Regulisani elektromotorni pogoni sa mašinama za jednosmernu struju

Osnovne karakteristike

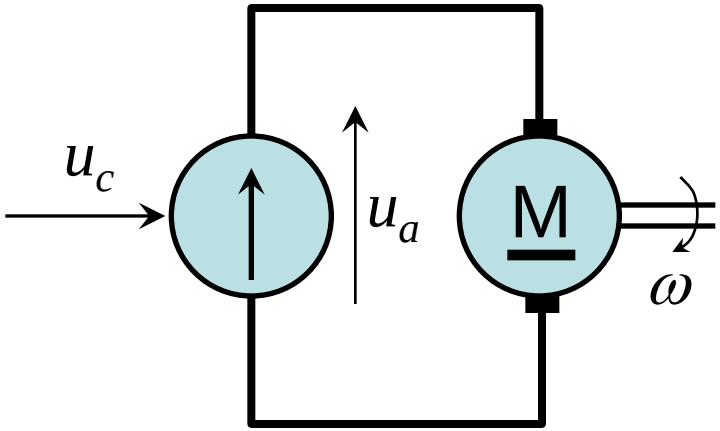
Načini realizacije (aktuatora)

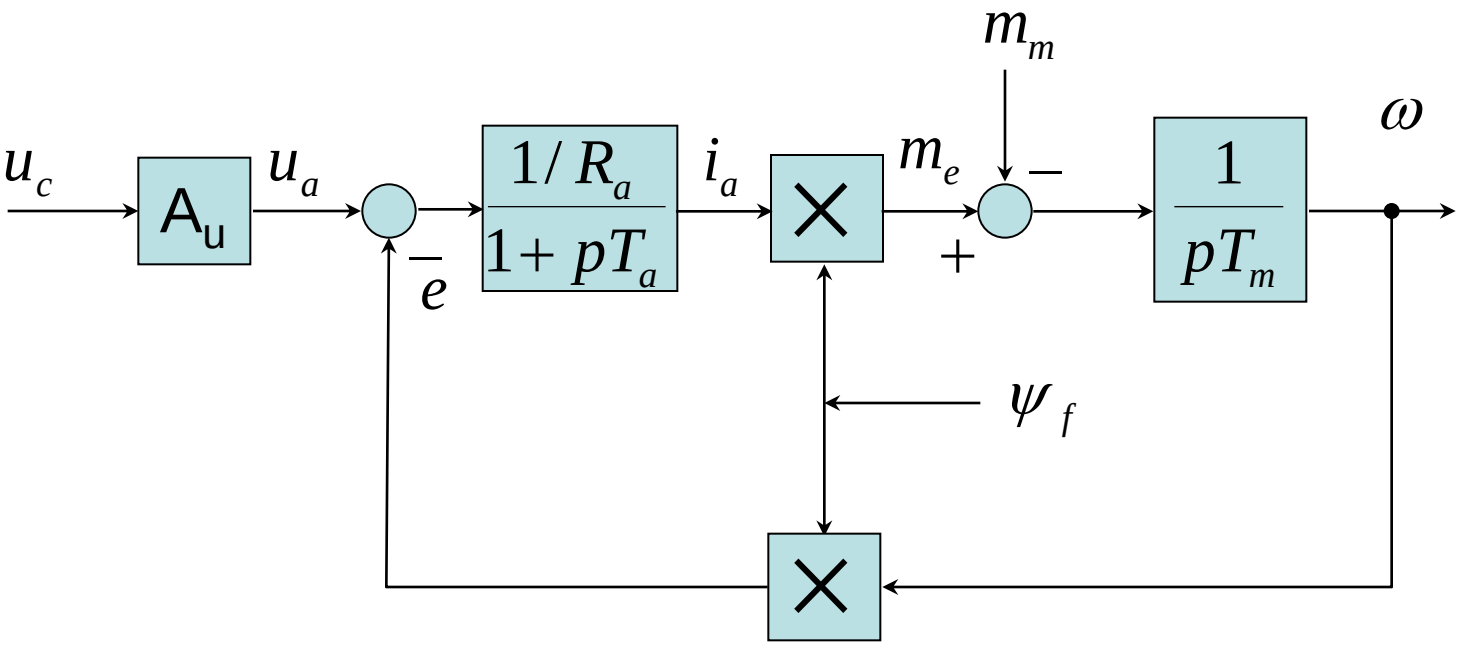
Rad u 2 ili 4 kvadranta

Rad u proširenom opsegu brzina

Naponski izvor

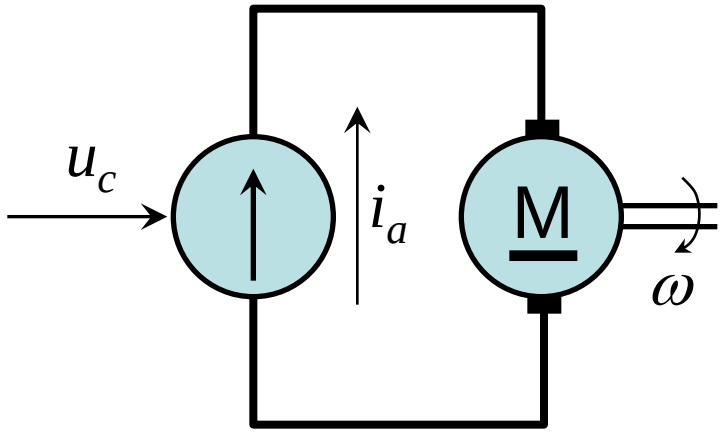
naponski upravljivi izvor

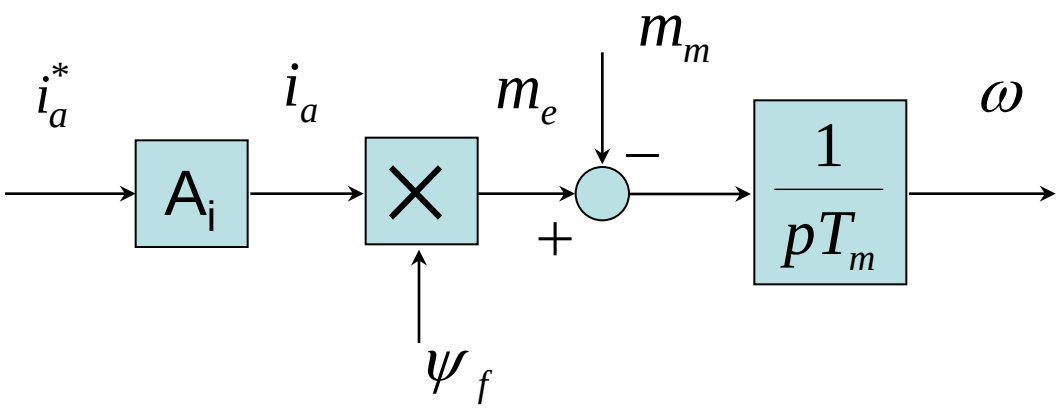




Strujni izvor

strujni upravljivi izvor

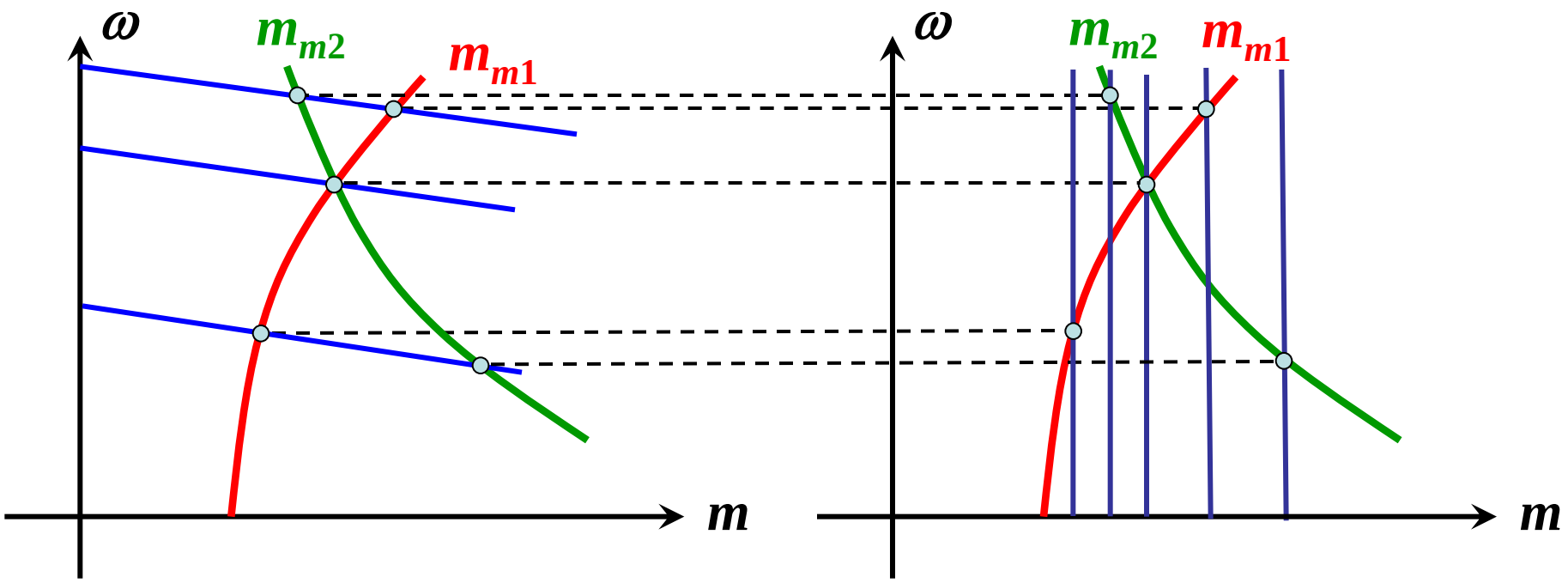




Poređenje statičkih mehaničkih karakteristika

Naponski izvor
(naponsko napajanje)

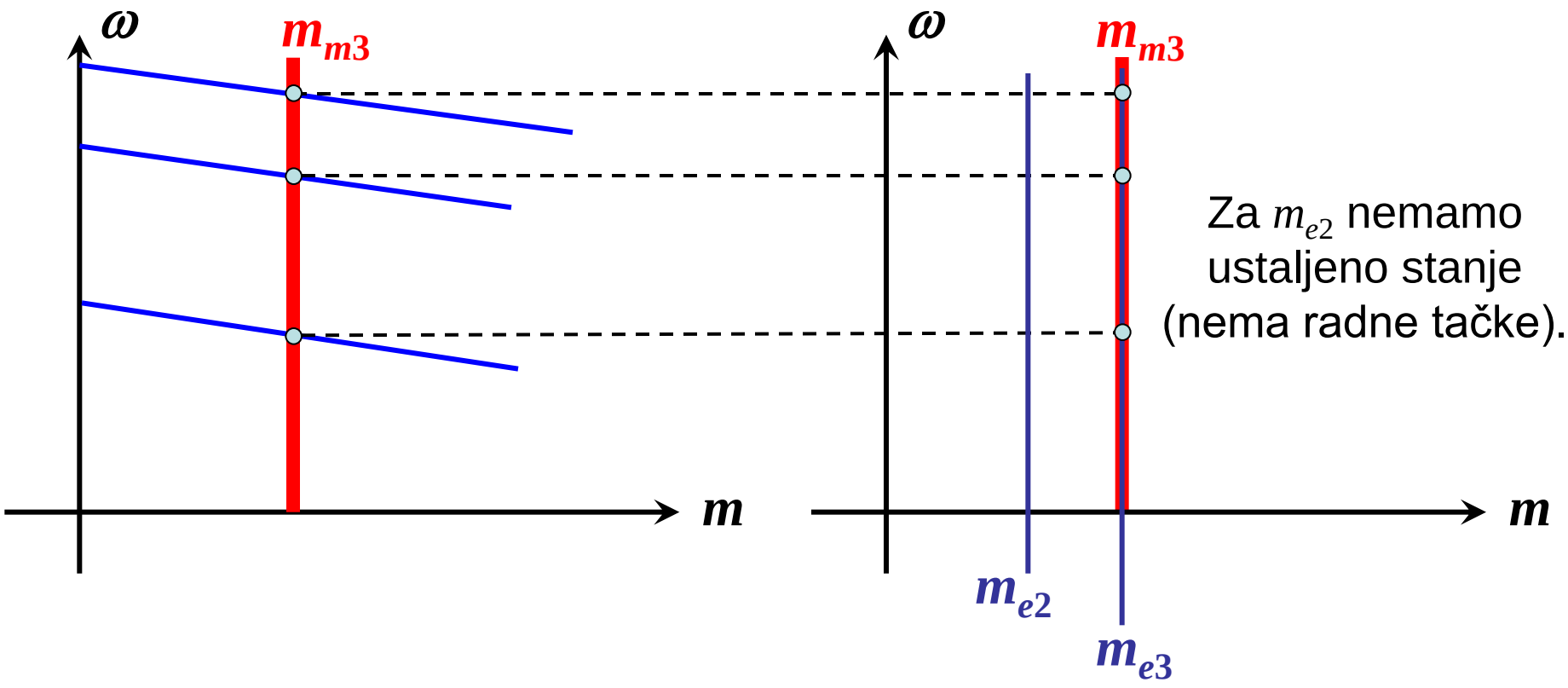
Strujni izvor
(strujno napajanje)



Ukoliko je mehanička karakteristika opterećenja nezavisna od brzine

Naponski izvor
(naponsko napajanje)

Strujni izvor
(strujno napajanje)



