Zadatak 1

Tri sustava rade paralelno. Snage proizvodnje i potrošnje u sustavima zadani su u tablici ispod. Što će se dogoditi ako se istodobno smanji proizvodnja u sustavima 1 i 2 za po 100 MW svaki. Odstupanja u ravnoteži proizvodnje i potrošnje do 10 MW su dopuštena.
Izračunati konačno stanje u svim sustavima te sva međustanja koja sustavi prolaze prije novog konačnog stacionarnog stanja. U sekundarnoj regulaciji sudjeluje samo sustav 3.
(9 bodova)

Proizvodnja		Potrošnja	
Snaga	Regulacijska energija	Snaga	Regulacijska energija
$P_{g1} = 400$ MW	$K_{g1} = 150\ \frac{\text{MW}}{\text{Hz}}$	$P_{l1} = 200$ MW	$K_{l1} = 50\ \frac{\text{MW}}{\text{Hz}}$
$P_{g2} = 350$ MW	$K_{g2} = 250\ \frac{\text{MW}}{\text{Hz}}$	$P_{l2} = 300$ MW	$K_{l2} = 100\ \frac{\text{MW}}{\text{Hz}}$
$P_{g3} = 550$ MW	$K_{g3} = 300\ \frac{\text{MW}}{\text{Hz}}$	$P_{l3} = 800$ MW	$K_{l3} = 100\ \frac{\text{MW}}{\text{Hz}}$

Zadatak 2

Na slici 1 prikazan je vjetroagregat kojem je rotor turbine povezan s rotorom generatora preko idealnog multiplikatora s prijenosnim omjerom $1 : n$; drugim riječima, mehanička brzina rotora generatora n je puta veća od mehaničke brzine rotora turbine:

$$\omega_g = n \cdot \omega_t = 100 \cdot \omega_t \tag{1}$$

Moment tromosti turbine iznosi $J_t = 5 \cdot 10^6$ kgm^2, a moment tromosti 6-polnog generatora iznosi $J_g = 100$ kgm^2. Nazivna snaga vjetroagregata iznosi 2 MVA, dok je frekvencija mreže 50 Hz. Potrebno je izračunati:

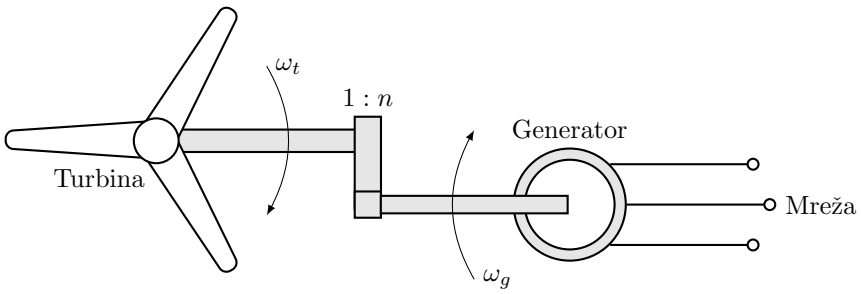
a) konstantu tromosti turbine H_t pri sinkronoj brzini

b) konstantu tromosti generatora H_g pri sinkronoj brzini;

c) ukupnu konstantu tromosti vjetroagregata H pri sinkronoj brzini;

d) promjenu kinetičke energije vjetroagregata ako se brzina vrtnje rotora smanji s 1 p.u. sinkrone brzine na 0.8 p.u. sinkrone brzine.

(8 bodova)



Slika 1: Vjetroagregat

Zadatak 3

Neka elektrana spojena je na krutu mrežu preko blok-transformatora, dalekovoda i tronamotnog energetskog transformatora prema slici 2. Tercijar (T) tronamotnog transformatora napaja lokalnu potrošnju $P_L = 0.1$ p.u., $\cos\varphi_L = 1.00$. Potrošnju modelirajte kao konstantnu impedanciju koja bi trošila zadanu snagu pri naponu $|v_L| = |v_5| = 1.0$ p.u. Sekundarom (S) tronamotnog transformatora smatrajte namot priključen na sabirnicu 4.

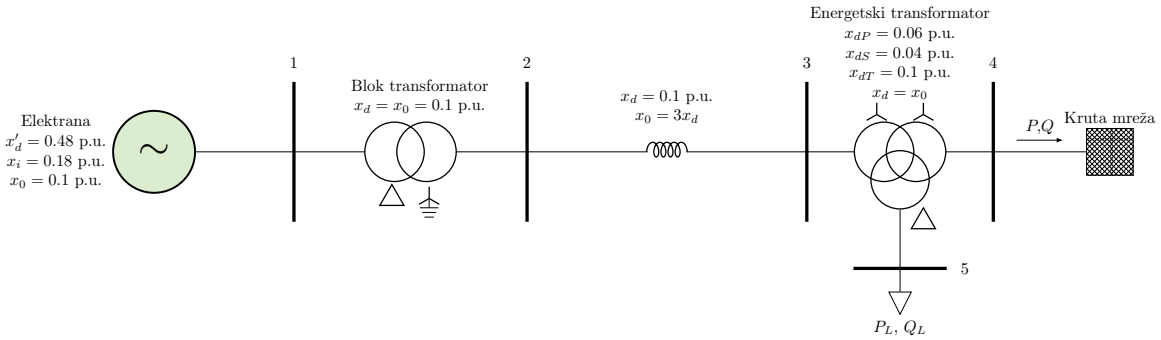
Elektrana u poduzbuđenom režimu rada u krutu mrežu predaje snagu $P = 0.7$ p.u. pri $\cos\varphi = 0.95$. Napon krute mreže iznosi $1\angle 0^{\circ}$ p.u. Na polovici dalekovoda nastaje dvopolni kratki spoj sa zemljom. Potrebno je 1) odrediti kritični kut uklanjanja kvara i 2) nacrtati nadomjesnu shemu 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 prolaska kratkog spoja (bez isključenja voda).

