DINAMIKA INDUSTRIJSKIH SUSTAVA

D I S

Predavanja 2015/2016

Drugi dio ciklusa

26.06.2016

Posebna zahvala kolegi *„jo5o92“* na jednom cijelom predavanju na kojem ja nisam bio nazočan.

Posebna zahvala kolegi *šjor „luka123“* na ukazanim greškama i konstruktivnim sugestijama.

Bez njihove pomoći ovaj dokument nikada ne bi ugledao svijetlo FER2 neta.

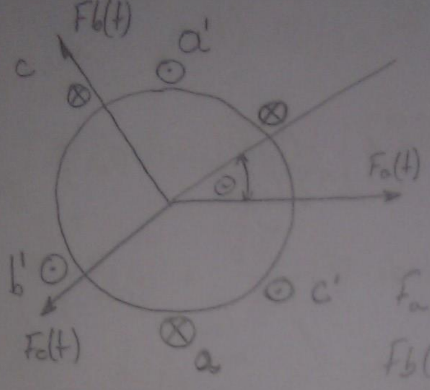
Obratite pozornost da se sa numerirane stranice „33“ prelazi na stranicu „35“: Naime dogodila se greška prilikom numeriranja, tako da se ne radi o manjku stranica u ovom dokumentu.

SRETNO

MATAN

DIS 2 DIO.

Predavanja



$$i_a(t) = I_s \cos(\omega t + \phi_0)$$

$$i_b(t) = I_s \cos\left(\omega t + \phi_0 - \frac{2\pi}{3}\right)$$

$$i_c(t) = I_s \cos\left(\omega t + \phi_0 - \frac{4\pi}{3}\right)$$

$$F_m = N_s I_s$$

$$F_a(t) = N_s \cdot i_a(t) = F_m \cos(\omega t + \phi_0)$$

$$F_b(t) = N_s \cdot i_b(t) = F_m \cos\left(\omega t + \phi_0 - \frac{2\pi}{3}\right)$$

$$F_c(t) = N_s \cdot i_c(t) = F_m \cos\left(\omega t + \phi_0 - \frac{4\pi}{3}\right)$$

$$\left.\begin{aligned} F_a(t)^{\Theta} &= F_a(t) \cdot \cos(0 - \Theta) \\ F_b(t)^{\Theta} &= F_b(t) \cdot \cos\left(\frac{2\pi}{3} - \Theta\right) \\ F_c(t)^{\Theta} &= F_c(t) \cdot \cos\left(\frac{4\pi}{3} - \Theta\right) \end{aligned}\right\} \quad F(t)^{\Theta} = F_a(t)\cos(-\Theta) + F_b(t) \cdot \cos\left(\frac{2\pi}{3} - \Theta\right) + F_c(t)\cos\left(\frac{4\pi}{3} - \Theta\right)$$

$$e^{-j\Theta} = \cos(-\Theta) + j\sin(-\Theta) = \cos\Theta - j\sin\Theta$$

$$\cos(-\Theta) = Re\left\{e^{-j\Theta}\right\}$$

$$F(t)^{\Theta} = Re\left\{F_a(t)e^{-j\Theta} + F_b(t)e^{-j\frac{2\pi}{3} - \Theta} + F_c(t) \cdot e^{j\left(\frac{4\pi}{3} - \Theta\right)}\right.$$

$$= \frac{3}{2} Re\left\{\frac{2}{3}\left(F_a(t) + F_b(t)e^{j\frac{2\pi}{3}} + F_c(t)e^{j\frac{4\pi}{3}}\right)e^{-j\Theta}\right.$$

$$= \frac{3}{2} Re\left\{\vec{F}(t)e^{-j\Theta}\right\}$$

$$\vec{F}(t) = \frac{2}{3} F_m \left[\cos(\omega t + \phi_0) + \cos(\omega t + \phi_0 - \frac{2\pi}{3}) + \cos(\omega t + \phi_0 - \frac{4\pi}{3}) e^{j\frac{4\pi}{3}} \right]$$

$$\cos\alpha = \frac{1}{2}(e^{j\alpha} + e^{-j\alpha})$$

$$\vec{F}(t) = \frac{2}{3} F_m \left[\frac{1}{2}\left(e^{j(\omega t + \phi_0)} + e^{-j(\omega t + \phi_0)}\right) + \frac{1}{2} e^{j\frac{2\pi}{3}} \left(e^{j(\omega t + \phi_0 - \frac{2\pi}{3})} + e^{-j(\omega t + \phi_0 - \frac{2\pi}{3})}\right) \right.$$

$$\left. + \frac{1}{2} e^{j\frac{4\pi}{3}} \left(e^{j(\omega t + \phi_0 - \frac{4\pi}{3})} + e^{-j(\omega t + \phi_0 - \frac{4\pi}{3})}\right) \right] = F_m \cdot e^{j(\omega t + \phi_0)}$$

$$F(t)^{\Theta} = \frac{3}{2} Re\left\{ \vec{F}(t) \cdot e^{-j\Theta} \right\} = \frac{3}{2} F_m \cos(\omega t + \phi_0 - \Theta)$$

OVO TREBA ZNAT IZVEST I RAZUMIT

Za trenutak 0 i $\phi_0 = 0$

$$\left.\begin{aligned} \vec{F_a}(t) &= F_m \cos 0 \\ \vec{F_b}(t) &= F_m \cos(-\tfrac{2\pi}{3}) e^{j\frac{2\pi}{3}} \\ \vec{F_c}(t) &= F_c \cos(-\tfrac{4\pi}{3}) e^{j\frac{4\pi}{3}} \end{aligned}\right\} + \Big/ \cdot \frac{2}{3}$$

$$\frac{2}{3} F_m \Rightarrow F(0)^{\Theta} = F_m \cos\Theta$$

2.

$$\vec{i_s}(t) = \frac{2}{3}\left(i_a(t) + i_b(t)\cdot e^{j\frac{2\pi}{3}} + i_c(t)\, e^{j\frac{4\pi}{3}}\right) = I_0\, e^{j(\omega t + \phi_0)}$$

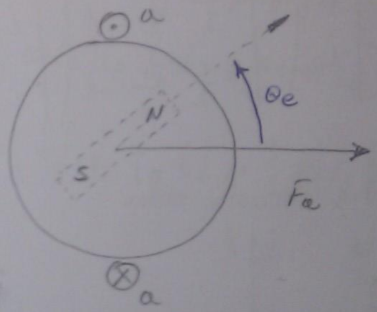
$$\vec{u}(t) = \frac{2}{3}\left(u_a(t) - u_b(t)\, e^{j\frac{2\pi}{3}} + u_c(t)\cdot e^{j\frac{4\pi}{3}}\right) = U_s\, e^{j(\omega t + \phi_0)}$$

$$\vec{\psi_s}(t) = L_s i_s(t) + \phi_{mg}\, e^{j\Theta_e} \longrightarrow$$ kut između toka faze a i trenutačnog položaja rotora

$$\vec{u_s} = R_s \vec{i_s} + \frac{d\vec{\psi_s}}{dt}$$

$$\frac{d\vec{\psi_s}}{dt} = \frac{d}{dt}\left(L_s \vec{i_s} + \phi_{mg}\, e^{j\Theta_e}\right)$$

$$= L_s \cdot \frac{d\vec{i_s}}{dt} + \phi_{mg}\, e^{j\Theta_e} \cdot j\omega_e$$



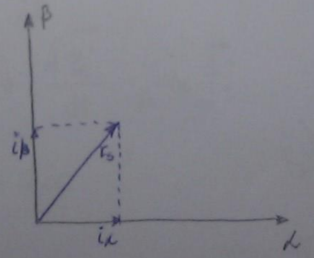
$$\boxed{\vec{u_s} = R_s \vec{i_s} + L_s \frac{di_s}{dt} + j\omega_e \phi_{mg}\, e^{j\Theta_e}}$$

MOTOR S VANJSKIM PERMANENTNIM MAGNETIMA (SMPM)

α-β kordinatni sustav

$$\vec{u_s} = u_\alpha + j u_\beta$$

$$\vec{i_s} = i_\alpha + j i_\beta$$



$$\vec{u_s} = R_s(i_\alpha + j i_\beta) + L_s \frac{d}{dt}(i_\alpha + j i_\beta) + j\omega_e \phi_{mg}\, e^{j\Theta_e}$$

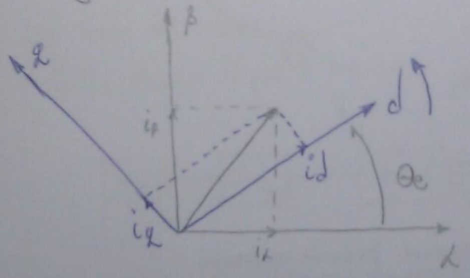
$$u_\alpha = R_s i_\alpha + L_s \frac{di_\alpha}{dt} - \omega_e \phi_{mg} \sin\Theta_e$$

$$u_\beta = R_s i_\beta + L_s \frac{di_\beta}{dt} + \omega_e \phi_{mg} \cos\Theta_e$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix}$$

d-q kordinatni sustav



$$\vec{u}_s = u_s e^{-j\Theta_e} = u_d + j u_q = i_s R_s e^{-j\Theta_e} + L_s \frac{di_s}{dt} e^{-j\Theta_e} + j\omega_e \phi_{mg}$$

$$\vec{i}_s = i_s e^{-j\Theta_e} = i_d + j i_q$$

$$u_d = i_d R_s + L_s \frac{di_d}{dt} - \omega_e L_s i_q$$

$$u_q = i_q R_s + L_s \frac{di_q}{dt} + \omega_e L_s i_d + \omega_e \phi_{mg}$$

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} \cos\Theta_e & \sin\Theta_e \\ -\sin\Theta_e & \cos\Theta_e \end{bmatrix} \begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix}$$

$$\frac{2}{3}\begin{bmatrix} \cos\Theta_e & \cos\left(\Theta_e-\frac{2\pi}{3}\right) & \cos\left(\Theta_e-\frac{4\pi}{3}\right) \\ -\sin\Theta & -\sin\left(\Theta_e-\frac{2\pi}{3}\right) & -\sin\left(\Theta_e-\frac{4\pi}{3}\right) \end{bmatrix}$$

$$\vec{\Psi}_s = \Psi \cdot e^{-j\Theta_e} = L_s(i_d + j i_q) + \phi_{mg}$$

$$\Psi_d = L_d i_d + \phi_{mg}$$

$$\Psi_q = L_d i_q$$

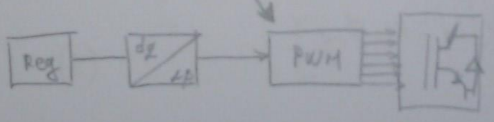
izmjenične veličine
teško za upravljanje

$$M_e = \frac{3}{2} p \cdot \vec{\Psi}_s \times i_s \ (\alpha-\beta) = \frac{3}{2} p \left[(L_s i_\alpha + \phi_{mg} \cdot \cos\Theta_e) i_\beta - (L_s i_\beta + \phi_{mg} \sin\Theta_e) i_\alpha \right]$$

$$= \frac{3}{2} p \vec{\Psi}_s' \times \vec{i}_s' \ (d-q) \Rightarrow M_e = \frac{3}{2} p (\Psi_d i_q - \Psi_q i_d) = \frac{3}{2} p \, i_q \phi_{mg}$$

konst

α-β koordinatni sustav
=> za paljenje sklopke u pretvaraču



$$\vec{u}_s = R_s \vec{i}_s + \frac{d\vec{\Psi}_s}{dt}$$

$$\vec{u}_s' = R_s \vec{i}_s' + \frac{d\vec{\Psi}_s'}{dt} + j\omega_e \vec{\Psi}_s'$$

$$\Psi_d = L_d i_d + \phi_{mg}$$

$$\Psi_q = L_q i_q$$

$$u_d = R_s i_d + L_d \frac{di_d}{dt} - \omega_e L_q i_q$$

$$u_q = R_s i_q + L_q \frac{di_q}{dt} + \omega_e L_d i_d + \omega_e \phi_{mg}$$

$$M_e = \frac{3}{2} p \left[\psi_d i_q - \psi_q i_d \right] = \frac{3}{2} p \phi_{mg} i_q + \underbrace{\frac{3}{2} p (L_d - L_q) \overset{\to 0}{i_d} i_q}_{0}$$

$$\omega_e = p \cdot \omega_m$$

$$J \frac{d\omega_m}{dt} = M_e - M_t - \underbrace{D\omega}_{\text{prigušenje}}$$