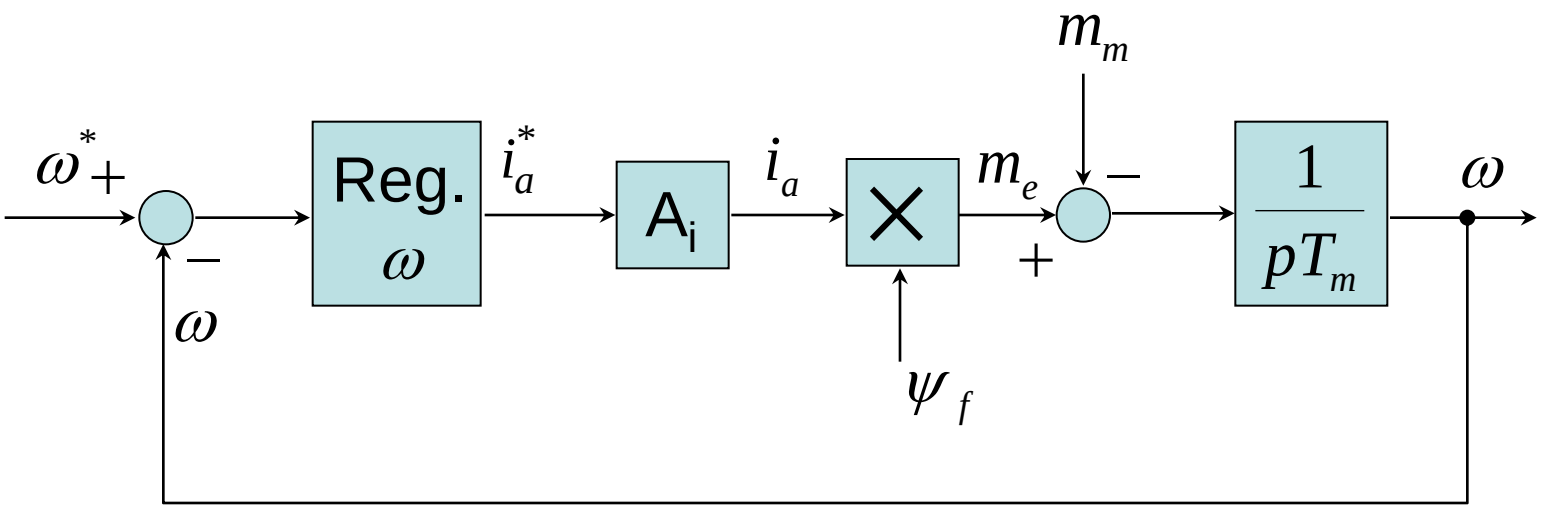
Naponsko napajanje:

- ☒ sporiji odziv
- ☑ statička stabilnost radne tačke
- ☒ nema kontrole nad strujom (prevazilazi se regulatorom struje)

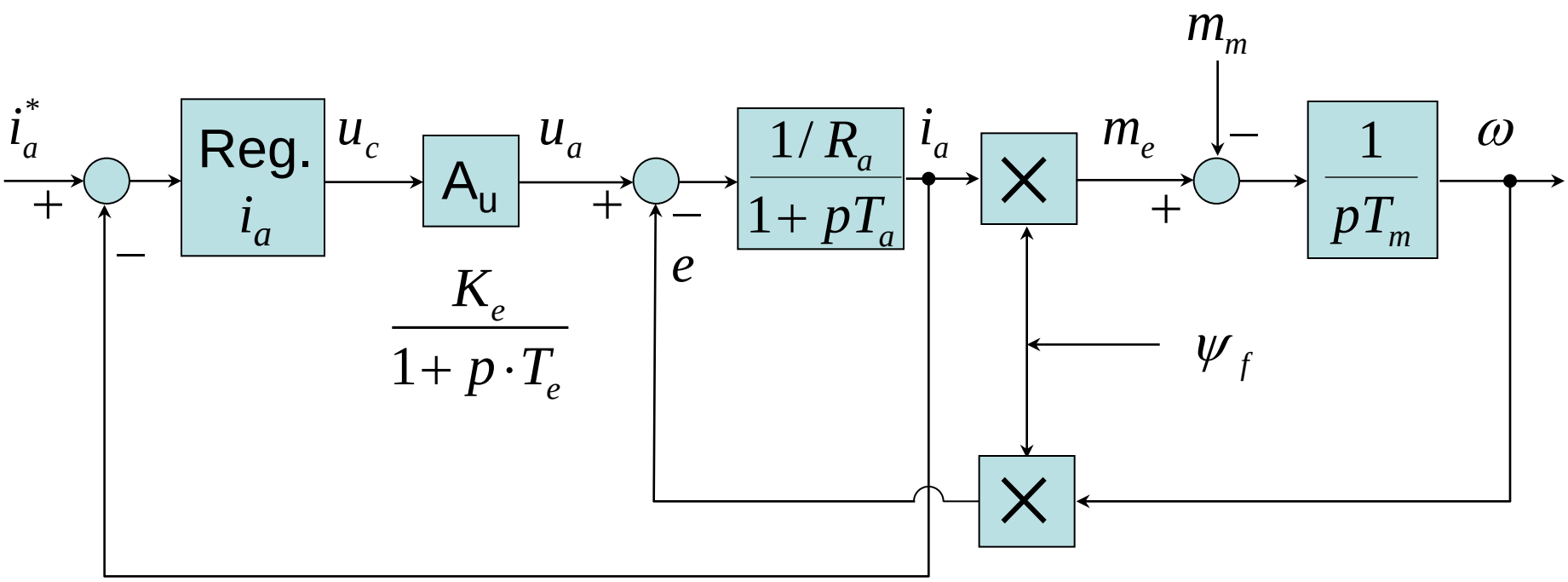
Strujno napajanje:

- ☑ brži odziv (!)
- ☒ statička stabilnost radne tačke - prevazilazi se regulatorom brzine
- ☑ neposredna kontrola nad strujom (momentom)

Regulisani pogon sa regulatorom brzine sa jednosmernim motorom napajanim iz strujnog izvora



Praktična realizacija strujnog izvora
Naponski izvor + regulator struje

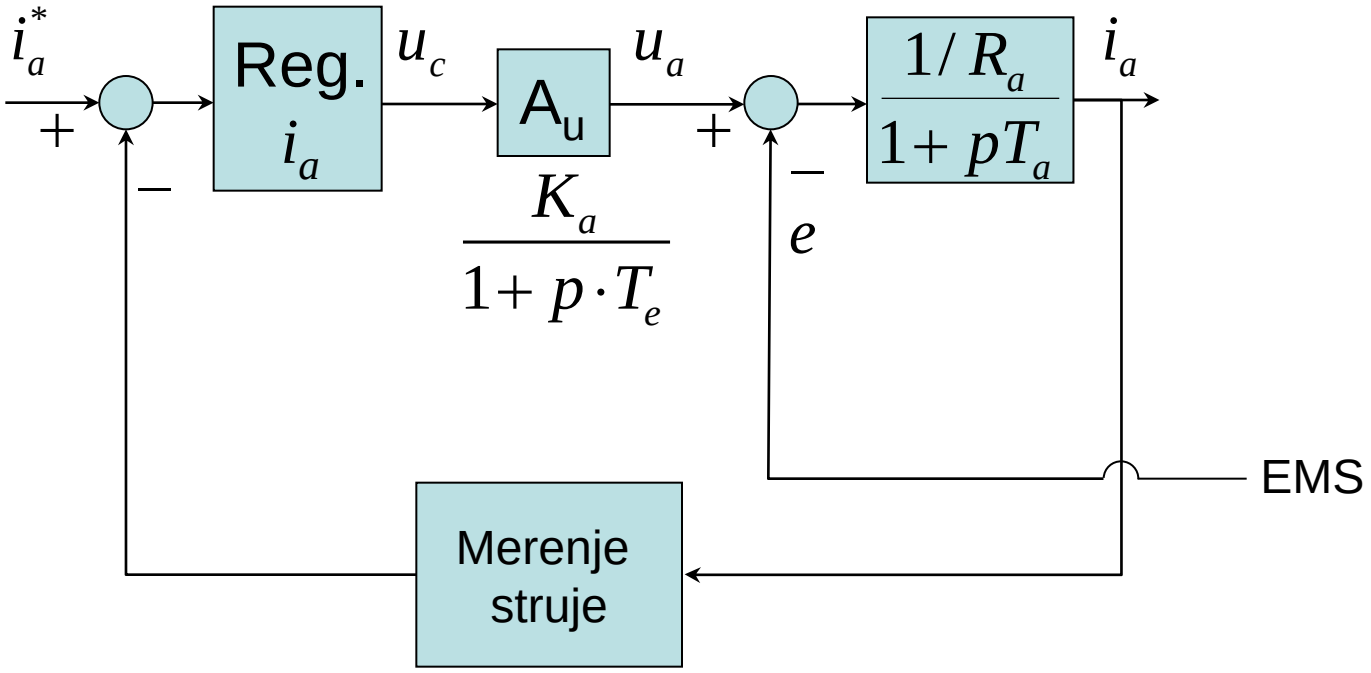


realni strujni izvor

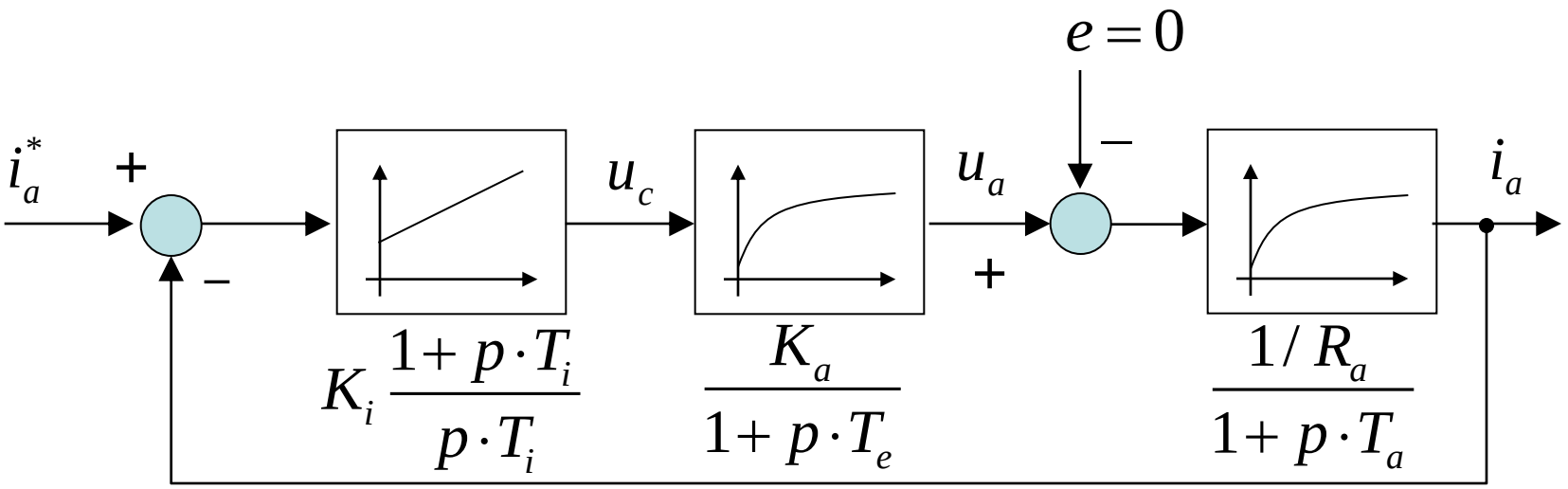
$T_e < T_a \ \left(T_e \ll T_a\right)$ $\qquad$ $T_a \ll T_m$

Podešavanje parametara regulatora struje

Blok dijagram sistema



Blok dijagram konture regulacije struje



$$F_{0i}(p) = K_i \cdot \frac{1+p\cdot T_i}{p\cdot T_i} \cdot \frac{K_a}{1+p\cdot T_e} \cdot \frac{1/R_a}{1+p\cdot T_a} \qquad T_a \gg T_e$$

Zanemarili smo blok (senzor) za merenje struje, smatramo da je idealan. Aktuator ima pojačanje i kašnjenje (uprošćeno).

Zanemarili smo uticaj elektromotorne sile, pošto se sporo menja. Smatramo da je to za konturu regulacije struje poremećaj, i u postupku podešavanja parametara vrednost je $e=0$

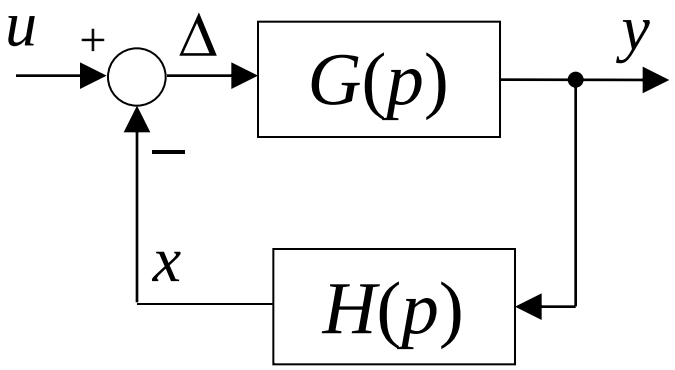
Funkcija prenosa konture regulacije struje

$$F_{0i}(p) = K_i \cdot \frac{1 + p \cdot T_i}{p \cdot T_i} \cdot \frac{K_a}{1 + p \cdot T_e} \cdot \frac{1/R_a}{1 + p \cdot T_a} \qquad T_a \gg T_e$$

Izvršimo kompenzaciju veće vremenske konstante

$$\rightarrow T_i = T_a$$

$$F_{0i}(p) = \frac{K_i \cdot K_a \cdot 1/R_a}{p \cdot T_i \cdot (1 + p \cdot T_e)}$$



$$\frac{y}{u}(p) = \frac{G(p)}{1 + G(p) \cdot H(p)} \qquad H(p) = 1$$

$$F_{wi}(p) = \frac{F_{0i}(p)}{1 + F_{0i}(p)}$$

Izbor parametara regulatora

$$F_{wi}(p) = \frac{K_i \cdot K_a \cdot (1/R_a)}{K_i \cdot K_a \cdot (1/R_a) + p \cdot T_i + p^2 \cdot T_i \cdot T_e}$$

$$a_0 = K_i \cdot K_a \cdot (1/R_a); \quad a_1 = T_i; \quad a_2 = T_i \cdot T_e$$

Primenjujemo definisan kriterijum optimizacije modula funkcije prenosa

$$a_1^2 = 2 \cdot a_0 \cdot a_2$$

$$K_i \cdot K_a \cdot 1/R_a = \frac{T_i}{2 \cdot T_e} \rightarrow$$

$$K_i = \frac{T_i}{2 \cdot K_a \cdot (1/R_a) \cdot T_e}$$

$$F_{wi}(p)_{opt.} = \frac{i_a(p)}{i_a^*(p)} = \frac{1}{1 + p \cdot 2 \cdot T_e + p^2 \cdot 2 \cdot T_e^2}$$

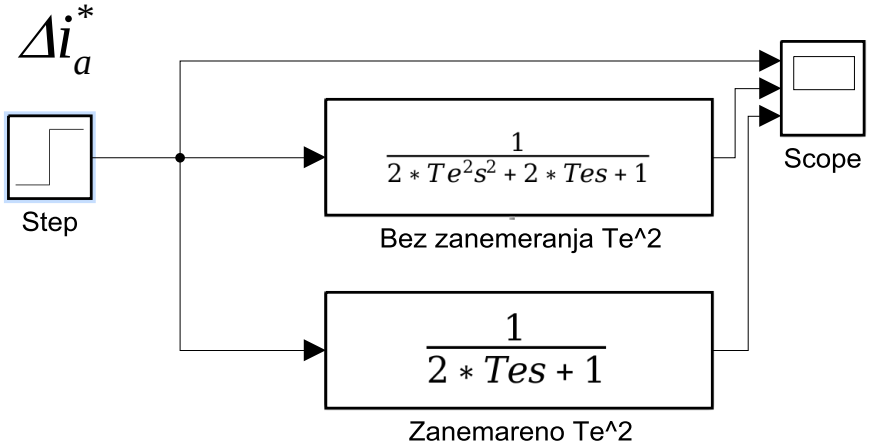
Brzina promene brzine je značajno manja od brzine promene struje indukta i_a.

