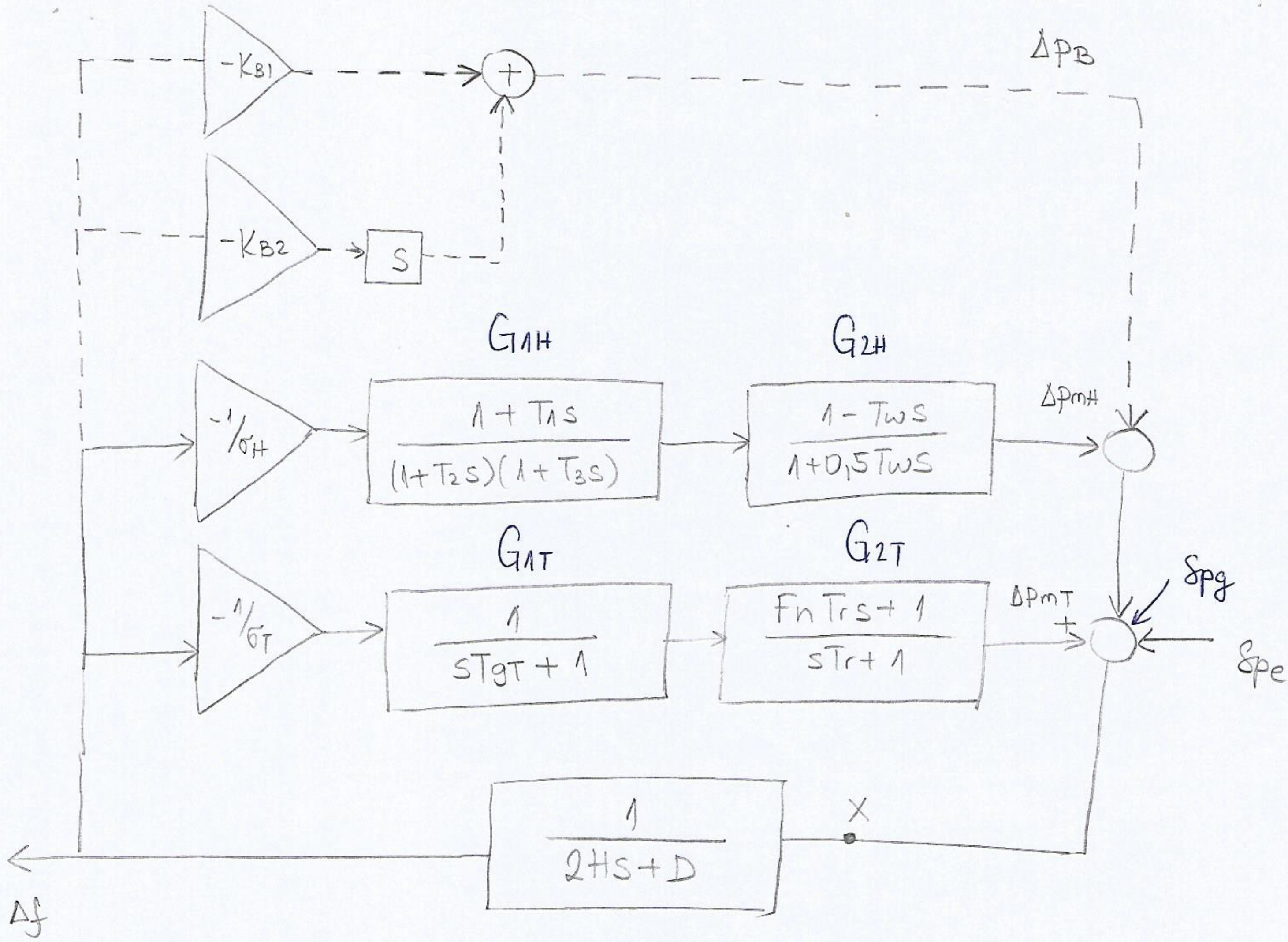
Koje vrste potrošača imaju regulacijsku energiju? Koja je uloga podfrekvencijskog rasterećenja?
(1 bod)

Zadatak 11

Nabrojite i opišite načine kompenzacije jalove snage kondenzatorskim baterijama.
(1 bod)

ZIR 2019./2020.

ZADATAK 1.



$S_B = 500 GW$ $F_h = 0{,}3 pu$ $T_2 = 0{,}4s$ $T_b = 0{,}02s$

$D = 0{,}5$ p.u. $T_r = 6s$ $T_3 = 48s$

$T_{gT} = 0{,}2s$ $T_1 = 5s$ $T_w = 0{,}8s$

a) ispad elektrane od 3000 MW => $\delta p_g = -3000 MW$

$\Delta f_\infty > -200 mHz$

$K = ?$ (min. en. proizv.)

$$\delta p_g = -\frac{3000M}{500G} = -0{,}006 \text{ p.u.}$$

$\Delta f_\infty > -200 mHz \;/:50 \Rightarrow \Delta f_\infty > -0{,}004$ p.u.