Nakon što se prebaci u električne veličine

$$\frac{d\omega_e}{dt} = \frac{p}{J_m} \left[\frac{3}{2} p \left(\phi_{mg} i_q + (L_d - L_q) i_d i_q \right) - M_t - \frac{D}{p} \omega_e \right] \quad (1)$$

$$\frac{di_d}{dt} = \frac{1}{L_d} \left[u_d - R_s i_d + \omega_e L_q i_q \right] \quad (2)$$

$$\frac{di_q}{dt} = \frac{1}{L_q} \left[u_q - R_s i_q - \omega_e L_d i_d - \omega_e \phi_{mg} \right] \quad (3)$$

PER UNIT SUSTAV

$U_B = \sqrt{2}\, U_f$

$I_B = \sqrt{2}\, I_f$

$\omega_B = 2\pi f = \omega_{eB}$

$S_B = \frac{3}{2} U_B \cdot I_B = S_n$

$\psi_B = \frac{U_B}{\omega_B}$

$Z_B = R_b = \frac{U_B}{I_B}$

$L_B = \frac{Z_B}{\omega_B}$

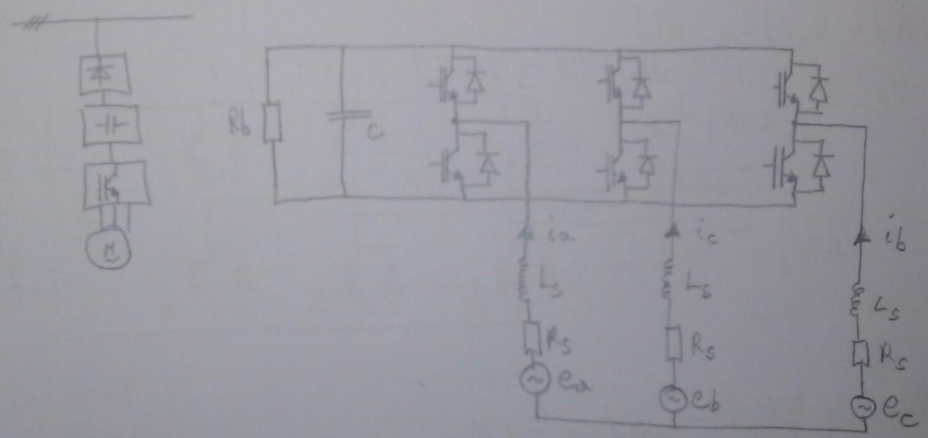
$t = \frac{1}{\omega_B}$

$M_B = \frac{S_B}{\omega_{mB}}$

$$\frac{di_d}{dt} = \frac{\omega_{cb}}{L_d}\left[u_d - R_s i_d + \omega_e L_q i_q\right] \qquad (4)$$

$$\frac{di_q}{dt} = \frac{\omega_{cb}}{L_q}\left[u_q - R_s i_q - \omega_e L_d i_d - \omega_e \phi_{mg}\right] \qquad (5)$$

$$\omega_{co}\frac{d\omega_e}{dt} = \frac{p}{J_m}\left[M_n \cdot M_e - M_b \cdot M_t - \frac{D}{p}\omega_{co}\cdot \omega_e\right] \qquad (6)$$



$$E_a(t) = E_m \cos(\omega_g t)$$

$$E_b(t) = E_m \cos\left(\omega_g t - \frac{2\pi}{3}\right)$$

$$E_c(t) = E_m \cos\left(\omega_g t - \frac{4\pi}{3}\right)$$

$$i_s(t) = \frac{2}{3}\left(i_a(t) + i_b(t)\, e^{j\frac{2\pi}{3}} + i_c(t)\, e^{j\frac{4\pi}{3}}\right.$$

$$u_s(t) = \frac{2}{3}\left(u_a(t) + u_b(t)\, e^{j\frac{2\pi}{3}} + u_c(t)\, e^{j\frac{4\pi}{3}}\right)$$

$$i_a + i_b + i_c = 0$$

$$E_a + E_b + E_c = 0$$

$$\omega_g = 2\pi f$$

$$u_s = -R_s \vec{i_s} - L_s \frac{di_s}{dt} + \vec{E_s}$$

$$u_\alpha = -R_s i_\alpha - L_s \frac{di_\alpha}{dt} + E_\alpha$$

$$u_\beta = -R_s i_\beta - L_s \frac{di_\beta}{dt} + E_\beta$$

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

$$u_q = -R_s i_q - L_s \frac{di_q}{dt} - \omega_g L_s i_d + \underbrace{E_q}_{=0}$$

$$P_e = P_g - P_L$$ uvrštavanjem izraza za snagu

$$u_{dc} \cdot i_c = \frac{3}{2} u_s i_s - i_L u_{dc} = \frac{3}{2}(u_\alpha i_\alpha + u_\beta \cdot i_\beta) - i_L u_{dc}$$

$$i_c = C \frac{du_{dc}}{dt}$$

$$C \cdot \frac{du_{dc}}{dt} = \frac{3}{2u_{dc}}(u_\alpha i_\alpha + u_\beta i_\beta) - i_L = \frac{3}{2u_{dc}}(u_d i_d + u_q i_q) - i_L$$

MATLAB / SIMULACIJA

$J_m = 0.47 \cdot 10^{-4}\,kgm^2$	$R_s = 2.98\,\Omega$	$p = 2$	$M_B = 1,1\,Nm$
$D = 1,1 \cdot 10^{-4}\,Nms$	$\phi_{mg} = 0.125\,Wb$	$P_b = 0,35\,kW$	$I_B = 8,083\,A$
$L_q = L_d = 7 \cdot 10^{-3}\,H$	$i_n = 2,9$	$U_B = \frac{150}{\sqrt{3}}\,V$	$R_B = 10,71\,\Omega$

$W_{eb} = 630.63 \frac{rad}{s}$

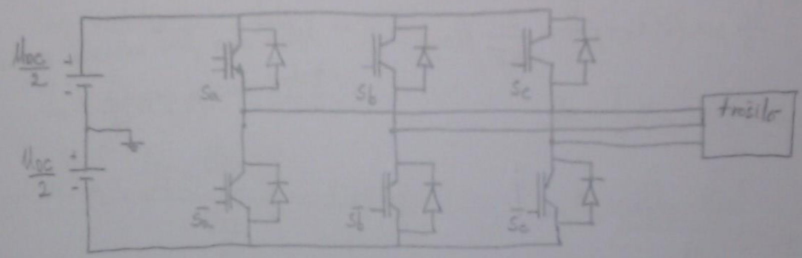
$L_b = 0.017 H$

$\phi_B = 0,1373 Wb$

$J_b = 0.0018 kgm^2$

$D_B = 0,0018$

Tipovi modulacije



$S_a + \bar{S_a} = 1$

$S_b + \bar{S_b} = 1$

$S_c + \bar{S_c} = 1$

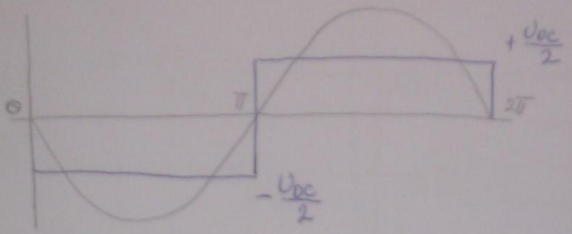
	U_0	U_1	U_2	U_3	U_4	U_5	U_6	U_7
U_a S_a	0 $-\frac{U_{DC}}{2}$	1 $\frac{U_{DC}}{2}$	1	0	0	0	1	1
U_b S_b	0 $-\frac{U_{DC}}{2}$	0 $-\frac{U_{DC}}{2}$	1	1	1	0	0	1
U_c S_c	0 $-\frac{U_{DC}}{2}$	0 $-\frac{U_{DC}}{2}$	0	0	1	1	1	1

aktivni vektori

$$U_i = U_{DC} S_i - \frac{U_{DC}}{2}$$

Ovisno o modulaciji imat ćemo izlazni napon

6 KORAKA - MODULACIJA



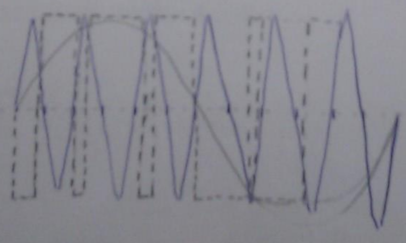
$$u(t) = b_1 \sin \omega_e t + b_3 \sin 3\omega_e t + \ldots + b_n \sin(n\omega_e t) + \ldots$$

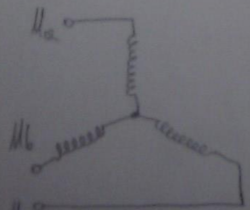
$$b_n = \frac{2\omega_e}{\pi} \int_0^{\frac{\pi}{\omega_e}} \frac{U_{DC}}{2} \sin(n\omega_e t)\, dt = \frac{2}{n\pi} U_{DC}$$

⇒ želimo samo prvi harmonik napona, ostali unose smetnje

S

$$\frac{f_s}{f_1} = 21$$





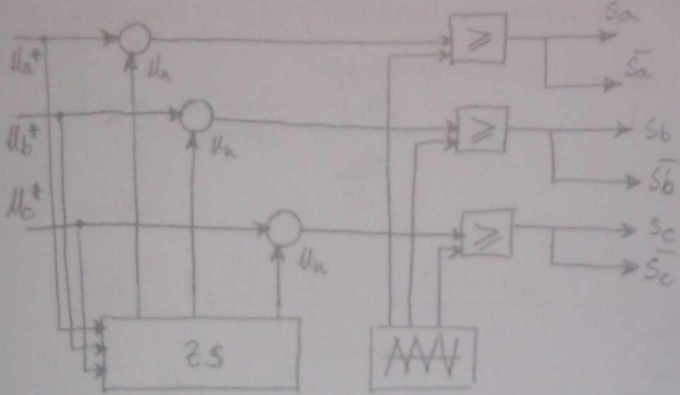
$$u_a^* = u_m \sin(\omega_e t) \qquad u_a^{**} = u_a^* + u_n$$

$$u_b^* = u_m \sin\left(\omega_e t - \frac{2\pi}{3}\right) \qquad u_b^{**} = u_b^* + u_n$$

$$u_c^* = u_m \sin\left(\omega_e t - \frac{4\pi}{3}\right) \qquad u_c^{**} = u_c^* + u_n$$

$$u_n = \frac{1}{6} u_m \sin(3\omega_e t)$$

STRUKTURA UPRAVLJANJA



Bolji modulacijski indeks

$$u_n = \frac{1}{6} u_m \sin(3\omega_e t)$$

$$m^* = \frac{\frac{2}{\sqrt{3}} \cdot \frac{u_{DC}}{2}}{\frac{u_{DC}}{2}} = 1.1547$$

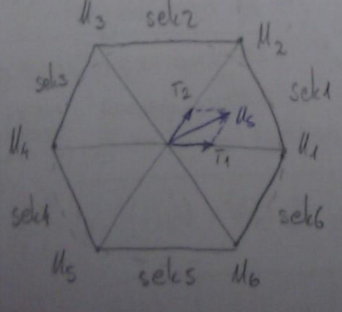
Bolji THD

$$u_n = \frac{1}{4} u_m \sin(3\omega_e t)$$

$$m^* = \frac{\frac{3\sqrt{3}}{\sqrt{4}} \cdot u_{DC}}{\frac{u_{DC}}{2}} = 1.1223$$

