Dis (18)

(29) OGRANIČENJE IZLAZA REGULATORA

-> VELIKE PROMJENE U BRZINI (ω_e) MOGU DOVESTI DO OGROMNIH STRUJA KOJE U PRETVARAČU MOGU BITI KATASTROFALNE

$$\underbrace{\sqrt{u_d^2+u_q^2}}_{\text{PITAGORIN POUČAK}} \le \frac{U_{DC}}{\sqrt{3}} \rightarrow \text{OGRANIČENJE PWM-a}$$

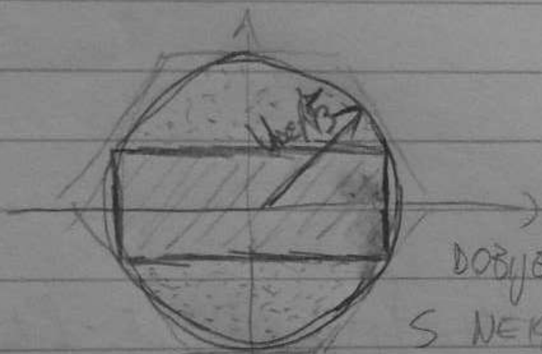
RJEŠENJA:

a) $u_{q\,MAX} = \varepsilon \frac{U_{DC}}{\sqrt{3}}$; $0<\varepsilon<1 \Rightarrow$ NAJGORI SLUČAJ

$$\sqrt{u_d^2+\frac{\varepsilon^2 U_{DC}^2}{3}} = \frac{U_{DC}}{\sqrt{3}} \quad /^2$$

$$u_d^2+\frac{\varepsilon^2 U_{DC}^2}{3} = \frac{U_{DC}^2}{3}$$

$$u_{d\,max} = \sqrt{1-\varepsilon^2}\,\frac{U_{DC}}{\sqrt{3}}$$



$$u_d = \sqrt{1-\varepsilon^2}\cdot\frac{U_{DC}}{\sqrt{3}}$$

DOBIJE SE PROMJENJIVI PRAVOKUTNIK, S NEISKORIŠTENIM PODRUČJEM IZVAN, A UNUTAR KRUGA ( )

b) PRESKALIRANJE KAD JE IZVAN KRUGA (UZME SE PRAVOKUTNIK □ KOJI OBUHVAĆA KRUG)

30. DISKRETIZACIJA REGULATORA

$$u(t) = K_c e(t) + \frac{K_c}{\tau_1} \int_0^t e(\tau) d\tau + f(t)$$

⇓ DISK. OBLIK

$$u(t_i) = K_c e(t_i) + \frac{K_c}{\tau_1} \left(\sum_{k=0}^{n-1} e(t_k) \Delta t \right) + f(t_i)$$

(OVAJ OBLIK NIJE POGODAN PA SE RADI DERIVACIJA):

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

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

⇓ DISKRETNI OBLIK

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

31. EFEKT NAMATANJA (DISKRETIZACIJA)

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

JER $u(t_i)$ MORA BITI U GRANICAMA $[-u_{max}, +u_{max}]$,

POSTAVLJA SE LIMIT KOJEG KAD DOSEGNE, OSTAJE NA TOJ VRIJEDNOSTI ($\pm u_{max}$)

DiS (19)

31 - nastavak

ALGORITAM:

1. INICIJALIZACIJA

STAVITI & IZRAČUNATI VRIJEDNOSTI: $u_d, u_q, i_d, i_q, \omega_e, f_d, f_q,$
e_d, e_q (t_{i-1})

$$u(t_i) = \boxed{u(t_{i-1})} + K_c\{e(t_i) - \boxed{e(t_{i-1})}\} + \frac{K_c}{T_i} e(t_i)\Delta t - f(t_i) - \boxed{f(t_{i-1})}$$

$$f_d(t) = -\omega_e(t) L_q \boxed{i_q(t)}$$
$$f_q(t) = \omega_e(t) L_d \boxed{i_d(t)} - \Phi_{mg} \boxed{\omega_e(t)}$$