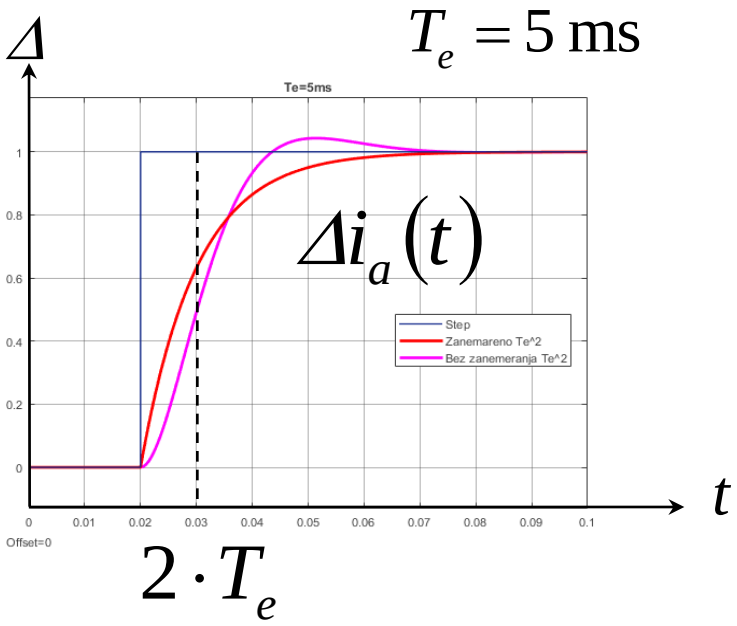
Pri promeni $\Delta i_a^* \sim \Delta i_a$ važi $\Delta\omega \approx 0$ i $\Delta e \approx 0$

Ukoliko vremenska konstanta T_e ima malu vrednost, možemo zanemariti kvadratni član.

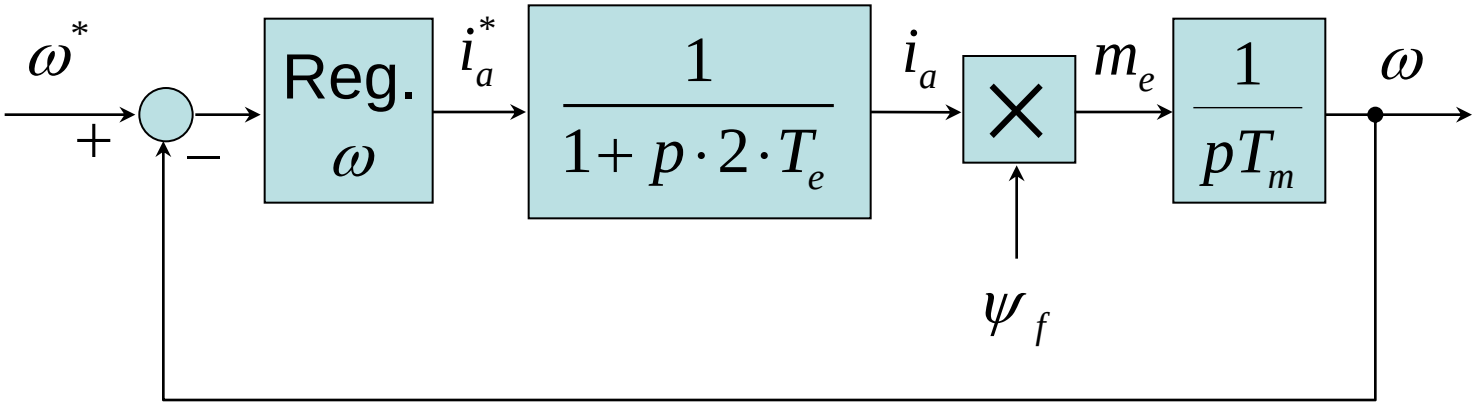
$$\frac{1}{1+p\cdot 2\cdot T_e+\underbrace{p^2\cdot 2\cdot T_e^2}_{\approx 0}} \approx \frac{1}{1+p\cdot 2\cdot T_e}$$

0





Regulator brzine:



$$F_\omega(p) = K_\omega \cdot \frac{1+p\cdot T_\omega}{p\cdot T_\omega}$$

$$F_{0\omega}(p) = \frac{K_\omega \cdot (1+p\cdot T_\omega)\cdot \psi_f}{p^2\cdot T_\omega \cdot T_m \cdot (1+p\cdot 2\cdot T_e)} = \frac{K'_\omega \cdot (1+p\cdot T_\omega)}{p^2\cdot T_\omega \cdot T_m \cdot (1+p\cdot 2\cdot T_e)}$$

$$K'_\omega = K_\omega \cdot \psi_f$$

$$F_{w\omega}(p) = \frac{F_{0\omega}(p)}{1+F_{0\omega}(p)}$$

Funkcija spregnutog prenosa brzinske petlje

$$F_{w\omega}(p)=\frac{K'_{\omega}\cdot(1+p\cdot T_{\omega})}{p^2\cdot T_{\omega}\cdot T_m\cdot(1+p\cdot 2\cdot T_e)+K'_{\omega}\cdot(1+p\cdot T_{\omega})}$$

$$F_{w\omega}(p)=\frac{K'_{\omega}\cdot(1+p\cdot T_{\omega})}{p^3\cdot\underbrace{T_{\omega}\cdot T_m\cdot 2\cdot T_e}_{a_3}+p^2\cdot T_{\omega}\cdot T_m+p\cdot\underbrace{T_{\omega}\cdot K'_{\omega}}_{a_1}+\underbrace{K'_{\omega}}_{a_0}}$$

Primenom optimizacije: $a_1^2=(a)\cdot a_0\cdot a_2 \quad a_2^2=(a)\cdot a_1\cdot a_3$

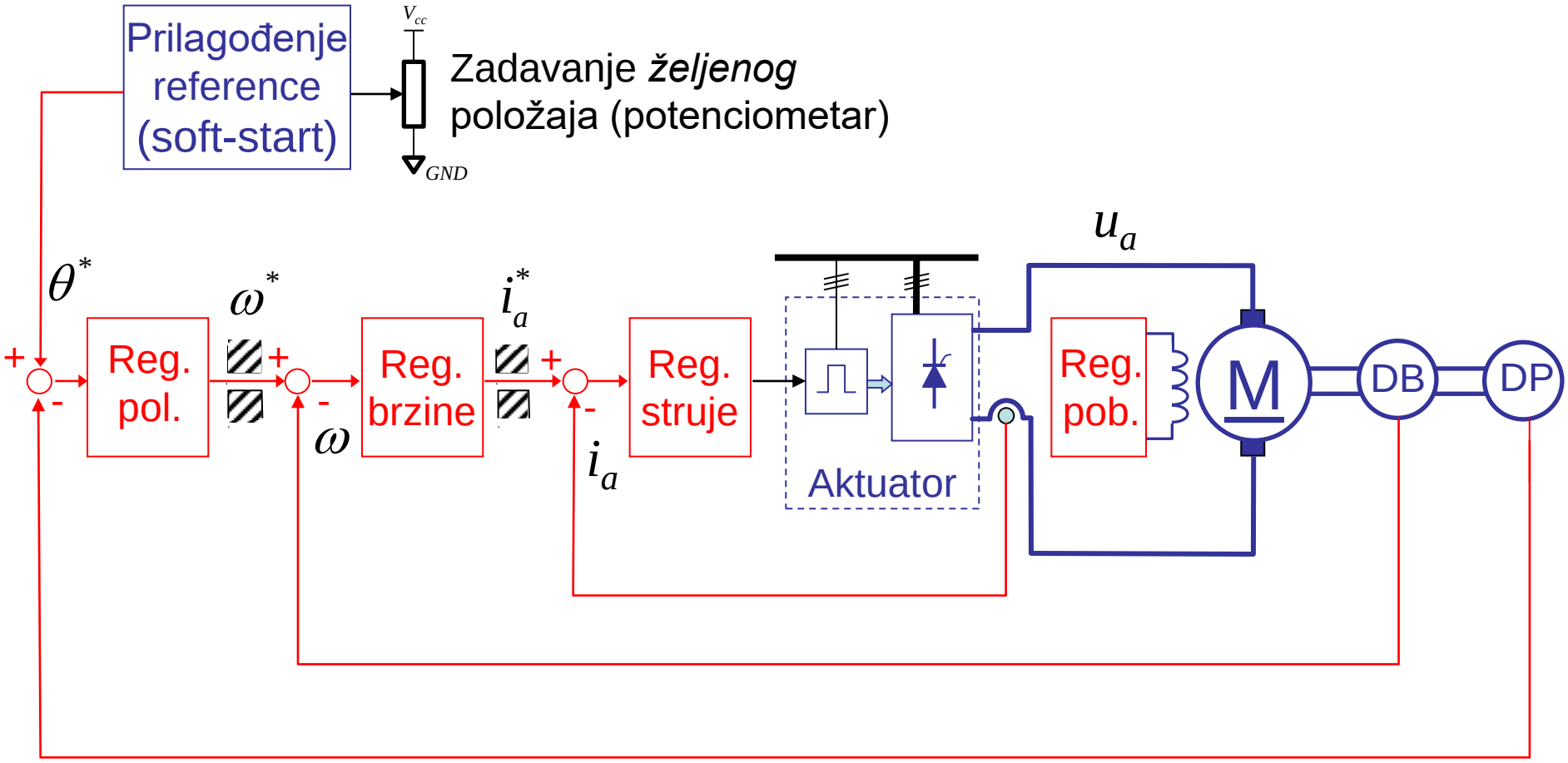
$$T_{\omega}=a^2\cdot 2\cdot T_e;\quad K'_{\omega}=\frac{1}{a}\cdot\frac{T_m}{2\cdot T_e}$$

gde je $a=2\zeta+1$

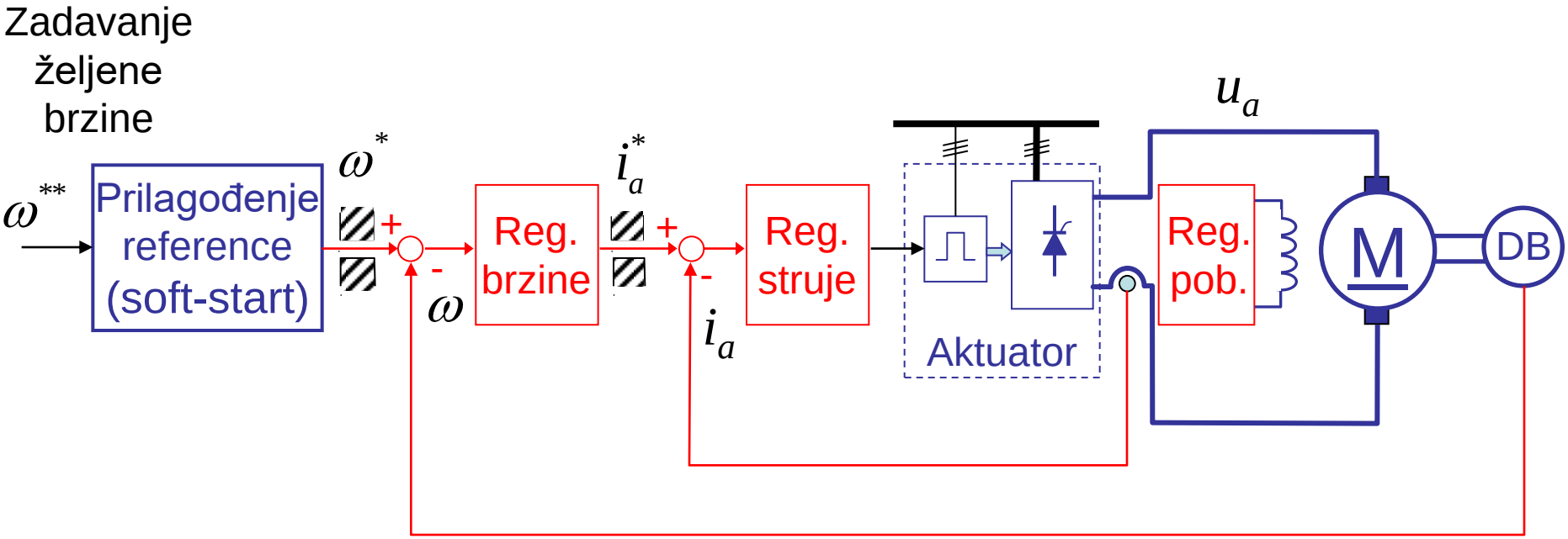
ζ - željeni relativni faktor prigušenja zatvorene brzinske petlje.