VEKTORSKA MODULACIJA

$$\vec{u}_s^* = \frac{2}{3}\left(u_{an}^* + u_{bn}^* e^{j\frac{2\pi}{3}} + u_{cn}^* e^{j\frac{4\pi}{3}}\right)$$



$$T_s \cdot \vec{u}_s^* = T_1 \vec{u}_1 + T_2 \vec{u}_2$$

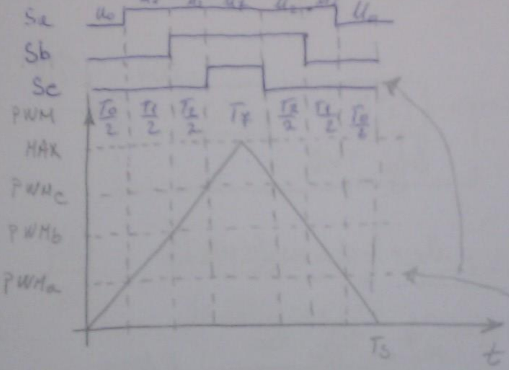
$$|\vec{u}_s^*| = \frac{1}{\sqrt{3}} u_{DC}$$

$$|u_1| = \frac{2}{3} u_{DC}$$

$$\frac{T_s\,|u_s^*|}{\sin\left(\frac{2\pi}{3}\right)} = \frac{T_1\,|u_1|}{\sin\left(\frac{\pi}{3}-\Theta\right)} = \frac{T_2\,|u_2|}{\sin\Theta}$$

$$\frac{T_1}{T_s} = \frac{|u_s^*|}{\frac{u_{DC}}{\sqrt{3}}}\sin\left(\frac{\pi}{3}-\Theta\right) \qquad \frac{T_2}{T_s} = \frac{|u_s^*|}{\frac{u_{DC}}{\sqrt{3}}}\sin\Theta$$

$$T_s - T_1 - T_2 = T_0 + T_7$$



$$0 < t < \frac{T_s}{2}$$

$$PWM_{tre} = \frac{2MAX}{T_s}\cdot t$$

$$\frac{T_s}{2} < t < T_s$$

$$PWM_{tre} = 2MAX - \frac{2MAX}{T_s}\cdot t$$

$$PWM_{Sa} = \frac{T_0}{T_s}$$

$$PWM_{Sb} = \frac{T_0 + T_1}{T_s}$$

$$PWM_{Sc} = \frac{T_0 + T_1 + T_2}{T_s}$$

Kako ćemo uključivati i isključivati sklopke

Indeks modulacije je

$$m^* = \frac{\frac{u_{DC}}{\sqrt{3}}}{\frac{u_{DC}}{2}} = 1.155$$

Prilikom implementacije paziti na ograničenja

- NESMIJEMO PRIJEĆI LIMIT OGRANIČENJA IZLAZNOG NAPONA MAX

Ograničenja koja se uzimaju u obzir kada se implementira sustav

$$\sqrt{u_\alpha(t)^2 + u_\beta(t)^2} \leq \frac{u_{DC}}{\sqrt{3}}$$

$$\sqrt{u_d(t)^2 + u_q(t)^2} \leq \frac{u_{DC}}{\sqrt{3}}$$

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Određivanje parametara regulatora

objekt upravljanja (MORAMO POZNAVATI)

↳ IDENTIFICIRATI I DEFINIRATI OBJEKT UPRAVLJANJA

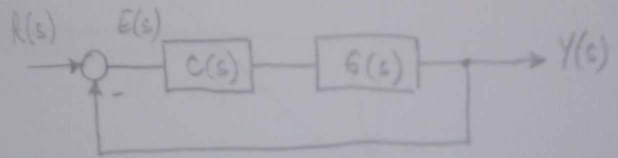
$$G(s) = \frac{b}{a+s}$$

PI regulator.

$$C(s) = K_c\left(1 + \frac{1}{T_I s}\right) = \frac{c_1 s + c_0}{s}$$

$$K_c = c_1$$

$$T_I = \frac{c_1}{c_0}$$



$$\frac{Y(s)}{R(s)} = \frac{G(s)\cdot C(s)}{1 + G(s)\cdot C(s)} = \frac{b(c_1 s + c_0)}{s(s+a) + b(c_1 s + c_0)}$$

$$s(s+a) + b(c_1 s + c_0) = s^2 + 2\xi\omega_n s + \omega_n^2$$

→ kolika iznose ova dva parametra da bi se dobilo željeno ponašanje sustava

$$s^2 + sa + sbc_1 + c_0 b = s^2 + 2\xi\omega_n s + \omega_n^2$$

$$\left.\begin{aligned} a + bc_1 &= 2\xi\omega_n \\ c_0 b &= \omega_n^2 \end{aligned}\right\} \quad c_1 = \frac{2\xi\omega_n - a}{b} \qquad c_0 = \frac{\omega_n^2}{b}$$

za faktor $\xi = \frac{\sqrt{2}}{2}$ faktor nadvišenja je do 5%

$0{,}707 < \xi < 1$, za $\xi = 1$ aperiodski odziv bez nadvišenja

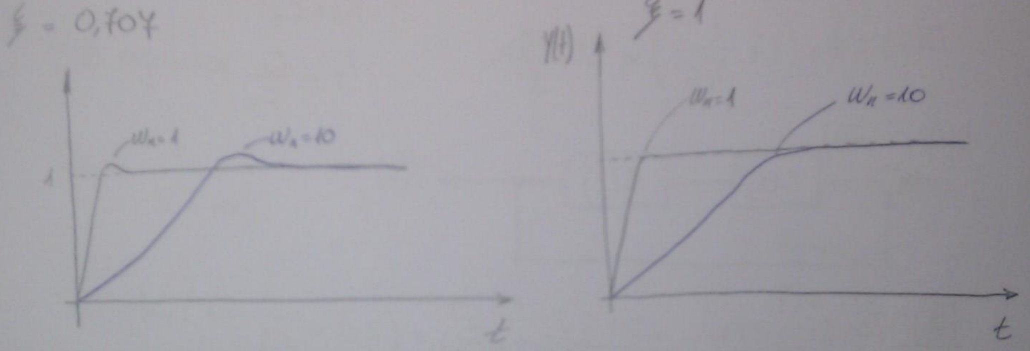
za $\xi = 1$ $\quad s_{1,2} = -\omega_n$

$\xi = 0{,}707$

$$s_{1,2} = -0{,}707\,\omega_n \pm j\,0{,}707\,\omega_n$$

"igramo" se s prigušenjem (ξ) ovisno o tome želimo li nadvišenje ili NE

$$T_s \approx \frac{5\xi}{\omega_N}$$



Primjer

$$G(s) = \frac{1}{s(s+1)^3} \qquad K_c = 0{,}56 \quad T_1 = 8$$

$$u(t) = K_c\underbrace{\big(r(t) - y(t)\big)}_{\text{Greška}} + \frac{K_c}{T_1}\int_0^t \underbrace{\big(r(\tau) - y(\tau)\big)}_{\text{greška}}\,d\tau$$

$$\frac{Y(s)}{R(s)} = \frac{K_c(T_1 s + 1)}{T_1 s^2 (s+1)^3 + K_c(T_1 s + 1)} \qquad (1)$$

upravljački dio

$$u(t) = -K_c\, y(t) + \frac{K_c}{T_1}\int_0^t \big(r(\tau) - y(\tau)\big)\,d\tau$$

$$\frac{Y(s)}{R(s)} = \frac{K_c}{T_1 s^2 (s+1)^3 + K_c(T_1 s + 1)} \qquad (2)$$

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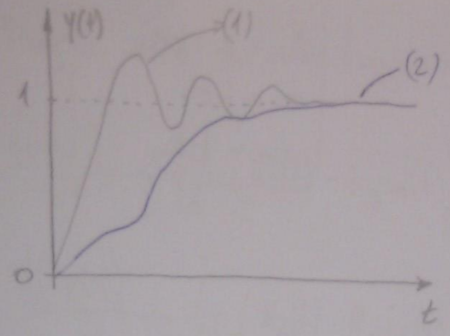


sve je kasnija regulacija

PID regulator

$$G(s) = \frac{b}{s(s+a)}$$

$$C(s) = K_c\left(1 + \frac{1}{T_I s} + T_D s\right) = \frac{c_2 s^2 + c_1 s + c_0}{s}$$

$K_c = c_1$

$T_I = \frac{K_c}{c_0} = \frac{c_1}{c_0}$

$T_D = \frac{c_2}{K_c} = \frac{c_2}{c_1}$

$$\frac{Y(s)}{R(s)} = \frac{b(c_2 s^2 + c_1 s + c_0)}{\boxed{s^2(s+a) + b(c_2 s^2 + c_1 s + c_0)}} \quad = s^3 + t_2 s^2 + t_1 s + t_0$$

$$s_{1,2} = -\xi\omega_n \pm j\omega_n\sqrt{1-\xi^2}$$

$$s_3 = -n\cdot\omega \quad (n >> 1 \ldots\ldots n = 10)$$

$$(s^2 + 2\xi\omega_n s + \omega_n^2)(s + n\omega_n) = s^3 + t_2 s^2 t_1 + t_0$$ → karakteristični polinom sustava za 3 red

$$= s^3 + s^2 n\omega_n + s^2 2\xi\omega_n^2 + s\omega_n^2 + s\,2\xi\omega_n^2 n + n\omega_n^3$$

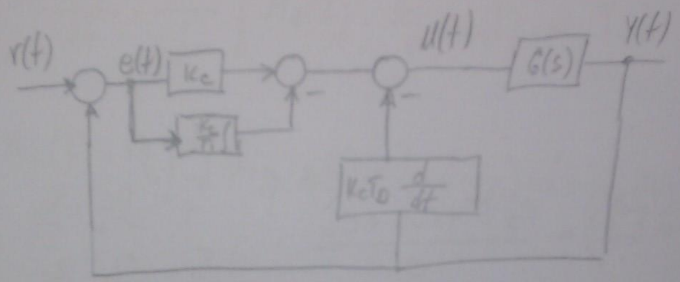
$$= s^3 + s^2\omega_n(2\xi + n) + s\omega_n^2(1 + 2\xi n) + n\omega_n^3$$

$$\boxed{\begin{aligned} t_2 &= (2\xi + n)\omega_n \\ t_1 &= (2\xi n + 1)\omega_n^2 \\ t_0 &= n\omega_n^3 \end{aligned}}$$

$$\left.\begin{aligned} C_2 &= \frac{t_2 - a}{b} \\ C_1 &= \frac{t_1}{b} \\ C_0 &= \frac{t_0}{b} \end{aligned}\right\} \quad \begin{aligned} K_c &= C_1 \\ T_I &= \frac{2\xi n + 1}{\omega_n} \\ T_D &= \frac{(2\xi + n)\omega_n + a}{(2\xi n + 1)\omega_n^2} \end{aligned}$$

$$\boxed{\begin{aligned} t_2 &= a + bc_2 \\ t_1 &= bc_1 \\ t_0 &= bc_0 \end{aligned}}$$

$$u_D(t) = -K_c T_D \frac{dy(t)}{dt}$$



NASTAVAK

$$c_2 = \frac{t_2 - a}{b} = \frac{(2\xi + n)\omega_n - a}{b}$$

$$c_1 = \frac{t_1}{b} = \frac{(2\xi n + 1)\omega_n^2}{b} = K_c$$

$$c_0 = \frac{t_0}{b} = \frac{n\omega_n^3}{b}$$

$$c_1 = K_c$$

$$T_I = \frac{c_1}{c_0} = \frac{\frac{(2\xi n + 1)\omega_n^{\cancel{2}}}{\cancel{b}}}{\frac{n\omega_n^{\cancel{3}}}{\cancel{b}}} = \frac{(2\xi n + 1)}{n\omega_n}$$

$$T_D = \frac{c_2}{c_1} = \frac{(2\xi + n)\omega_n - a}{(2\xi n + 1)\omega_n^2}$$

