Ime i prezime:
JMBAG:

Završni ispit (30 bodova)
Dinamika i regulacija EES-a

Ak. god. 2019./2020.

Zadatak 1

HE Dubrava sastoji se od dva identična agregata. Jedan agregat sastoji se od 48-polnog sinkronog generatora i nazivne snage 42 MVA. Ukupni moment tromosti jednog agregata iznosi 441 tm^2. Kolika je ekvivalentna konstanta tromosti HE Dubrava (oba agregata zajedno)? Koliko iznosi maksimalni dozvoljeni poremećaj kako bi početni RoCoF ($t = 0^+$) bio $< \pm 2$ Hz/s? Nakon koliko vremena HE Dubrava dostiže frekvenciju 49.2 Hz za maksimalni dozvoljeni poremećaj? U izračunu pretpostaviti da oba agregata rade s konstantnom mehaničkom snagom.
(5 bodova)

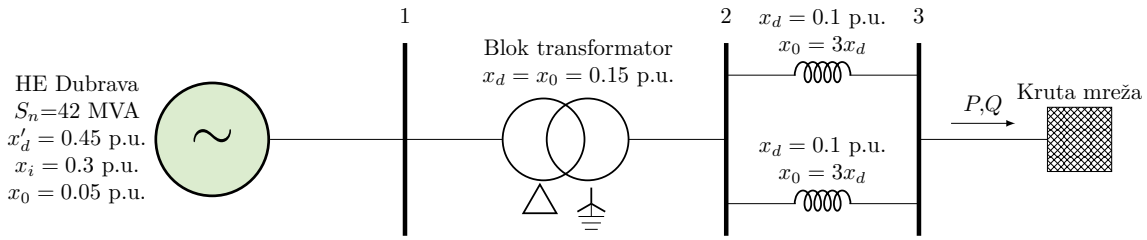
Zadatak 2

Jedan agregat u HE Dubrava (drugi nije u pogonu) spojen je na krutu mrežu preko blok-transformatora i dva paralelna voda te u poduzbuđenom režimu rada u mrežu predaje snagu $P = 0.9$ p.u. pri $\cos\varphi = 0.95$ kap. (Slika 1). Napon krute mreže iznosi $1\angle 0^\circ$ p.u. Na jednom od dva paralelna voda nastaje izravni jednopolni kratki spoj u točki koja se nalazi na 75% duljine voda gledano od sabirnice 2. Nacrtati nadomjesnu shemu sustava sa slike 1 te odrediti izraz i skicirati krivulje za prijenos električne snage između generatora i krute mreže za slučajeve:

a) prije nastanka kratkog spoja;

b) tijekom kratkog spoja;

c) nakon isključenja voda u kvaru.



Slika 1: Spoj HE Dubrava s krutom mrežom

(9 bodova)

Zadatak 3

Za sustav sa slike 1 odrediti kritični kut i kritično vrijeme uklanjanja kvara za izravni tropolni kratki spoj na sabirnici 3. Podaci za izračun konstante tromosti jednog agregata nalaze se u Zadatku 1. Generator u naduzbuđenom režimu rada u mrežu predaje snagu $P = 0.5$ p.u. pri $\cos\varphi = 0.95$ ind. Napon krute mreže iznosi $1\angle 0^\circ$ p.u. Nacrtati nadomjesnu shemu sustava te odrediti izraz i skicirati krivulje za prijenos snage između generatora i krute mreže za slučajeve:

a) prije nastanka kratkog spoja;

b) tijekom kratkog spoja;

c) nakon isključenja kvara.

(6 bodova)

Zadatak 4

Nacrtajte blok dijagram dinamičkog sustava opisanog jednadžbama (1)–(2), gdje su H, f_n, P_m i C konstante, a δ i ω varijable stanja.

$$\frac{d\delta}{dt} = 2\pi f_n(\omega - 1) \tag{1}$$

$$2H\frac{d\omega}{dt} = P_m - C\sin\delta \tag{2}$$

(2 boda)

Zadatak 5

Kakve vrste kutne nestabilnosti pri malim poremećajima postoje s obzirom na oscilatornost? Skicirajte te promjene kuta opterećenja u vremenu.
(2 boda)

