Dis - LJ/R 2016/17.

(1.) [9] OBJASNITI NAČIN RADA I NACRTATI BLOKOVSKU SHEMU ESTIMATORA ELEKTRIČNOG KUTA MREŽE θ_g (PLL, PHASE LOCKED LOOP)!

RJ.: → ISTO KAO I 1. ZADATAK – Z1 2016/17

(2.) [10] SMPM IMA PARAMETRE: $p=2$ (BROJ PARI POLOVA);
$L_d = 7\cdot10^{-3}H$ (d OS IND.), $L_q = 7\cdot10^{-3}H$ (q OS IND.), $R_s = 2.98\,\Omega$ (OTPOR STATORA)

$\phi_{mg} = 0.125\,Wb$ (mag. tok. perm. magn.); $J_m = 0.47\cdot10^{-4}\,kg\,m^2$ (MOMENT INERCIJE),

$D = 1.1\cdot10^{-4}\,Nms$ (FAKTOR PRIGUŠENJA)

ODREDITI PROPORCIONALNA POJAČANJA I VREM. INT. KONST. REGULATORA STRUJA i_d, i_q I REG. BRZINE ω_e (SVI REG. PI TIPA). ODABRATI FAKTOR PRIGUŠENJA $\xi=1$ ZA SVE REGULATORE, ZA i_d i i_q JE $\omega_{ni} = 200\,[1/s]$, ZA REG. BRZINE VRTNJE $\omega_{n\omega} = 20\,[1/s]$.

$L_d = L_q \Rightarrow$ SMVMP

$$\frac{di_d}{dt} = \frac{1}{L_d}\left(u_d - R_s i_d + L_q i_q \omega_e\right)$$

$$\frac{di_q}{dt} = \frac{1}{L_q}\left(u_q - R_s i_q - L_d i_d \omega_e - \omega_e \phi_{mg}\right)$$

$$\frac{d\omega_e}{dt} = \frac{p}{J_m}\left[\frac{3}{2}p\,\phi_{mg} i_q - \frac{D}{p}\omega_e - \underbrace{M_t}_{=0}\right]$$

$=0$ POSTAVLJA SE, SMETNJA

$$\hat{V}_d = V_d + L_g I_g \Omega_e$$

$$\hat{V}_d = K_c^d (I_d^* - I_d) + \frac{K_c^d}{s\tau_1^d}(I_d^* - I_d)$$

$\boxed{V_d \to PI ?}$

$$sI_d = \cancel{\frac{1}{L_d}}\frac{\hat{V}_d}{L_d} - \frac{R_s}{L_d} I_d$$

$$\frac{I_d}{\hat{V}_d} = \frac{\frac{1}{L_d}}{s + \frac{R_s}{L_d}} \qquad \frac{b}{s+a} ; \quad b = \frac{1}{L_d} \quad a = \frac{R_s}{L_d}$$

$\boxed{V_q \to PI ?}$

$$\hat{V}_q = V_q^* - L_d i_d \omega_e - \omega_e \phi_{mg}$$

$$\hat{V}_q = K_c^q (I_q^* - I_q) + \frac{K_c^q}{s\tau_1^q}(I_q^* - I_q)$$

$$\frac{I_q}{\hat{V}_q} = \frac{\frac{1}{L_q}}{s + \frac{R_s}{L_q}} \; ; \; b = \frac{1}{L_q} \; , \; a = \frac{R_s}{L_q}$$

OPÇÃO PI ?

$$K_c\left(1 + \frac{1}{s\tau_1}\right) = \frac{sK_c\tau_I + K_c}{s\tau_1} = \frac{sK_c + \frac{K_c}{\tau_1}}{s} = C(s)$$

$$G(s) = \frac{b}{s+a} \qquad Z.K. ? \quad \frac{C(s)G(s)}{1 + C(s)G(s)} = \frac{\frac{\left(sK_c + \frac{K_c}{\tau_1}\right)b}{s(s+a)}}{1 + \frac{\left(sK_c + \frac{K_c}{\tau_1}\right)b}{s(s+a)}} =$$

$$= \frac{\left(sK_c + \frac{K_c}{\tau_1}\right)b}{s^2 + sa + sK_c b + \frac{bK_c}{\tau_1}} \quad s^2 + 2\xi\omega_n s + \omega_n^2$$