Sledi da je: $$K_{\omega}=\frac{1}{\psi_f}\cdot\frac{T_m}{a\cdot 2\cdot T_e}$$

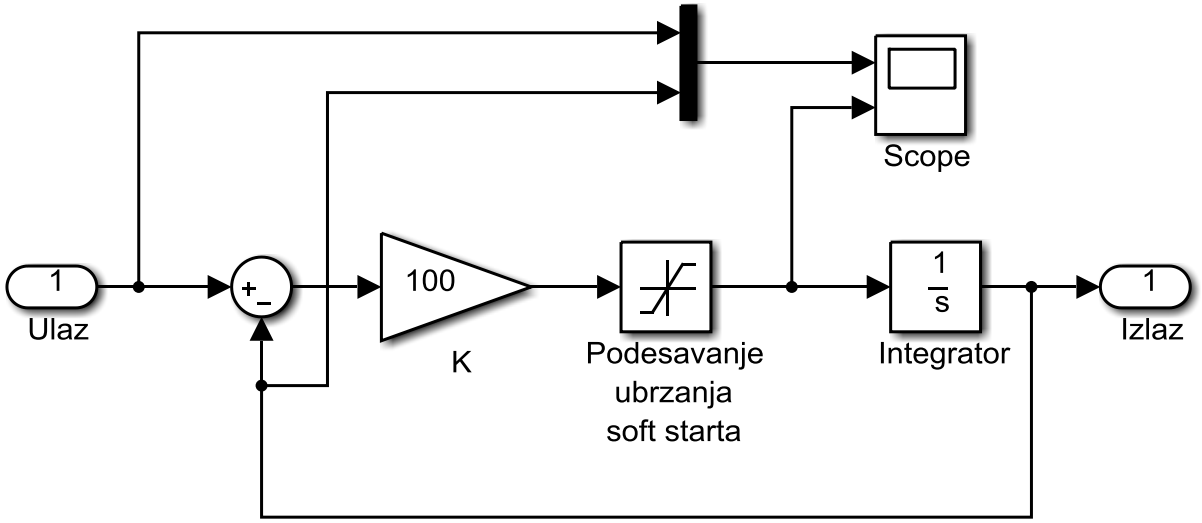
Regulisani elektromotorni pogon sa motorom jednosmerne struje - osnovna struktura



Regulisani elektromotorni pogon sa motorom jednosmerne struje bez regulacije položaja

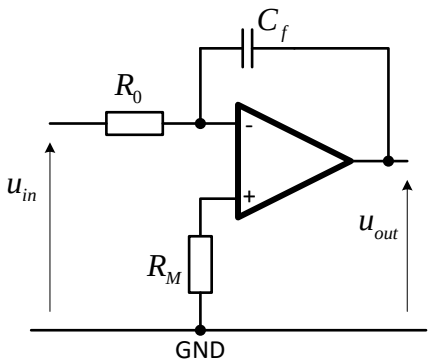


Realizacija bloka za prilagođenje reference

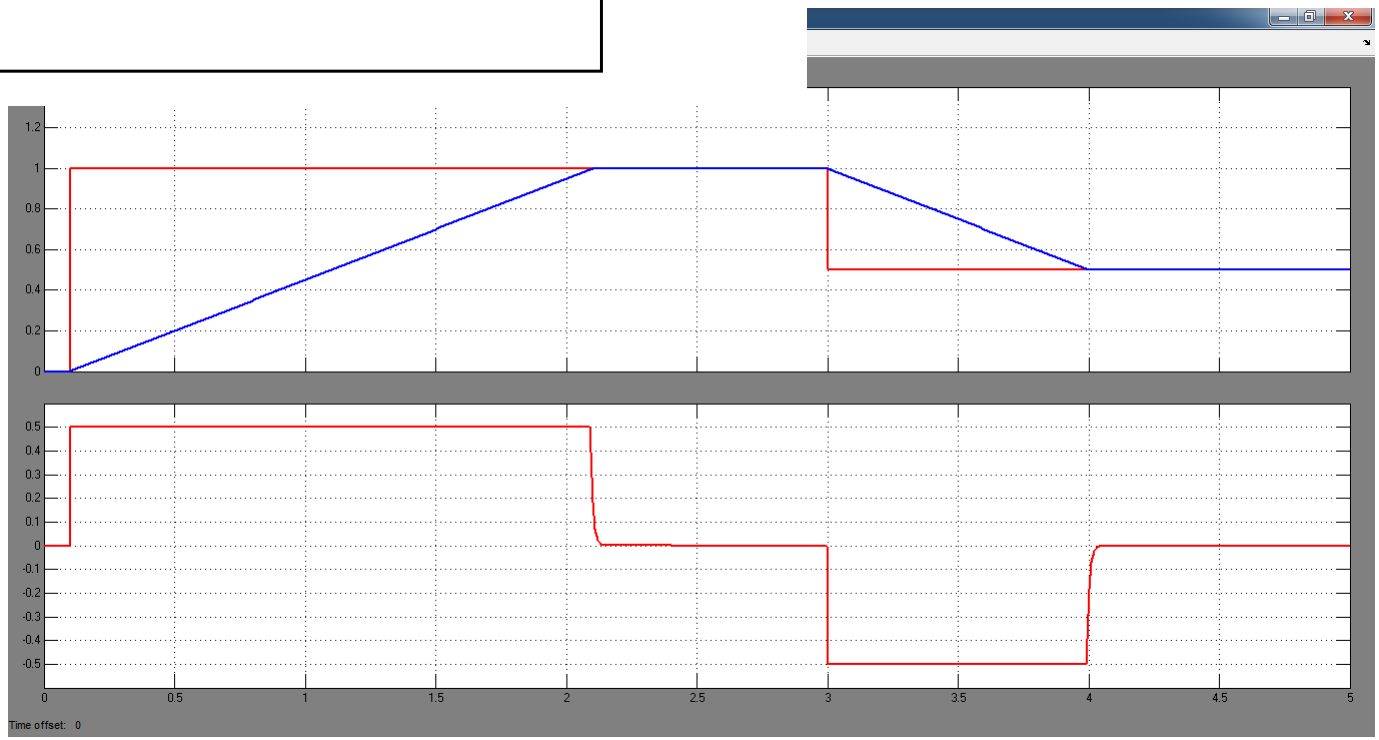


Integrator u kontinualnom vremenskom domenu

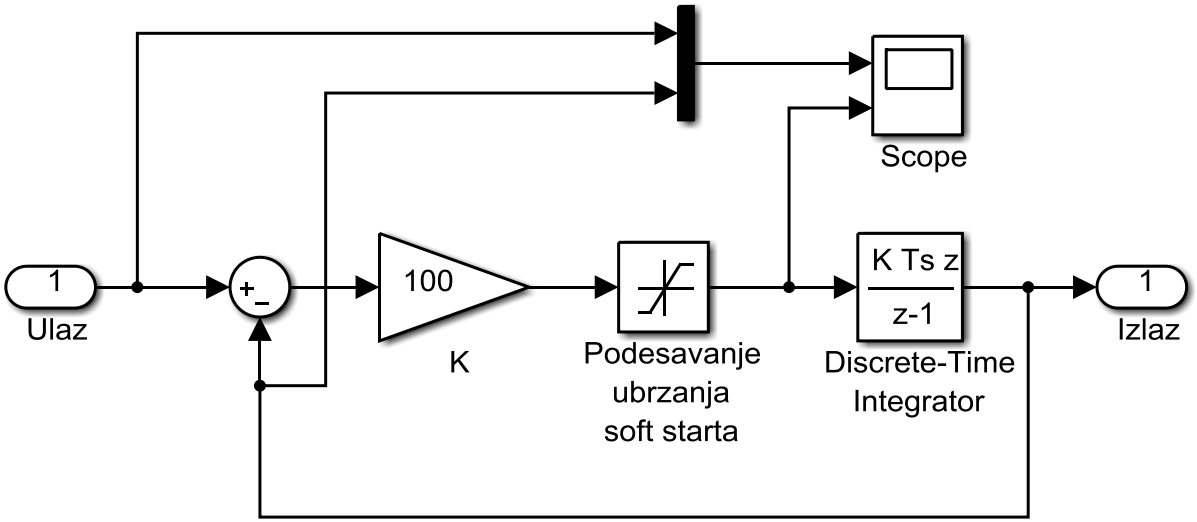
Limit = ±0,5



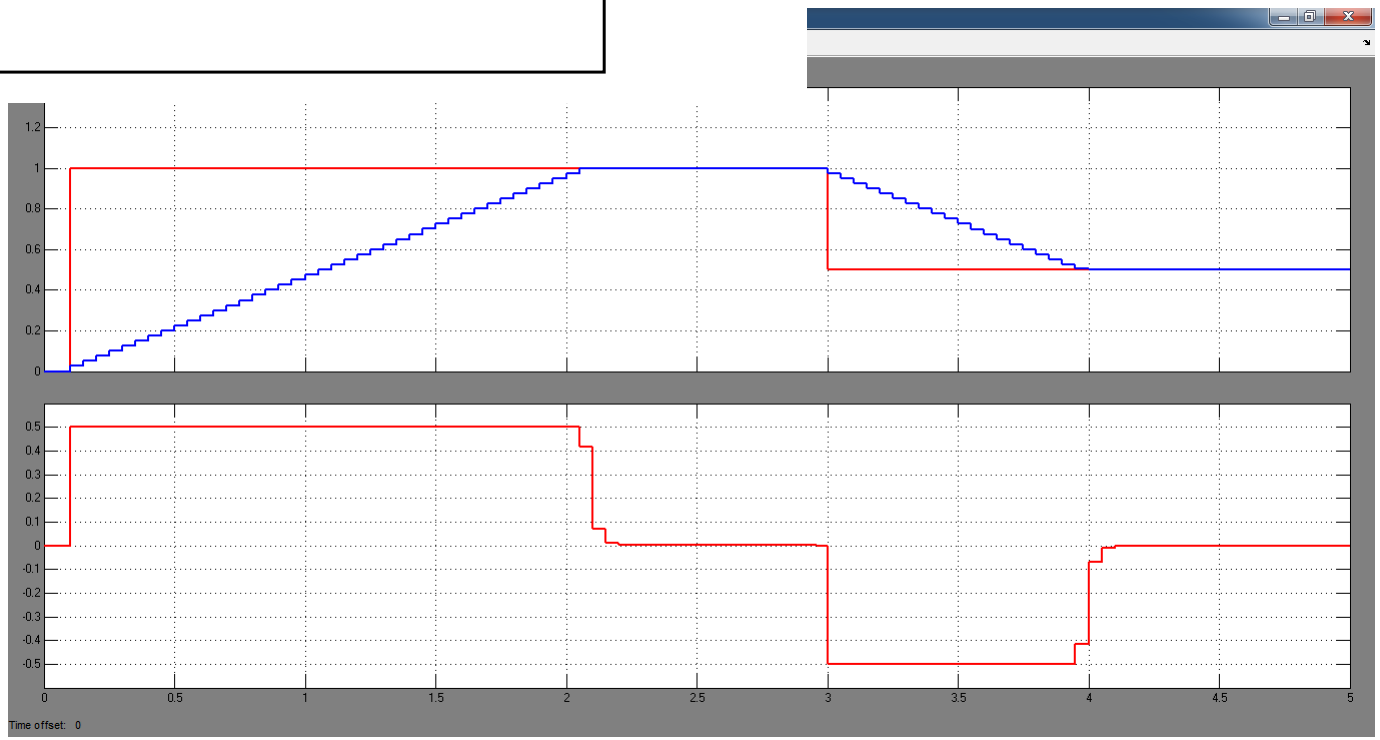
Invertuje signal



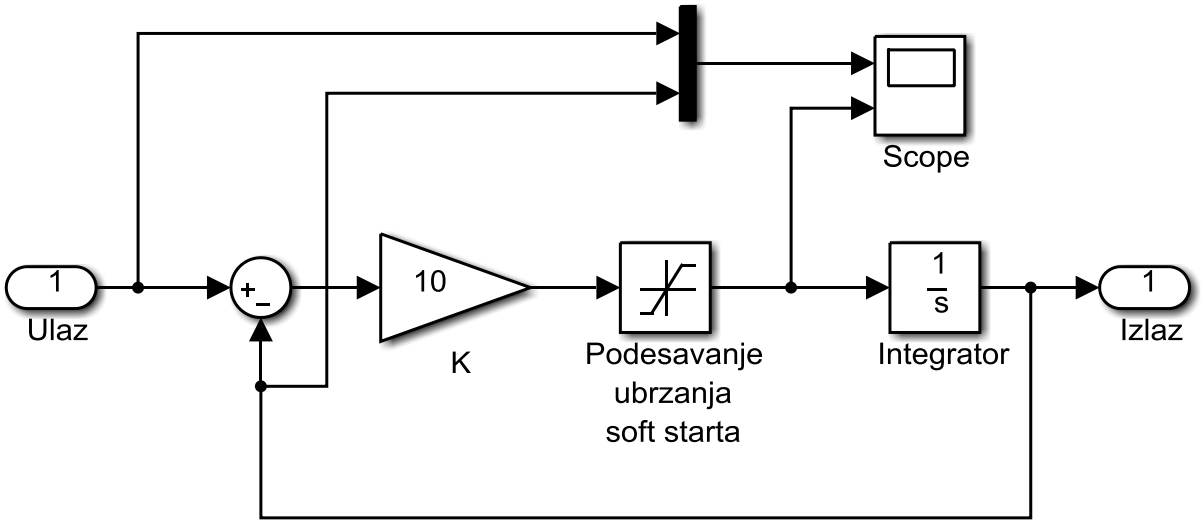
Realizacija bloka za prilagođenje reference



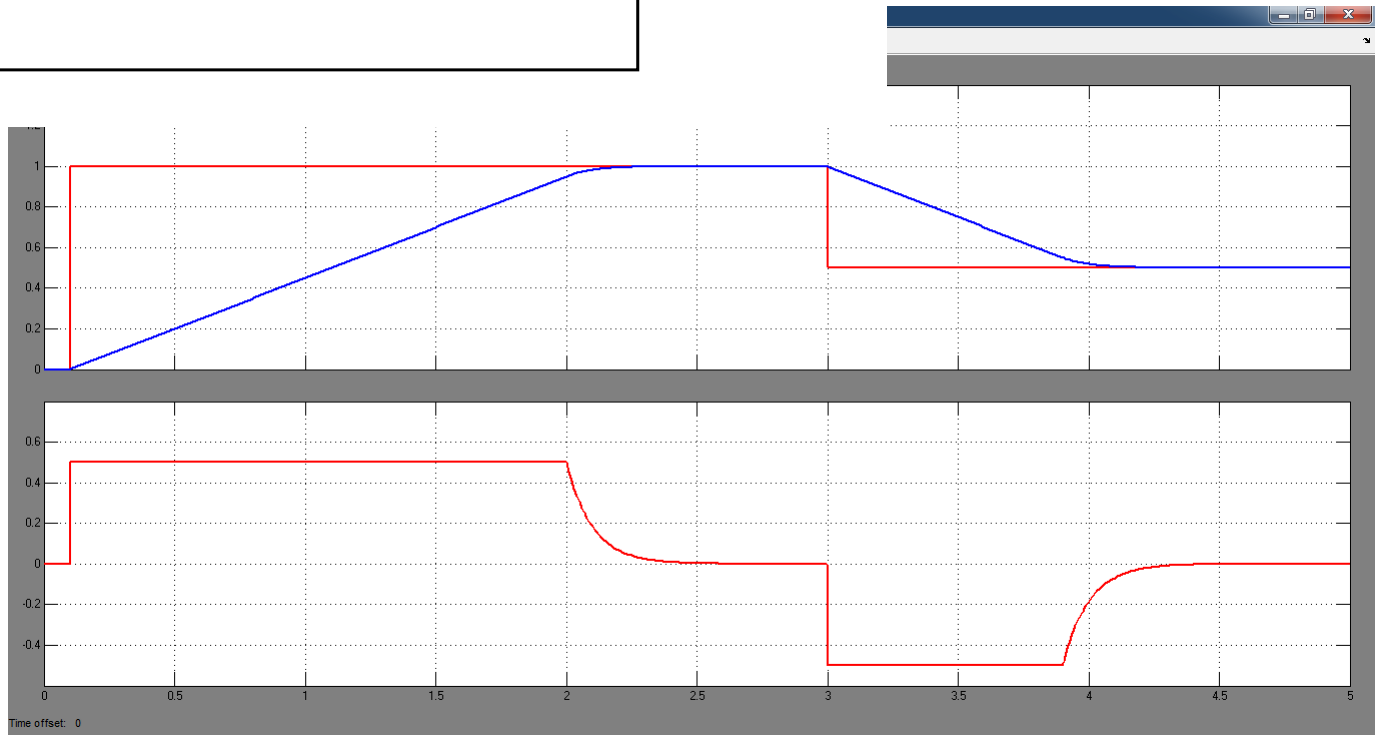
Integrator u diskretnom vremenskom domenu