Zadatak 6

Nacrtajte karakteristiku snaga-kut za slučaj dugog otklanjanja kvara (nestabilno stanje) i slučaj kratkog otklanjanja kvara (nestabilno stanje). Označite površine ubrzavanja i usporavanja generatora. O čemu ovisi stabilnost odziva?
(2 boda)

Zadatak 7

Što su FACTS uređaji? Prikažite osnovnu podjelu FACTS uređaja. Objasnite osnovnu ideju serijske kapacitivne kompenzacije i nabrojite neke FACTS uređaje za takvu vrstu kompenzacije.
(2 boda)

Zadatak 8

Što je osnovni građevni element Wide Area Monitoring sustava? Koja je uloga GPS-a u WAMS-u?
(1 bod)

Zadatak 9

Objasnite princip rada transformatora s poprečnom regulacijom kuta (*Phase shifting transformer*).
(1 bod)

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1. ZADATAK

2 identična agregata

$p = 24$

$S_n = 42\,MVA$

$J = 441 \cdot 10^3\ kgm^2$

$H_{ekv} = ?$

$\frac{df}{dt}(t=0) < \pm 2\frac{Hz}{s}$

$\delta_{pe} = ?$

$f' = 49{,}2\,Hz$

$t = ?$

a) $$E_K = \frac{J(2\pi\frac{f}{p})^2}{2} = \frac{441\cdot10^3(2\pi\frac{50}{24})^2}{2} = 37{,}78\,Ws$$

$$E_{UK} = 2\cdot E_K = 75{,}56\cdot10^6\,Ws$$

$$H_{ekv} = \frac{E_{UK}}{\Sigma S_n} = \frac{75{,}56\cdot10^6\,Ws}{84\,MW} = 0{,}9\,s$$

b) $RoCoF\,(t=0+) < \pm 2\,Hz/s \;/:50\,Hz$

$< \pm 0{,}04\,pu/s$

$$\frac{d\omega_e}{dt} = \pm 0{,}04\ pu/s$$

$$2H\frac{d\omega_e}{dt} = P_m - P_e \rightarrow 2H\frac{d\omega_e}{dt} = \delta P$$

$$2\cdot0{,}9\cdot0{,}04 = \delta P_{max}$$

$$\delta P_{max} = 0{,}072\ p.u \;/\cdot S_B$$

$$\delta P_{max} = 6{,}048\,MVA$$

c) $f(t_1) = 49{,}2\,Hz$

$\delta P = 6{,}048\,MVA$

$t_1 = ?$

$$\frac{df}{dt} = 2\frac{Hz}{s}$$

$$\Delta f(t_1) = 0{,}8\,Hz$$

$$\Delta f = \frac{df}{dt}$$

$$\Delta f(t_1) = \int_0^{t_1}\frac{df}{dt}\,dt$$

$$0{,}8 = \int_0^{t_1} 2\,dt = 2(t_1 - 0) = 2t_1$$

$$t_1 = \frac{0{,}8}{2} = 0{,}4\,s$$

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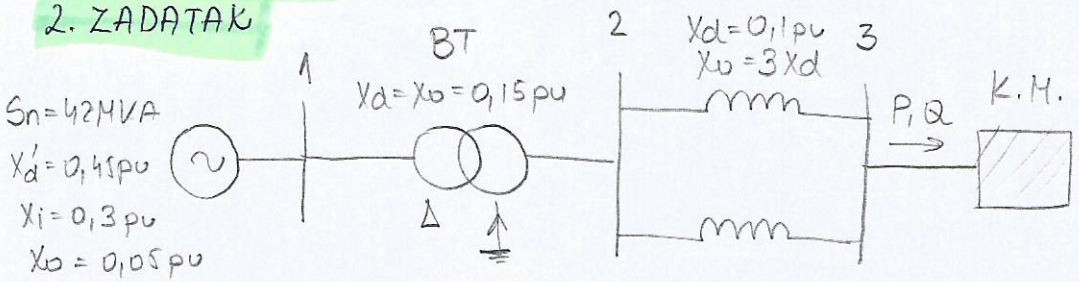
2. ZADATAK



$P = 0,9$ p.u.