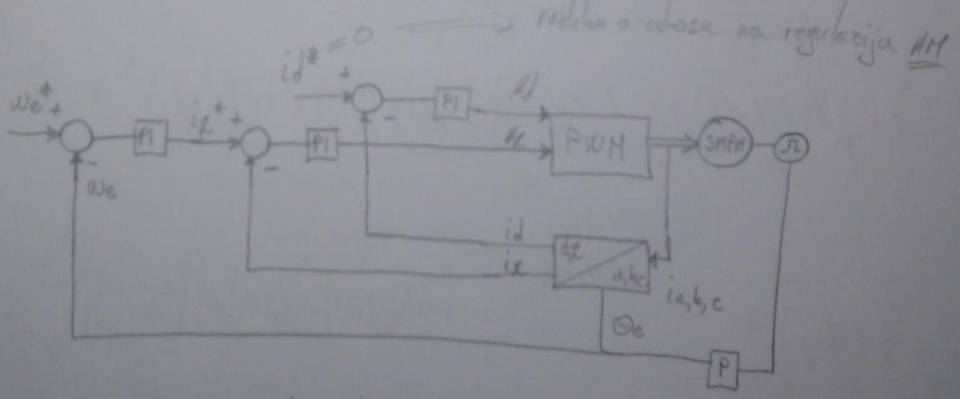
Primjena veze za određivanje parametara po povratnoj vezi struja i_d i i_q

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

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

$$\frac{d\omega_e(t)}{dt} = \frac{p}{J_m}\left[M_e(t) - \frac{D}{p}\omega_e(t) - M_t\right]$$

$$M_e(t) = \frac{3}{2}p\left[\phi_{rq} i_q(t) + (L_d - L_q) i_d(t) i_q(t)\right]$$

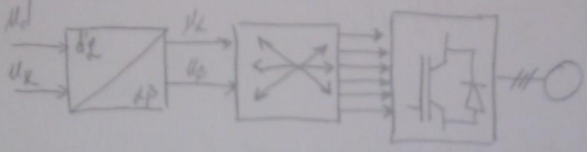


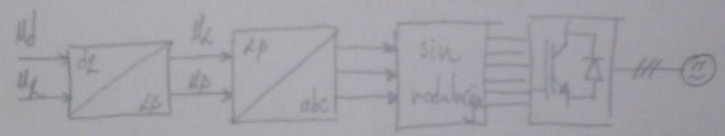
$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\Theta_e & \sin\Theta_e \\ -\sin\Theta_e & \cos\Theta_e \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} \begin{bmatrix} \cos\Theta_e & -\sin\Theta_e \\ \sin\Theta_e & \cos\Theta_e \end{bmatrix} \begin{bmatrix} u_d \\ u_q \end{bmatrix}$$

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix} \begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix}, \quad u_0 = 0$$





$$M_e = \frac{3}{2} p \left[\psi_{mq} i_q(t) + \underbrace{(L_d - L_q)\, i_d(t)\, i_q(t)}_{\emptyset} \right] \qquad \underline{i_d^* = 0}$$

$L_d = L_q$

$L_d \neq L_q \Rightarrow$ za Taylor red

$$i_d(t)\, i_q(t) = \underset{0}{i_d^*} i_q^* + \underline{i_d^*}\left[i_q(t) - i_q^*\right] + i_q^* \underset{\approx 0}{\left(i_d(t) - i_d^*\right)}$$

$$M_e^* = \frac{3}{2} p \psi_{mg} i_q^*$$

$$i_q^* = \frac{2}{3} \frac{M_e^*}{p \psi_{mg}}$$

(18.)

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

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

$$\hat{u}_d = u_d + \omega_e L_q i_q$$

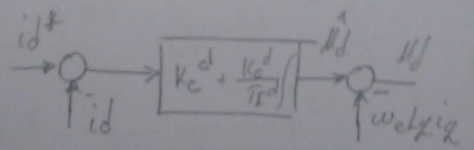
$$\hat{u}_q = u_q - \omega_e L_d i_d - \omega_e \phi_{mg}$$

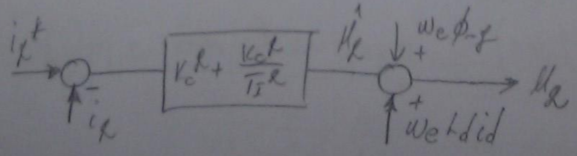
$$\frac{di_d}{dt} = \frac{1}{L_d}\left(\hat{u}_d - R_s i_d\right)$$

$$\frac{di_q}{dt} = \frac{1}{L_q}\left(\hat{u}_q - R_s i_q\right)$$

$$\hat{u}_d = K_c^d\left[i_d^*(t) - i_d(t)\right] + \frac{K_c^d}{T_I^d}\int\left[i_d^*(\tau) - i_d(\tau)\right]d\tau$$

$$\hat{u}_q = K_c^q\left[i_q^*(t) - i_q(t)\right] + \frac{K_c^q}{T_I^q}\int\left[i_q^*(\tau) - i_q(\tau)\right]d\tau$$





$$\frac{di_d}{dt} = \frac{1}{L_d}\hat{u}_d - \frac{R_s}{L_d} i_d \qquad \frac{I_d(s)}{U_d(s)} = \frac{\frac{1}{L_d}\, b}{s + \frac{R_s}{L_d}\, a}$$

$$\frac{di_q}{dt} = \frac{1}{L_q}\hat{u}_q - \frac{R_s}{L_q} i_q \qquad \frac{I_q(s)}{U_q(s)} = \frac{\frac{1}{L_q}\, b}{s + \frac{R_s}{L_q}\, a}$$

$$C^d(s) = K_c^d\left(1 + \frac{1}{T_I^d s}\right) \qquad K_c^d = \frac{2\zeta\omega_n - a}{b} = \frac{2\zeta\omega_n - \frac{R_s}{L_d}}{\frac{1}{L_d}} = 2\zeta\omega_n L_d - R_s$$

$$C^q(s) = K_c^q\left(1 + \frac{1}{T_I^q s}\right) \qquad K_c^q = 2\zeta\omega_n L_q - R_s$$

$$T_I^d = \frac{2\zeta\omega_n - a}{\omega_n^2} = \frac{2\zeta\omega_n - \frac{R_s}{L_d}}{\frac{1}{L_d}} = \frac{2\zeta\omega_n L_d - R_s}{\omega_n^2 L_d}$$

$$T_I^q = \frac{2\zeta\omega_n L_q - R_s}{\omega_n^2 L_q}$$

$$\omega_n^d = \frac{1}{1-\gamma}\,\frac{R_s}{L_d}$$ $\gamma = 0{,}9$ $(0{,}7 - 0{,}9)$ odabir gore   često baš 0,9

$$\omega_n^q = \frac{1}{1-\gamma}\cdot\frac{R_s}{L_q} \qquad \frac{1}{1-0{,}9} = \frac{1}{0{,}1} = 10$$

$$\frac{I_d(s)}{U_d(s)} = \frac{\frac{1}{L_d}}{s + \frac{R_s}{L_d}} = \frac{\frac{1}{L_d}}{\frac{R_s}{L_d}\left(s\underbrace{\frac{L_d}{R_s}}_{10} + 1\right)}$$

→ Proširuje se frekvencijsko područje

P-tip - statička pogreška
P1 - nadređeni član izregulira statičku pogrešku

P-tip regulatora - bolja dinamika
- statička pogreška (izregulira se nadređenim regulatorom PI)

$$\hat{U}_q(s) = K_c^q\left(I_q^*(s) - I_q(s)\right)$$

otvoreni krug

$$\frac{di_q}{dt} = \frac{1}{L_q}u_q - \frac{R_s}{L_q}i_q \Rightarrow G(s) = \frac{I_q(s)}{U_q(s)} = \frac{\frac{1}{L_q}}{s + \frac{R_s}{L_q}}$$ otvoreni krug

$$sL_qI_q(s) + R_sI_q(s) = K_c^q\left(I_q^*(s) - I_q(s)\right)$$

jeba odrediti zatvoreni krug prijenosnu funkciju

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

$s = 0$

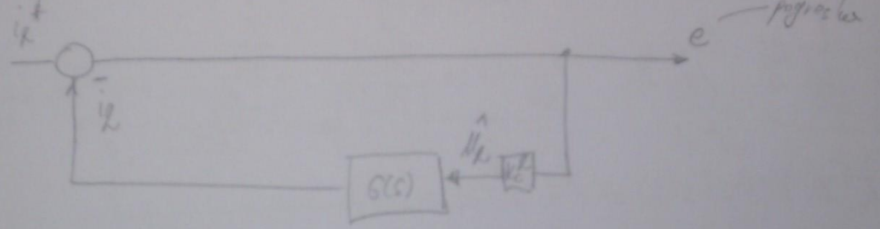
$$\frac{I_q(0)}{I_q^*(0)} = \frac{\frac{K_c^q}{L_q}}{\frac{R_s}{L_q} + \frac{K_c}{L_q}} = \alpha$$

$$K_c^q = \frac{\alpha}{1-\alpha}R_s$$

$$\frac{I_q(s)}{I_q^*(s)} = \frac{\frac{\alpha}{1-\alpha}\cdot\frac{R_s}{L_q}}{s + \frac{R_s}{L_q} + \frac{\alpha}{1-\alpha}\frac{R_s}{L_q}} = \frac{\frac{\alpha}{1-\alpha}\frac{R_s}{L_q}}{s + \frac{1}{1-\alpha}\frac{R_s}{L_q}}$$ => zatvoreni prijenosni krug

Usporedba zatvoreni i otvoreni krug

$$\frac{-\frac{1}{1-\lambda}\frac{R_s}{L_q}}{-\frac{R_s}{L_q}} = \frac{1}{1-\lambda} = 0,9$$

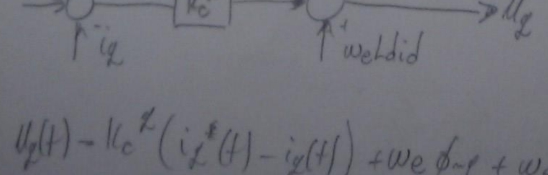


$$\frac{E(s)}{I_q^*(s)} = \frac{1}{1+K_c^q G(s)} = \frac{1}{1+K_c^q \frac{1}{sL_q+R_s}} = \frac{sL_q+R_s}{sL_q+R_s+K_c^q} \Rightarrow \frac{R_s}{R_s+K_c^q}$$

$$\lim_{t\to\infty} e(t)$$

$$= \frac{R_s}{R_s+9R_s} = \frac{1}{1+9} = 0.1$$

Reg. po struji i_q

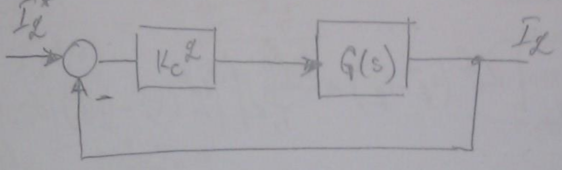


$$u_q(t) = K_c^q\left(i_q^*(t) - i_q(t)\right) + \omega_e\phi_{rq} + \omega_e L_d i_d$$

$$\frac{d\omega_e}{dt} = \frac{p}{J_m}\left[M_e - \frac{D}{p}\omega_e - M_t\right] = \frac{3}{2}\frac{p^2}{J_m}\phi_{mg} i_q + \cancel{\frac{3}{2}\frac{p^2}{J_m}(L_d - L_q) i_d i_q}^{\,0}$$

$$- \frac{D}{J_m}\omega_e - \cancel{\frac{p}{J_m} M_t} \xrightarrow{\text{zanemareno}} \text{poremećajna veličina}$$

$$M_e = \frac{3}{2} p \left[\phi_{mg} i_q + (L_d - L_q) i_d i_q\right]$$



$$\frac{I_q(s)}{I_q^*(s)} = \frac{\frac{\alpha}{1-\alpha}\frac{R_s}{L_q}}{s + \frac{1}{1-\alpha}\cdot\frac{R_s}{L_q}}$$

$$s\,\Omega(s) = \frac{3}{2}\frac{p^2}{J_m}\phi_{mg} I_q(s) - \frac{D}{J_m}\Omega(s)$$

reg. po brzini i struji

$$\Omega(s)\left[s + \frac{D}{J_m}\right] = \frac{3}{2}\frac{p^2}{J_m}\phi_{mg}\,\frac{\frac{\alpha}{1-\alpha}\frac{R_s}{L_q}}{s + \frac{1}{1-\alpha}\frac{R_s}{L_q}}\, I_q^*(s)$$

$$\underbrace{\frac{\Omega(s)}{I_q^*(s)} = \frac{\frac{3}{2}\frac{p^2}{J_m}\phi_{mg}}{s + \frac{D}{J_m}} \cdot \frac{\alpha}{s(1-\alpha)\frac{L_q}{R_s} + 1}}_{\rightarrow\ 2.\ \text{red}}$$

a treba nam P regulator (1 reda)

$$\frac{\Omega(s)}{I_q^*(s)} = \frac{\frac{3}{2}\frac{p^2}{D}\phi_{mg}}{s\frac{J_m}{D} + 1} \cdot \frac{\alpha}{s(1-\alpha)\frac{L_q}{R_s} + 1}$$