LOOP →

2. IZRAČUNATI t_i vrijednosti & ODBITATI POTREBNE ZA u_d & u_q

3. $u_d'(t_i) = ---$
   $u_q'(t_i) = ---$

4. JE LI UNUTAR GRANICA: $\sqrt{u_d'^2(t_i) + u_q'^2(t_i)} \le \frac{U_{DC}}{\sqrt{3}}$

KRUŽNICA

AKO NIJE, ONDA:

$$u_d(t_i) = \frac{u_d'(t_i)}{\sqrt{u_d'^2(t_i) + u_q'^2(t_i)}} \cdot U_{DC}/\sqrt{3}$$

$$u_q(t_i) = ---$$

5. ANTI WIND-UP: $u_d'(t_i) = u_d(t_i)$ DA SLJEDEĆI KORAK,
   $u_q'(t_i) = u_q(t_i)$ DA SE NE NAMOTA

6. POVRATAK NA KORAK 2.

END LOOP

(32) IMPLEMENTACIJA STRUJNIH REGULATORA PREMA MREŽI (DISKR.)

(UNUTARNJA PETLJA)

$$s_d = \frac{u_d}{U_{DC}/2} \qquad s_q = \frac{u_q}{U_{DC}/2}$$

$$u_d = s_d \frac{U_{DC}}{2} \qquad u_q = s_q \frac{U_{DC}}{2}$$

$$\sqrt{u_d^2 + u_q^2} \le \frac{U_{DC}}{\sqrt{3}}$$

$$\sqrt{s_d^2 \frac{U_{DC}^2}{4} + s_q^2 \frac{U_{DC}^2}{4}} \le \frac{U_{DC}}{\sqrt{3}}$$

$$\boxed{\sqrt{s_d^2 + s_q^2} \le \frac{2}{\sqrt{3}}}$$

→ OGRANIČENJA IZLAZA IZ STRUJNIH REGULATORA ZA PRETVARAČ

$$f_d(t) = 2 L_s \omega_g i_q(t) + e_d$$

$$f_q(t) = -2 \omega_g L_s i_d(t) \qquad (*e_q = 0*)$$

$$u_d(t) = K_c^d \left(i_d^*(t) - i_d(t)\right) + \frac{K_c^d}{\tau_i^d} \int \left[i_d^*(\tau) - i_d(\tau)\right] d\tau + f_d(t)$$

u_q → ISTO

DISKRETNA DOMENA:

DERIVACIJA ISTO...

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

u_q → ISTO

s_d & s_q OGRANIČITI KAO I u_d, u_q PRIJE...

DUS 20

33 IMPLEMENTACIJA REG. ω_e (UKNJSA?, DISKRETIZACIJA)

→ I_q IZRAZ IZ REG. ω_e (UVIJEK, NEOVISNO O UPRAVLJANJU), ŠTO JE PROPORCIONALNO MOMENTU...

→ POTREBNO OGRANIČITI ZBOG NADSTRUJA, BEZ OBZIRA NA NAPONE

$$-I_{q_{MAX}} \leq i_q^* \leq I_q^{MAX}$$

$\Downarrow$

NIJE DOVOLJNO OGRANIČITI ŽELJENU, NEGO I STVARNU, i_q

$$e = i^* - i$$

PRAVO OGRANIČENJE: $-I_{q_{MAX}} \leq I_q \leq I_{q_{MAX}}$

$$-I_{q_{MAX}} \leq I_q^* - E \leq I_{q_{MAX}}$$

$$\boxed{-I_{q_{MAX}} + e_q(t) \leq i_q^*(t) \leq I_{q_{MAX}} + e_q(t)}$$

$$-I_{d_{MAX}} + e_d(t) \leq \underbrace{i_d^*(t)}_{=\emptyset} \leq I_{d_{MAX}} + e_d(t)$$

→ OGRANIČENJE SLUŽI ZA NEGIRANJE UTJECAJA MAGNETA NA ROTORU PRI ZASIĆENJU

(34) DTC (DIRECT TORQUE CONTROL)