$$K_c b + a = 2\xi\omega_n$$

$$\boxed{K_c = \frac{2\xi\omega_n - a}{b}}$$

$$\omega_n^2 = \frac{bK_c}{\tau_1} \Rightarrow \tau_1 = \frac{bK_c}{\omega_n^2} = \boxed{\frac{2\xi\omega_n - a}{\omega_n^2}}$$

$$k_c^d = \frac{2\xi\omega_n - R_s/L_d}{1/L_d} = -0.18$$

$$\tau_i^d = \frac{2\xi\omega_n - R_s/L_d}{\omega_n^2} = -6.43\cdot 10^{-4}\ s$$

$$k_c^q = \frac{2\xi\omega_n - R_s/L_q}{1/L_q} = -0.18$$

$$\tau_i^q = \frac{2\xi\omega_n - R_s/L_q}{\omega_n^2} = -6.43\cdot 10^{-4}\ s$$

$k_c^d = k_c^q$; $\tau_i^d = \tau_i^q$ ...

$$\boxed{\begin{array}{c} L_d = L_q = 7\cdot 10^{-3}\,H \\ \omega_n = \omega_n = 200 \\ \xi = \xi = 1 \end{array}}$$

$R_s = 2.98\ \Omega$

$\boxed{\omega_e \to PI:}$

$$s\Omega_e = \frac{p}{J_m}\left[\frac{3}{2}p\phi_{mg}I_q - \frac{D}{p}\Omega_e\right]$$

$$\Omega_e\left(s + \frac{D}{J_m}\right) = I_q\left(\frac{3p^2\phi_{mg}}{2J_m}\right)$$

$$\frac{\Omega_e}{I_q} = \frac{\frac{3p^2\phi_{mg}}{2J_m}}{s + \frac{D}{J_m}}$$

$$sI_q = -\frac{R_s}{L_q}I_q + \frac{k_c^q}{L_q}(I_q^* - I_q) + \frac{k_c^q}{sL_q\tau_i^q}(I_q^* - I_q)$$

$$I_q\left(s + \frac{R_s + k_c^q}{L_q} + \frac{k_c^q}{sL_q\tau_i^q}\right) = I_q^*\left(\frac{k_c^q}{L_q} + \frac{k_c^q}{sL_q\tau_i^q}\right)$$

$$\frac{I_q}{I_q^*} = \frac{(k_c^q s\tau_i^q + k_c^q)/\cancel{(s\tau_i^q)}}{(s^2L_q\tau_i^q + s\tau_i^q(R_s + k_c^q) + k_c^q)/\cancel{(s\tau_i^q)}}$$

$$\frac{\Omega_e}{I_q^*} = \frac{\frac{3}{2}p^2\frac{\phi_{mg}}{J_m}}{s+\frac{D}{J_m}} \cdot \underbrace{\frac{K_i^2 s \tau_i^2 + K_i^2}{s^2 L_q \tau_i^2 + s\tau_i^2(R_s+R_i^2) + K_i^2}}_{\text{EL. DINAMIKA PUNO VEĆA OD MEH. PA SE ZANEMARUJE}}$$

$$\Downarrow$$

$$\frac{\Omega_e}{I_q^*} = \frac{\frac{3}{2}p^2\frac{\phi_{mg}}{J_m}}{s+D/J_m} \qquad \frac{b}{s+a}; \quad b = \frac{3}{2}p^2\frac{\phi_{mg}}{J_m}$$

$$a = D/J_m$$

PI: $K_i^\omega = \frac{2\xi\omega_n - a}{b} = \frac{2\xi\omega_n - D/J_m}{\frac{3}{2}p^2\frac{\phi_{mg}}{J_m}} = 2{,}36\cdot 10^{-3}$

$$\tau_i^\omega = \frac{2\xi\omega_n - a}{\omega_n^2} = \frac{2\xi\omega_n - D/J_m}{\omega_n^2} = 0{,}094\ s$$

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3. [6] IZLAZI IZ REGULATORA i_d i i_q PRIJE OGRANIČENJA IZNOSE $u_d = 200V$, $u_q = 346{,}41V$. ODREDI IZNOSE NAKON OGRANIČENJA AKO SE KORISTE:

a) NEPROMJENJIVA (FIXNA) OGRANIČENJA IZLAZA IZ REG. i_d i i_q UZ $\varepsilon = 0{,}5$

b) PROMJENJIVA OGRANIČENJA — II — — II — i_d i i_q. NAPON ISTOSMJERNOG MEĐUKRUGA PRETVARAČA NAPONA I FREKV. SE MOŽE SMATRATI KONST. I IZNOSI $U_{DC} = 560V$. NAVESTI GLAVNE RAZLIKE NEPROMJ. & PROMJ. OGRANIČENJA.