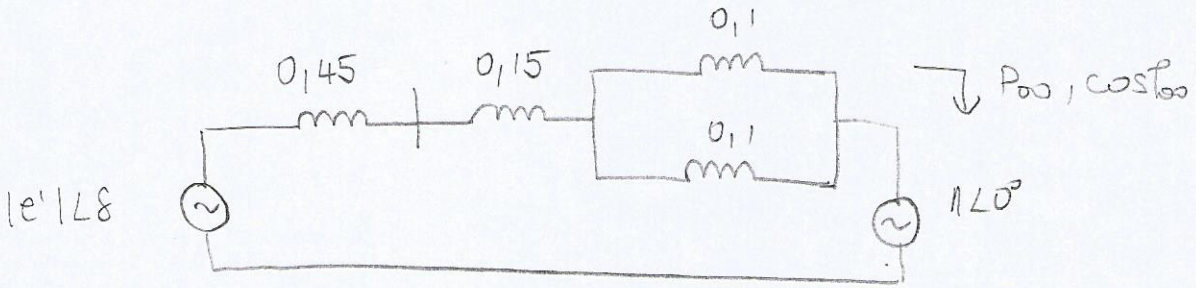
$\cos\varphi = 0,95$ kap.

$U_{\infty} = 1\angle 0°$ p.u.

1 PKS, 75% dV od sab. 2

$X_f = X_i + X_o$

PRIJE KVARA



$X_d = 0,45 + 0,15 + 0,05 = 0,65$ p.u.

$$|e'|\angle\delta = |U_{\infty}|\angle 0° + j i'_{\infty} X_d$$

$$S_{\infty} = P_{\infty} + jQ_{\infty} = U_{\infty} \cdot i^{*}_{\infty}$$

$$i_{\infty} = \left(\frac{S_{\infty}}{U_{\infty}}\right)^{*} = \left(\frac{P_{\infty} + jP_{\infty}tg\varphi_{\infty}}{\underbrace{U_{\infty}}_{=1}}\right)^{*} = 0,9 - j0,9 \cdot tg(\arccos(-0,95))$$

$$= 0,9 + j0,3 = 0,95\angle 18,43°$$

$$|e'|\angle\delta = |U_{\infty}|\angle 0° + j i_{\infty} X_d = 1 + 0,65\angle 90° \cdot 0,95\angle +18,43° =$$

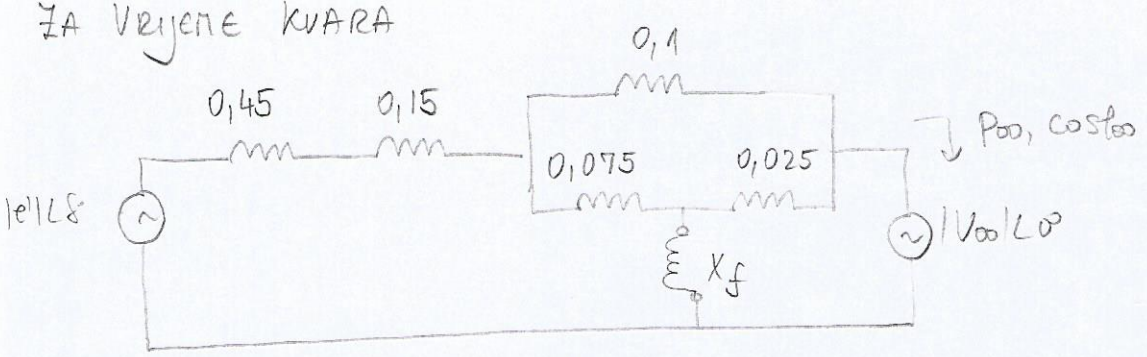
$$= 1 - 0,195 + j0,586 = 0,805 + j0,586 =$$

$$= 0,996\angle 36,05°$$

$$P_e^{d} = \frac{|e'||U_{\infty}|}{X_d}\sin\delta = \frac{0,996 \cdot 1}{0,65}\sin\delta = 1,532\sin\delta$$