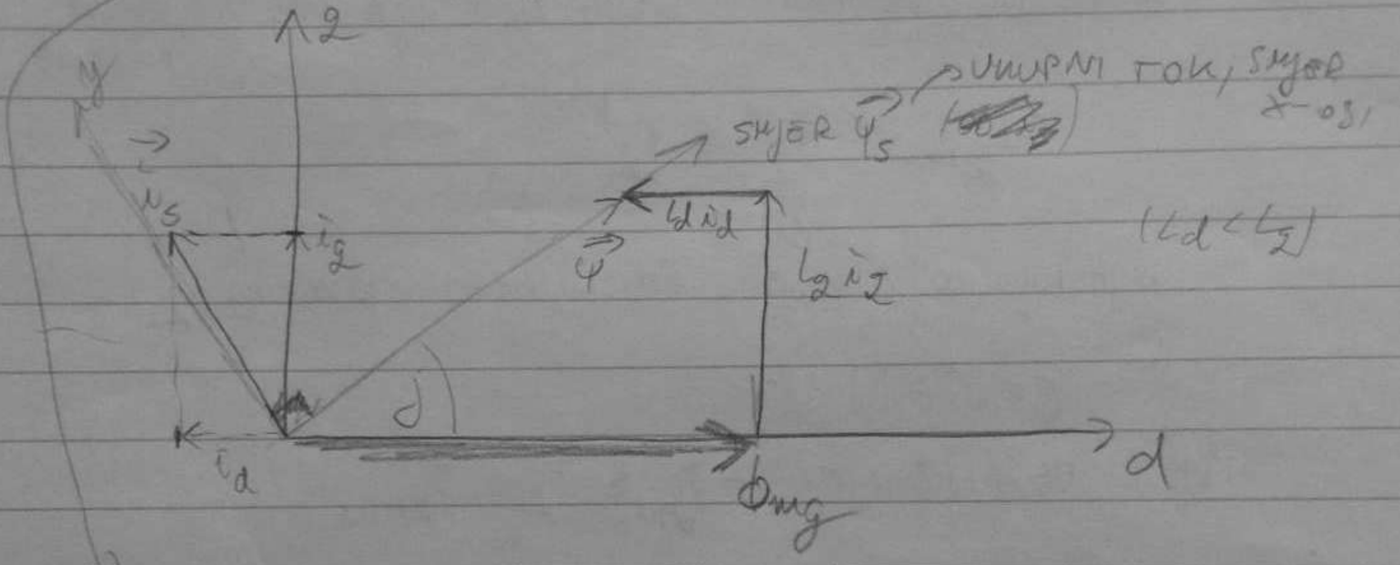
→ d OS NIJE U SMJERU MAGNETA, NEGO ULANČANOG TOKA

→ promatra se ukupni tok, u vektorskom prostoru:

$$\vec{\psi}_s = (\psi_d + j\psi_q)\underbrace{e^{j\omega t}}$$

PODRAZUMIJEVA SE...

gdje $\vec{\psi}_s' = \vec{\psi}_s \cdot e^{j\theta_e}$



$$\psi_d + j\psi_q = (L_s \vec{i}_s + \phi_{mg} e^{j\theta_e}) e^{-j\theta_e} = L_s \vec{i}_s' + \phi_{mg} =$$

$$= \underbrace{L_d i_d + \phi_{mg}}_{\psi_d} + j \underbrace{L_q i_q}_{\psi_q} \quad \text{(OBJAŠNJENJE SLIKE)}$$

KUT OPTEREĆENJA (IZMEĐU ROTORA, d OSI & ψ_s) ... $\delta = \operatorname{arctg} \dfrac{L_q \vec{i}_q}{\underbrace{L_d \vec{i}_d + \vec{\phi}_{mg}}}$ → VEKTORSKO ZBRAJANJE

$dq \xrightarrow[\text{PARK}]{} xy$ (ZAKRETANJE ZA δ)

$$\begin{bmatrix} \psi_x \\ \psi_y \end{bmatrix} = \begin{bmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{bmatrix} \begin{bmatrix} \psi_d \\ \psi_q \end{bmatrix}$$

$$M_{em} = \frac{3}{2} p \begin{vmatrix} \psi_d & \psi_q \\ i_d & i_q \end{vmatrix} = \frac{3}{2} p \vec{\psi}_s \times \vec{i}_s = \frac{3}{2} p \vec{\psi}_s' \times \vec{i}_s' = \frac{3}{2} p \vec{\psi}_{xy} \times \vec{i}_{xy} = \begin{vmatrix} \psi_x & \psi_y \\ i_x & i_y \end{vmatrix} \frac{3}{2} p$$

$$= \frac{3}{2}(\psi_x i_y - \underbrace{\psi_y}_{=0} i_x) = \frac{3}{2} p \psi_x i_y = \boxed{\frac{3}{2} p \psi i_y}$$