RJ.: 2. i 3. ZADATAK → ZI 2016/17

4. [5]
SMPM ČIJI SU PARAMETRI U ZAD. 2. RADI U REGULACIJI MOMENTA. REG. STRUJE i_q JE P TIPA S POJAČANJEM $K_c^q = 10 R_s$. ODREDITI STATIČKU GREŠKU (ODSTUPANJE STVARNE OD ŽELJENE VRIJEDNOSTI U STAC. STANJU) STRUJE i_q NA SKOKOVITU PROMJENU VELIČINE MOMENTA M_{em}^* S $\varnothing$ NA 1 Nm.

q:

$$\frac{di_q}{dt} = \frac{1}{L_q}\left(u_q - R_s i_q - L_d i_d \omega_e - \phi_{mg}\omega_e\right)$$

$$M_{em} = \frac{3}{2} p \left(\phi_{mg} i_q + \underbrace{(L_d - L_q) i_d i_q}_{=\varnothing,\ L_d = L_q}\right)$$

'P' TIP

$$\hat{U}_q = U_q - L_d i_d \omega_e - \phi_{mg}\omega_e = K_c^q (I_q^* - I_q)$$

$$s I_q = \frac{\hat{U}_q}{L_q} - \frac{R_s}{L_q} I_q$$

$$s I_q = \frac{K_c^q}{L_q}(I_q^* - I_q) - \frac{R_s}{L_q} I_q$$

$$\frac{I_q}{I_q^*} = \frac{K_c^q / L_q}{s + \frac{K_c^q + R_s}{L_q}} = \frac{K_c^q}{s L_q + K_c^q + R_s}$$

$$\frac{M_{em}}{I_q^*} = \frac{\frac{3}{2} p \phi_{mg} \cdot K_c^q}{s L_q + K_c^q + R_s}$$

STVARNA − ŽELJENA = $I_2 - I_2^*$

$\cancel{E}$ $\cancel{I_2 - I_2^*}$

$E = I_2 - I_2^*$

$$\frac{E}{I_2^*} = \frac{I_2 - I_2^*}{I_2^*} = \frac{I_2}{I_2^*} - 1 = \frac{k_c^2}{sL_2 + k_c^2 + R_s} - 1$$

$$\frac{E}{I_2^*} = \frac{\cancel{k_c^2} - sL_2 - \cancel{k_c^2} - R_s}{sL_2 + k_c^2 + R_s} = \frac{-sL_2 - R_s}{sL_2 + k_c^2 + R_s}$$