→ meh. vremenska konstanta → el. vrem. konstanta

Ø

$$\frac{J_m}{D} \ggg \frac{L_q}{R_s}(1-\alpha)$$

$$\approx \frac{\frac{3}{2}\frac{p^2}{D}\phi_{mg}\cdot L}{s\frac{J_m}{D}+1} = \frac{\overbrace{\frac{3}{2}\frac{p^2}{J_m}\phi_{mg}\cdot L}^{b}}{s+\underbrace{\frac{J_m}{D}}_{=a}}$$

$$K_c^{\omega} = \frac{2\zeta\omega_n\cdot a}{b} \qquad T_I^{\omega} = \frac{2\zeta\omega_n\cdot a}{\omega_n^2}$$

PARAMETRI PI regulatora po struji I_q (robusniji)

$$\frac{di_q(t)}{dt} = \frac{1}{L_q}\hat{u}_q - \frac{R_s}{L_q}i_q = \frac{1}{L_q}\left[K_c^q(i_q^* - i_q) + \frac{K_c^q}{T_I^q}\int\left[i_q^*(\tau) - i_q(\tau)\right]d\tau\right] - \frac{R_s}{L_q}i_q$$

$$\hat{u}_q = u_q - \omega_e\phi_{mg} - \omega_e L_d i_d$$

$$sI_q(s) = \frac{K_c^q}{L_q}\left[I_q^*(s) - I_q(s)\right] + \frac{K_c^q}{T_I^q L_q}\cdot\frac{1}{s}\left[I_q^*(s) - I_q(s)\right] - \frac{R_s}{L_q}I_q(s)$$

$$K_c^q = \frac{2\zeta\omega_n - a}{b} = 2\zeta\omega_n L_q - R_s$$

$$T_I^q = \frac{2\zeta\omega_n - a}{\omega_n^2} = \frac{2\zeta\omega_n L_q - R_s}{L_q\omega_n^2}$$

$$\frac{I_q(s)}{I_q^*(s)} = \frac{\left(2\zeta\omega_n - \frac{R_s}{L_q}\right)s + \omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$\frac{\Omega(s)}{I_q(s)} = \frac{\frac{3}{2}\frac{p^2}{J_m}\phi_{mg}}{s+\frac{D}{J_m}} \Rightarrow \frac{\Omega(s)}{I_q^*(s)} = \frac{\frac{3}{2}\frac{p^2}{J_m}\phi_{mg}}{s+\frac{D}{J_m}} \cdot \underbrace{\frac{\left(2\zeta\omega_n - \frac{b_s}{b_g}\right)s+\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}}_{1}$$

pavo brži

$\hookrightarrow$ 3 red

$$\boxed{\omega_n \ggg \frac{D}{J_m}\ !!}$$

$$\frac{\Omega(s)}{I_q^*(s)} = \frac{\frac{3}{2}\frac{p^2}{J_m}\phi_g}{s+\frac{D}{J_m}}$$

$b = \frac{3}{2}\frac{p^2}{J_m}\phi_g$, $a = \frac{D}{J_m}$

$$K_c^{\omega} = \frac{2\zeta^{\omega}\omega_n^{\omega} - a}{b}$$

$$T_i^{\omega} = \frac{2\zeta^{\omega}\omega_n^{\omega} - a}{\omega_n^{\omega\,2}}$$

SIMULACIJA MATLAB P reg

KADA NEMAMO RASPREZANJE $i_d \approx 1A$

KADA IMAMO RASPREZANJE $i_d \approx 0$

→ ODZIV SE DRŽI, NADVIŠENJE SE MANJE

→ ako nakon rasprezanja za $\boxed{P}$ reg kod i_q nije je nadvišenje ali i_d nije više u nuli stalno, ima skokove u zaletu i kočenju

→ $\boxed{PI}$ → spaja sustav

PID po položaju

$$\Theta_e = \int \omega_e(t)\,dt$$

$$\frac{\Theta_e(s)}{\Omega(s)} = \frac{1}{s}$$

$$\frac{\Omega(s)}{I_q(s)} = \frac{\frac{3}{2}\frac{p^2}{J_m}\phi_{rq}}{s + \frac{D}{J_m}}$$

$$\frac{I_q(s)}{I_q^*(s)} = \frac{\frac{\lambda}{1-\lambda}\cdot\frac{R_s}{L_q}}{s + \frac{1}{1-\lambda}\cdot\frac{R_s}{L_q}}$$

$$\frac{\Theta_e(s)}{I_q^*(s)} = \frac{\frac{3}{2}\frac{p^2}{J_m}\phi_{rq}}{s\left(s+\frac{D}{J_m}\right)} \cdot \frac{\frac{\lambda}{1-\lambda}\cdot\frac{R_s}{L_q}}{s+\frac{1}{1-\lambda}\frac{R_s}{L_q}} = \frac{3}{2}\frac{p^2}{J_m}\phi_{rq}\frac{1}{s\left(s+\frac{D}{J_m}\right)}\cdot\frac{\lambda}{\underbrace{(1-\lambda)\left(\frac{L_q}{R_s}\right)+1}_{G(s)+1}}$$

$$\frac{\Theta_e(s)}{I_q^*(s)} = \frac{3}{2}\frac{p^2}{J_m}\phi_{rq}\cdot\frac{\lambda}{s\left(s+\frac{D}{J_m}\right)} = \frac{b}{s(s+c)}$$

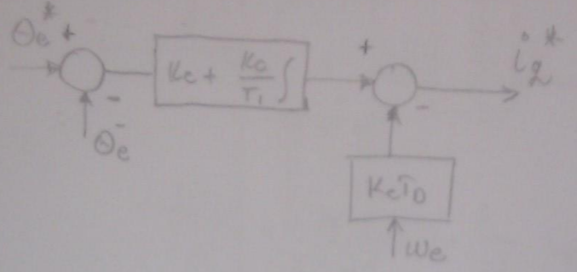
$$C(s) = K_c\left(1 + \frac{1}{T_I s} + T_D s\right)$$

$$K_c = \frac{(2\xi\omega_n}{}$$

$T_I =$

$T_D =$

$$i_q^* = K_c\left(\Theta_e^*(t) - \Theta_e(t)\right) + \frac{K_c}{T_I}\int\left(\Theta_e^*(\tau) - \Theta_e(\tau)\right)d\tau - \underbrace{K_c T_D \omega_e(t)}_{\frac{d}{dt} K_c T_D\left(\Theta_e^*(t) - \Theta_e(t)\right)}$$



Regulator napona DC MEĐUKRUGA OD pretvarača (gledano s mreže)

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

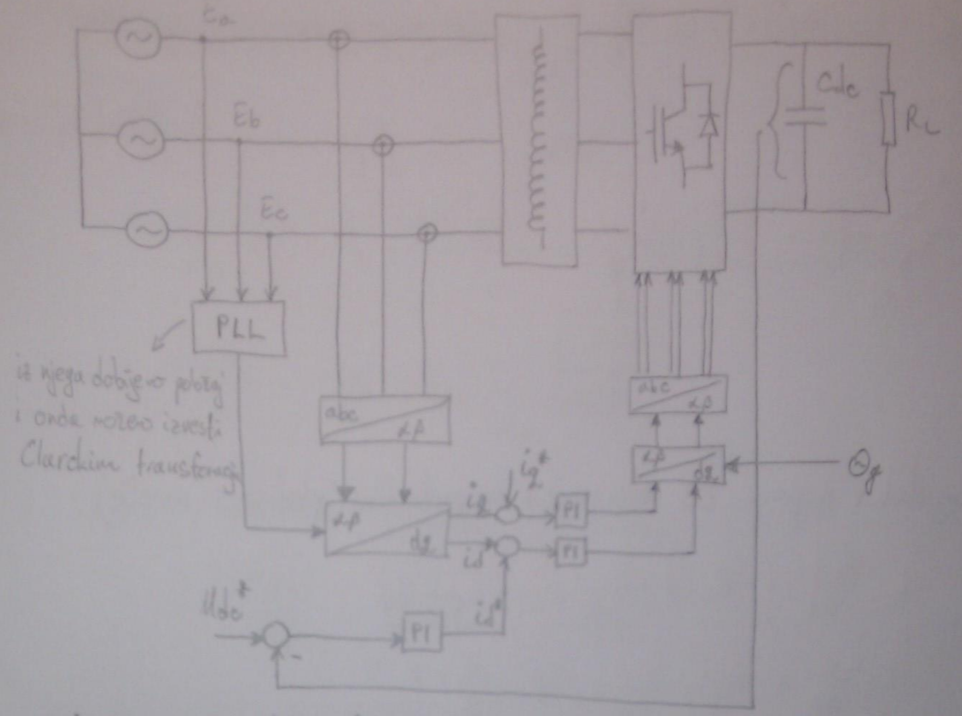
$$L_s \frac{di_q}{dt} = -R_s i_q - \omega_g L_s i_d - U_q$$

$$C_{dc} \frac{dU_{dc}}{dt} = \frac{3}{4}\left(S_d i_d + S_q i_q\right) - i_c$$

$$U_d = S_d \frac{U_{dc}}{2}$$

$$U_q = S_q \frac{U_{dc}}{2}$$

$$\omega_g = 2\pi f$$



$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\Theta_g & \sin\Theta_g \\ -\sin\Theta_g & \cos\Theta_g \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

$$\begin{bmatrix} S_\alpha \\ S_\beta \end{bmatrix} = \begin{bmatrix} \cos\Theta_g & -\sin\Theta_g \\ \sin\Theta_g & \cos\Theta_g \end{bmatrix} \begin{bmatrix} S_d \\ S_q \end{bmatrix}$$

$$\begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix} \begin{bmatrix} S_\alpha \\ S_\beta \\ \underset{0}{\underset{\parallel}{S_0}} \end{bmatrix}$$

Odredivanje parametara regulatora

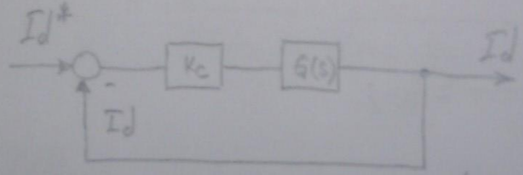
$$L\frac{di_d}{dt} = -R_s i_d + \omega_g i_q + E_d - \frac{1}{2} s_d U_{dc}$$

$$-\frac{1}{2L_s}\hat{s}_d(t) = -\frac{1}{2}\,\frac{s_d(t)\cdot U_{dc}(t)}{L_s} + \frac{\omega_g i_q(t)}{L_s} + \frac{\bar{E}_d}{L_s}$$

$$\frac{di_d(t)}{dt} = -\frac{R_s}{L_s} i_d(t) - \frac{1}{2L_s}\hat{s}_d(t)$$

$$sI_d(s) = -\frac{R_s}{L_s} I_d(s) - \frac{1}{2L_d}\hat{s}_d(s)$$

$$\frac{I_d(s)}{\hat{s}_d(s)} = \frac{-\frac{1}{2L_d}}{s+\frac{R_s}{L_s}} = G(s)$$



$$\frac{I_d(s)}{I_d^*(s)} = \frac{K_c\cdot G(s)}{1+K_c G(s)} = \frac{K_c\cdot\frac{-\frac{1}{2L_s}}{s+\frac{R_s}{L_s}}}{1+K_c\cdot\frac{-\frac{1}{2L_s}}{s+\frac{R_s}{L_s}}} = \frac{-\frac{K_c}{2L_s}}{s+\frac{R_s}{L_s}-\frac{K_c}{2L_s}}$$

$$\alpha = \frac{-\frac{K_c}{2L_s}}{\frac{R_s}{L_s}-\frac{K_c}{2L_s}} \Rightarrow K_c = \frac{-2\alpha}{1-\alpha} R_s$$

$$\frac{I_d}{I_d^*} = \frac{\alpha R_s}{sL_s(1-\alpha)+R_s} = \frac{\alpha}{(1-\alpha)\frac{L_s}{R_s}\cdot s+1}$$