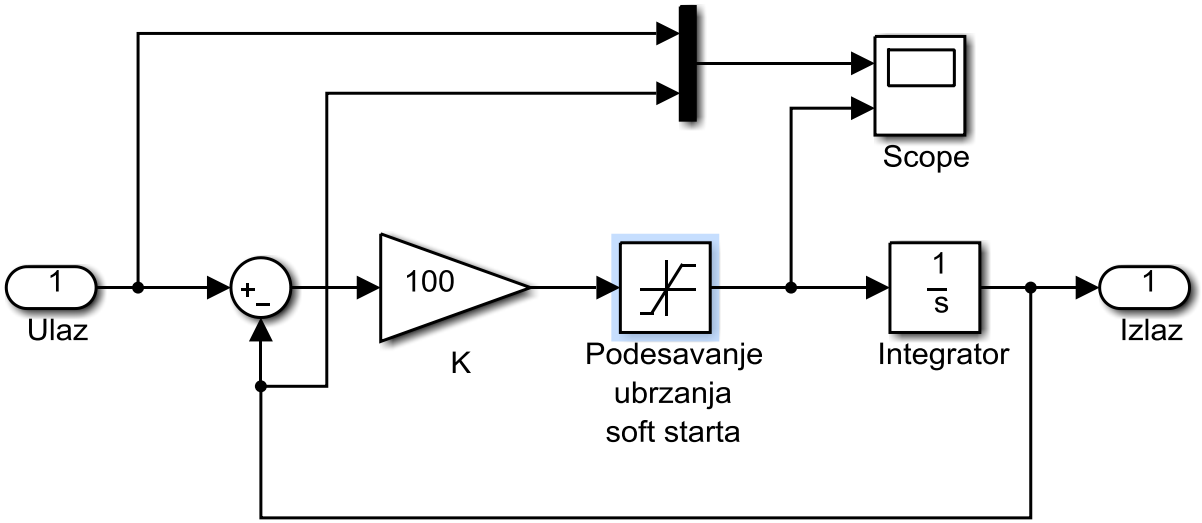
Realizacija bloka za prilagođenje reference