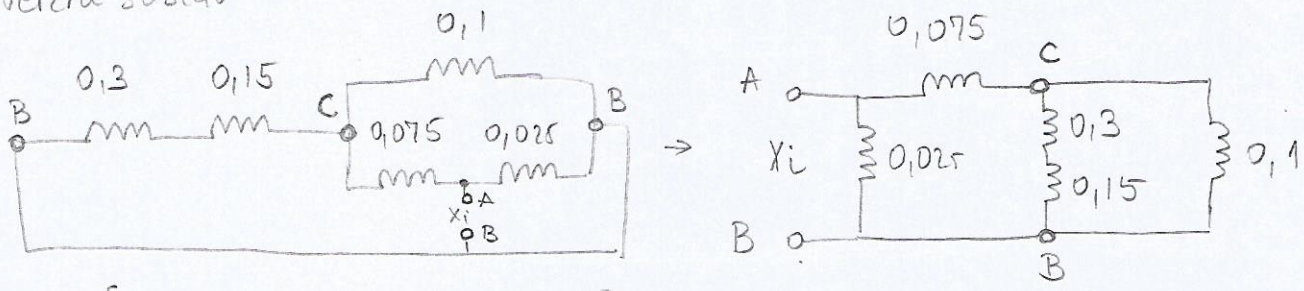
$$P_m = 1,532\sin(36,05°) = 0,9$$

ZA VRIJEME KVARA



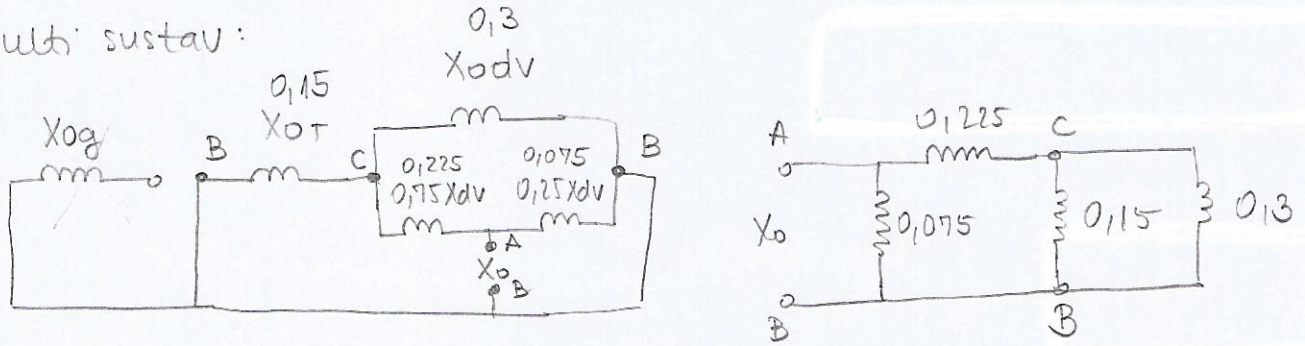
$$X_f = X_i + X_o$$

Inverzni sustav:



$$X_i = \left[0{,}1 \,||\, (0{,}3+0{,}15)+0{,}075\right] || \, 0{,}025 = \underline{0{,}023}$$

Nulti sustav:

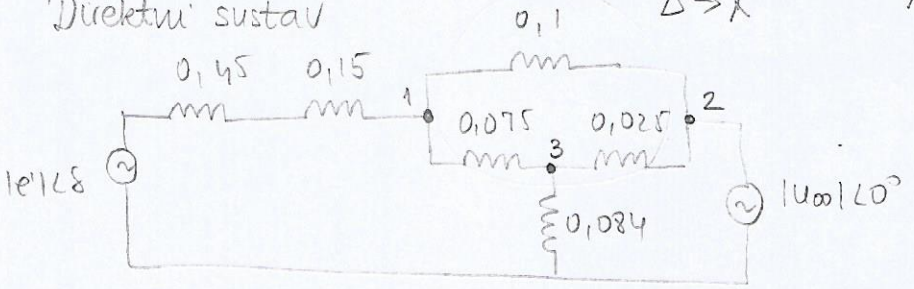


$$X_o = \left[0{,}3 \,||\, 0{,}15 + 0{,}225\right] || \, 0{,}075 = \underline{0{,}061}$$