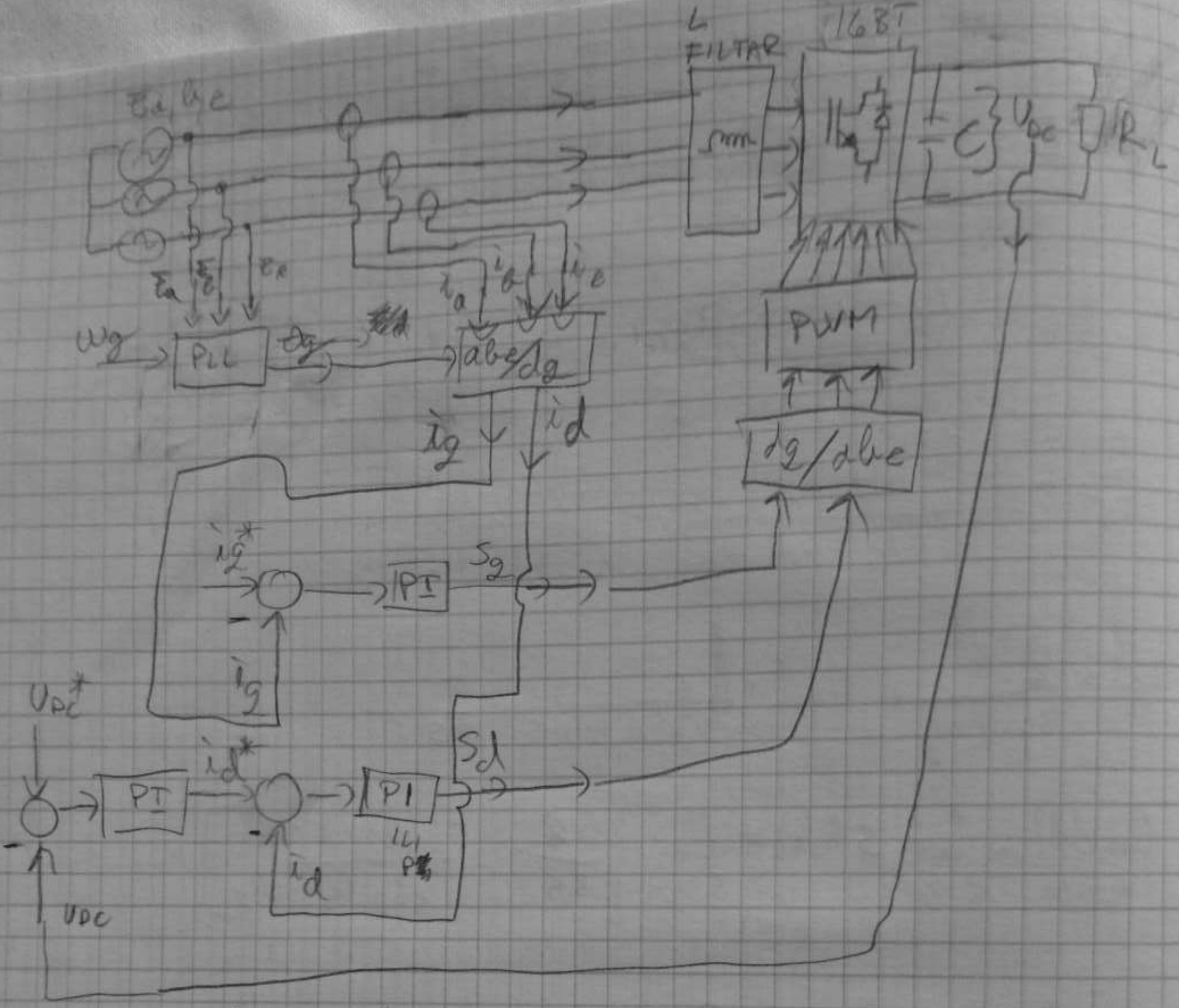
$$I_2^* = \frac{2}{3p\,\Psi_{mg}} \cdot M_{em}^* = \frac{\cancel{2}}{3 \cdot \cancel{2} \cdot 0{,}125 \cdot s} = \frac{8}{3s}$$

$$\lim_{t \to \infty} e(t) = \lim_{s \to 0} sE(s) = \lim_{s \to 0} \left[\frac{\cancel{s} \cdot 8}{3\cancel{s}} \cdot \frac{-sL_2 - R_s}{sL_2 + k_c^2 + R_s} \right] =$$

$$= \frac{8}{3} \cdot \frac{-\cancel{R_s}}{11\cancel{R_s}} = -\frac{8}{33} = -0{,}24\ A$$

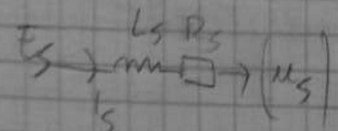
(ISTI ZAD. KAO 4. → MI 2016/17, SAMO PITANJE JE PREDZNAKA ...)

5. [6] NACRTATI BLOKOVSKU SHEMU SUSTAVA REGULATORA NAPONA ISTOSMJERNOG MEĐUKRUGA PRETVARAČA NAPONA I FREKV. (OZNAČITI BLOKOVE I SIGNALE U STRUKTURI). IZVESTI IZRAZE ZA PARAMETRE (PROPORCIONALNO POJAČ. I INT. VREM. KONST.) PI TIPA REGULATORA STRUJE i_d.



$$\frac{di_d}{dt} = \frac{1}{L_s}\left(-u_d - R_s i_d + L_s \omega_g i_q + E_d\right)$$

$$\frac{di_q}{dt} = \frac{1}{L_s}\left(-u_q - R_s i_q - L_s \omega_g i_d\right) \quad ; E_q = \emptyset$$