$$\Delta f(2Hs + D) = X$$

poremećaj proizvodnje, poremećaj potrošnje

$$\left.\begin{array}{l} X = \Delta p_{mT}(s) + \Delta p_{mH}(s) + \delta p_g(s) - \underbrace{\delta p_e(s)}_{=0} \end{array}\right\} X = X$$

$$\begin{array}{c|c} t & s \\ \hline C & \frac{C}{s} \end{array}$$

$$\Delta p_{mT}(s) = \Delta f(s)\left(-\frac{1}{\sigma_T}\right) G_{1T}(s)\, G_{2T}(s)$$

$$\Delta p_{mH}(s) = \Delta f(s)\left(-\frac{1}{\sigma_H}\right) G_{1H}(s)\, G_{2H}(s)$$

$$\delta p_g(t) = -0{,}006 \text{ p.u.} \; / \mathcal{L}$$

$$\delta p_g(s) = -\frac{0{,}006}{s}$$

$$\Delta f(s) = \frac{\delta p_g(s)}{2Hs + D + \frac{1}{\sigma_T} G_{1T}(s) G_{2T}(s) + \frac{1}{\sigma_H} G_{1H}(s) G_{2H}(s)}$$

$$\Delta f_\infty = \lim_{s \to 0} \cancel{s} \frac{\frac{\delta p_g(0)}{\cancel{s}}}{\cancel{2H \cdot 0} + D + \frac{1}{\sigma_T} \underbrace{G_{1T}(0) G_{2T}(0)}_{1} + \frac{1}{\sigma_H} \underbrace{G_{1H}(0) G_{2H}(0)}_{1}}$$

$$\Delta f_\infty = \frac{\delta p_g}{D + \frac{1}{\sigma_T} + \frac{1}{\sigma_H}} = \frac{\delta p_g}{D + K_{uk}} > -0{,}004 \text{ p.u.}$$

$$\frac{-0{,}006}{0{,}5 + K_{uk}} > -0{,}004 \rightarrow K_{uk} > 1{,}5 - 1 \rightarrow \underline{\underline{K_{uk} > 1}}$$

SI :

$$K_{uk}^{SI} > 1 \text{ p.u. } \frac{S_B}{f_B} = \frac{500G}{50}, \quad K_{uk}^{SI} > 10 \frac{GW}{Hz}$$

b) poremećaj snage 5% = 0,05

max dozvoljeni RoCoF $0{,}5\ \frac{Hz}{s}$

$H_{min} = ?$

$G_{1H} \cdot G_{2H} = G_H \qquad G_{1T} \cdot G_{2T} = G_T$

$$\Delta f(s) = \frac{\delta p g}{2Hs + D + \frac{1}{\sigma_T} G_T(s) + \frac{1}{\sigma_H} G_H(s)}$$

t	s
$\frac{d}{dt}$ ∘—•	s
$\Delta f(t)$ ∘—•	$\Delta f(s)$
$\frac{d\Delta f(t)}{dt}$ ∘—•	$s\Delta f(s)$

$\boxed{s\Delta f(s) = \text{RoCoF}(s)} = ?$

$$s\Delta f(s) = \frac{s\delta p}{2Hs + D + \frac{1}{\sigma_H} G_H + \frac{1}{\sigma_T} G_T}$$

$$\boxed{\left.\frac{df}{dt}\right|_{t=0+} = \lim_{s\to\infty} s \cdot s\Delta f(s) = \lim_{s\to\infty} s^2 \Delta f(s)}$$

$$\boxed{\left.\frac{df}{dt}\right|_{t=0+} = \lim_{s\to\infty} s^{\cancel{2}} \frac{\frac{\delta p}{\cancel{s}}}{2Hs + D + \frac{1}{\sigma_T} G_T + \frac{1}{\sigma_H} G_H}}$$

$$= \lim_{s\to\infty} \frac{\delta p}{2H + \underbrace{\frac{D}{s}}_{0} + \underbrace{\frac{1}{s\sigma_T} G_T}_{0} + \underbrace{\frac{1}{s\sigma_H} G_H}_{0}}$$

Početni RoCoF je max RoCoF

$$\boxed{\left.\frac{df}{dt}\right|_{t\to 0} = \frac{\delta p}{2H} = \left.\frac{df}{dt}\right|_{max}}$$

$$\left.\frac{df}{dt}\right|_{max} < \frac{0{,}5\ \frac{Hz}{s}}{50 Hz} = 0{,}01\ \frac{pu}{s}$$

$$\frac{\delta p}{2H} < 0{,}01$$

$$H > \frac{\delta p}{2 \cdot 0{,}01} = \frac{0{,}05}{2 \cdot 0{,}01} = 2{,}5\,s$$

$$H \geq 2{,}5\,s$$

c) $H = 1\,s$

$K_{B2} = ?$

$$\left.\frac{df}{dt}\right|_{t=0+} < 2\,\frac{Hz}{s} \quad /:50 \rightarrow \frac{df}{dt} < 0{,}04\,\frac{pu}{s}$$

$$\left.\frac{df}{dt}\right|_{t=0+} = \lim_{s\to\infty}\left[s\cdot\Delta f(s)\right] \longrightarrow \boxed{\left.\frac{df}{dt}\right|_{t=0+} = \frac{-\delta p_e}{2H + K_{B2}}}$$

$$\left|\frac{-\delta p_e}{2H+K_{B2}}\right| < 0{,}04\,\frac{pu}{s}$$

$$2H + K_{B2} > \frac{1}{0{,}04}\left|-\delta p_e\right|$$

$$K_{B2} > \frac{1}{0{,}04}\left|-\delta p_e\right| - 2H$$

$$K_{B2} > \frac{1}{0{,}04}\cdot 0{,}1 - 2\cdot 1$$

$$\underline{K_{B2} > 0{,}5\,Hz}$$

d) $\sigma_{B1} = ?$ (min)