Uticaj pojačanja

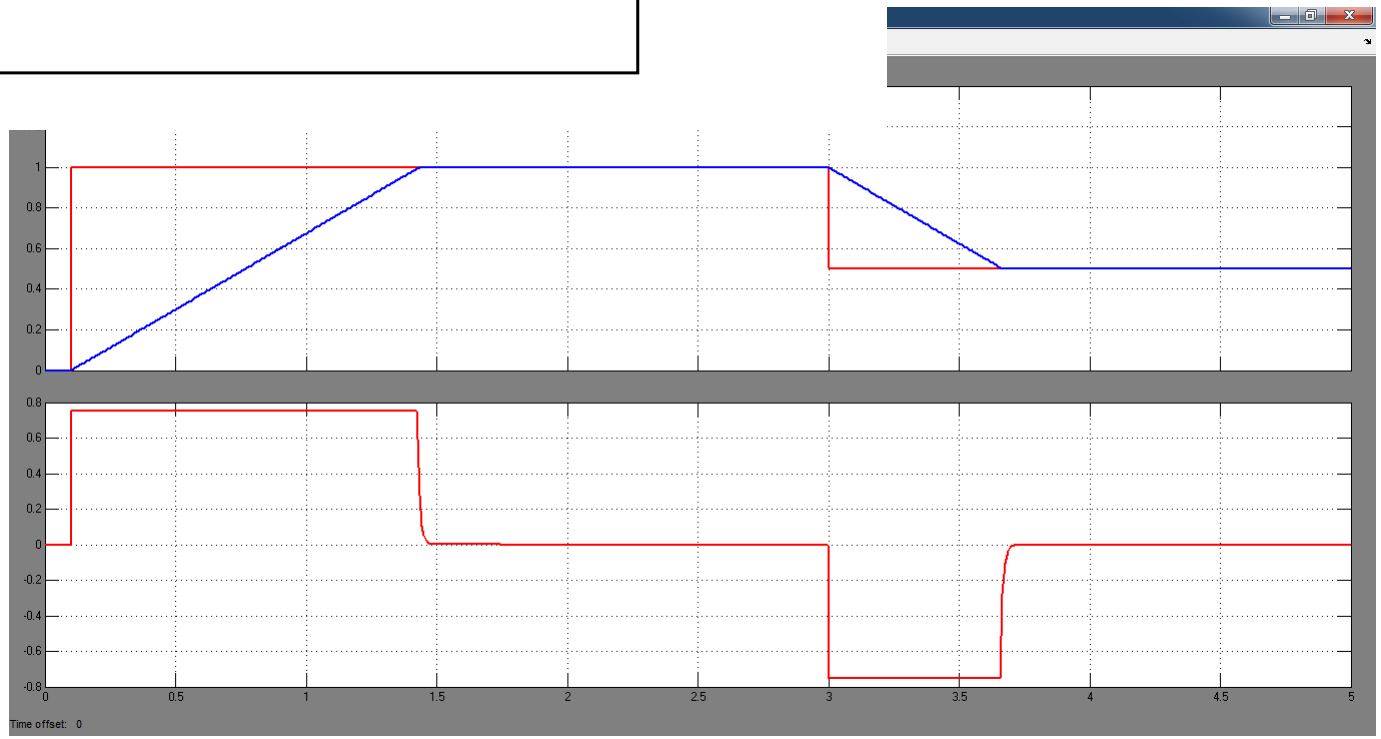


Realizacija bloka za prilagođenje reference

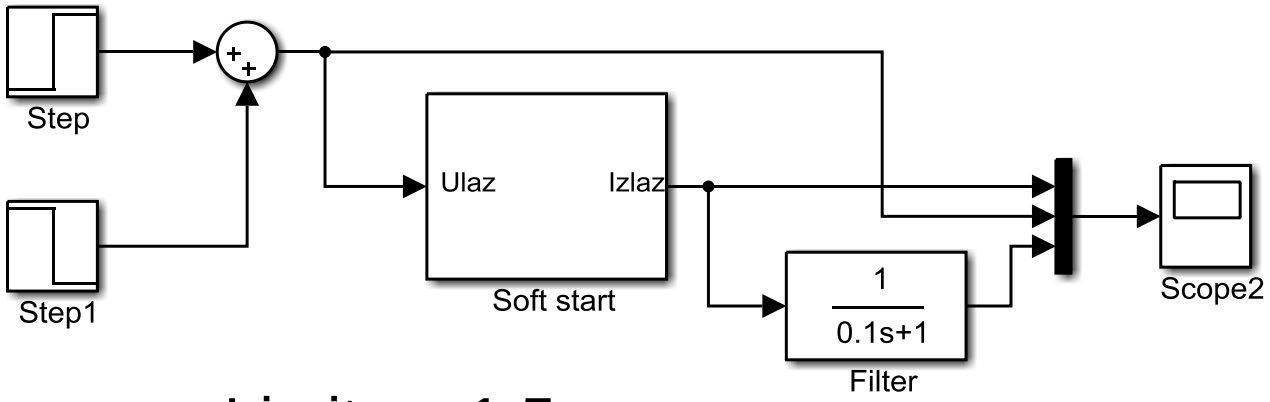


Uticaj promene limita na ubrzanje

Limit = ±0,75

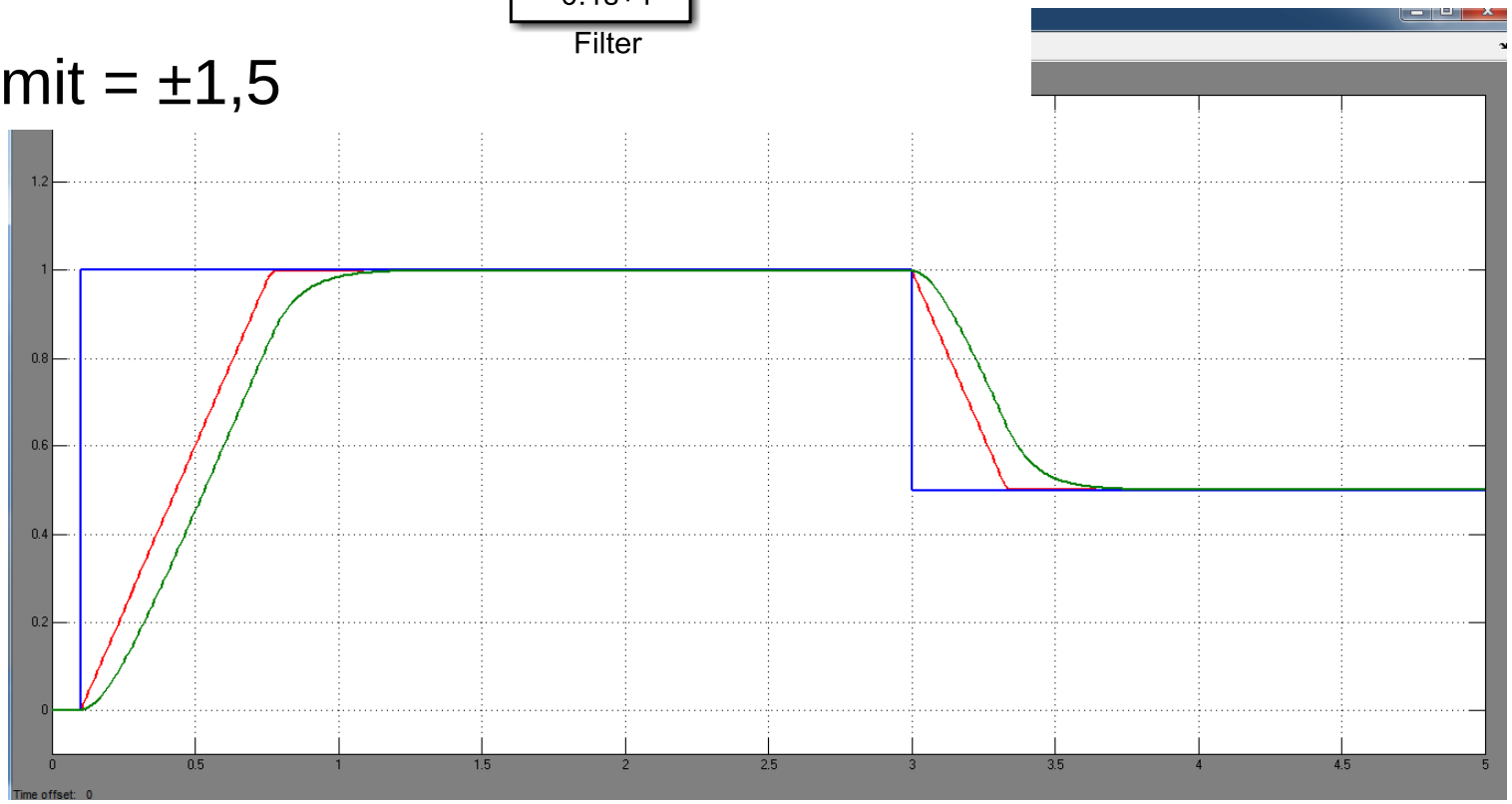


Realizacija bloka za prilagođenje reference

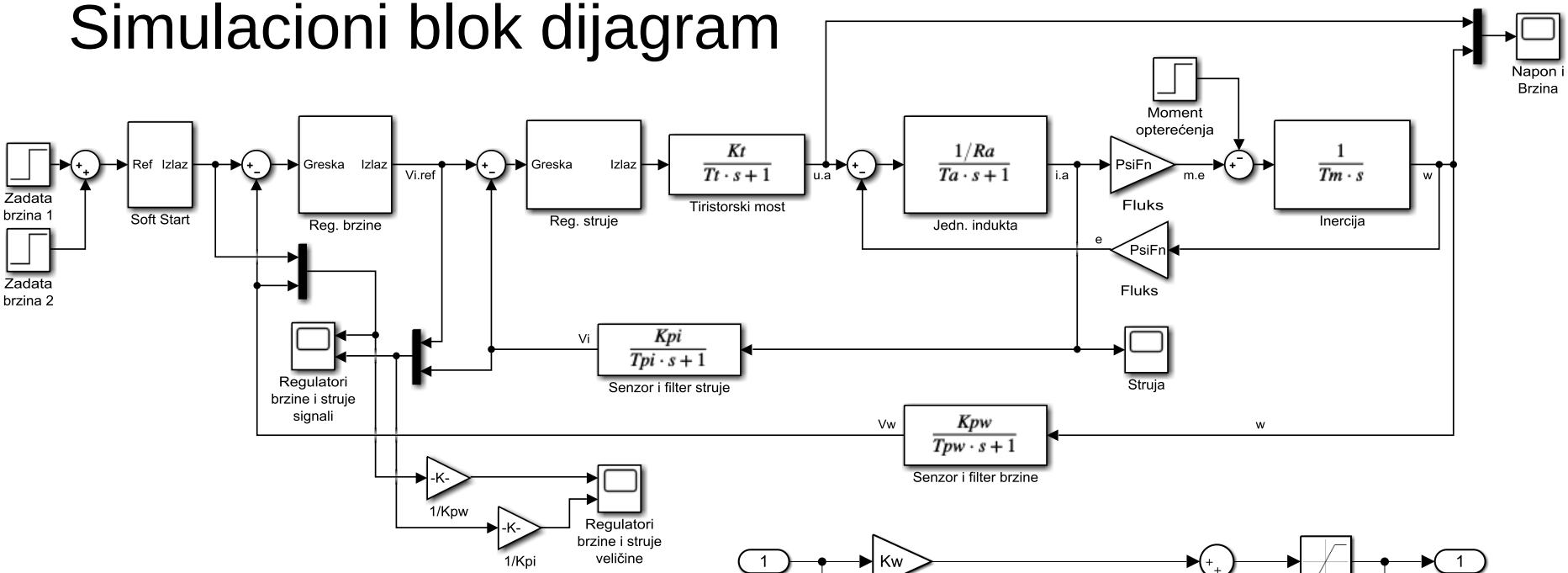


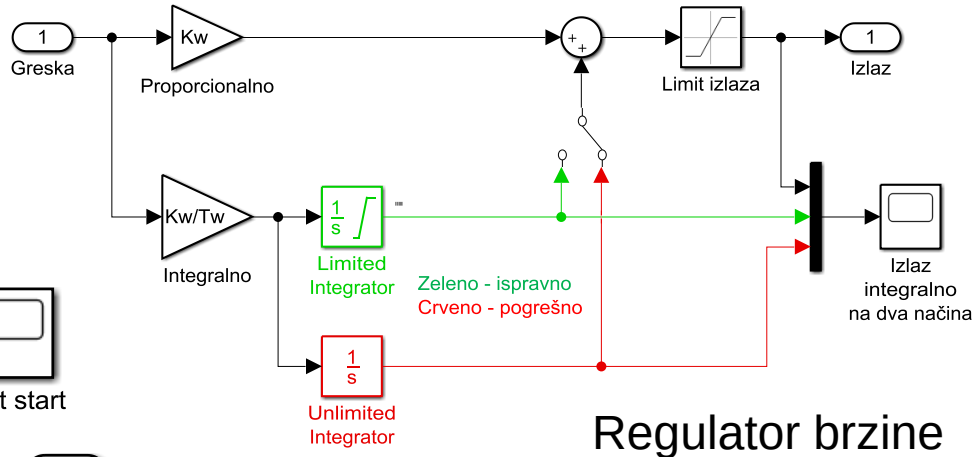
Soft-start
+
filter

Limit = ±1,5

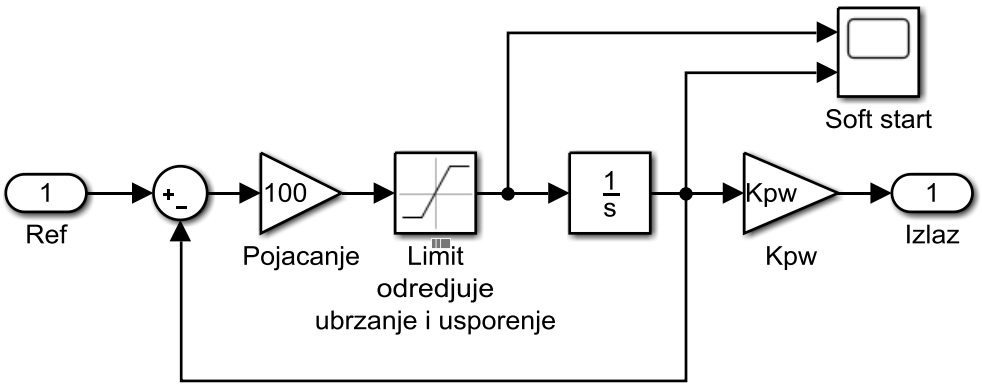


Simulacioni blok dijagram





Soft start



Regulator brzine

Regulator struje ima isti blok dijagram, ali druge parametre: pojačanje (Ki), vremensku konstantu integralnog dejstva (Ti) i limite integralnog dejstva i izlaza (LIM_UC)

Parametri

```
Ra = 0.075;
% u relativnim jedinicama
PsiFn = 1-Ra;
Ta = 30e-3;
Tm = 1.92;
Mmn = PsiFn;
mm = Mmn/2;

ktg = 0.05;
Kpw = ktg;
Tpw = 52.8e-3;
Kpi = 0.025;
Tpi = 2.6e-3;
Tt = 1.66e-3;
Kt = 30;

Te = Tt+Tpi;
Te2 = 2*Te+Tpw;
```

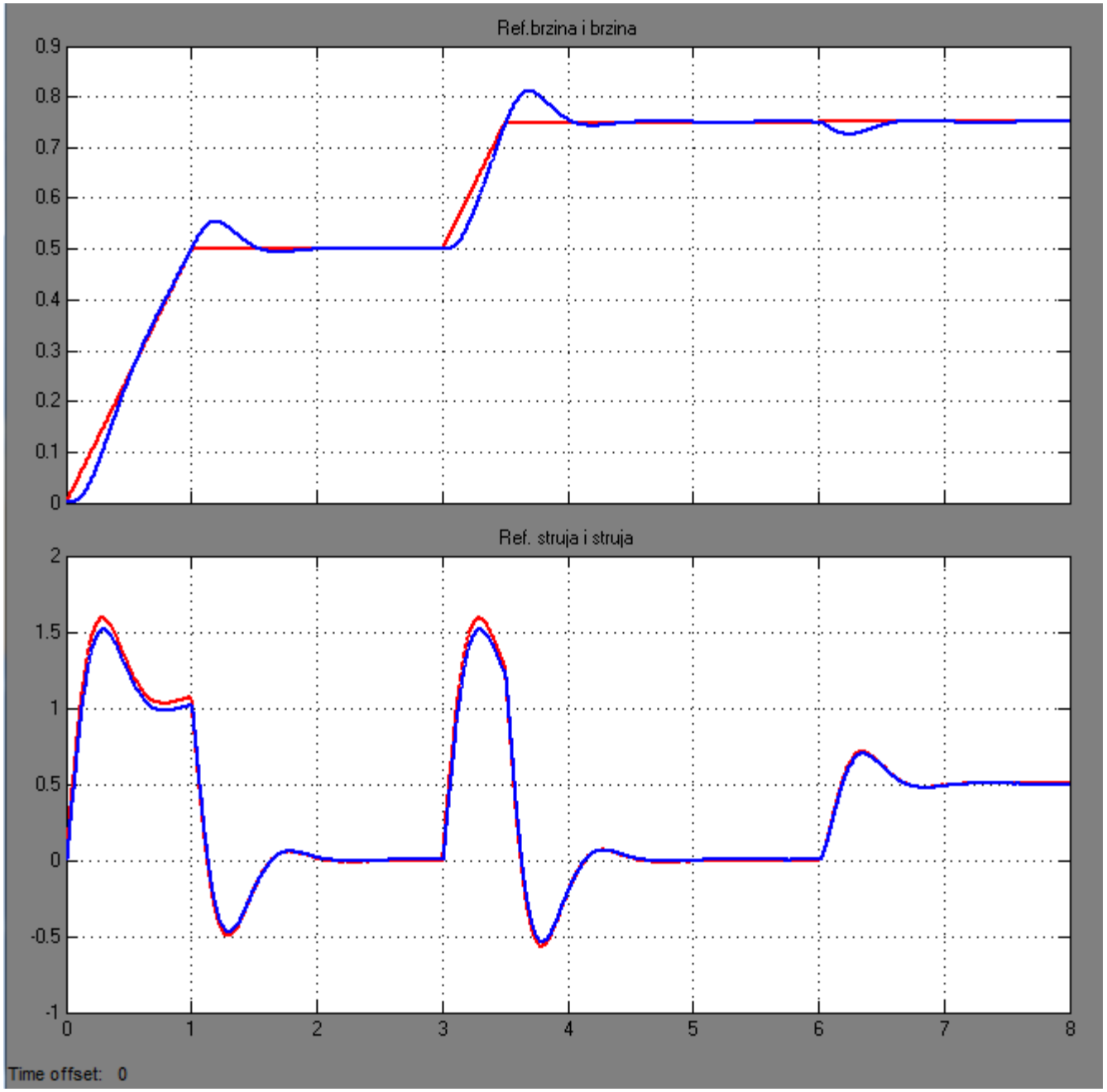
```
% reg. struje
Ti = Ta;
Ki = Ta/(2*Kt*Kpi*(1/Ra)*Te);
% reg. brzine
Tw = 4*Te2;
Kw = (Tm*Kpi)/(2*Te2*Kpw*PsiFn);

Vwref1 = 0.5;  % * Kpw;
Vwref2 = 0.25; % * Kpw;
LIM_UC = 1;
LIM_IA = 2 * Kpi;
LIM_SS = 0.5;
```

Početna zadata brzina je 0,5 ω_{nom}.

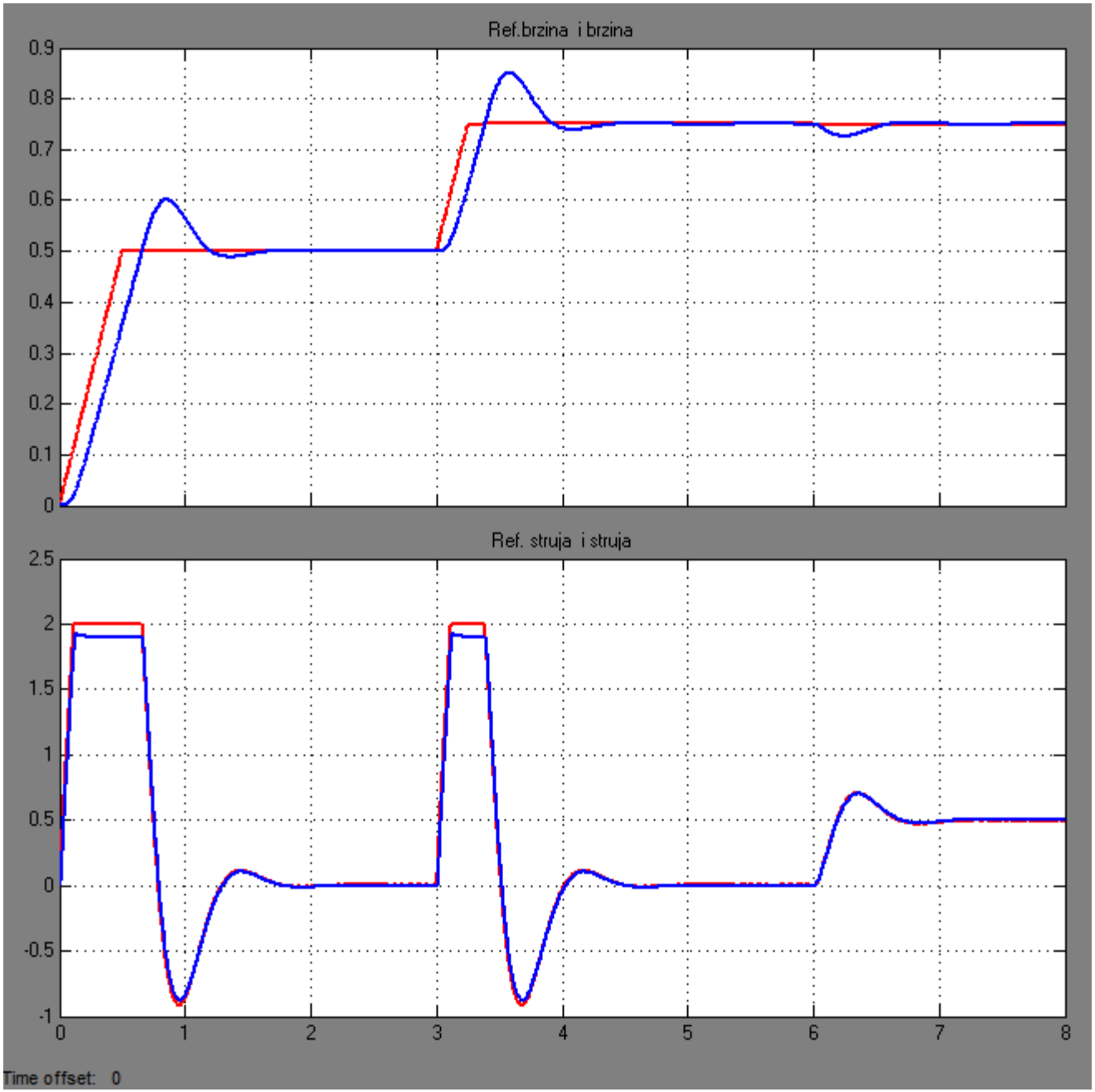
U trenutku t=3s zadaje se brzina 0,75 ω_{nom}.