(15 bodova)



Slika 2: Spoj elektrane s krutom mrežom

Zadatak 4

Na slici 3 prikazan je dvostruki dalekovod u praznom hodu. Za koliko se promjeni napon sabirnice 2 ako se uključi prigušnica u spoju zvijezda nazivne snage $S_n = 50$ MVA (nazivna snaga odnosi se na nazivni napon prigušnice 220 kV)? Napon krute mreže iznosi 220 kV. Parametri voda su sljedeći: $R = 0.05\Omega$/km, $L = 1.553$ mH/km, $C = 10.73$ nF/km. Parametri su izraženi po fazi za jedan dalekovod. Duljina dalekovoda je 200 km. Frekvencija sustava je 50 Hz.
(8 bodova)

Slika 3: Dalekovod u praznom hodu

Zadatak 5

Nacrtajte fazorski dijagram sustava sa slike 2 u direktnom sustavu prije nastanka kvara. Zanemarite grupu spoja i satni broj transformatora u modelu.
(5 bodova)

Zadatak 6

Dva trofazna asinkrona motora opterećena nazivnim mehaničkim opterećenjem ($P_{n1}^m = 3$ MW, $\cos\varphi_1 = 0.8$, $\eta_1 = 0.95$, $P_{n2}^m = 4.0$ MW, $\cos\varphi_2 = 0.70$, $\eta_2 = 0.98$) paralelno su priključena na zajedničke sabirnice u mreži nazivnog napona 1 kV. η predstavlja učinkovitost motora. Potrebno je izračunati:

a) ukupnu struju koja teče iz mreže prema sabirnicama na koje su motori priključeni;

b) cos φ na predmetnim sabirnicama;

c) snagu kondenzatorske baterije koju treba paralelno priključiti na motorske sabirnice da bi na njima cos φ iznosio 0.95; zašto se kompenzira do tog iznosa cos φ?

d) Koliko iznosi kapacitet kondenzatorske baterije po fazi ako je ona spojena u spoj trokut?

(5 bodova)

KIR 2019./2020.

1. ZADATAK

PROIZVODNJA		POTROŠNJA	
Snaga	Reg.en.	Snaga	Reg.en
$P_{g1} = 400$	$K_{g1} = 150$	$P_{l1} = 200$	$K_{l1} = 50$
$P_{g2} = 350$	$K_{g2} = 250$	$P_{l2} = 300$	$K_{l2} = 100$
$P_{g3} = 550$	$K_{g3} = 300$	$P_{l3} = 800$	$K_{l3} = 100$