$-\frac{1}{1-\alpha}\cdot\frac{R_s}{L_s}$ $\alpha = 0.9$

$$\hat{S}_d(t) = K_c\left(i_d^*(t) - i_d(t)\right)$$

$$\hat{S}_d(t)\,\frac{1}{U_{dc}(t)} = S_d(t) - \frac{2L_s}{U_{dc}(t)}\,\omega_g\, i_q(t) - \frac{2}{U_{dc}(t)}\cdot E_d$$

$$S_d(t) = \frac{1}{U_{dc}(t)}\left[K_c\left(i_d^*(t) - i_d(t)\right) + 2L_s\,\omega_g\, i_q(t) + 2E_d\right]$$

$$\frac{di_q}{dt} = -\frac{R_s}{L_s}\, i_q(t) \underbrace{- \omega_g\, i_d(t) - \frac{1}{2L_s}\, S_q(t)\, U_{dc}(t)}_{\substack{\text{zamjena} \\ -\frac{1}{2L_s}\hat{S}_q(t)}}$$

$$C(s) = K_c\left(1 + \frac{1}{T_I s}\right)$$

$$\frac{I_q}{\hat{S}_q(s)} = \frac{-\frac{1}{2L_s}}{s + \frac{R_s}{L_s}} = G(s)$$

$$S_q(t) = \frac{1}{U_{dc}(t)}\left[K_c\left(i_q^* - i_q(t)\right) + \frac{K_c}{T_I}\right]\left[i_q^* - i_q(\tau)\right]d\tau - 2\omega_g\, i_q(t)\, L_s\Big]$$

$$C_{dc}\,\frac{dU_{dc}}{dt} = \frac{3}{4}\left(S_d i_d + S_q i_q\right) - i_L$$

→ dolazim radne točke

$$S_d(t)\cdot i_d(t) = f\left(S_d^{ss} + S_d,\ i_d^{ss} + i_d\right) = S_d^{ss}\cdot i_d^{ss} + i_d^{ss} S_d + S_d^{ss}\cdot i_d + \ldots$$

$$S_q(t)\cdot i_q(t) = f\left(S_q^{ss} + S_q,\ i_q^{ss} + i_q\right) = S_q^{ss}\, i_q^{ss} + i_q^{ss}\, S_q + S_q^{ss}\cdot i_q + \ldots\ldots$$

$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad = 0 \qquad\qquad\qquad \approx 0$$

30 želimo da je nula samo jer je onda faktor snage 1

$$C_{dc}\,\frac{du_{dc}}{dt} = \frac{3}{4}\left[S_d^{ss}\cdot i_d^{ss} + i_d^{ss}\cdot S_d + S_d^{ss}\cdot i_d\right] - i_L$$

poremećaj

$$C_{dc}\cdot s\,U_{dc}(s) = \frac{3}{4}\,S_d^{ss}\,I_d(s)$$

$$\frac{U_{dc}(s)}{I_d(s)} = \frac{\frac{3}{4}S_d^{ss}}{s\,C_{dc}}$$

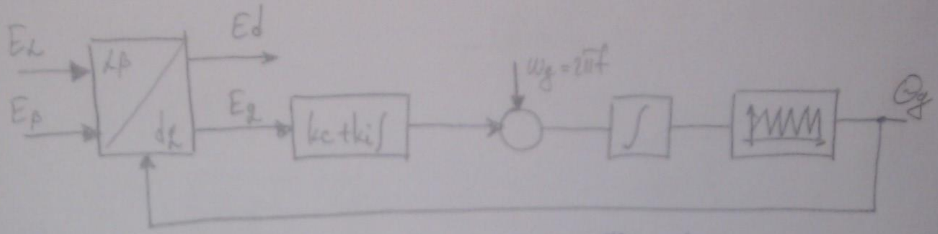
$$\frac{I_d}{I_d^*} = \frac{\lambda}{(1-\lambda)\frac{L_s}{R_s}s+1}$$

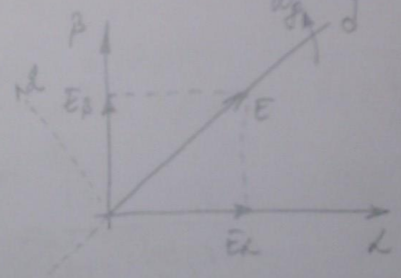
$$\frac{U_{dc}(s)}{I_d^*(s)} = \frac{\frac{3}{4}S_d^{ss}}{s\,C_{dc}}\cdot\frac{\lambda}{\underbrace{(1-\lambda)\frac{L_s}{R_s}}_{\tau_0}\cdot s+1} \approx \frac{\frac{3}{4}S_d^{ss}\cdot\lambda}{s\,C_{dc}} = \frac{a+b}{ss}$$

$$i_d^*(t) = K_c\left(U_{dc}^*(t) - U_{dc}(t)\right) + \frac{K_c}{T_i}\int\left(U_{dc}^*(\tau) - U_{dc}(\tau)\right)d\tau$$

"PHASE LOCKED LOOP" (PLL)

→ pozicioniranje dq koordinatnog sustava tako da komponenta u d osi napona bude d-os našeg sustava, a q-komponenta treba biti nula





$$E_\alpha(t) = E\cos\Theta_g(t)$$
$$E_\beta(t) = E\sin\Theta_g(t)$$

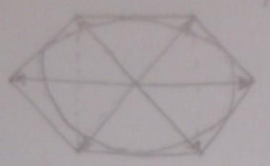
$$Ed(t) = \cos\Theta_g \cdot E_\alpha + \sin\Theta_g E_\beta$$
$$= \cos\Theta_g\cos\Theta_g E + \sin\Theta_g\sin\Theta_g E = E$$

$$E_q = -\sin\Theta_g E_\alpha + \cos\Theta_g E_\beta = -\cancel{\sin\Theta_g\cos\Theta_g E} + \cancel{\cos\Theta_g\sin\Theta_g E}$$

$$\boxed{E_q = 0}$$

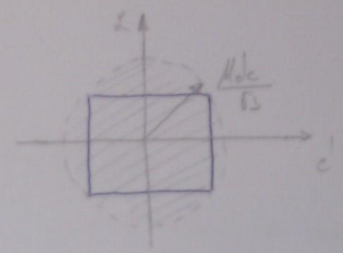
$$G(s) = \frac{\sqrt{Ed^2+E_q^2}}{s} = \frac{k_p}{s} \qquad K_c = \frac{2\xi\omega_n}{k_p}$$

$$k_i = \frac{k_c}{T_1} = \frac{\omega_n^2}{k_p}$$



MAX $\quad \frac{U_{dc}}{\sqrt{3}} \geq \sqrt{U_d^2 + U_q^2}$

ideja eliminirati parametre



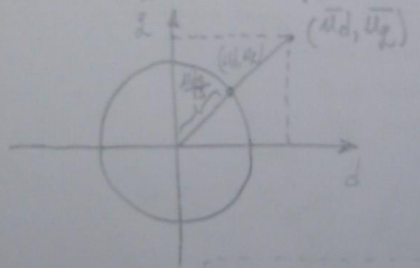
$0 < \varepsilon < 1$

$U_q^{MAX} = \varepsilon \frac{U_{dc}}{\sqrt{3}}$

$U_d^{MAX} = \sqrt{1-\varepsilon^2} \; \frac{U_{dc}}{\sqrt{3}}$

→ gubi se područje rada u gornjem dijelu

$$\sqrt{\bar{U}_d^2 + \bar{U}_q^2} > \frac{U_{dc}}{\sqrt{3}}$$



$$\frac{\bar{U}_d}{\bar{U}_q} = \frac{U_d}{U_q} \Rightarrow \boxed{\frac{U_d}{\frac{U_{dc}}{\sqrt{3}}} = \frac{\bar{U}_d}{\sqrt{\bar{U}_d^2 + \bar{U}_q^2}}} \quad \boxed{\frac{U_q}{\frac{U_{dc}}{\sqrt{3}}} = \frac{\bar{U}_q}{\sqrt{\bar{U}_d^2 + \bar{U}_q^2}}}$$

$$\left.\begin{aligned} U_d &= \frac{\bar{U}_d}{\sqrt{\bar{U}_d^2 + \bar{U}_q^2}} \cdot \frac{U_{dc}}{\sqrt{3}} \; ! \\ U_q &= \frac{\bar{U}_q}{\sqrt{\bar{U}_d^2 + \bar{U}_q^2}} \cdot \frac{U_{dc}}{\sqrt{3}} \; ! \end{aligned}\right\} ! \quad \sqrt{U_d^2 + U_q^2} = \frac{U_{dc}}{\sqrt{3}}$$

P-regulator

pogreška u tom trenutku

$$u(t) = K_c e(t) + f(t)$$

Δt -> DISKRETIZIRAMO

$$u(t_i) = K_c e(t_i) + f(t_i)$$

PI-regulator

$$u(t) = K_c e(t) + \frac{K_c}{T_I} \int_0^t e(\tau)\, d\tau + f(t)$$

→ memorijski element, čuva stacionarnu vrijednost na temelju prošlih vrijednosti računa što će dati na izlazu

$$\int e(\tau)\, d\tau \approx \sum_{k=0}^{n-1} e(t_k) \Delta t$$

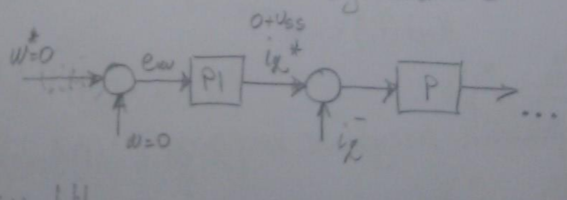
$$t_i = t_0 + (n-1)\Delta t$$

$$u(t_i) = K_c e(t_i) + \frac{K_c}{\tau_I} \sum_{t=0}^{n-1} e(t_k) \Delta t + f(t_i)$$

$$u_{act}(t_i) = u(t_i) + u_{ss}$$

→ stacionarna vrijednost da bi razvili moment koji daje brzinu 0

Nije poželjan ovaj oblik implementacije (moramo stalno prilagođavati U_{ss} da bi znali tu stacionarnu vrijednost)