$\Delta f_\infty < \pm 0{,}15\,Hz$

$\delta p_e = 20\% = 0{,}2$

$\sigma_H = 0{,}04\,pu$

$\sigma_T = 0{,}08\,pu$

$$\Delta f(t\to\infty) = \lim_{s\to 0} s\,\Delta f(s) \longmapsto \boxed{\Delta f_\infty = \frac{-\delta p_e}{\frac{1}{\sigma_H} + \frac{1}{\sigma_T} + K_{B1} + D}}$$

$$\left|\Delta f_\infty\right| < \left|\frac{\pm 0{,}15}{50}\right|$$

$$\frac{\left|-\delta p_e\right|}{\frac{1}{\sigma_H} + \frac{1}{\sigma_T} + K_{B1} + D} < \left|\frac{\pm 0{,}15}{50}\right|$$

$$\frac{1}{\sigma_H} + \frac{1}{\sigma_T} + K_{B1} + D > \frac{50}{0{,}15}\left|-\delta p_e\right|$$

$$K_{B1} > \frac{50}{0{,}15}\left|-\delta p_e\right| - D - \frac{1}{\sigma_T} - \frac{1}{\sigma_H}$$

$$K_{B1} > \frac{50}{0{,}15}\cdot 0{,}2 - 0{,}5 - \frac{1}{0{,}08} - \frac{1}{0{,}04}$$

$$K_{B1} > 28{,}\dot{6}$$

$$\underline{\sigma_{B1} = 0{,}0349\,pu}$$

ZIR 2019./2020.

ZADATAK 2.

$$\frac{1}{K}\frac{d\delta}{dt} = (\omega - 1)$$

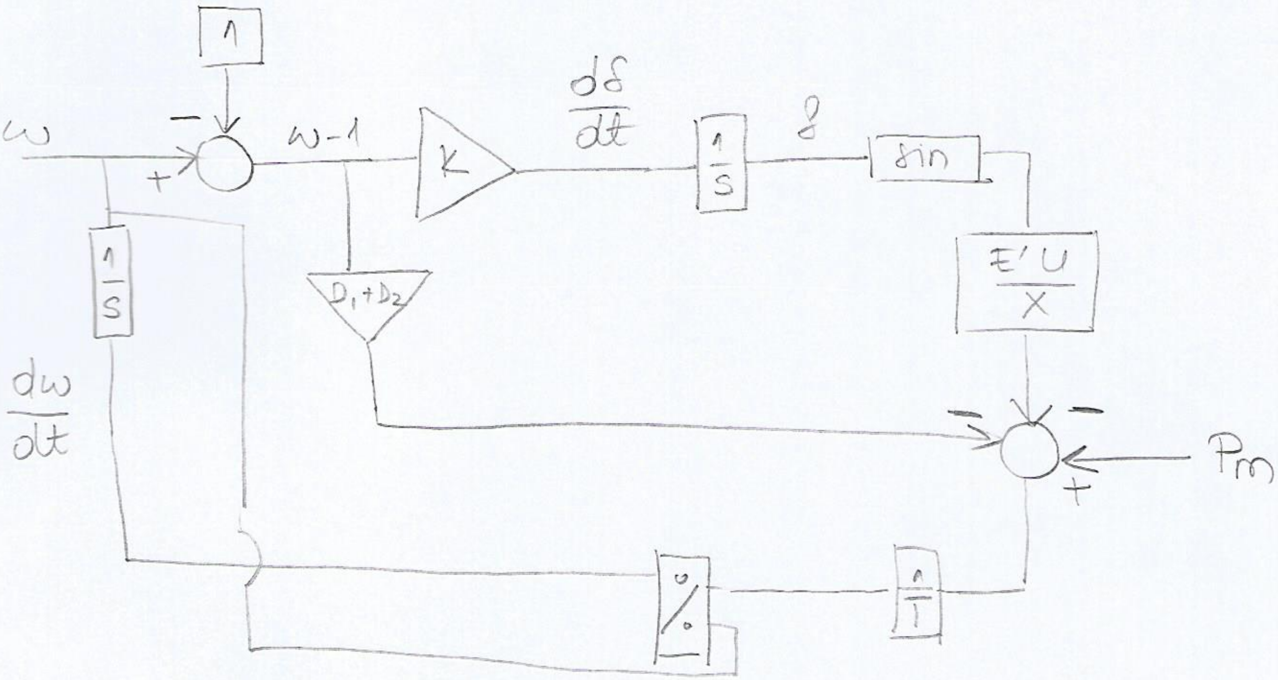
$$T\omega \frac{d\omega}{dt} + (D_1 + D_2)(\omega - 1) = P_m - \frac{E'U}{X}\sin\delta$$