$=0$ (OKOMITO NA $\vec{\psi}_s$)

Dis 21

34 - nastavak 1

Iz $xy \to dq$: $i_y = -\sin\delta\, i_d + \cos\delta\, i_q$

Iz SLIKE: $\cos\delta = \frac{\phi_{mg} + L_d i_d}{\psi} \Rightarrow i_d = \frac{1}{L_d}\cdot(\psi\cos\delta - \phi_{mg})$

$$\sin\delta = \frac{L_q i_q}{\psi} \Rightarrow i_q = \frac{\psi \sin\delta}{L_q}$$

$$i_y = -\sin\delta\left(\frac{\psi\cos\delta - \phi_{mg}}{L_d}\right) + \cos\delta \sin\delta \cdot \frac{\psi}{L_q} =$$

$$= -\frac{\psi}{L_d}\cdot\sin\delta\cos\delta + \frac{\phi_{mg}}{L_d}\sin\delta + \frac{\psi}{L_q}\sin\delta\cos\delta =$$

$$= \frac{\phi_{mg}}{L_d}\sin\delta + \psi\sin\delta\cos\delta\left(\frac{L_d - L_q}{L_d L_q}\right) = \frac{1}{L_d}\sin\delta\left[\phi_{mg} + \frac{\psi\cos\delta}{L_q}(L_d - L_q)\right]$$

SMVPM:

$$i_y = \frac{\phi_{mg}}{L_d}\sin\delta$$

↳ OVISI SAMO o δ

$$M_{em} = \frac{3}{2}p\,\psi\, i_y = \frac{3}{2}p\frac{\phi_{mg}}{L_d}\psi\sin\delta$$

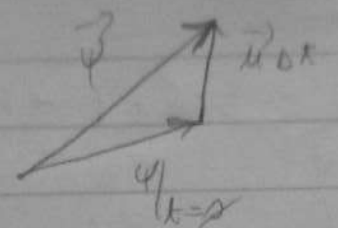
→ MIJENJAJUĆI KUT MIJENJAMO MOMENT!

$$u_s = i_s R_s + \frac{d\psi}{dt} \Rightarrow \frac{d\psi}{dt} = u_s - i_s R_s$$

$$\psi = \int_0^t (u_s - \underbrace{R_s}_{\substack{\text{MALI}\\ \text{OTPOR STATORA} \approx 0}} i_s)\,d\tau + \psi_s\Big|_{t=0} = \underbrace{u_s \Delta t}_{} + \psi_s\Big|_{t=0}$$