Poželjniji oblik

$$\frac{du(t)}{dt} = K_c \frac{de(t)}{dt} + \frac{K_c}{T_I} e(t) + \frac{df(t)}{dt} \qquad u(t) = K_c e(t) + \frac{K_c}{T_I}\int_0^t e(\tau)\,d\tau + f(t)$$

$$\frac{du(t)}{dt} \approx \frac{u(t_i) - u(t_{i-1})}{\Delta t} \qquad t_{i-1} = t_i - \Delta t$$

$$\frac{de(t)}{dt} \approx \frac{e(t_i) - e(t_{i-1})}{\Delta t}$$

$$\frac{df(t)}{dt} \approx \frac{f(t_i) - f(t_{i-1})}{dt}$$

pamtimo samo prethodni trenutak

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

$$u_{act}(t_i) = u(t_i) + u_{ss}$$

$$u_{act}(t_{i-1}) = u(t_{i-1}) + u_{ss}$$

$$u_{act}(t_i) = u_{act}(t_{i-1}) + \ldots$$

Želimo da naš izlazni signal bude unutar zadanih granica

tu se događa efekt [illegible]

$$u_{act}(t_i) = u_{act}(t_{i-1}) + K_c\left[e(t_i) - e(t_{i-1})\right] + \frac{K_c}{T_I} e(t_i)\Delta t + f(t_i) - f(t_{i-1})$$

$$-u^{max} \leq u_{act}(t) \leq u^{max}$$

npr. $u_{act}(t_i) > u^{max}$ $\quad$ $u_{act}(t_i) < -u^{max}$

$\quad u_{act}(t_i) = u^{max}$ $\quad$ $u_{act}(t_i) = -u^{max}$

Na početku je potrebno postaviti INICIJALNE VRIJEDNOSTI $\left[e(t_{i-1}) \; f(t_{i-1})\right]$

$$f_d(t) = -\omega_e(t) L_q i_q(t)$$

$$f_q(t) = +\omega_e(t) L_d i_d(t) + \phi_{avg}\, \omega_e(t)$$

1. INICIJALIZACIJA

$$u_d(t_{i-1}),\ u_q(t_{i-1}),\ i_q(t_{i-1}),\ i_d(t_{i-1}),\ i_d(t_{i-1}),\ f_d(t_{i-1}),\ f_q(t_{i-1})$$

$$e_d(t_{i-1}),\ e_q(t_{i-1}),\ \omega_e(t_{i-1})$$

$$i=0$$

2. ZA t_i $\omega_e(t_i),\ i_q(t_i);\ i_d(t_i)$

3. IZLAZNE VRIJEDNOSTI

$$u_d(t_i) = u_d(t_{i-1}) + K_c^d\left[e_d(t_i) - e_d(t_{i-1})\right] + \frac{K_c^d}{T_i} e_d(t_i)\Delta t + f_d(t_i) - f_d(t_{i-1})$$

$$u_q(t_i) = \ldots.$$

4. JESMO LI UNUTAR GRANICA

$$\sqrt{u_d^2(t_i) + u_q^2(t_i)} \leq \frac{u_{dc}}{\sqrt{3}}$$

$$u_{dact}(t_i) = u_d(t_i)$$

$$u_{qact}(t_i) = u_q(t_i)$$

$$u_d^\circ = \frac{u_d(t_i)}{\sqrt{u_d^2(t_i) + u_q^2(t_i)}} \cdot \frac{u_{dc}}{\sqrt{3}} = u_{dact}(t_i)$$

$$u_q^\circ = \frac{u_q(t_i)}{\sqrt{u_d^2(t_i) + u_q^2(t_i)}} \cdot \frac{u_{dc}}{\sqrt{3}} = u_{qact}(t_i)$$

5. U slučaju DA SE LIMIT PRORADIO UZIMAMO OVE VRIJEDNOSTI

$$u_d(t_i) = u_{dact}(t_i)$$

$$u_q(t_i) = u_{qact}(t_i)$$

6. VRATI SE NA KORAK 2.

$\xi \qquad 0 < \xi < 1$

gledamo dali se signal nalazi unutar granica

$$U_d^{MAX} = \xi \frac{U_{dc}}{\sqrt{3}} \qquad -U_d^{MAX} \leq U_d(t_i) \leq U_d^{MAX} \qquad U_{d\,act}(t_i) = U_d(t_i)$$

$$U_q^{MAX} = \sqrt{1-\xi^2}\,\frac{U_{dc}}{\sqrt{3}} \qquad -U_q^{MAX} \leq U_q(t_i) \leq U_q^{MAX} \qquad U_{q\,act}(t_i) = U_q(t_i)$$

ograničenje koje moramo zadovoljiti na izlazu iz strujnih regulatora frekv. pretvarača

$$U_d = S_d \frac{U_{dc}}{2} \qquad \sqrt{U_d^2 + U_q^2} \leq \frac{U_{dc}}{\sqrt{3}}$$

$$U_q = S_q \frac{U_{dc}}{2}$$

$$\sqrt{S_d^2 \cdot \left(\frac{U_{dc}}{2}\right)^2 + S_q^2 \left(\frac{U_{dc}}{2}\right)^2} \leq \frac{U_{dc}}{\sqrt{3}}$$

$$\sqrt{S_d^2 + S_q^2} \leq \frac{2}{\sqrt{3}}$$

$$f_d(t) = 2 L_s \omega_g i_q(t) + \underbrace{E_d}_{\text{napon mreže}}$$

$$f_q(t) = -2\omega_g L_s i_d(t)$$

$$U_d(t) = K_c^d \left[i_d^*(t) - i_d(t) \right] + \frac{K_c^d}{\tau_I^d} \int_0^t \left[i_d^*(\tau) - i_d(\tau) \right] d\tau + f_d(t)$$

$$U_q(t) = K_c^q \left[i_q^*(t) - i_q(t) \right] + \frac{K_c^q}{\tau_I^q} \int_0^t \left[i_q^*(\tau) - i_q(\tau) \right] d\tau + f_q(t)$$

$$U_d(t_i) = U_d(t_{i-1}) + K_c^d \left[e_d(t_i) - e_d(t_{i-1}) \right] + \frac{K_c^d}{\hat{\tau}_I^d} e$$

$U_q(t_i)$

ograničenja regulatora

$$S_d(t_i) = \frac{U_d(t_i)}{\frac{U_{dc}}{2}} \qquad S_q(t_i) = \frac{U_q(t_i)}{\frac{U_{dc}}{2}}$$

što se tiče

unutarnjih povratnih veza povezivanja pretvarača na mrežu

- Izlaz iz regulatora brzine vrtnje (struja i_q) (proporcionalna momentu)

neovisno o načinu upravljanja i neovisno o brzini vrtnje

ograničit je potrebno struju i_q da nebi došlo do prekostruje

$$-I_q^{max} \leq i_q^*(t) \leq I_q^{max}$$ → ovo pazi da prilikom tranzijenta može biti izvan ovih granica potrebno je ograničiti struju u prijelaznoj pojavi

KORISTIMO P-tip regulatora za razmatranje

$$\lim_{t \to \infty} e_q(t) = \lim_{t \to \infty} (i_q^*(t) - i_q(t)) \neq 0$$

$$e_q(t) = i_q^*(t) - i_q(t)$$

$$\underline{i_q(t) = i_q^*(t) - e(t)}$$

tvrdo ograničenje $-I_q^{max} \leq i_q(t) \leq I_q^{max}$

$$-I_q^{MAX} \leq i_q^*(t) - e_q(t) \leq I_q^{MAX}$$

$$-I_q^{MAX} + e_q(t) \leq i_q^*(t) \leq I_q^{MAX} + e_q(t)$$

ista stvar vrijedi i za struju id ⟶ ograničenje po struji

$$-I_d^{MAX} + e_d(t) \leq i_d^*(t) \leq I_d^{MAX} + e_d(t)$$

$$i_q^*(t_i) = i_q^*(t_{i-1}) + K_c\left[e_\omega(t_i) - e_\omega(t_{i-1})\right] + \frac{K_c}{\tau_I} e_\omega(t_i)\Delta t$$

$$e_\omega(t_i) = \omega^*(t_i) - \omega(t_i)$$

$$i_q^*(t_i) = i_q^*(t_{i-1}) + K_c\left[\omega(t_i) - \omega(t_{i-1})\right] + \frac{K_c}{\tau_I}\left(\omega^*(t_i) - \omega(t_i)\right)\Delta t$$

SMPM - vektorsko upravljanje ⟶ sve do sada

DTC (Direct Torque Control)

→ radi u α,β koordinatnom sustavu

→ na čemu počiva načelo DTC-a

izraz za elekt. mag. MOMENT

$$M_{em} = \frac{3}{2} p \left[\psi_{\alpha s} \cdot i_{\beta s} + \psi_{\beta s} \cdot i_{\alpha s} \right]$$

gledamo kut između toka statora i toka rotora

$$\psi_{\alpha s} = L_s i_{\alpha s} + L_m i_{\alpha r}$$

$$\psi_{\alpha r} = L_m i_{\alpha s} + L_r i_{\alpha r} \longrightarrow i_{\alpha r} = \frac{\psi_{\alpha r} - L_m i_{\alpha s}}{L_r}$$

$$\psi_{\alpha s} = L_s i_{\alpha s} + L_m \frac{\psi_{\alpha r} - L_m i_{\alpha s}}{L_r} \cdot i_{\alpha r}$$

$$= \left(L_s - \frac{L_m^2}{L_r} \right) i_{\alpha s} + \frac{L_m}{L_r} \psi_{\alpha r} = L_s \sigma i_{\alpha s} + \frac{L_m}{L_r} \psi_{\alpha r}$$

$$= L_s \underbrace{\left(1 - \frac{L_m^2}{L_r L_s} \right)}_{\sigma - \text{rasipanje}}$$

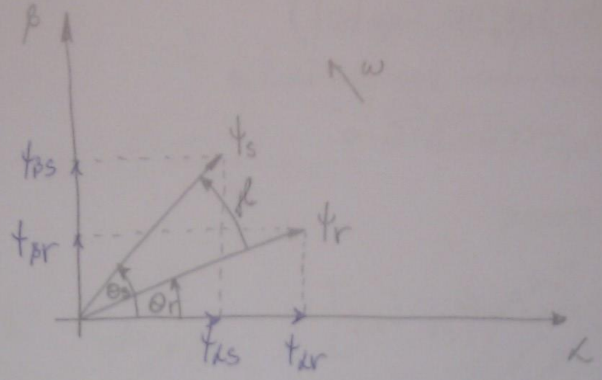
$$i_{\alpha s} = \frac{1}{L_s \sigma} \left(\psi_{\alpha s} - \frac{L_m}{L_r} \psi_{\alpha r} \right)$$

$$i_{\beta s} = \frac{1}{L_s \sigma} \left(\psi_{\beta s} - \frac{L_m}{L_r} \psi_{\beta r} \right)$$

$$M_{em} = \frac{3}{2} p \left[\psi_{\alpha s} \frac{1}{L_s \sigma} \left(\psi_{\beta s} - \frac{L_m}{L_r} \psi_{\beta r} \right) - \psi_{\beta s} \frac{1}{L_s \sigma} \left(\psi_{\alpha s} - \frac{L_m}{L_r} \psi_{\alpha r} \right) \right]$$

$$= \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} \left[\psi_{\beta s} \cdot \psi_{\alpha r} - \psi_{\alpha s} \cdot \psi_{\beta r} \right]$$

41. 3.



$$\psi_{\alpha s} = \psi_s \cdot \cos\Theta_s \qquad \psi_{\alpha r} = \psi_r \cdot \cos\Theta_r$$

$$\psi_{\beta s} = \psi_s \cdot \sin\Theta_s \qquad \psi_{\beta r} = \psi_r \cdot \sin\Theta_r$$

$$M_{em} = \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} \left[\psi_s \sin\Theta_s \psi_r \cos\Theta_r - \psi_s \cos\Theta_s \psi_r \sin\Theta_r \right]$$

$$= \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} \underbrace{\psi_s \psi_r}_{} \sin(\underbrace{\Theta_s - \Theta_r}_{\gamma})$$

možemo mijenjati ali ne mijenjamo jer nije potrebno
→ do nazivne brzine ψ_s ne mijenjamo

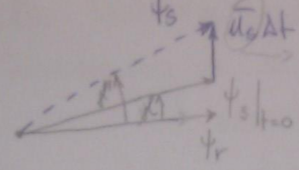
γ ⟶ kut između njih
⟶ što je veći kut veći moment
⟶ što je manji kut manji moment

iz jednadžbe statora dobijemo

$$\frac{d\bar{\psi}_s}{dt} = \bar{u}_s - R_s \bar{i}_s$$

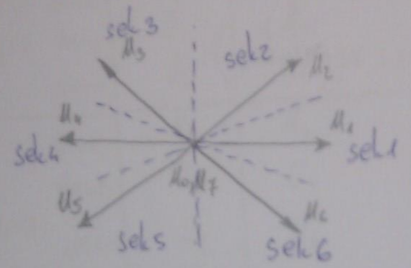
$$\bar{\psi}_s = \int_0^t (u_s - R_s i_s)\, d\tau + \psi_s\Big|_{t=0} = \int_0^t u_s\, d\tau - \cancel{R_s \int_0^t i_s(t)\, d\tau} + \bar{\psi}_s\Big|_{t=0}$$