$\delta_{g1} = \delta_{g2} = -100\,MW$

Sekundarna regul. → Sustav 3

Smanjila se proizv → Freku. se smanj

$$\Delta f = \frac{-200}{700+250} = -0,2\,Hz$$

$\Delta P_{g1} = -K_{g1} \cdot \Delta f = -150 \cdot (-0,2) = 30\,MW$

$\Delta P_{g2} = 50\,MW$

$\Delta P_{g3} = 60\,MW$

$\Delta P_{e1} = K_{e1} \cdot \Delta f = 50 \cdot (-0,2) = -10\,MW$

$\Delta P_{e2} = -20\,MW$

$\Delta P_{e3} = -20\,MW$

$P_{g1}' = P_{g1} + \Delta P_{g1} + \delta P_{g1} = 400 + 30 - 100 = 330\,MW$

$P_{g2}' = P_{g2} + \Delta P_{g2} + \delta P_{g2} = 350 + 50 - 100 = 300\,MW$

$P_{g3}' = P_{g3} + \Delta P_{g3} + \delta P_{g3} = 550 + 60 + 0 = 610\,MW$

$\Sigma P_g' = \Sigma P_e'$

$1240 \approx 1250$

$P_{e1}' = P_{e1} + \Delta P_{e1} + \delta P_{l1} = 200 - 10 + 0 = 190\,MW$

$P_{e2}' = P_{e2} + \Delta P_{e2} + \delta P_{l2} = 300 - 20 + 0 = 280\,MW$

$P_{l3}' = P_{l3} + \Delta P_{e3} + \delta P_{l3} = 800 - 20 + 0 = 780\,MW$

Sekundarna regulacija: $\Delta f = +0,2\,Hz$

$\Delta P = \Delta f (\Sigma K_g + \Sigma K_e) = 0,2 \cdot 950 = 190\,MW$

$\Delta P_{g1}' = -30\,MW$

$\Delta P_{g2}' = -50\,MW$

$\Delta P_{g3}' = -60\,MW$

$\Delta P_{e1}' = 10\,MW$

$\Delta P_{l2}' = 20\,MW$

$\Delta P_{l3}' = 20\,MW$

$P_{g1}'' = P_{g1}' + \Delta P_{g1}' + \delta P_{g1}' = 330 - 30 + 0 = 300\,MW$

$P_{g2}'' = 300 - 50 + 0 = 250\,MW$

$P_{g3}'' = 610 - 60 + 190 = 740\,MW$

$P_{e1}'' = 190 + 10 + 0 = 200\,MW$

$P_{l2}'' = 280 + 20 + 0 = 300\,MW$

$P_{l3}'' = 780 + 20 + 0 = 800\,MW$

KIR 2019./2020.

2. ZADATAK

$\omega_g = n \cdot \omega_t = 100\omega_t$

$J_t = 5 \cdot 10^6 \text{ kgm}^2$

$p = 3$

$J_g = 100 \text{ kgm}^2$

$S_n = 2 \text{ MVA}$

$f = 50 \text{ Hz}$

---

a) $H_t = ?$

b) $H_g = ?$

c) $H_{uk} = ?$

d) $\Delta E_k = ?$

1 p.u. → 0.8 p.u.

$$\omega_g = 2\pi f_g = 2\pi \frac{f_n}{p} = 2\pi \frac{50}{3} = \frac{100\pi}{3} \frac{\text{rad}}{\text{s}}$$

$$\omega_t = \frac{\omega_g}{100} = \frac{\pi}{3} \frac{\text{rad}}{\text{s}}$$

$$E_{kg} = \frac{J\omega_g^2}{2} = \frac{100 \cdot \left(\frac{100\pi}{3}\right)^2}{2} = 548311 \text{ Ws}$$

$$E_{kt} = \frac{J\omega_t^2}{2} = \frac{5 \cdot 10^6 \left(\frac{\pi}{3}\right)^2}{2} = 2741556 \text{ Ws}$$

a) $H_t = \frac{E_{kt}}{S_n} = \frac{2741556}{2M} = 1{,}37 \text{ s}$

b) $H_g = \frac{E_{kg}}{S_n} = \frac{548311}{2M} = 0{,}274 \text{ s}$

c) $H_{uk} = \frac{\Sigma H_i S_i}{S_n} = \frac{1{,}37 \cdot 2M + 0{,}274 \cdot 2M}{2M} = 1{,}6 \text{ s}$

d) 1 p.u. → 0,8 p.u

$$E_{kg}' = \frac{J(0{,}8\omega_g)^2}{2} = 0{,}8^2 E_{kg}$$

$$E_{kt}' = 0{,}8^2 E_{kt}$$

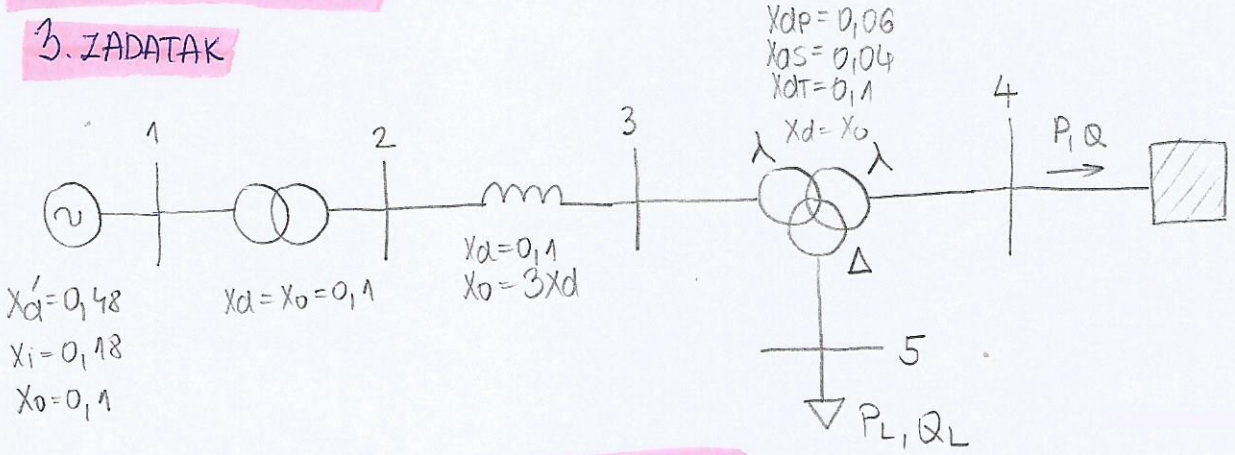
$$\Delta E_k = E_k' - E_k$$

$$= 0{,}8^2 E_{kuk} - E_{kuk}$$

$$= -1184352{,}12 \text{ Ws}$$

KIR 2019./2020.