Opterećenje pogona polovinom nominalnog momenta je u $t = 6s$

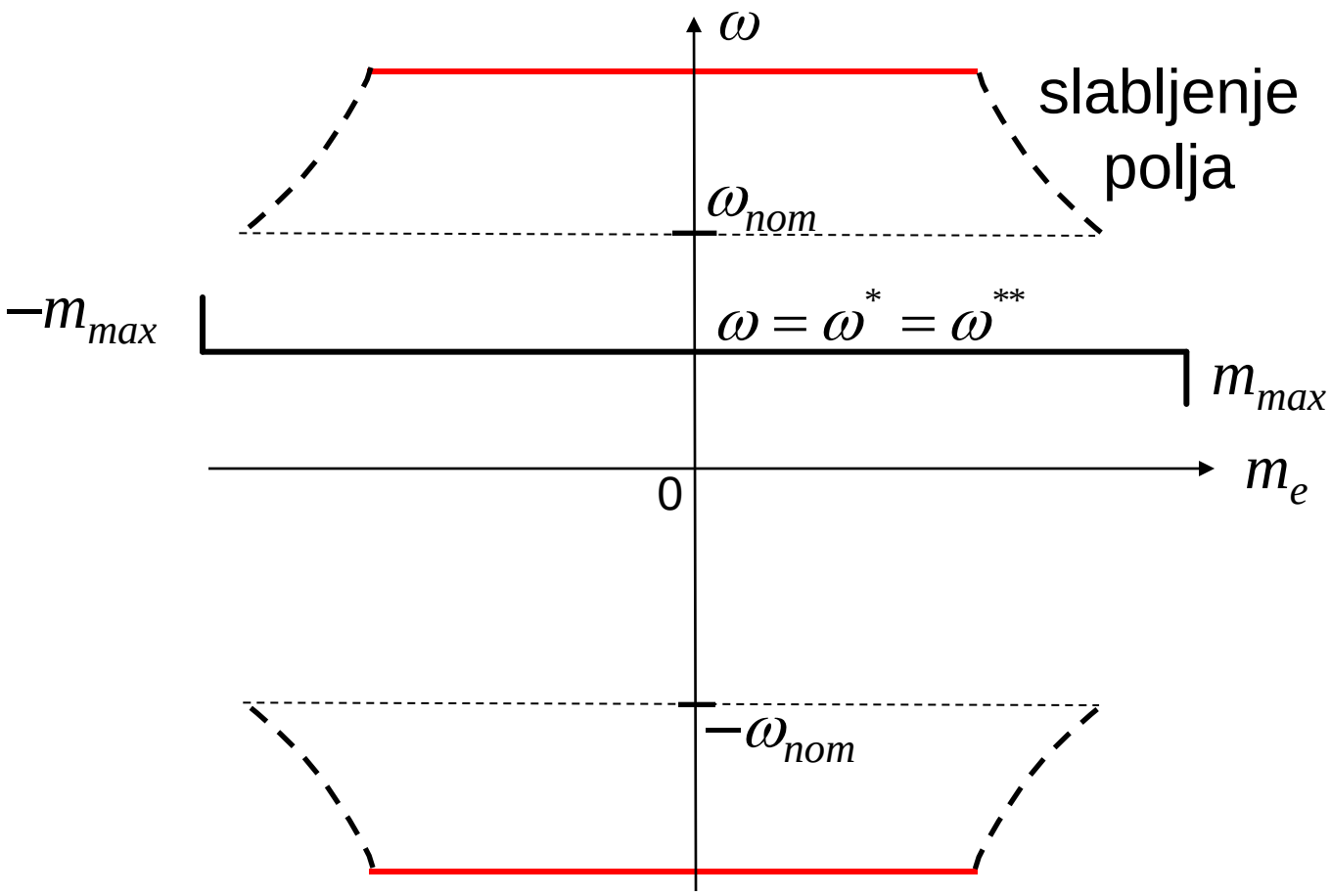


Uticaj limita momenta na odziv regulatora brzine

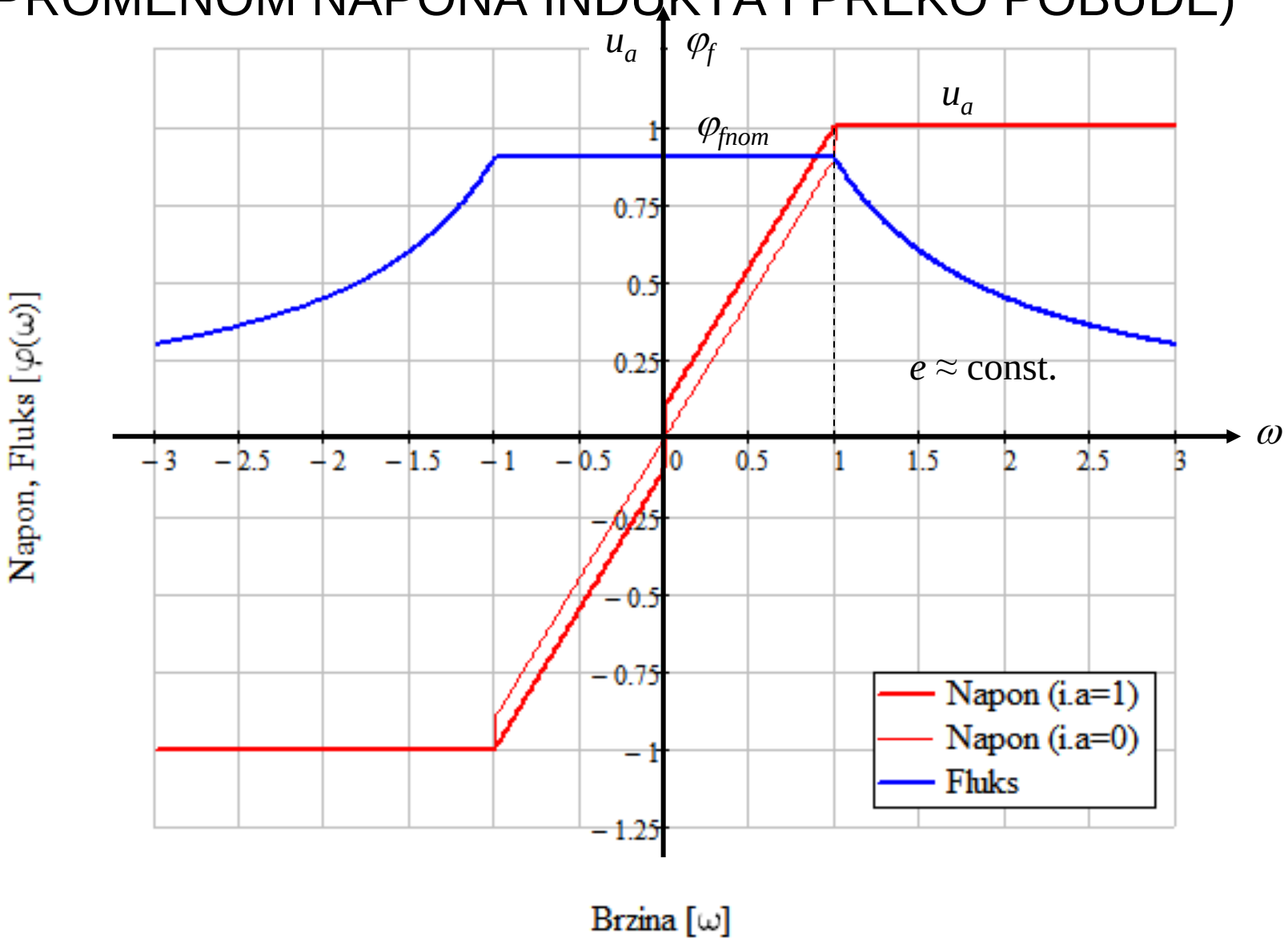
Povećano je željeno ubrzanje u bloku soft starta. Zbog ograničenja struje, ne dostiže se zadata brzina u toku soft-starta.



Statička karakteristika regulisanog pogona



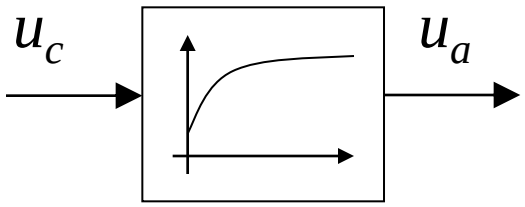
KOMBINOVANO UPRAVLJANJE
(PROMENOM NAPONA INDUKTA I PREKO POBUDE)



Aktuatori

- Tiristorski ispravljači
  (mosne sprege, mrežna komutacija)
- Više-kvadrantni rad
- Generator jednosmerne struje (Vard Leonard)
- Čoperi

Uprošćeni blok dijagram aktuatora



Uprošćena prenosna funkcija aktuatora

$$\frac{U_a}{U_c}(p) = \frac{K_a}{1 + p \cdot T_{ak}}$$

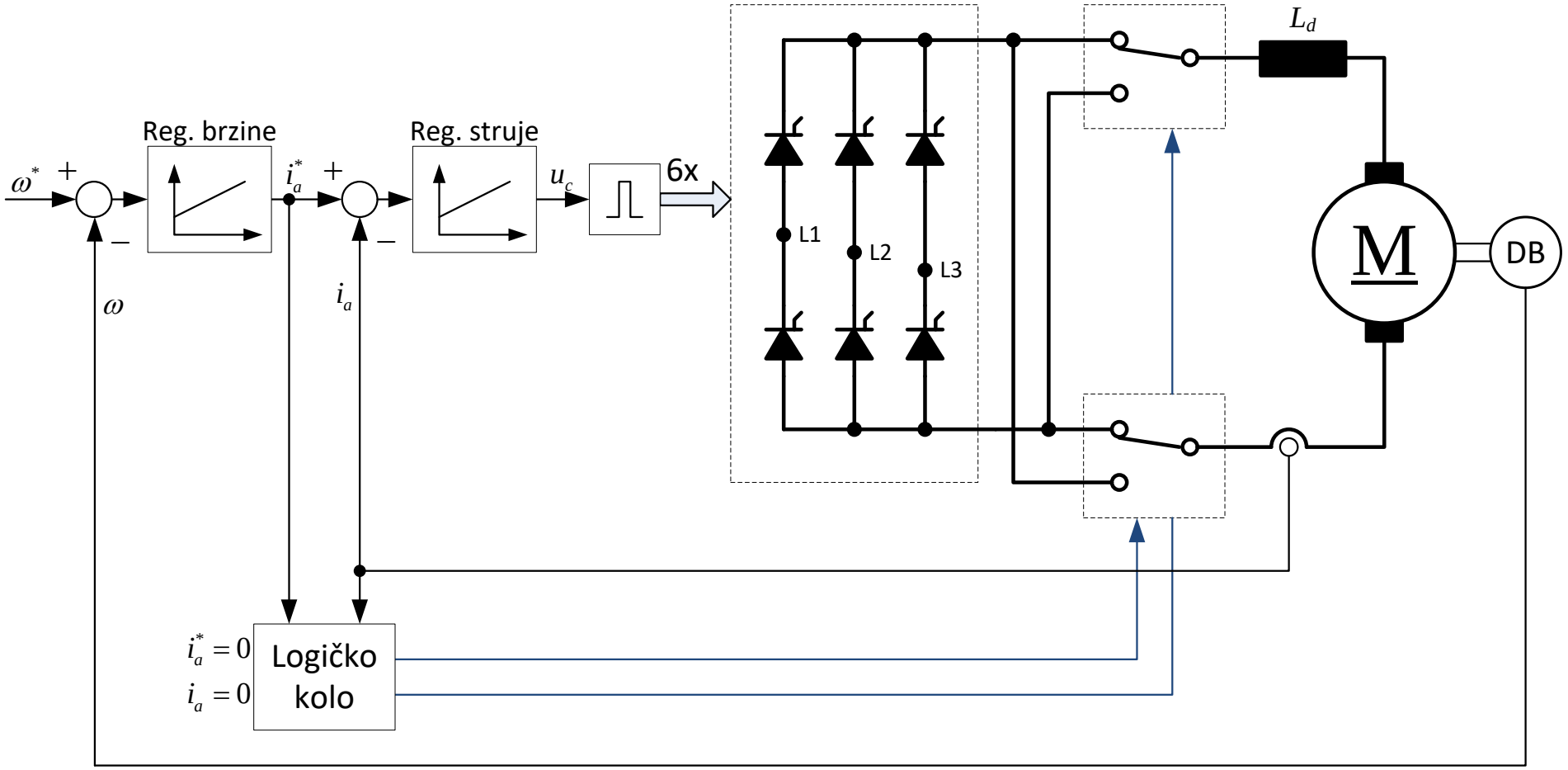
$T_{ak} = ?$ zavisi od vrste aktuatora

Četvoro- kvadratni rad sa preklopnikom

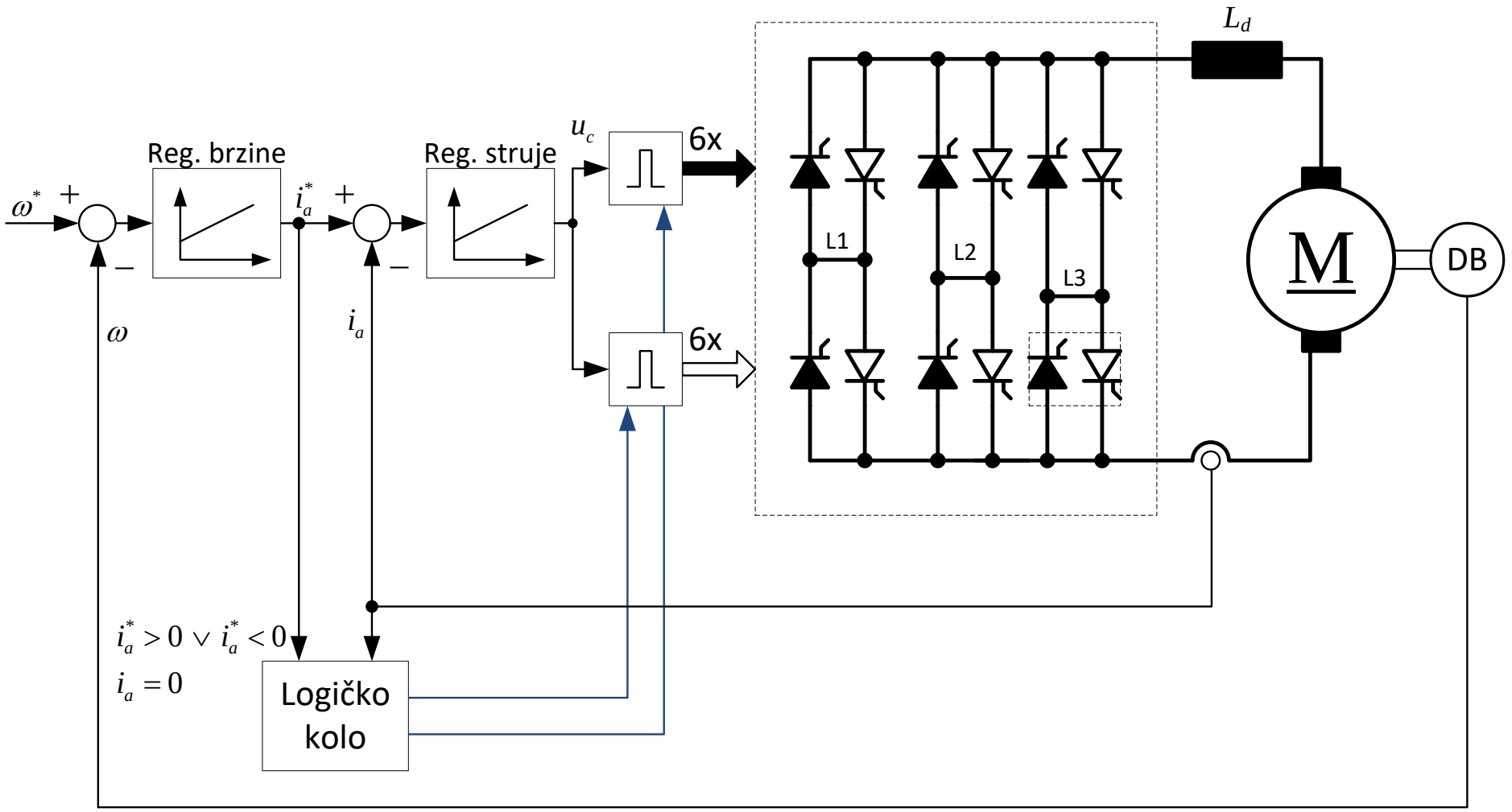
Regulacija brzine za male brzine reversa!