T, K, P_m, E', U, X, D_1, D_2 konstante

δ, ω varijable stanja

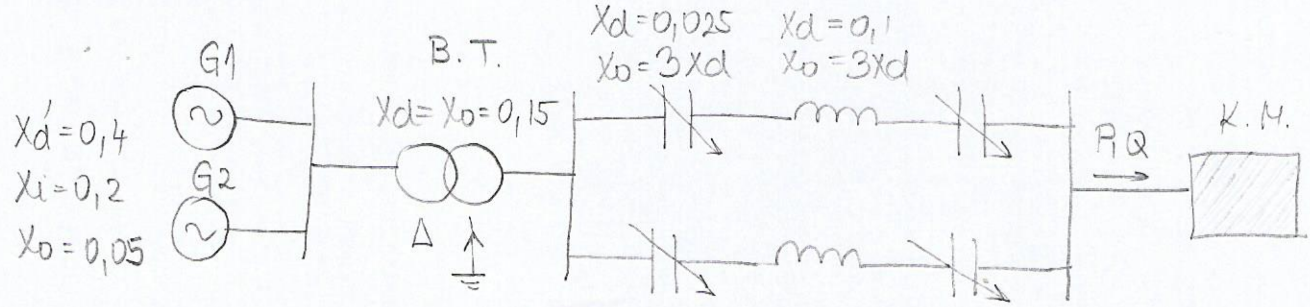
$$\frac{d\delta}{dt} = K(\omega - 1)$$

$$\frac{d\omega}{dt} = \frac{1}{T\omega}\left[P_m - \frac{E'U}{X}\sin\delta - (D_1 + D_2)(\omega - 1)\right]$$



ZIR 2019./2020.

ZADATAK 3.



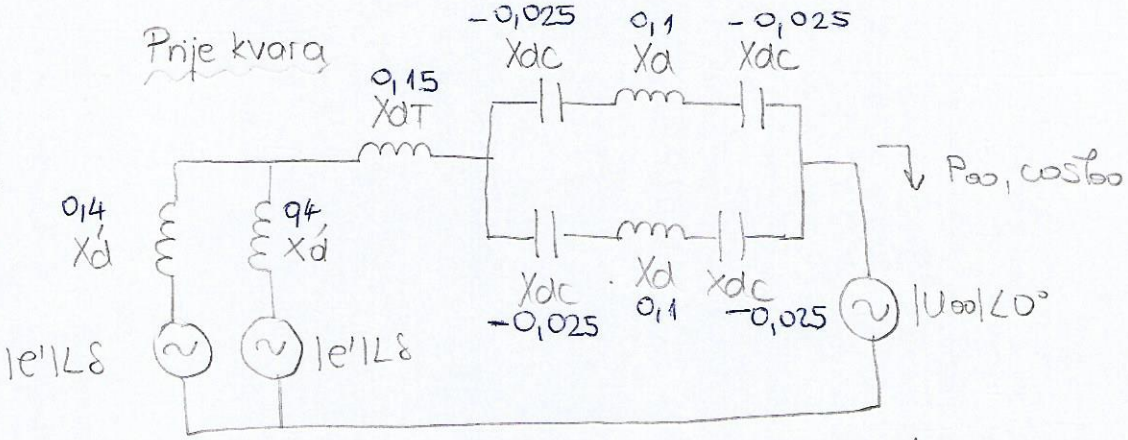
$P = 0,9$ p.u.

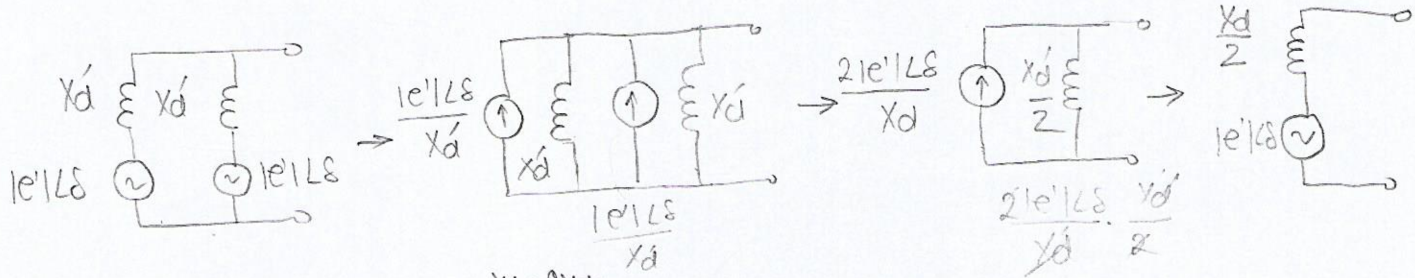
$\cos\varphi = 0,95$ kap.