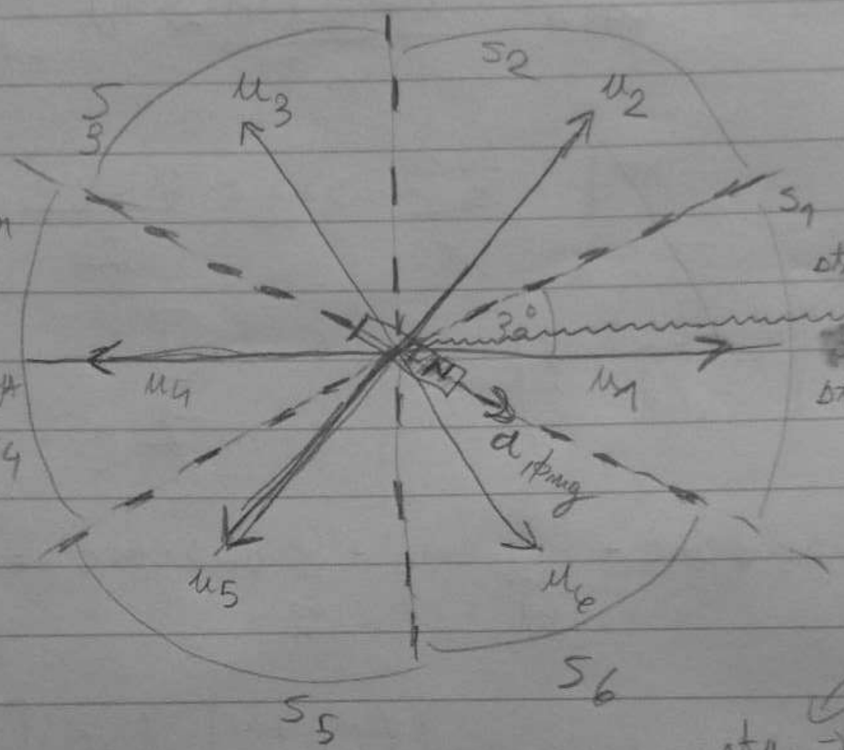
TO UZ MALI $\Delta t \approx d\tau$

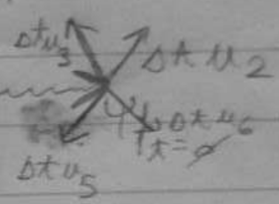
↳ PROMJENOM u_s (KRATKOM) MIJENJAMO ψ_s I/ILI KUT → DJELUJEMO NA MOMENT



→ MIJENJA SE MOMENT S KUTOM, ODNOSNO NAPONOM, A OVISNO O SEKTORU MOŽEMO I φ MIJENJATI (DONJA SLIKA)

NEMA VEZE SA MODULACIJOM (6STEP, PWM...), TO JE ČISTO NAČIN UPRAVLJANJA





u_0, u_7 → nema promjene

$\Delta t\, u_2 \rightarrow \psi \nearrow \quad M \nearrow$

$\Delta t\, u_3 \rightarrow \psi \searrow \quad M \nearrow$

$\Delta t\, u_5 \rightarrow \psi \searrow \quad M \searrow$

$\Delta t\, u_6 \rightarrow \psi \nearrow \quad M \searrow$

IZNOS KUT

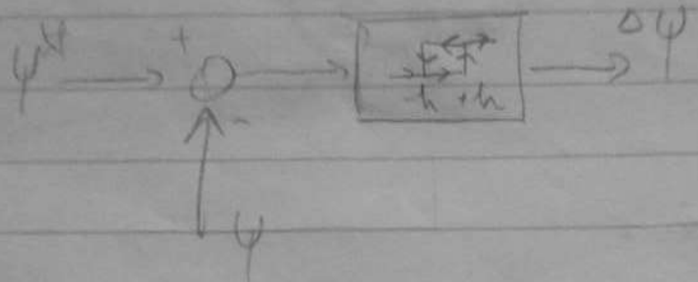
		S1	S2	S3	S4	S5	S6
	ΔM=-1	u_6	u_1	u_2	u_3	u_4	u_5
Δψ=1	ΔM=0	u_7	u_7	u_7	u_7	u_7	u_7
(povećanje)	ΔM=1	u_2	u_3	u_4	u_5	u_6	u_1
	ΔM=-1	u_5	u_6	u_1	u_2	u_3	u_4
	ΔM=0	u_0	u_0	u_0	u_0	u_0	u_0
Δψ=0	ΔM=1	u_3	u_4	u_5	u_6	u_1	u_2
(smanjenje)							

→ TOK SE UVIJEK SPORIJE MIJENJA (BRŽE SE KUT MIJENJA → M_{em})

Dis (22)

(34) - nastavak 2

$\rightarrow \psi_s$ SE REGULIRA 2-RAZINSKIM HISTEREZNIM REG. (KOMPARATOR)
A M_{em} 3-RAZINSKIM

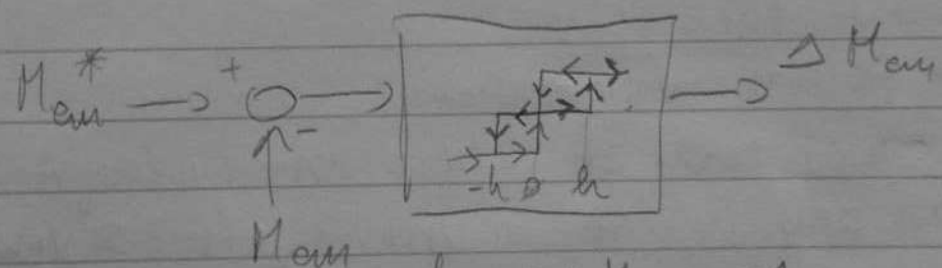


a) $\psi^* - \psi < -h \Rightarrow \Delta\psi = \emptyset$

b) $-h < \psi^* - \psi < h \ \& \ \Delta\psi = \emptyset \Rightarrow \Delta\psi = \emptyset$