$$X_f = X_i + X_o = 0{,}023 + 0{,}061 = 0{,}084$$

Direktni sustav

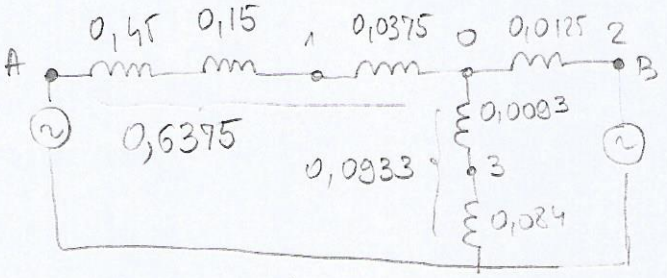
$\Delta \rightarrow \lambda$



$$X_{10} = \frac{X_{12}X_{13}}{X_{12}+X_{13}+X_{23}} = 0{,}0375$$

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

$$X_{30} = \frac{X_{13}X_{23}}{X_{12}+X_{13}+X_{23}} = 0{,}0093$$



$\lambda \rightarrow \Delta$

$$X_{AB} = X_L + X_D + \frac{X_L X_D}{X_{DO}} =$$

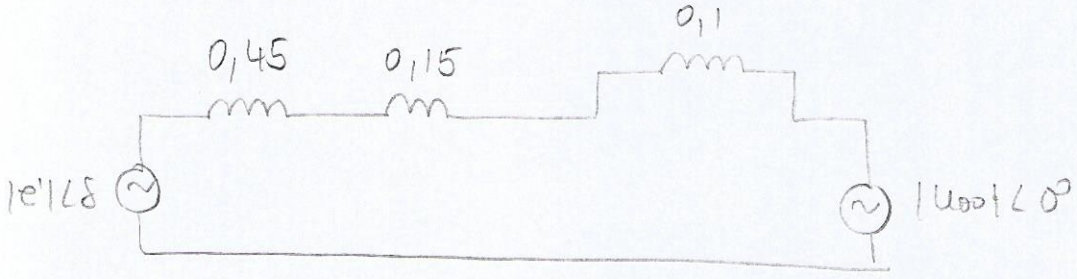
$$= 0{,}6375 + 0{,}0125 + \frac{0{,}6375 \cdot 0{,}0125}{0{,}0933} =$$

$$= \underline{0{,}7354}$$

$$X_{AB} = X_D = 0{,}7354$$

$$P_e^{\beta} = \frac{|e'||U_{00}|}{X_\beta} \sin\delta = \frac{0{,}996 \cdot 1}{0{,}7354} \sin\delta = 1{,}35 \sin\delta$$

NAKON KVARA



$$X_\gamma = 0{,}45 + 0{,}15 + 0{,}1 = 0{,}7$$

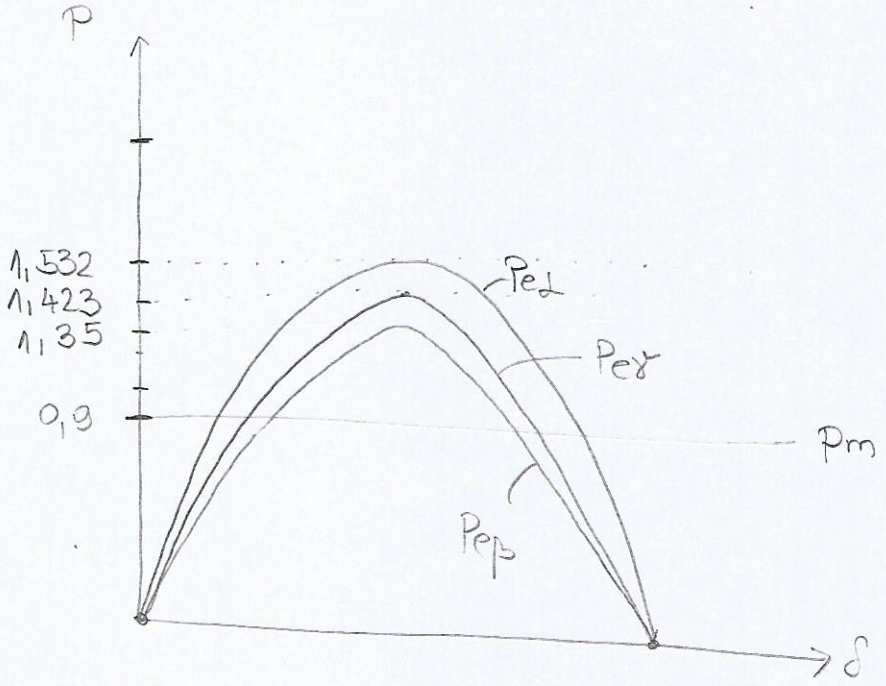
$$P_{e\gamma} = \frac{|e'||U_{00}|}{X_\gamma} \sin\delta = \frac{0{,}996}{0{,}7} \sin\delta = 1{,}423 \sin\delta$$