3. ZADATAK



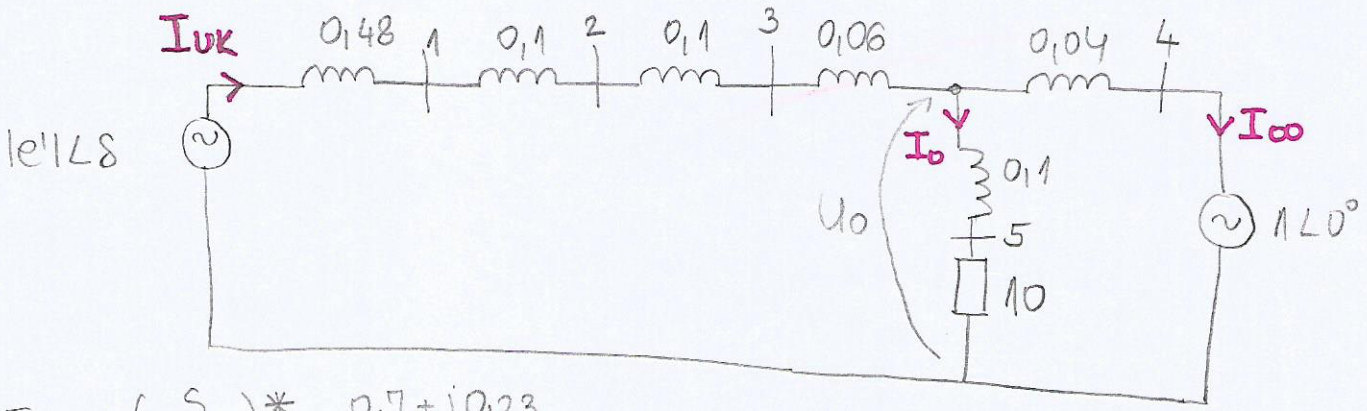
$P_L = 0,1$ p.u.
$\cos\varphi_L = 1$
$|U_L| = |U_5| = 1$ p.u.

$$Z_L = \frac{U^2}{P_.} = \frac{1}{0,1} = 10\Omega$$

$P = 0,7$
poduzb. režim
$\cos\varphi = 0,95$ (kap)
$U_\infty = 1$ p.u.

$$Q = P_. \cdot tg[\arccos(-0,95)] = 0,7 \cdot tg[\arccos(-0,95)] = -0,23 \text{ p.u.}$$

2PKSŽ, 50% DV



$$I_\infty = \left(\frac{S}{U_\infty}\right)^* = \frac{0,7 + j0,23}{1} = 0,7 + j0,23$$

$$U_o = U_\infty + jI_\infty \cdot 0,04 = 1 + j0,04(0,7 + j0,23) = 0,9908 + j0,028 = 0,991\angle 0,028$$

$$I_o = \frac{U_o}{Z} = \frac{0,991\angle 0,028}{10\angle 0,01} = 0,0991\angle 0,018 = 0,099 + j1,78 \cdot 10^{-3}$$

$$I_{UK} = I_\infty + I_o = 0,832\angle 0,282$$

$$|e'|\angle\delta = I_{UK} \cdot j(0,148 + 0,1 + 0,1 + 0,06) + U_o =$$
$$= 0,832\angle 0,282 \cdot 0,74\angle \pi/2 + 0,9908 + j0,028 =$$
$$= -0,171 + j0,591 + 0,9908 + j0,028 =$$
$$= 1,027\angle 0,647$$

$|e'| = 1,027$
$\delta_0 = 0,647$ rad

$$Z_d = X_L + X_D + \frac{X_L X_D}{X_{DO}} = j0,74 + j0,04 - \frac{0,0296}{10\angle 0,01} = 0,78 + 2,9\cdot 10^{-3} + j2,95\cdot 10^{-5}$$

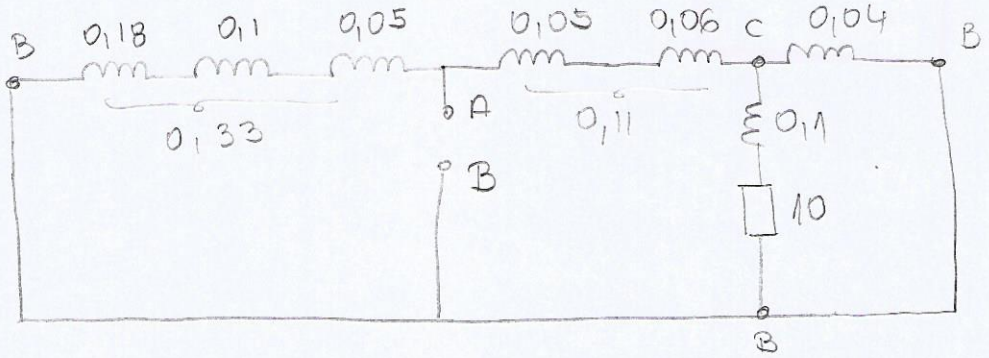
$$X_d \approx 0,78$$

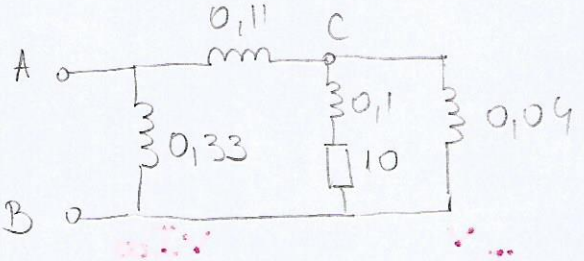
$$P_d = \frac{|e'||U_{00}|}{X_d}\sin\delta = \frac{1,027}{0,78}\sin\delta = 1,317\sin\delta$$

$$P_m = 0,8$$

ZA VRIJEME KVARA

$X_f = \frac{X_i X_0}{X_i + X_0}$, 50% dV, Inverzni sustav:



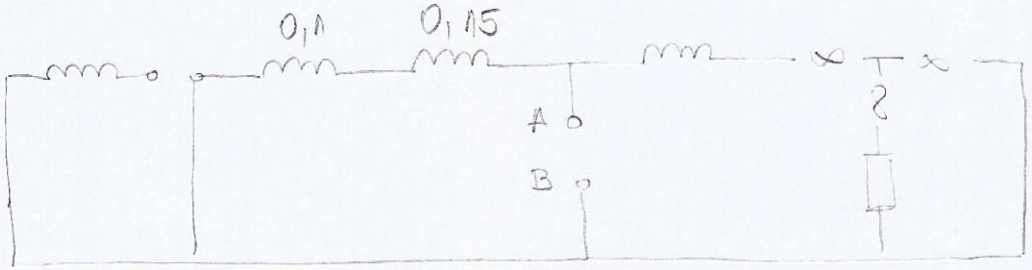


$$X_i = X_{AB} = \left[(j0,04) \,||\, (10 + j0,1) + j0,11 \right] || \, j0,33 =$$

$$= \left[\frac{0,04\angle 90^\circ \cdot 10\angle 0,573^\circ}{10\angle 0,8^\circ} + j0,11 \right] || \, j0,33 =$$

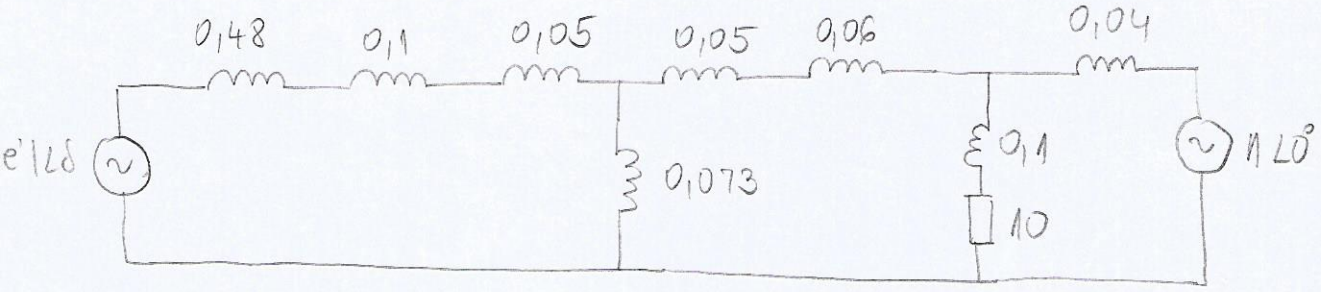
$$= \left[j0,04 + j0,11 \right] || \, j0,33 = j0,103125$$

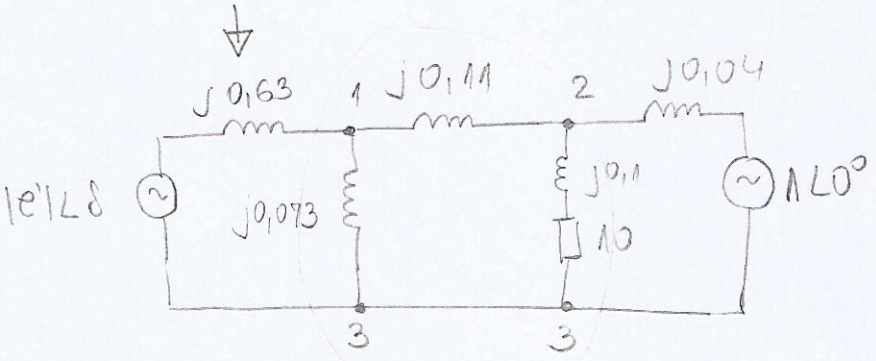
Nulti sustav:



$$jX_0 = jX_{AB} = j0,1 + j0,15 = j0,25$$

$$X_F = \frac{X_0 X_i}{X_0 + X_i} = 0,073 \text{ p.u.}$$



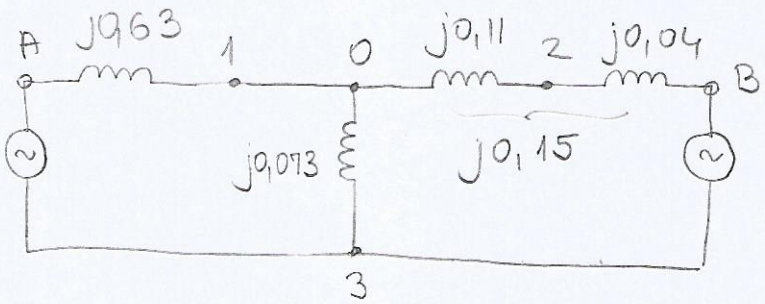


$$X_{10} = \frac{X_{12}X_{13}}{X_{12}+X_{13}+X_{23}} = \frac{0,00803\angle 180^\circ}{10\angle 1,62^\circ} \approx 0$$