IZVOD:

$$E_s = u_s + R_s i_s + L_s \frac{di_s}{dt} \quad ; E_s' = E_s \cdot e^{-j\vartheta_g t} \quad ; i_s = i_s' e^{j\vartheta_g t}$$
$$= E_d + jE_q$$

$$E_d + jE_q = u_s' + R_s i_s' + L_s\left[i_s' \cdot j\omega_g e^{j\vartheta_g t} + e^{j\vartheta_g t} \cdot \frac{di_s'}{dt}\right] \cdot e^{-j\vartheta_g t}$$

$$E_d + jE_q = u_d + ju_q + R_s(u_d + ju_q) + L_s\left[j\omega_g(i_d + ji_q) + \frac{di_d}{dt} + j\frac{di_q}{dt}\right]$$

$$E_d = u_d + R_s u_d - L_s \omega_g i_q + L_s \frac{di_d}{dt}$$

$$E_q = u_q + R_s u_q + L_s \omega_g i_d + L_s\, di_q/dt \quad //$$

$$S_d = \frac{u_d}{u_{DC}/2} \Rightarrow u_d = S_d \cdot \frac{u_{DC}}{2}$$

$$\frac{di_d}{dt} = \frac{1}{L_s}\left(-S_d \frac{u_{DC}}{2} - R_s i_d + L_s \omega_g i_q + E_d\right)$$

$$= -\frac{S_d}{L_s}\frac{u_{DC}}{2} - \frac{R_s}{L_s} i_d + \omega_g i_q + \frac{E_d}{L_s}$$

$$-\frac{1}{2L_s}\hat{S_d} = -\frac{S_d}{2L_s} u_{DC} + \omega_g i_q + \frac{E_d}{L_s}$$

$$s I_d = -\frac{1}{2L_s}\hat{S_d} - \frac{R_s}{L_s} I_d \quad ; \quad \hat{S_d} = k_c\left(I_d^* - I_d\right) + \frac{k_c}{s\tau_1}\left(I_d^* - I_d\right)$$

$$I_d\left(s + \frac{R_s}{L_s}\right) = -\frac{1}{2L_s}\hat{S_d}$$

$$\frac{I_d}{\hat{S_d}} = \frac{-\frac{1}{2L_s}}{s + \frac{R_s}{L_s}} \quad ; \quad \frac{b}{s+a} \rightarrow \quad b = -\frac{1}{2L_s}, \quad a = R_s/L_s$$

$$k_c^d = \frac{2\xi\omega_n - a}{b} \qquad \tau_1^d = \frac{2\xi\omega_n - a}{\omega_n^2}$$

IZVOD U ZADATKU 2

$$k_c^d = \frac{2\xi\omega_n - R_s/L_s}{-1/2L_s} \qquad \tau_1^d = \frac{2\xi\omega_n - R_s/L_s}{\omega_n^2}$$

6. [4] NAPISATI IZRAZE ZA MATEM. MODEL SMUPM U dq KOORD. SUSTAVU U RELATIVNIM JEDINICAMA (PER UNIT), ZA ELEKTRIČNE VELIČINE $\left(\frac{di_d}{dt} \text{ i } \frac{di_q}{dt}\right)$. BAZNE VRIJEDNOSTI SU $u_B = \sqrt{2}\, U_{fn}$,

$I_B = \sqrt{2}\, I_{fn}$, $\omega_b = \omega_{el} = 2\pi f_n$

eff. vrij. FAZNE

NAZIVNA VRIJ. ELE. BRZINE VRTNJE

Rj.: 1. ZADATAK → MI 2016/17

7. [5] OBJASNITI EFEKT NAMATANJA (WINDUP) KOD PI regulatora, NAPISATI NAČIN KAKO GA SPRJEČITI (ANTI-WINDUP).