$P_m = 0{,}9$

$P_e^{\alpha} = 1{,}532 \sin\delta$

$P_e^{\beta} = 1{,}35 \sin\delta$

$P_e^{\gamma} = 1{,}423 \sin\delta$



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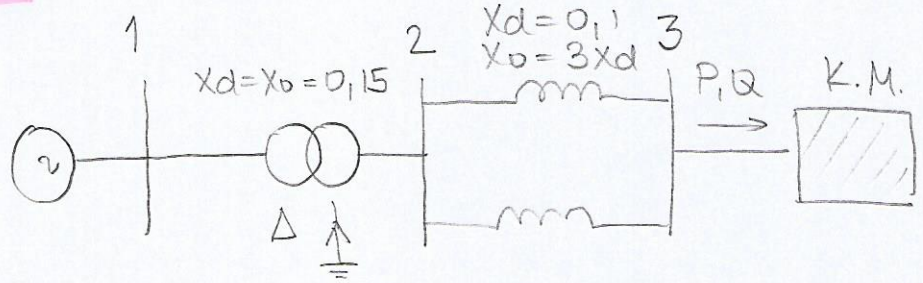
3. ZADATAK



- odrediti kr. kut i kr. vrijeme uklanjanja kvara
- 3PKS na sabirnici 3
- naduzbuđeni režim rada

$P = 0,5$ p.u., $\cos\varphi = 0,95$ ind.

$U_{\infty} = 1\angle 0°$ p.u

$P = 24$

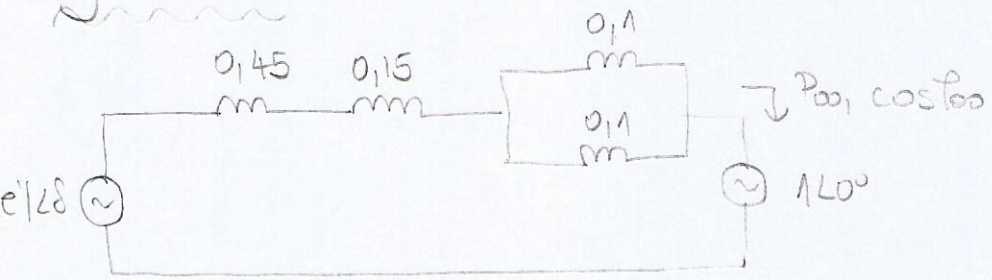
$S_n = 42$ MVA

$J = 441 \cdot 10^3$ kgm^2

$$H = \frac{J\left(2\pi \frac{f}{p}\right)^2}{2S_n} = \frac{441\cdot 10^3 \left(2\pi \frac{50}{24}\right)^2}{2\cdot 42M}$$

$H = 0,9$ s

Prije kvara



$X_d = 0,45 + 0,15 + 0,05 = 0,65$

$$|e'|\angle\delta = |U_{\infty}|\angle 0° + jX_d \cdot i_{\infty}$$

$$i_{\infty} = \left(\frac{S}{U_{\infty}}\right)^* = \left(\frac{P_{\infty} + jP_{\infty}\operatorname{tg}\varphi_{\infty}}{1\angle 0°}\right)^* = 0,5 - j0,5\cdot \operatorname{tg}(\arccos 0,95)$$

$$= 0,5 - j0,164$$

$i_{\infty} = 0,526\angle -18,16°$

$|e'|\angle\delta = 1 + 0,526\angle -18,16° \cdot 0,65\angle 90° = 1,107 + j0,325$