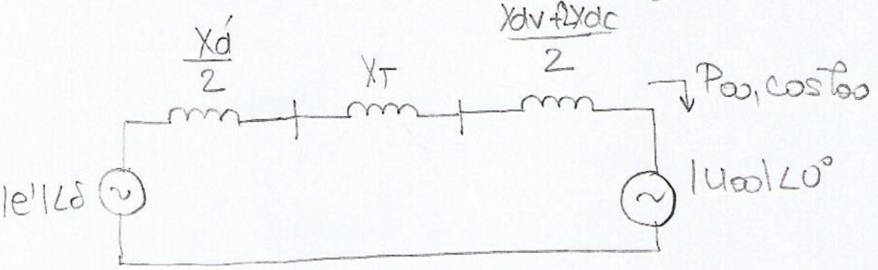
$U_\infty = 1\angle 0°$ p.u

2PKS, 50% dv

Prije kvara







$$X_d = \frac{X_d'}{2} + X_T + \frac{X_{dv} - 2X_{dc}}{2}$$

$$= 0,2 + 0,15 + \frac{0,1 - 2\cdot 0,025}{2}$$

$$= 0,375$$

$$|e'|\angle\delta_0 = |U_\infty|\angle 0 + i_\infty \cdot jX_d$$

$$i_\infty = \left(\frac{S}{U_\infty\angle 0}\right)^* = \left(\frac{P_\infty + jP_\infty \operatorname{tg}\varphi_\infty}{U_\infty\angle 0}\right)^* = 0,9 - j0,9\cdot \operatorname{tg}(\operatorname{acos}(-0,95)) =$$

$$= 0,9 + j0,296 = 0,947\angle 0,318 \text{ rad}$$

$$|e'|\angle\delta_0 = 1 + 0,947\angle 0,318 \cdot 0,375\angle \pi/2 = 0,889 + j0,337 = \underline{0,951\angle 0,362 \text{ rad}}$$

$|e'| = 0,951$

$\delta_0 = 0,362$ rad

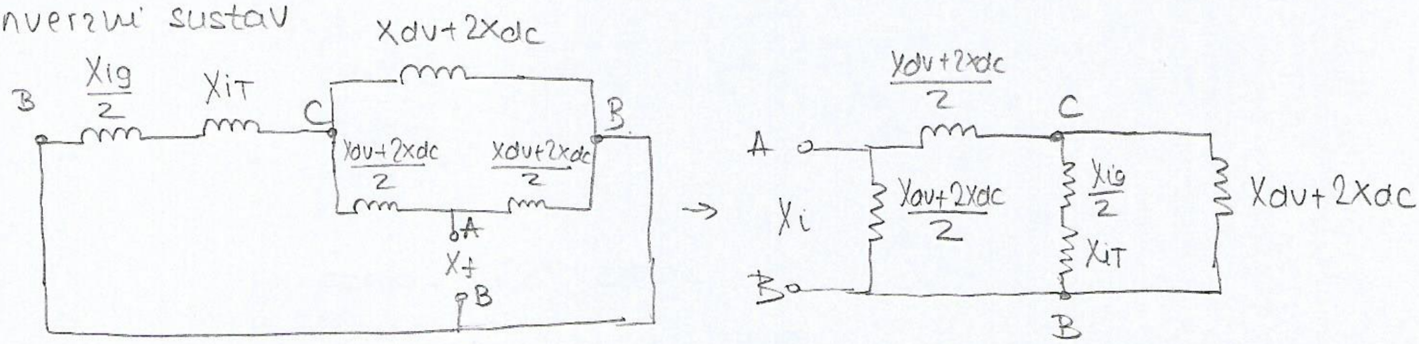
$P_m = 0,9$

$$P_d = \frac{0,951\cdot 1}{0,375}\sin\delta = 2,536\sin\delta$$

Za vrijeme kvara

- Kvar na 50% duljine dv
- 2PKS , $X_f = X_i$

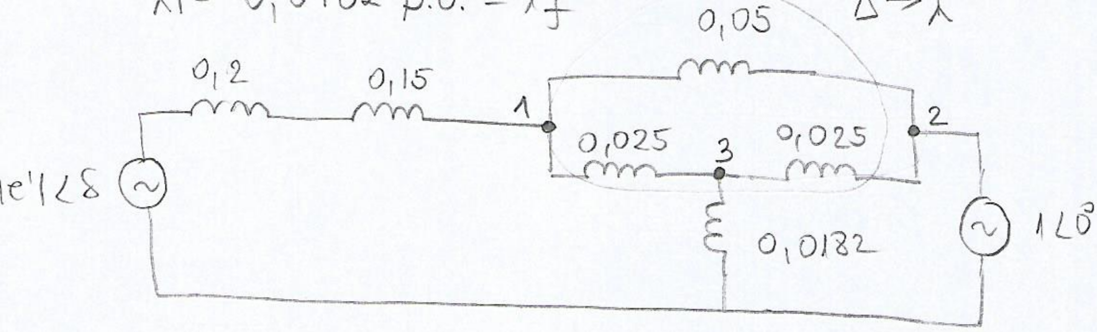
inverzni sustav



$$X_i = \left[\underbrace{(X_{dv}+2X_{dc})}_{0,05} \| \left(\underbrace{\frac{X_{ig}}{2} + X_{iT}}_{0,25} \right) + \underbrace{\frac{X_{dv}+2X_{dc}}{2}}_{0,025} \right] \| \underbrace{\frac{X_{dv}+2X_{dc}}{2}}_{0,025}$$