c) $\psi^* - \psi > +h \Rightarrow \Delta\psi = 1$

d) $-h < \psi^* - \psi < +h \ \& \ \Delta\psi = 1 \Rightarrow \Delta\psi = 1$



a) $M_{em}^* - M_{em} < -h \Rightarrow \Delta M_{em} = -1$

b) $-h < M_{em}^* - M_{em} < \emptyset \ \& \ \Delta M_{em} = -1 \Rightarrow \Delta M_{em} = -1$

c) $\emptyset < M_{em}^* - M_{em} < h \ \& \ \Delta M_{em} = -1 \Rightarrow \Delta M_{em} = \emptyset$

d) $M_{em}^* - M_{em} > h \Rightarrow \Delta M_{em} = 1$

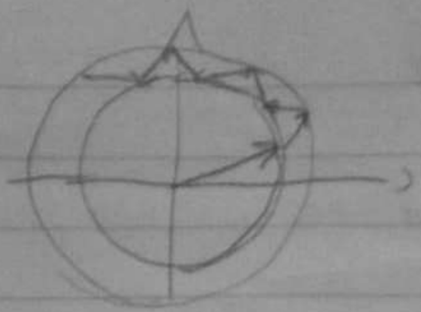
e) $\emptyset < M_{em}^* - M_{em} < h \ \& \ \Delta M_{em} = 1 \Rightarrow \Delta M_{em} = 1$

f) $-h < M_{em}^* - M_{em} < \emptyset \ \& \ \Delta M_{em} = 1 \Rightarrow \Delta M_{em} = \emptyset$

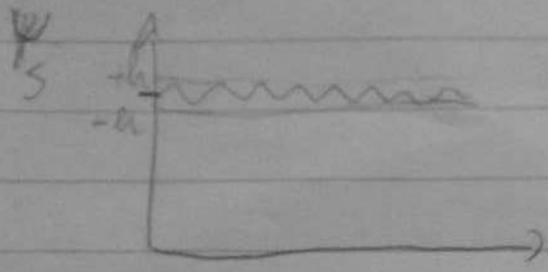
$\hookrightarrow$ MOŽE I 2RAZINSKI ALI SU OSCILACIJE ONDA PREVELIKE, PA TIME I ω_c, NO MOGUĆ I 2 2-RAZINSKA

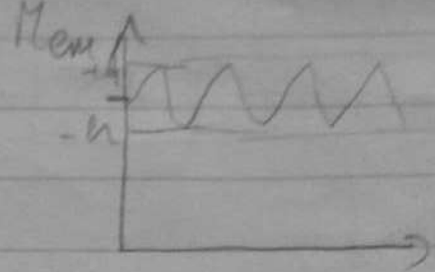
ESTIMATOR: $u = Ri + \frac{d\psi}{dt} \Rightarrow \psi = \int_0^t (u - Ri)\,d\tau \Rightarrow \psi_\alpha = \int_0^t (u_\alpha - R i_\alpha)\,d\tau$ (1)

(2) $M_{em} = \frac{3}{2} p\, \psi \times i = \frac{3}{2} p (\psi_\alpha i_\beta - \psi_\beta i_\alpha)$ | $\theta = \text{arctg} \frac{\psi_\beta}{\psi_\alpha}$ (3) | $\psi_\beta = \int_0^t (u_\beta - R i_\beta)\,d\tau$, $\psi = \sqrt{\psi_\alpha^2 + \psi_\beta^2}$



OSCILACIJE → manje h – UŽE GRANICE →
→ VIŠA FREKVENCIJA
OSCILACIJA (I SKLAPANJA)