$$u(t) = K_c e(t) + \frac{K_c}{\tau_1}\int_0^t e(\tau)d\tau + \underbrace{f(t)}_{\text{ovisi jeli } u_d, u_q, \ldots}$$

$$\frac{dx}{dt} \approx \frac{x(t_i) - x(t_{i-1})}{\Delta t} \quad \text{ZA MALI } \Delta t$$

$$\frac{du(t)}{dt} = K_c\frac{de(t)}{dt} + \frac{K_c}{\tau_1}e(t) + \frac{df(t)}{dt}$$

$$\frac{u(t) - u(t_{i-1})}{\Delta t} = \frac{K_c}{\Delta t}\left(e(t_i) - e(t_{i-1})\right) + \frac{K_c}{\tau_1}e(t) + \frac{f(t) - f(t_{i-1})}{\Delta t} \quad / \cdot \Delta t$$

$$u(t) = u(t_{i-1}) + K_c\left[e(t_i) - e(t_{i-1})\right] + \frac{K_c}{\tau_1}e(t)\cdot\Delta t + f(t) - f(t_{i-1})$$

↳ U DISKRETNOJ DOMENI PROBLEM PREDSTAVLJA $u(t)$ jer SE SUMIRA S PRETHODNIM VRIJEDNOSTIMA → A MORAJU SE POŠTOVATI GRANICE $[-u_{MAX}, u_{MAX}]$

→ POSTAVLJA SE LIMIT KOJEG KAD DOSEGNE OSTAJE NA NJEMU, ODNOSNO SKALIRA SE AKO GA PREĐE:

KORACI:
1) INICIJALIZACIJA - RAČUNANJE SVIH t_{i-1} VRIJEDNOSTI (e, f, i_d, i_q, u_d, u_q)
2) RAČUNANJE t_i VRIJEDNOSTI POTREBNE ZA $u(t_i)$
3) RAČUNANJE $u(t_i)$ IZ VRIJEDNOSTI DOBIVENIH IZ PRETHODNIH KORAKA
4) AKO JE $\sqrt{u_d^2 + u_q^2} \geq \frac{U_{DC}}{r_3}$ PROVODI SE SKALIRANJE

$$u_d'(t_i) = \frac{u_d(t_i)}{\sqrt{u_d^2(t_i) + u_q^2(t_i)}} \cdot U_{DC}/r_3$$

ISTO S u_q

5) $u_d(t_i) = u_d'(t_i)$ & $u_q(t_i) = u_q'(t_i)$ -> ZA

SLJEDEĆU SE PRIPREMAJU (SPREMAJU)

VRIJEDNOSTI - ANTI-WINDUP, TE SE

KREĆE NA SLJEDEĆU ITERACIJU I

KORAK 1)

8. [6] NAVESTI IZRAZE I NACRTATI BLOK SHEMU ESTIMATORA ULANČANOG TOKA STATORA, MOMENTA MOTORA TE KUTA POLOŽAJA VEKTORA ULANČANOG MAGNETSKOG TOKA KOD DTC NAČINA UPRAVLJANJA.

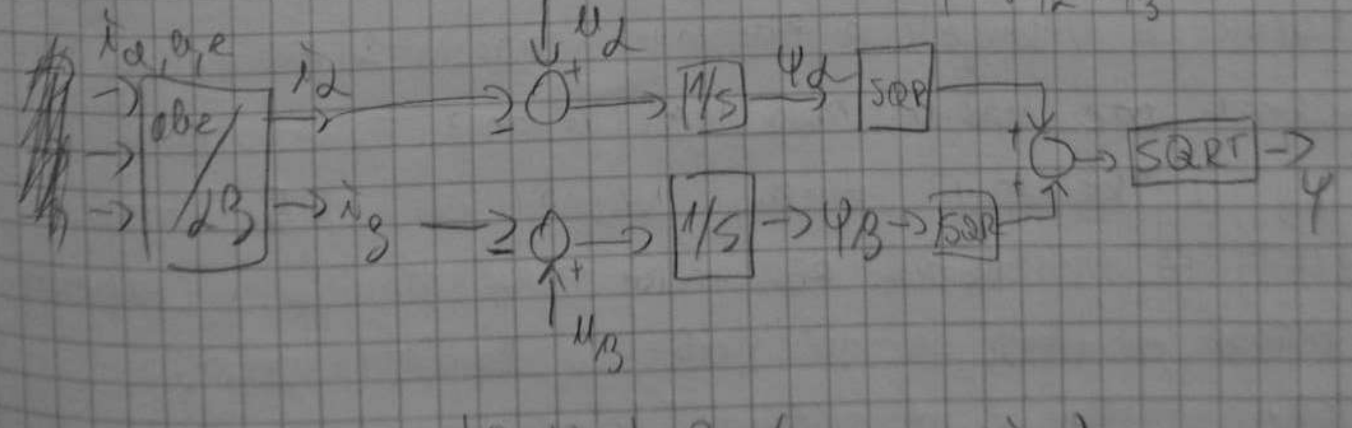
KOMPLETNA SHEMA U 4. ZADATKU ZIR-2016/17,