$X_i = 0,0182$ p.u. $= X_f$

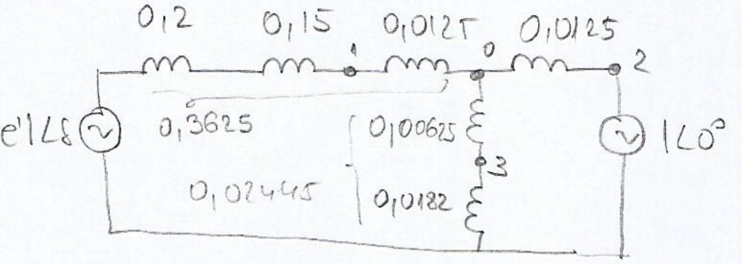
$\Delta \rightarrow \lambda$



$$X_{10} = \frac{X_{12} X_{13}}{X_{12}+X_{13}+X_{23}} = 0,0125$$

$$X_{20} = \frac{X_{12} X_{23}}{X_{12}+X_{13}+X_{23}} = 0,0125$$

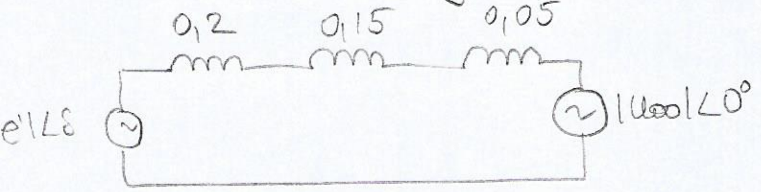
$$X_{30} = \frac{X_{13} X_{23}}{X_{12}+X_{13} X_{23}} = 0,00625$$



$$X_{AB} = X_L + X_D + \frac{X_L X_D}{X_{D0}} = 0,56 = X_\beta$$

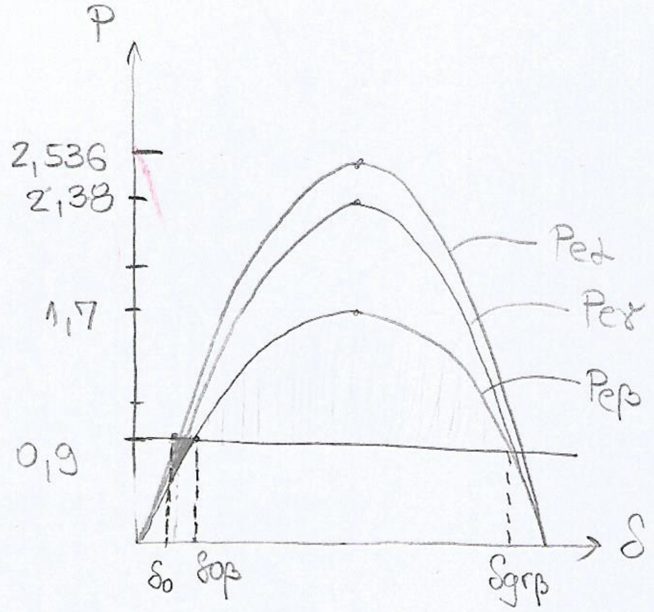
$$P_\beta = \frac{|e'||U_\infty|}{X_\beta} \sin\delta = \frac{0,951}{0,56} \sin\delta = \underline{\underline{1,7 \sin\delta}}$$

Nakon kvara (isključuje se vod)



$X_\gamma = 0,4$

$$P_\gamma = \frac{0,951}{0,4} \sin\delta = \underline{\underline{2,38 \sin\delta}}$$



$P_m = 0{,}9$

$P_\alpha = 2{,}536 \sin\delta$

$P_\beta = 1{,}7 \sin\delta$

$P_\gamma = 2{,}38 \sin\delta$

$A_d > A_a$

Sustav je stabilan.

$$A_a = \int_{\delta_0}^{\delta_{o\beta}} (p_m - 1{,}7\sin\delta)\,d\delta$$

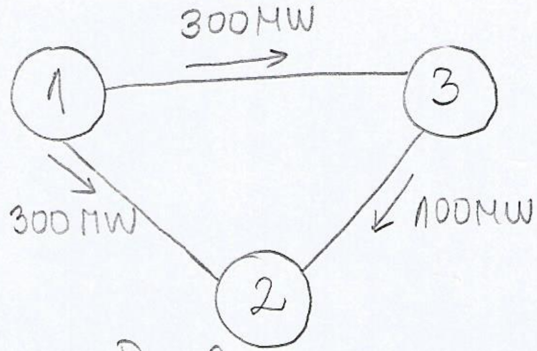
$$A_d = \int_{\delta_{o\beta}}^{\delta_{gr\beta}} (1{,}7\sin\delta - p_m)\,d\delta$$

ZIR 2019./2020.

4. ZADATAK

- interkonekcija
- isklj. vod 1-3
- max opt. 500MW
- sek. reg. : svi sustavi jednako sudjeluju

$P_{G1} = 10000\,MW$
$P_{L1} = 9400\,MW$
$K_{G1} = 2700\,MW/Hz$
$K_{L1} = 300\,MW/Hz$



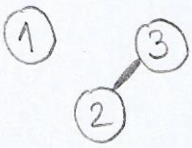
$P_{G3} = 1000$
$P_{L3} = 1200$
$K_{G3} = 250$
$K_{L3} = 50$

$P_{G2} = 2000$
$P_{L2} = 2400$
$K_{G2} = 550$
$K_{L2} = 50$

Isključen vod 1-3:

- sustav 1 vidi kao ispad potrošnje 600MW
- sustav 3 vidi kao ispad elektrane

SUSTAV 1



- 1 u otočnom pogonu
- gubitak potrošnje 600MW → frekv. raste

$$\boxed{\Delta f = \frac{\Delta P}{K_g + K_L}} = \frac{600}{3000} = +0{,}2\,Hz$$

$f = 50{,}2\,Hz$

Primarna:

$P_{g1}' = P_{g1} + \Delta P_{g1} + \delta P_{g1} = 10000 - 2700 \cdot 0{,}2 + 0 = 9460\,MW$

$P_{l1}' = P_{l1} + \Delta P_{l1} + \delta P_{l1} = 9400 + 300 \cdot 0{,}2 + 0 = 9460\,MW$

Sekundarna

$\Delta f = -0{,}2\,Hz \rightarrow f = 50\,Hz$, $\Delta P = \Delta f\,(K_g + K_l) = -0{,}2 \cdot 3000 = -600\,MW$

$P_{g1}'' = P_{g1}' + \Delta P_{g1}' + \delta P_{g1}' = 9460 - 2700 \cdot (-0{,}2) - 600 = 9400\,MW$

$P_{l1}'' = P_{l1}' + \Delta P_{l1}' + \delta P_{l1}' = 9460 + 300 \cdot (0{,}2) + 0 = 9400\,MW$

SUSTAV 2-3

Ispad proizvodne jedinice 600MW → Fr. se smanjila

$\Delta f = \frac{-600}{900} = -0{,}667\,Hz \rightarrow f = 49{,}33\,Hz$

$P_{g2}' = P_{g2} + \Delta P_{g2} + \delta P_{g2} = 2000 - (-0{,}667) \cdot 550 + 0 = 2366{,}85\,MW$

$P_{g3}' = P_{g3} + \Delta P_{g3} + \delta P_{g3} = 1000 - (-0{,}667) \cdot 250 + 0 = 1166{,}75\,MW$

$P_{l2}' = P_{l2} + \Delta P_{l2} + \delta P_{l2} = 2400 + (-0{,}667) \cdot 50 + 0 = 2366{,}65\,MW$

$P_{l3}' = P_{l3} + \Delta P_{l3} + \delta P_{l3} = 1200 + (-0{,}667) \cdot 50 + 0 = 1166{,}65\,MW$

$\sum P_g' \approx \sum P_l'$

Sekundarna regulacija

$\Delta f = +0,667 Hz$, $f = 50 Hz$

$P_{g2}'' = P_{g2}' + \Delta P_{g2}' + \delta P_{g2}' = 2366,85 - (-0,667) \cdot 550 + 300 = 2300 MW$

$P_{g3}'' = P_{g3}' + \Delta P_{g3}' + \delta P_{g3}' = 1166,75 - (-0,667) \cdot 250 + 300 = 1300 MW$

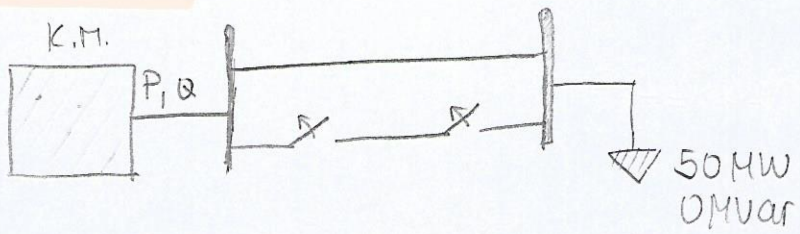
$P_{l2}'' = P_{l2}' + \Delta P_{l2}' + \delta P_{l2}' = 2366,85 + (-0,667) + 0 = 2400 MW$

$P_{l3}'' = P_{l3}' + \Delta P_{l3}' + \delta P_{l3}' = 1166,75 + (-0,667) + 0 = 1200 MW$

$$\sum P_g'' \approx \sum P_l''$$

XIR 2019./2020.

5. ZADATAK



$\Delta U_2 = ?$

Oba dv uključena:

$P = 50{,}4\,MW$

$Q = 63{,}5\,Mvar$

Jedan dv uključen

$P = 50{,}6\,MW$

$Q = 27{,}8\,Mvar$

$U = 220\,kV$

$R = 0{,}05\,\frac{\Omega}{km}$

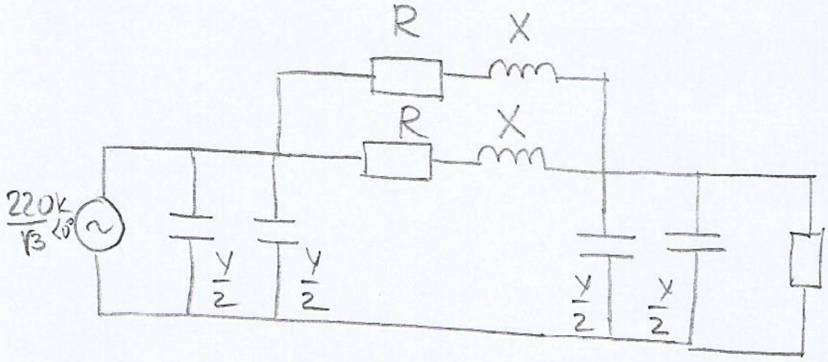
$L = 1{,}553\,\frac{mH}{km}$

$C = 10{,}73\,\frac{nF}{km}$

$l = 200\,km$

$f = 50\,Hz$

2 dalekovoda:



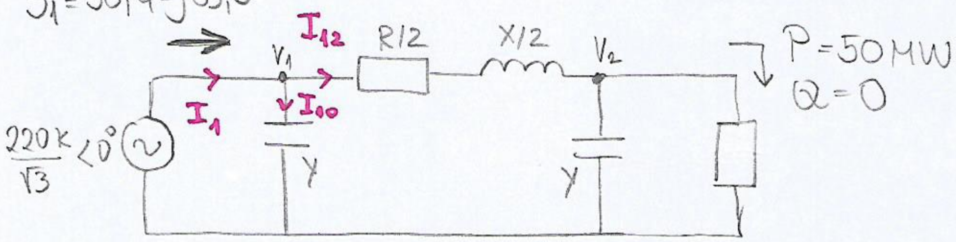
$R = R \cdot l = 0{,}05 \cdot 200 = 10\,\Omega$

$X = \omega L \cdot l = 2\pi \cdot 50 \cdot 1{,}553m \cdot 200 = 97{,}6\,\Omega$

$y = j\omega C \cdot l = j2\pi \cdot 50 \cdot 10{,}73n \cdot 200 = j0{,}674 \cdot 10^{-3}\,\Omega^{-1}$

$\frac{y}{2} + \frac{y}{2} = y$

$S_1 = 50{,}4 - j63{,}5$



$$I_1 = \left(\frac{S_1}{\sqrt{3}U_1}\right)^*$$

$$I_{10} = V_1 \cdot y = \frac{U_1}{\sqrt{3}} \cdot y$$

$$I_{12} = \left(\frac{S_1}{\sqrt{3}U_1}\right)^* - \frac{U_1}{\sqrt{3}}y$$

$\downarrow$

$I_{12} = I_1 - I_{10}$

$U_1 = 220\angle 0°\,kV$

$V_1 = \frac{220\angle 0°}{\sqrt{3}}\,kV$

$$V_2 = V_1 - I_{12}\left(\frac{R}{2} + j\frac{X}{2}\right)$$

(FAZNI NAPON)

$$U_2 = V_2\sqrt{3} = U_1 - I_{12}\left(\frac{R}{2} + j\frac{X}{2}\right)\sqrt{3}$$

(LINIJSKI NAPON)

$$I_1 = \left(\frac{S_1}{\sqrt{3}U_1}\right)^* = \left(\frac{150,4 - j63,5M}{\sqrt{3}\cdot 220\angle 0°(k)}\right)^* = 132,26 + j166,64\ A$$

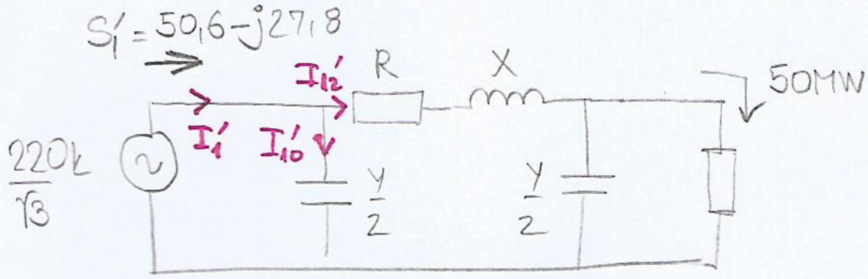
$$I_{10} = \frac{U_1}{\sqrt{3}}\cdot y = \frac{220k}{\sqrt{3}}\cdot 0,674\cdot 10^{-3}\angle -90° = -j85,61\ A$$

$$I_{12} = I_1 - I_{10} = 132,26 + j166,64 + j85,61 = 132,26 - j81,03\ A$$
$$= 155,11\angle\ 0,55\ A$$

$$V_2 = V_1 - I_{12}\left(\frac{R}{2} + j\frac{X}{2}\right) = \frac{220k}{\sqrt{3}} - 155,11\angle +0,55 \cdot 49,05\angle 1,469$$
$$= \frac{220k}{\sqrt{3}} + 3296,97 - j6856,67 =$$
$$= 130494\angle \approx 0 \Rightarrow U_2 = V_2\cdot\sqrt{3}$$

$$U_2 = 226\ kV$$

1 dalekovod:



$$I_1' = \left(\frac{S_1'}{\sqrt{3}U_1}\right)^* = \frac{50,6 + j27,8M}{\sqrt{3}\cdot 220k} = 132,79 + j72,96 = 151,51\angle 0,502$$

$$I_{10}' = \frac{U_1}{\sqrt{3}}\cdot\frac{Y}{2} = \frac{220k}{\sqrt{3}}\cdot\frac{0,674\cdot 10^{-3}}{2}\angle \pi/2 = +j42,8$$

$$I_{12}' = I_1' - I_{10}' = 132,79 + j72,96 - j42,8 = 136,2\angle 0,223$$

$$V_2' = V_1' - I_{12}'(R + jX) = \frac{220k}{\sqrt{3}} - 136,2\angle 0,223 \cdot 98,11\angle 1,469 =$$
$$= 129,3\ kV$$

$$U_2' = V_2'\cdot\sqrt{3} = 224\ kV$$

$$\Delta U = |U_2'| - |U_2| = -2\ kV$$