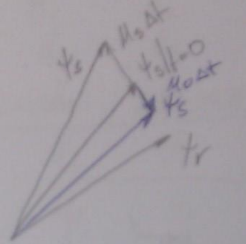
(12) $$\bar{\psi}_s = \int_0^t u_s\, d\tau + \bar{\psi}_s\Big|_{t=0} \approx u_s \Delta t + \psi_s\Big|_{t=0}$$



koji je to napon?? Taj U_s možemo ostvariti sa 6 aktivnih heksagona šesterokuta ili dva nul vektora

za kratko vrijeme narinemo konstantni napon





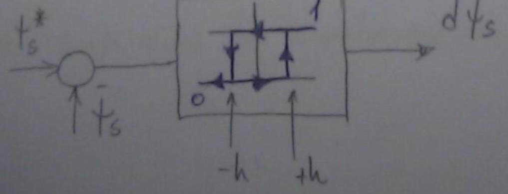
HISTEREZNI REGULATOR – kako radi

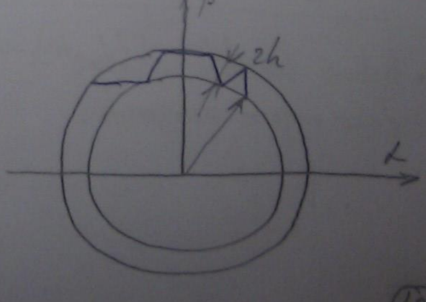
ako je $\psi_s^* - \psi_s > +h \xRightarrow{\text{onda je}} d\psi = 1$

ako je $-h \le \psi_s^* - \psi_s \le +h$ i $d\psi_s = 1 \Rightarrow d\psi_s = 1$

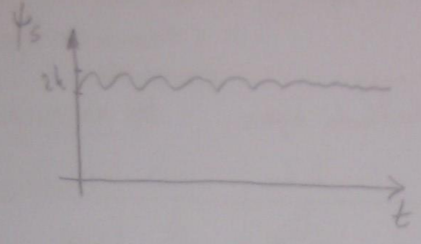
ako je $\psi_s^* - \psi_s < -h \Rightarrow d\psi_s = 0$

ako je $-h < \psi_s^* - \psi_s < +h$ i $\psi_s = 0 \Rightarrow d\psi_s = 0$



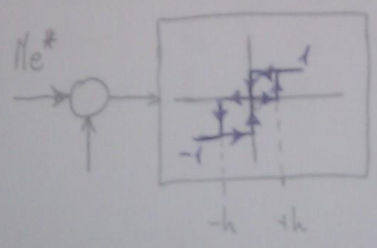


Što je to u vremenu?



Da nemamo valovitost suzimo granice $-h, h$ ali smo povećali broj sklapanja pretvarača

REGULATOR MOMENTA (tropozicijski histerezni regulator)



ako je $M_e^* - M_e > +h \Rightarrow dM = 1$

ako je $0 < M_e^* - M_e > +h$ i $dM = 1 \Rightarrow dM = 1$

ako je $M_e^* - M_e < -h \Rightarrow dM = -1$

ako je $-h < M_e^* - M_e < 0$ i $dM = -1 \Rightarrow dM = -1$

ako je $0 < M_e^* - M_e < +h$ i $dM = -1 \Rightarrow dM = 0$

ako je $-h < M_e^* - M_e < 0$ i $dM = 1 \Rightarrow dM = 0$

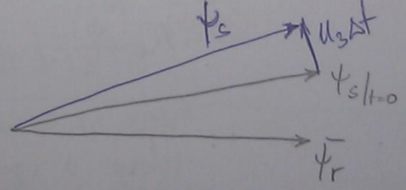
- trebamo odrediti sektore u kojima se nalazimo da znamo koje ćemo napone narinuti.

$\Theta_s = \mathrm{arctg}\left(\frac{\psi_{\beta s}}{\psi_{\alpha s}}\right)$

znao kut na kojem s-o u odnosu na vektor α i krećeš se

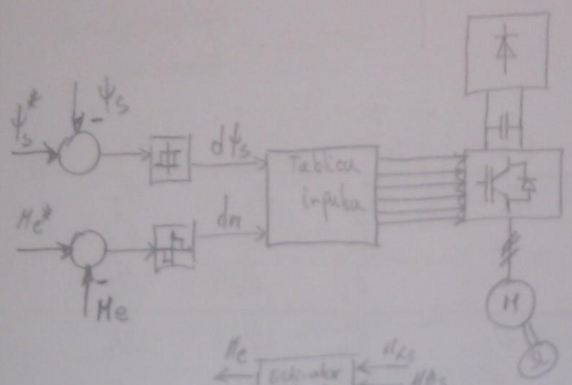
sekt. / izlaz iz regulatora		S1	S2	S3	S4	S5	S6
$d\psi_s=1$	$dM=1$	$\bar{u}_2$	$\bar{u}_3$	$\bar{u}_4$	$\bar{u}_5$	$\bar{u}_6$	$\bar{u}_1$
	$dM=0$	$\bar{u}_7$	$\bar{u}_0$	$\bar{u}_7$	$\bar{u}_0$	$\bar{u}_7$	$\bar{u}_0$
	$dM=-1$	$\bar{u}_6$	$\bar{u}_1$	$\bar{u}_2$	$\bar{u}_3$	$\bar{u}_4$	$\bar{u}_5$
$d\psi_s=0$	$dM=1$	u_3	u_4	$\bar{u}_5$	$\bar{u}_6$	$\bar{u}_1$	$\bar{u}_2$
	$dM=0$	u_0	u_7	u_0	u_7	u_0	u_7
	$dM=-1$	u_5	u_6	u_1	u_2	u_3	u_4

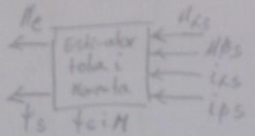
$d\psi_s=1 \quad dM=0$



$\vec{\psi}_s = \overset{0}{\cancel{u_7 \Delta t}} + \psi|_{t=0} = \vec{\psi}_s|_{t=0}$

u DTC prioritet ima moment u odnosu na tok





$$u_{\alpha s} = R_s i_{\alpha s} + \frac{d\psi_{\alpha s}}{dt}$$

Tako dobijemo ψ_s

$$\underline{\psi_{\alpha s}} = \int (u_{\alpha s} - R_s i_{\alpha s})\, dt$$

znamo

mjeri mjeri

izračunaj

$$\psi_{\beta s} = \int (u_{\beta s} - R_s i_{\beta s})\, dt$$

mjeri mjeri

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

a moment

$$M_e = \frac{3}{2} p \left[\psi_{\alpha s} \cdot i_{\beta s} - \psi_{\beta s} \cdot i_{\alpha s} \right]$$

nigdje ne estimiramo položaj toka rotora u tome je prednost DTC nad vektorskom regulacijom

1. $I_s = \frac{2}{3}\left(i_a(t) + i_b(t)e^{j\frac{2\pi}{3}} + i_c(t)e^{j\frac{4\pi}{3}}\right)$

GRUPA : A

BLIC

2. $u(t) = \frac{1}{6} U_m \sin \omega t$

3. $\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$

4. $i_d \to PI$ → držimo konstantnim
$i_q \to PI$ → regulacija momenta

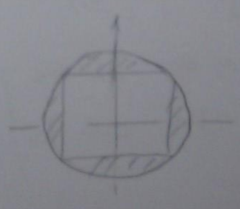
regulacija momenta, nemamo nadređeni član reg. brzine vrtnje

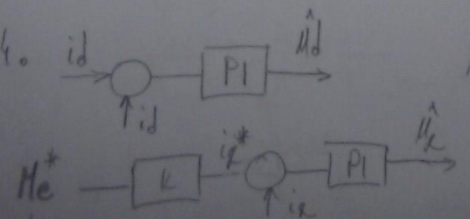
NEMAMO ZADAVANJE BRZINE VRTNJE

5. $u(t) = -K_c y(t) + \frac{K_c}{T_I}\int_0^t \left[r(t) - y(t)\right] d\tau - K_c T_D \frac{dy(t)}{dt}$

6. $V_d^{max} = \varepsilon \frac{U_{dc}}{\sqrt{3}} \qquad 0 < \varepsilon < 1$

$V_q^{max} = \sqrt{1-\varepsilon^2}\,\frac{U_{dc}}{\sqrt{3}}$



4. 

$M_e \sim i_q$

→ mi zadajemo moment (otklanjamo stacionarno odstupanje) zato ide PI regulator

47.

GRUPA B.

BLIC

1. Motor uzet predstavljen zavojima

$$U_s = R_s \vec{i_s} + \frac{d\psi_s}{dt}$$

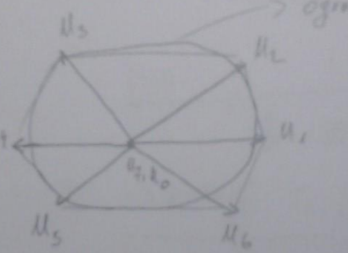
$$\vec{\psi_s} = L_s i_s + \phi_{mg} e^{j\theta_e}$$

induktivitet — kako utječe magnet na njega (ali on rotira)

$$\frac{d\psi_s}{dt} = L_s \frac{di_s}{dt} + \phi_{mg} e^{j\theta_e} \cdot j \underbrace{\frac{d\theta_e}{dt}}_{\omega_e}$$

$$\boxed{U_s = R_s \vec{i_s} + L_s \frac{di_s}{dt} + j\phi_{mg}\omega_e \cdot e^{j\theta_e}}$$

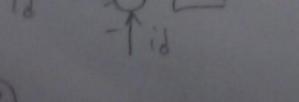
2. NAČIN VEKTORSKO ŠIRINSKO IMPULSNE MODULACIJE

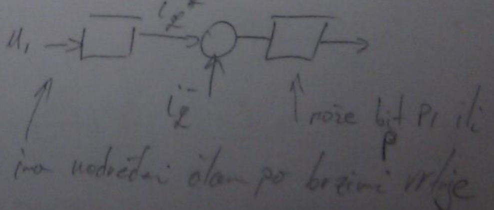


3. iz α,β mirujući u d,q rotirajući

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta_e & \sin\theta_e \\ -\sin\theta_e & \cos\theta_e \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

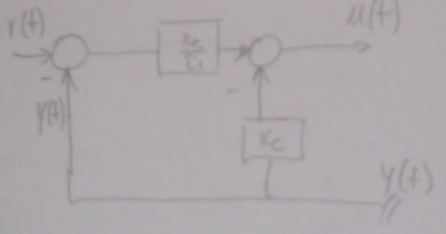
4. Reg. položaja





(48.)

5. $u(t) = -K_c\, y(t) + \frac{K_c}{T_i} \int_0^t (r(t) - y(\tau))\, d\tau$



6. $U_d^{max} = \frac{U_{d_L}}{\sqrt{U_d^2 + U_L^2}} \cdot \frac{U_{dc}}{\sqrt{3}}$

Prednost u odnosu na fiksni je što koristimo cijelo područje koje možemo koristiti

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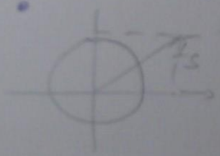
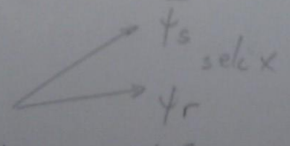
ZA ISPIT ???

1. dobijemo I_s → računaj I_x, I_y



2. imamo tok statora i tok rotora

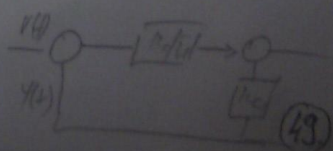


$\Psi \rightarrow$ $\quad M \nearrow$

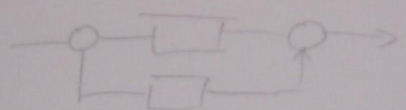
$d\Psi = 0 \quad dM = 1$

3. kako je razlika izvedena

$u(t) = -K_c\, y(t) + \frac{K_c}{T_i}(r(t) - y(t)) \Rightarrow$



$u(t) = K_c(r(t) - y(t))$ ...



Tu moraš imati nadvišenje
a u prvom slučaju ala u
sustavu ne želim nadvišenje

4. $i_a, i_b, i_c, \alpha, \beta, d, q$ => znati jednadžbe