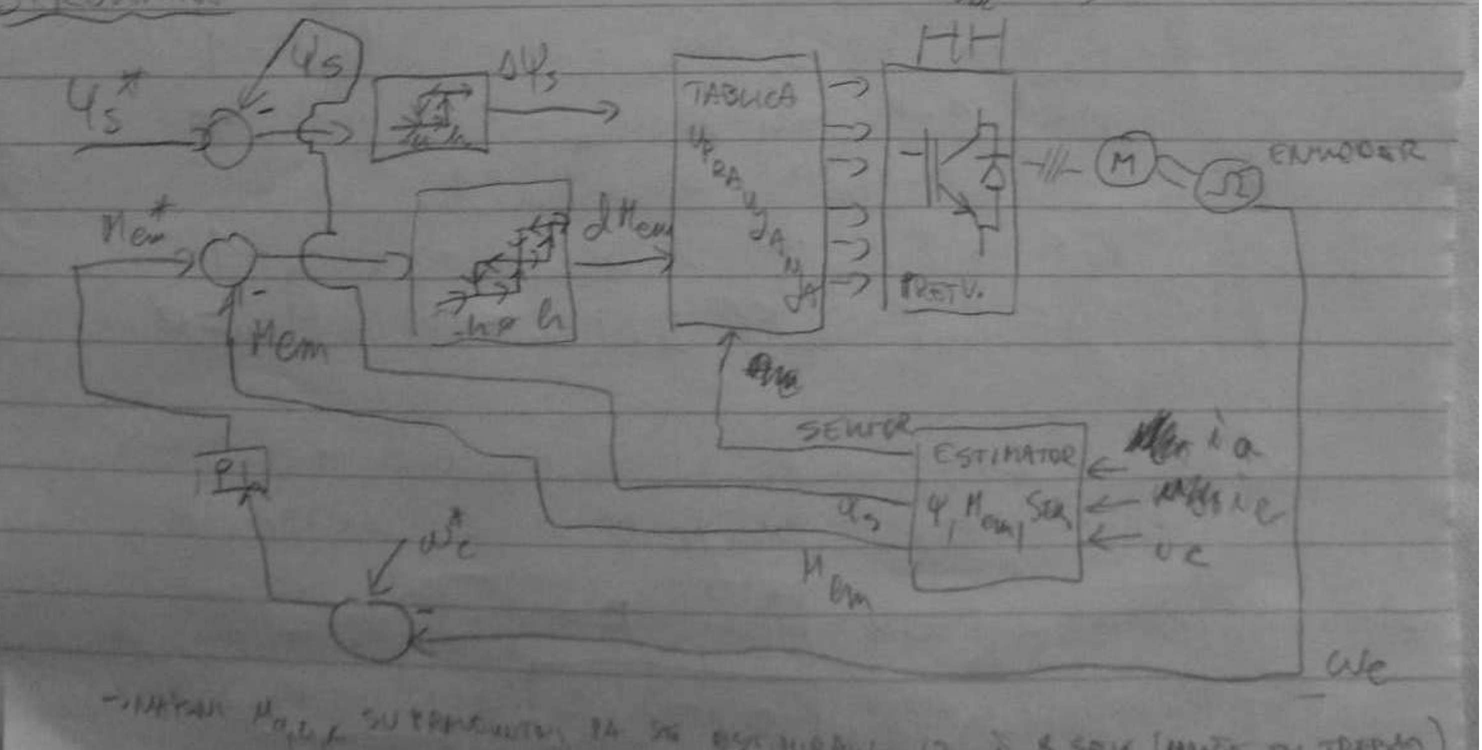


→ PREDNOSTI: trebaju nam struja kao i kod vektorskog, ali ne treba nam δ, NI POZICIJA
- ZADAJEMO DIREKTNO MOMENT
- NEMA PRETVORBE U dq
- JEDNOSTAVNIJI REGULATORI (HISTEREZNI - NEMA PRORAČUNA PARAMETARA)

→ MANE: - MANJA PRECIZNOST
- PRISUTNI VIŠI HARMONICI
- NISU DOBRI ZA ZADAĆE POZICIONIRANJA

→ ISTO: NEMA RAZLIKE U BRZINI UPRAVLJANJA (DTC & VEKTORSKA)

STRUKTURA:



→ NAPON $U_{a,b,c}$ SU PRAVOKUTNI PA SE ESTIMIRAJU IZ i & SEK. (INAČE BI TREBAO FILTER)