GDJE SU ESTIMATORI...

$$u_s = R_s i_s + \frac{d\psi_s}{dt} \Rightarrow \psi_s = \int_0^t \left(u_s(\tau) - R_s i_s(\tau)\right) d\tau$$

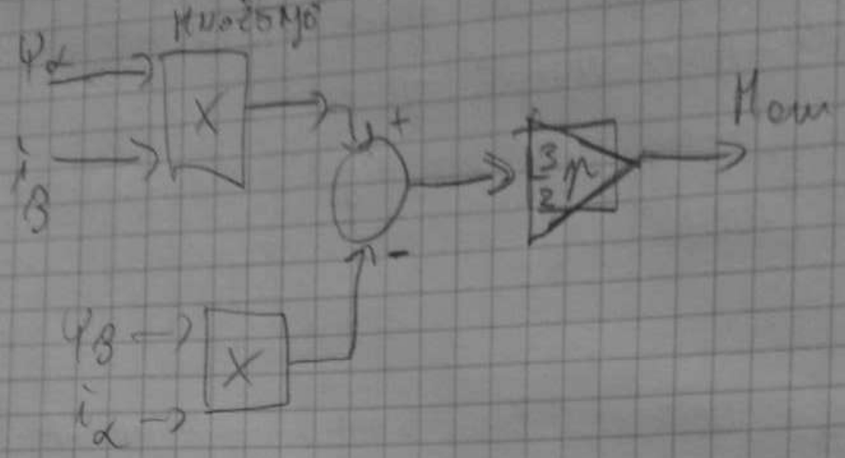
$$\psi_\alpha = \int_0^t \left[u_\alpha(\tau) - R_s i_\alpha(\tau)\right] d\tau \; ; \; \psi_\beta = \int_0^t \left[u_\beta(\tau) - R_s i_\alpha(\tau)\right] d\tau$$

$$\psi = \sqrt{\psi_\alpha^2 + \psi_\beta^2}$$

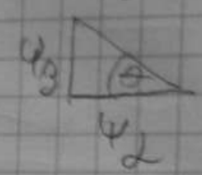


$$M_{em} = \frac{3}{2} p \, \psi \times i = \frac{3}{2} p \begin{vmatrix} \psi_\alpha & \psi_\beta \\ i_\alpha & i_\beta \end{vmatrix} = \frac{3}{2} p \left(\psi_\alpha i_\beta - \psi_\beta i_\alpha\right)$$

S PRETHODNE SLIKE SE UZMU $\psi_\alpha, \psi_\beta, i_\alpha, i_\beta$

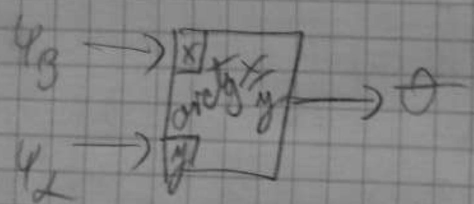


$\theta = \operatorname{arctg} \frac{\psi_\beta}{\psi_\alpha}$ ....> TO JE KUT KOJI OMEĐUJU ψ_β & ψ_α