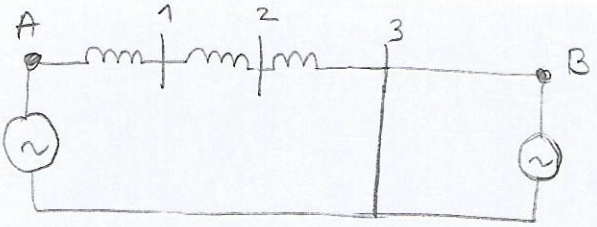
$|e'|\angle\delta = 1,154\angle 16,36°$ ($\delta_0 = 16,36° = 0,285$ rad)

$$P_{ed} = \frac{1,154\cdot 1}{0,65}\sin\delta = 1,77\sin\delta$$

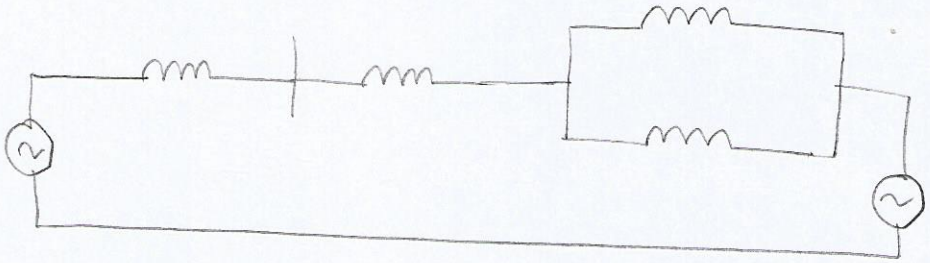
$P_m = 0,5$

Za nijansc kvara

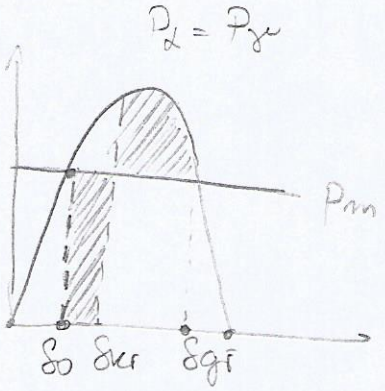
$\left(P_e^{1b} = 0\right)$
3PKS



Nakon kvara



$P_e^{\gamma} = P_e^{\alpha} = 1{,}77 \sin\delta$



Površina ubrzavanja

$$A_a = P_m (\delta_{kr} - \delta_0)$$

Površina usporavanja

$$A_d = \int_{\delta_{kr}}^{\delta_{gr}} (P_\gamma - P_m)\, d\delta$$

$$\delta_{gr} = \pi - \delta_0 = \pi - 0{,}285$$

$$\delta_{gr} = 2{,}856$$

$$A_a = A_d$$

$$P_m\delta_{kr} - P_m\delta_0 = 1{,}77(-\cos\delta_{gr} - (-\cos\delta_{kr})) - P_m(\delta_{gr} - \delta_{kr})$$

$$P_m\delta_{kr} - P_m\delta_0 = -1{,}77\cos\delta_{gr} + 1{,}77\cos\delta_{kr} - P_m\delta_{gr} + P_m\delta_{kr}$$

$$1{,}77\cos\delta_{kr} = 1{,}77\cos\delta_{gr} - P_m\delta_0 + P_m\delta_{gr} \;/:1{,}77$$

$$\cos\delta_{kr} = \cos\delta_{gr} + \frac{P_m(\delta_{gr} - \delta_0)}{1{,}77} = \cos(2{,}856) + \frac{0{,}5\,(2{,}856 - 0{,}1285)}{1{,}77}$$

$$\delta_{kr} = 1{,}8 \text{ rad} = 103°$$

$$t_{kr} = \sqrt{\frac{4H(\delta_{kr} - \delta_0)}{\omega_s P_m}} = \sqrt{\frac{4 \cdot 0{,}3\,(1{,}8 - 0{,}285)}{2\pi \cdot 50 \cdot 0{,}5}} = 0{,}186\,s = 186\,ms$$

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4. ZADATAK

H, f_n, P_m, C konstante

δ, ω varijable stanja

$$\frac{d\delta}{dt} = 2\pi f_n(\omega - 1)$$

$$2H\frac{d\omega}{dt} = P_m - C\sin\delta$$

$$\frac{d\delta}{dt} = 2\pi f_n(\omega - 1)$$

$$\frac{d\omega}{dt} = \frac{1}{2H}(P_m - C\sin\delta)$$