N

$$X_{20} = \frac{X_{12}X_{23}}{X_{12}+X_{13}+X_{23}} = \frac{1,1\angle 90^\circ}{N} = j0,11$$

$$X_{30} = \frac{X_{13}\cdot X_{23}}{X_{12}+X_{13}+X_{23}} = \frac{0,73\angle 90^\circ}{N} = j0,073$$



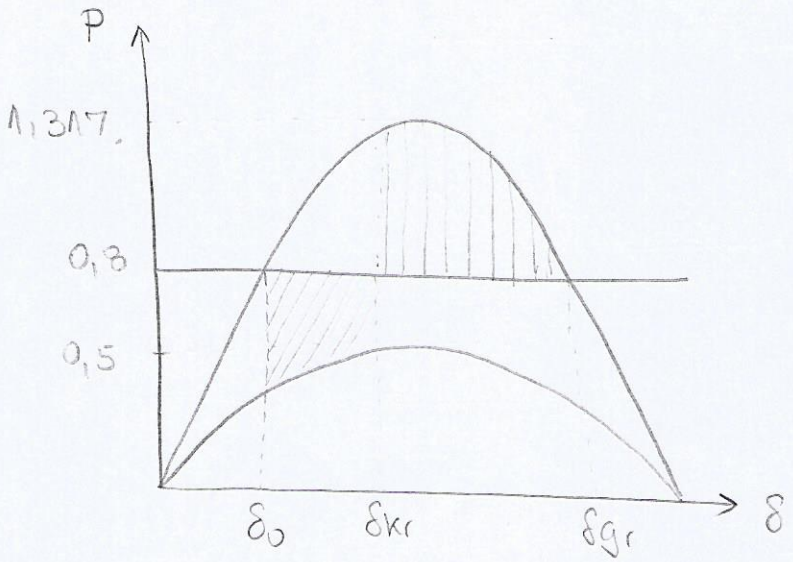
$\lambda \rightarrow \Delta$

$$jX_\beta = X_{AB} = X_L + X_D + \frac{X_L X_D}{X_{DO}} = j0,63 + j0,15 + \frac{j0,63 \cdot j0,15}{j0,073} = j2,074$$

$$P_{e\beta} = \frac{|e'||U_{oo}|}{X_\beta}\sin\delta = \frac{1,027}{2,074}\sin\delta = 0,5\sin\delta$$

NAKON KVARA

$$P_{e\gamma} = P_{ed} = 1,317\sin\delta$$



$P_m = 0,8$

$P_2 = 1,317 \sin\delta$

$P_b = 0,5 \sin\delta$

$P_y = 1,317 \sin\delta$

$P_m = P_2 \sin\delta_{gr} \rightarrow \sin\delta_{gr} = \frac{P_m}{P_2} = 0,6 \rightarrow \delta_{gr}' = 37°$

$\delta_{gr} = \pi - \delta_{gr}' = 143° = 2,49$ rad

$Aa = Ad$

$$\int_{\delta_0}^{\delta_{kr}} (p_m - P_\beta)\, d\delta = \int_{\delta_{kr}}^{\delta_{gr}} (P_2 - p_m)\, d\delta$$

$$P_m(\delta_{kr} - \delta_0) - P_B(-\cos\delta_{kr} + \cos\delta_0) = P_2(-\cos\delta_{gr} + \cos\delta_{kr}) - p_m(\delta_{gr} - \delta_{kr})$$

$$P_m\delta_{kr} - P_m\delta_0 + P_B\cos\delta_{kr} - P_B\cos\delta_0 = P_2\cos\delta_{kr} - P_2\cos\delta_{gr} - p_m\delta_{gr} + p_m\delta_{kr}$$

$$\cos\delta_{kr}(P_\beta - P_2) = p_m(\delta_0 - \delta_{gr}) + P_\beta\cos\delta_0 - P_2\cos\delta_{gr}$$

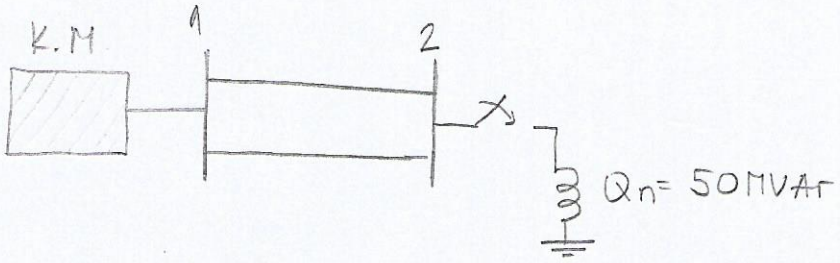
$$\cos\delta_{kr}(0,5 - 1,317) = 0,8(0,647 - 2,49) + 0,5 \cdot \cos(0,647) - 1,317\cos(2,49)$$

$$-0,217\cos\delta_{kr} = -0,028, \quad \cos\delta_{kr} \frac{-0,028}{-0,817}$$

$\delta_{kr} = 1,54$ rad $\approx 90°$

KIR 2019./2020.