UZMU SE S PRVE SLIKE ψ_α & ψ_β

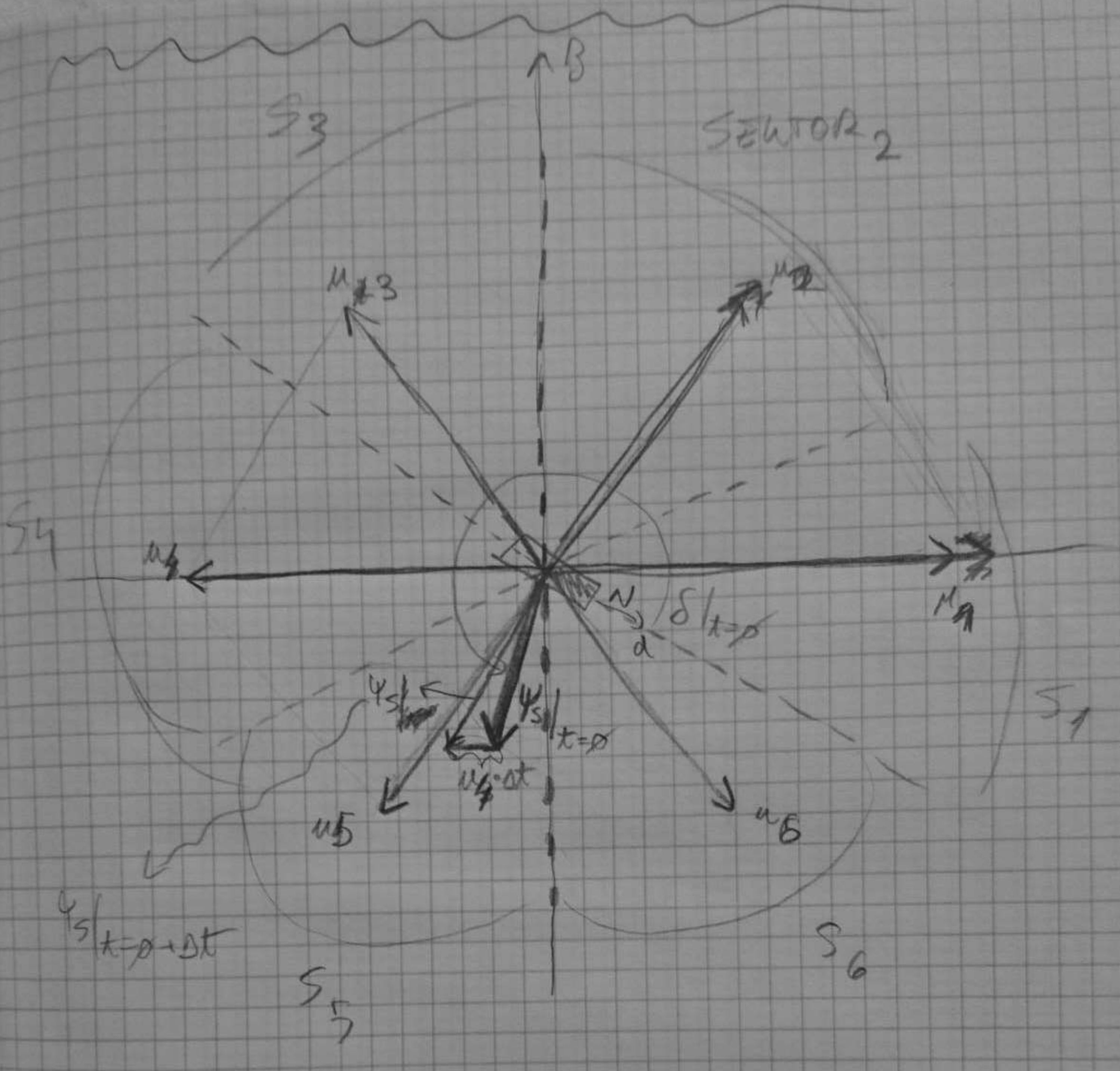
↓



ZAJEDNO SE SVE TRI SLIKE OBJEDINE...

9. [4]

MOTOR JE UPRAVLJAN IZ PRETVARAČA NAPONA & FREKV. KOJI KORISTI DTC NAČIN UPRAVLJANJA. VEKTOR TOKA STATORA ψ_s U TRENUTKU $t = 0s$ NALAZI SE U 5. SEKTORU. IZLAZI IZ HISTEREZNIH REGULATORA TOKA STATORA I MOMENTA MOTORA SU TAKVI DA JE POTREBNO POVEĆATI IZNOS TOKA STATORA ψ_s, A SMANJITI IZNOS MOMENTA MOTORA. KOJI VARIJANT. VEKTOR JE POTREBNO POSTAVITI NA IZLAZU IZ PRETVARAČA NAPONA I FREKV.? NACRTATI POČETNI I REZULTANTNI VEKTOR TOKA STATORA ψ_s U KOORDINATNOM SUSTAVU STATORA.



$\Delta \Psi_S = 1$

$\Delta M = -1$

POTREBNO JE $u_4 \rightarrow$ $\Psi_S \nearrow$ (IZNOS)

$M \searrow$ (KUT)