4. ZADATAK



$S_n = 50MVA$

prigušnica

$U = 220kV$

$R = 0,05\Omega/km \rightarrow 10\Omega$

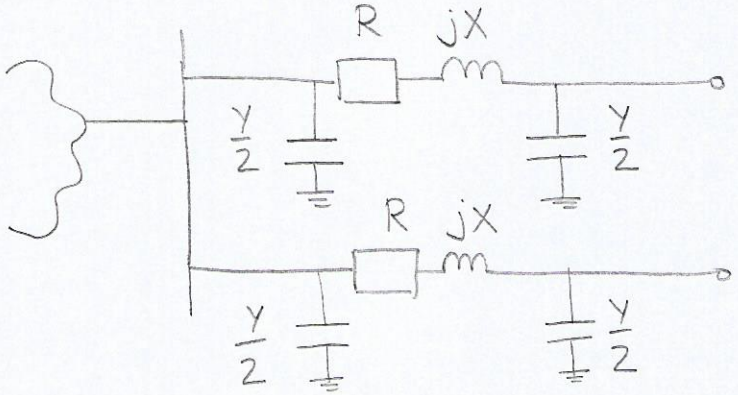
$L = 1,553\,mH/km \rightarrow X_L = j97,58\Omega$

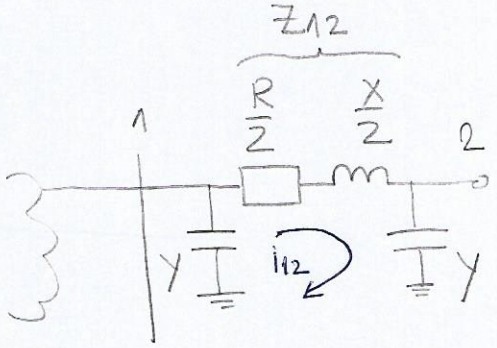
$C = 10,73\,nF/km \rightarrow B = 0,674 \cdot 10^{-3} S$ $(Y = jB,\ Z = jX)$

$l = 200km$

$f = 50Hz$

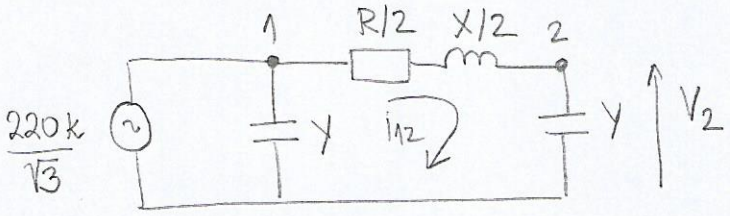
$\Delta U_2 = ?$





$Z_{12} = 5 + j48,79$

$\hat{Y} = -j1483,7$



$$V_2 = V_1 - i_{12} \cdot Z_{12}$$

$$i_{12} = \frac{U_1}{Z_{12} + \frac{\hat{Y}}{2}} = \frac{220k/\sqrt{3}}{5 + j48,79 - j1483,7}$$

$$i_{12} = \frac{220k/\sqrt{3}}{1434,9\angle -1,57} = 88,5\angle 1,57$$

$$i_{12} = 0,07 + j88,5$$

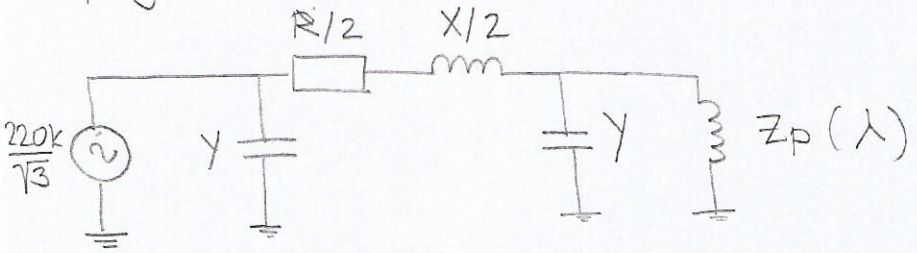
$$V_2 = V_1 - i_{12} \cdot Z_{12} =$$

$$= \frac{220k}{\sqrt{3}} - 88,5\angle 1,57 \cdot 49,04\angle 1,47$$

$$= \frac{220k}{\sqrt{3}} + 4317,66 - j440,16 = 131335\angle -3,35 \cdot 10^{-3}$$

$$\Rightarrow U_2 = \sqrt{3} \cdot V_2 = \sqrt{3} \cdot 131335 = 227,5\,kV$$

S prigušnicom



PRIGUŠNICA:

$U = 220\,kV$

$S_n = 50\,MVA$

3f:

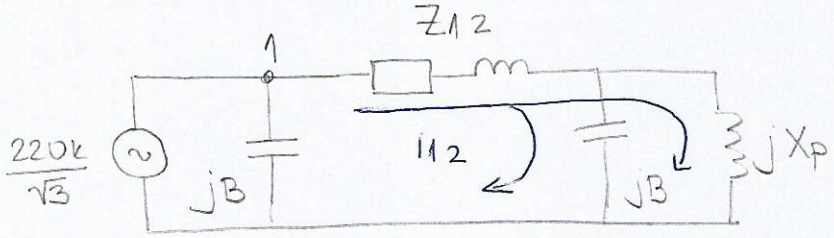
$S_n = 3U_f I_f^* =$

$= 3\frac{U_f}{\sqrt{3}}\left(\frac{U}{\sqrt{3}}\cdot\frac{1}{Z_L}\right) = \frac{U_L^2}{Z_L}$

$$S_n = \frac{U_L^2}{(jX)^*} = \frac{U_L^2}{-jX}\cdot\frac{j}{j} = j\frac{|U_n|^2}{X}$$

$$S_n = j\frac{|U_n|^2}{X} = P_n + jQ_n$$

$$Q_n = 50M = \frac{U_{in}^2}{X_p} \rightarrow X_p = \frac{|U_n|^2}{50M} = \frac{(220k)^2}{50M} = 968 \rightarrow Z_p = j968\,\Omega$$



$$i_{12} = \frac{V_1}{Z_{12} + \left(\frac{1}{Y} \,||\, jX_p\right)}$$

$$\frac{1}{Y} \,||\, jX_p = \frac{1}{j0{,}674\cdot10^{-3}} \,||\, j968 = \frac{1483{,}7\cdot 968}{-j1483{,}7 + j968} = j2785{,}06$$

$$i_{12}' = \frac{220k/\sqrt{3}}{5 + j42{,}79 + j2785{,}06} = \frac{220k/\sqrt{3}}{2833{,}85\angle 1{,}569} = 44{,}82\angle -1{,}569 =$$

$$= 0{,}08 - j44{,}82$$

$$V_2' = V_1' - i_{12}'\cdot Z_{12} = \frac{220k}{\sqrt{3}} - 44{,}82\angle -1{,}569 \cdot 49{,}05\angle 1{,}469 =$$

$$= \frac{220k}{\sqrt{3}} - 2187{,}43 + j219{,}476 = 124{,}83\,kV \,/\cdot\sqrt{3}$$

$$U_2' = 216{,}211\,kV$$

$$\Delta U_2 = U_2' - U_2 = 216{,}211 - 227{,}5 = -11{,}289\,kV$$

Prazno mjesto za 5. zadatak

KIR 2019./2020.

6. ZADATAK

$P_{n1}^m = 3\,MW$ $P_{n2}^m = 4\,MW$ $U = 1\,kV$

$\cos\varphi_1 = 0,8$ $\cos\varphi_2 = 0,7$

$\eta_1 = 0,95$ $\eta_2 = 0,98$

a) $I = ?$

b) $\cos\varphi = ?$

c) $Q_{KB} = ?$, $\cos\varphi' = 0,95$

d) $C_{KB}\ (\Delta) = ?$

$$P_{e1} = \frac{P_{n1}^m}{\eta} = 3,158\,MW \qquad P_{e2} = 4,082\,MW$$

$$P_{UK} = P_1 + P_2 = 7,24\,MW$$

$$Q_1 = P_{e1}\,tg\varphi_1 = 2,368\,MVAr \qquad Q_2 = P_{e2}\,tg\varphi_2 = 4,164\,MVAr$$

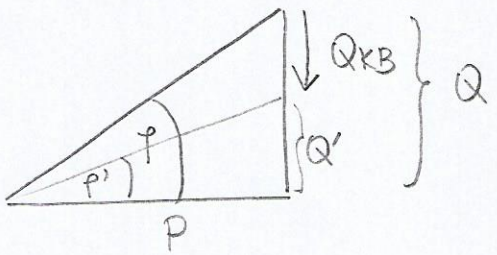
$$Q_{UK} = Q_1 + Q_2 = 6,532\,MVAr$$

a) $$S = \sqrt{P_{UK}^2 + Q_{UK}^2} = \sqrt{3}\cdot|U|\cdot|I|$$

$$|I| = \frac{|S|}{\sqrt{3}\cdot|U|} = \frac{\sqrt{7,24^2 + 6,532^2}\,(M)}{\sqrt{3}\cdot 1\,(k)} = 5,63\,kA$$

b) $$tg\varphi = \frac{Q_{UK}}{P_{UK}} = \frac{6,532}{7,24}, \quad \cos\varphi = \cos\left(atg\left(\frac{6,532}{7,24}\right)\right) = 0,74$$

c) $Q_{KB} = ?$, $\cos\varphi' = 0,95$



$$Q' = P\cdot tg\varphi' = 7,24\cdot tg(a\cos 0,95) = 2,37\,MVAr$$

$$Q_{KB} = Q - Q' = 6,532 - 2,37 = 4,15\,MVAr$$

d) $C\ (\Delta) = ?$

$Q_{KB} = 4,15\,MVAr$

$|Q_{KB}| = 3U_f\cdot I_f = 3U_f(U_f\omega C)$

$$\boxed{Q_{KB} = 3U_L^2\omega C}$$

$$C = \frac{Q_{KB}}{3U_L^2\omega} = \frac{4,15M}{3\cdot(1k)^2\cdot 2\pi\cdot 50} = 4,4\,mF$$