Logičko kolo: - promena stanja prekidača samo kada je $i_a = 0$

- položaj prekidača u funkciji od znaka i_a*

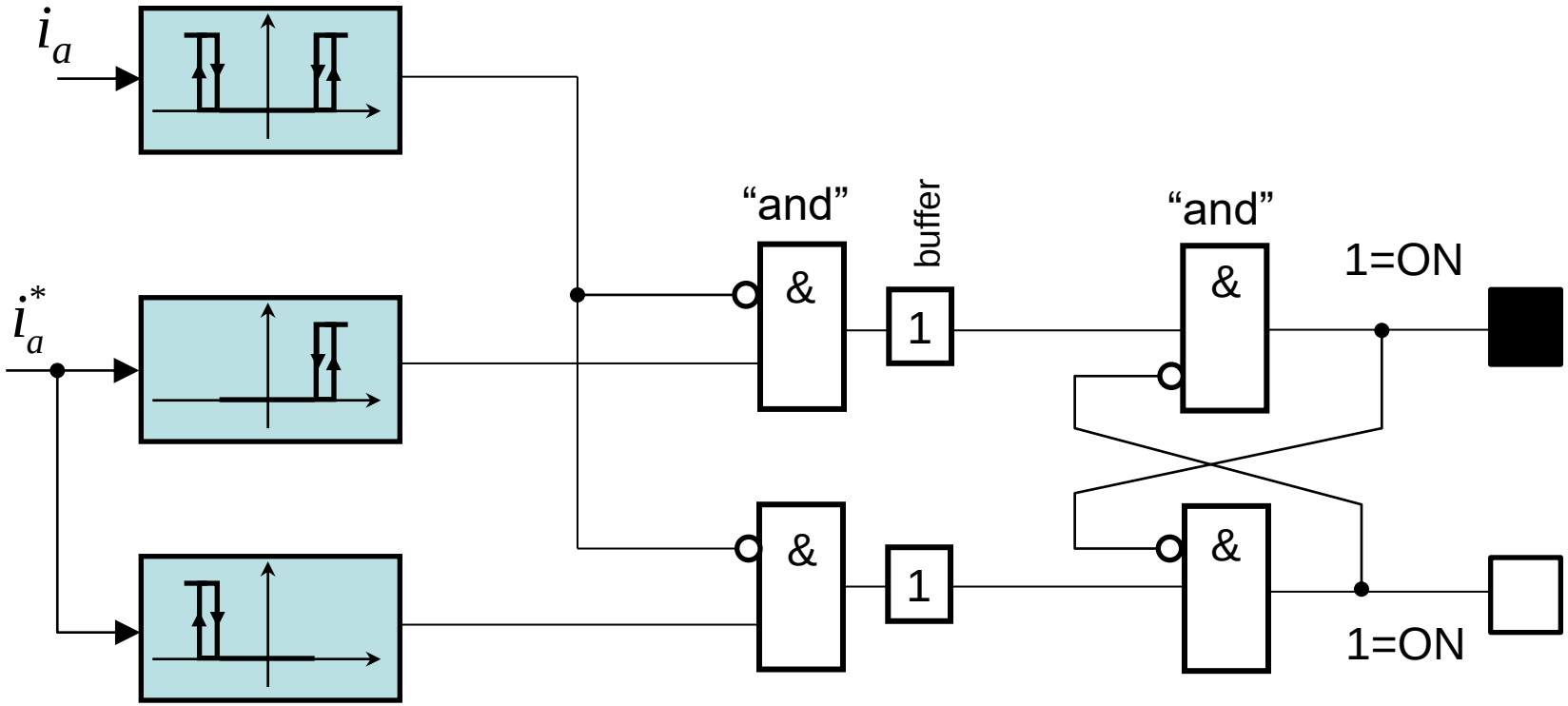


Četvoro-kvadratni rad sa dva anti-paralelna mosta (razdeljeno upravljanje)



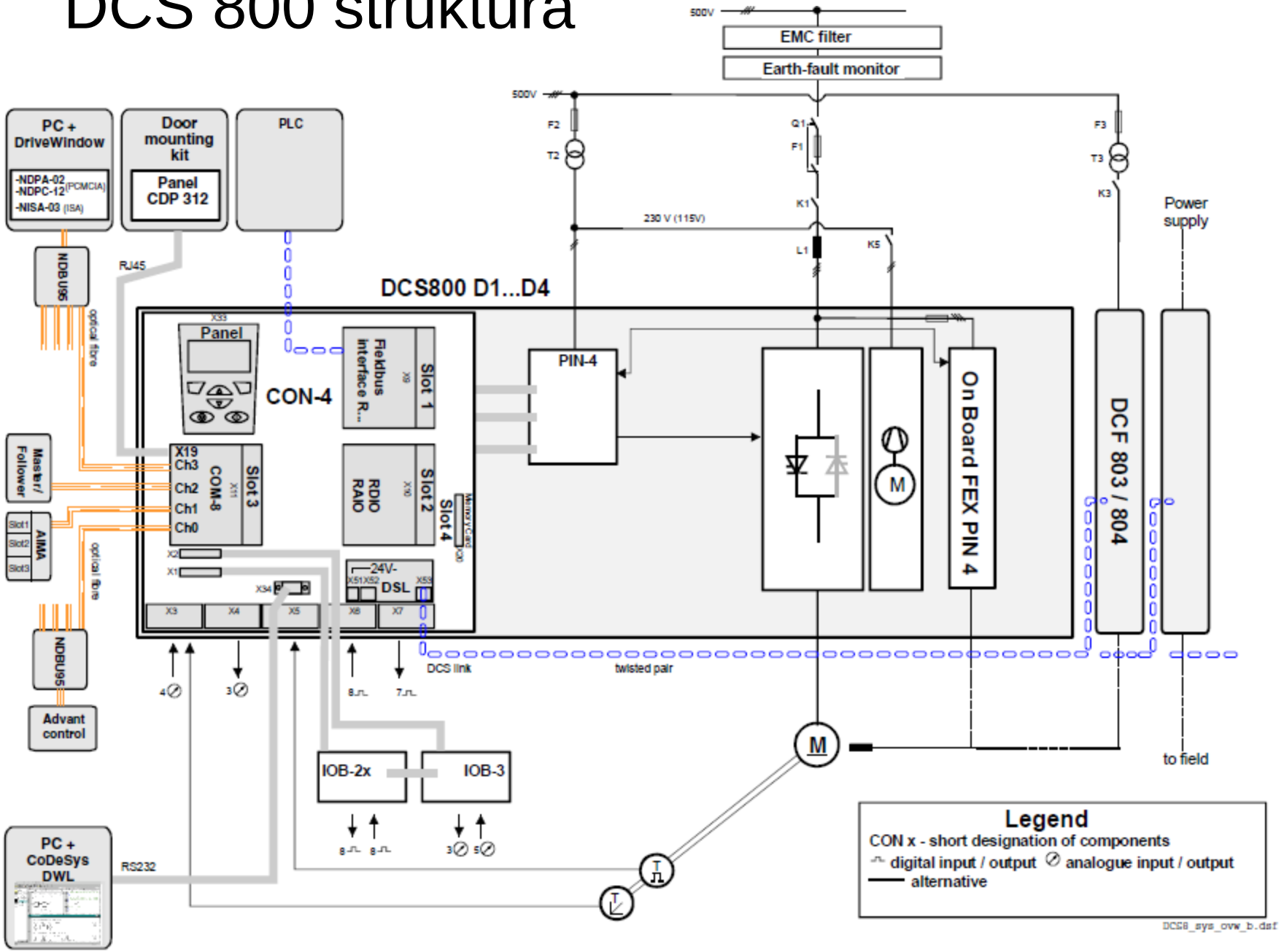
Logičko kolo

Logičko kolo deluje na blokiranje impulsa mosta koji ne treba da vodi.



Pogoni sa razdeljenim upravljanjem mogu da ostvare bržu promenu znaka struje nego pogoni sa preklopnikom.

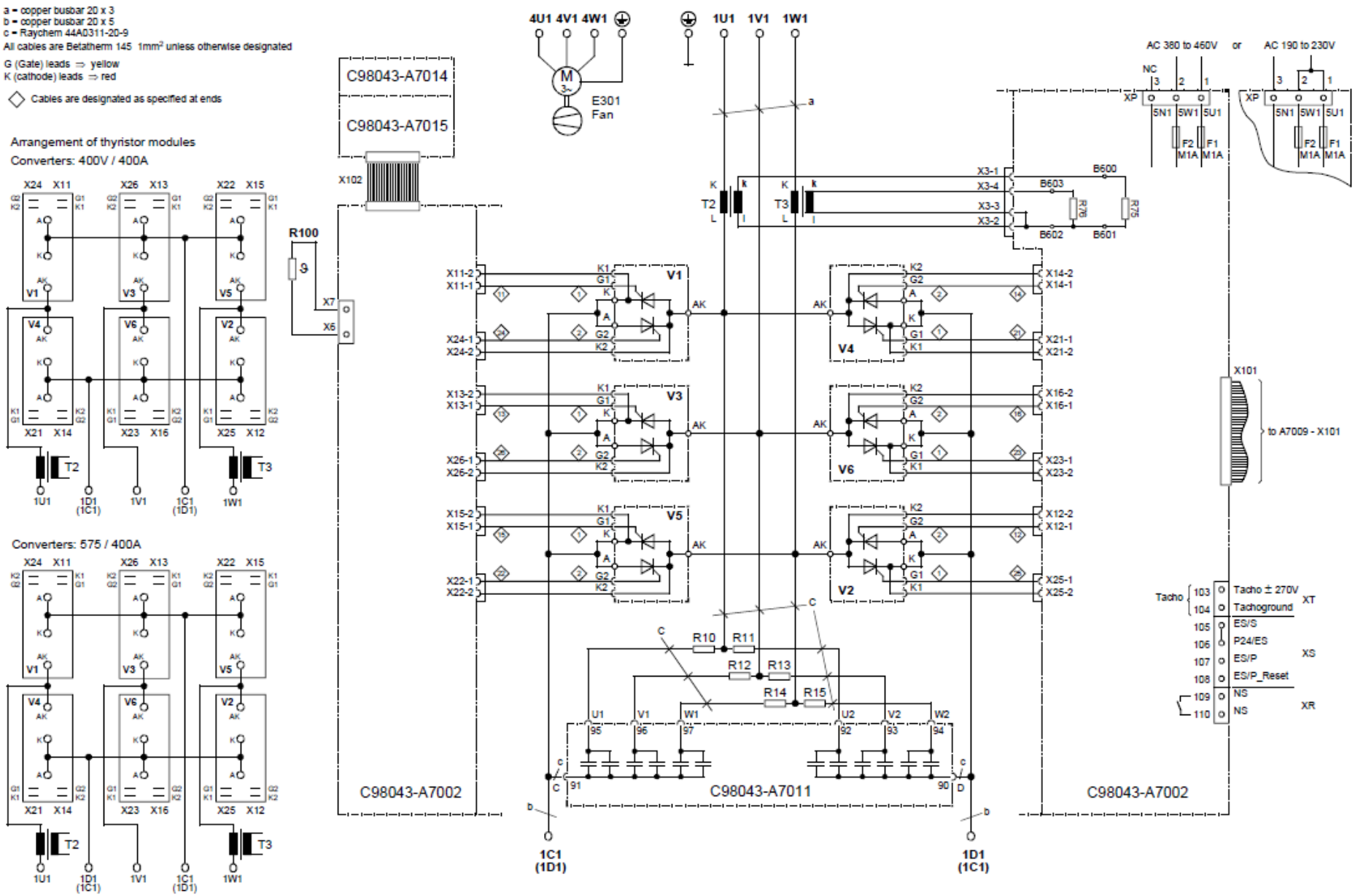
DCS 800 struktura



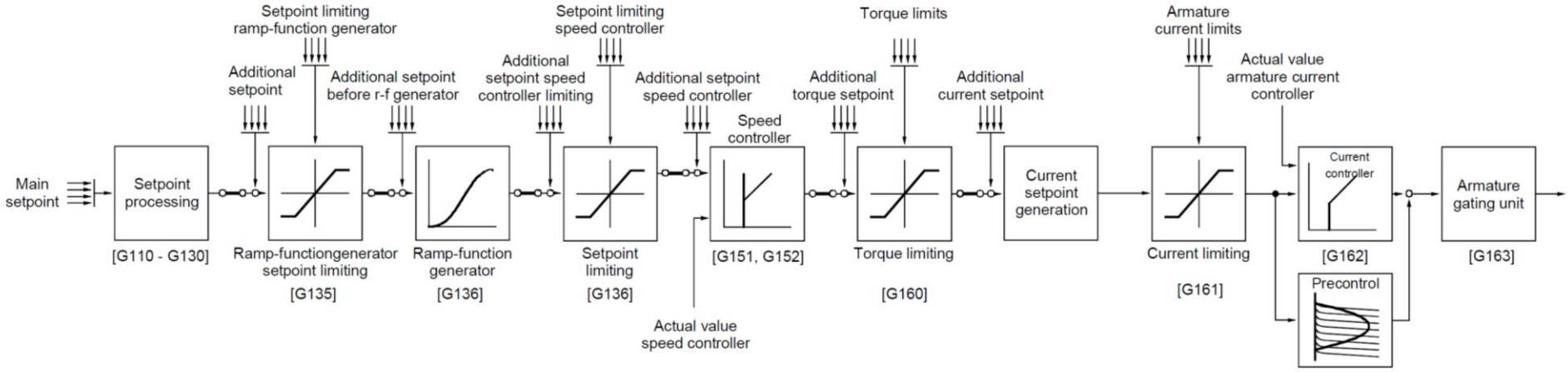
Armature circuit converter DCS800 D1...D4

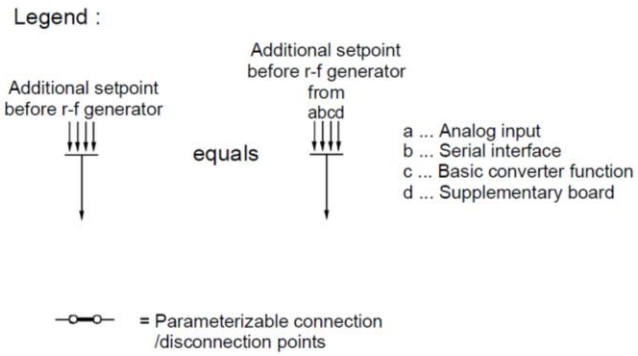
400 V and 500 V units with Onboard field exciter
600 V units are always without Onboard field exciter

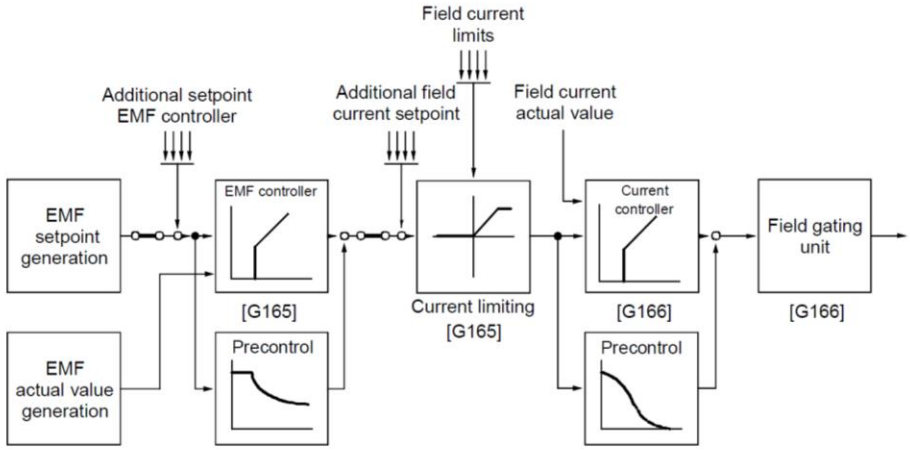
SIMOREG struktura (energetski deo)



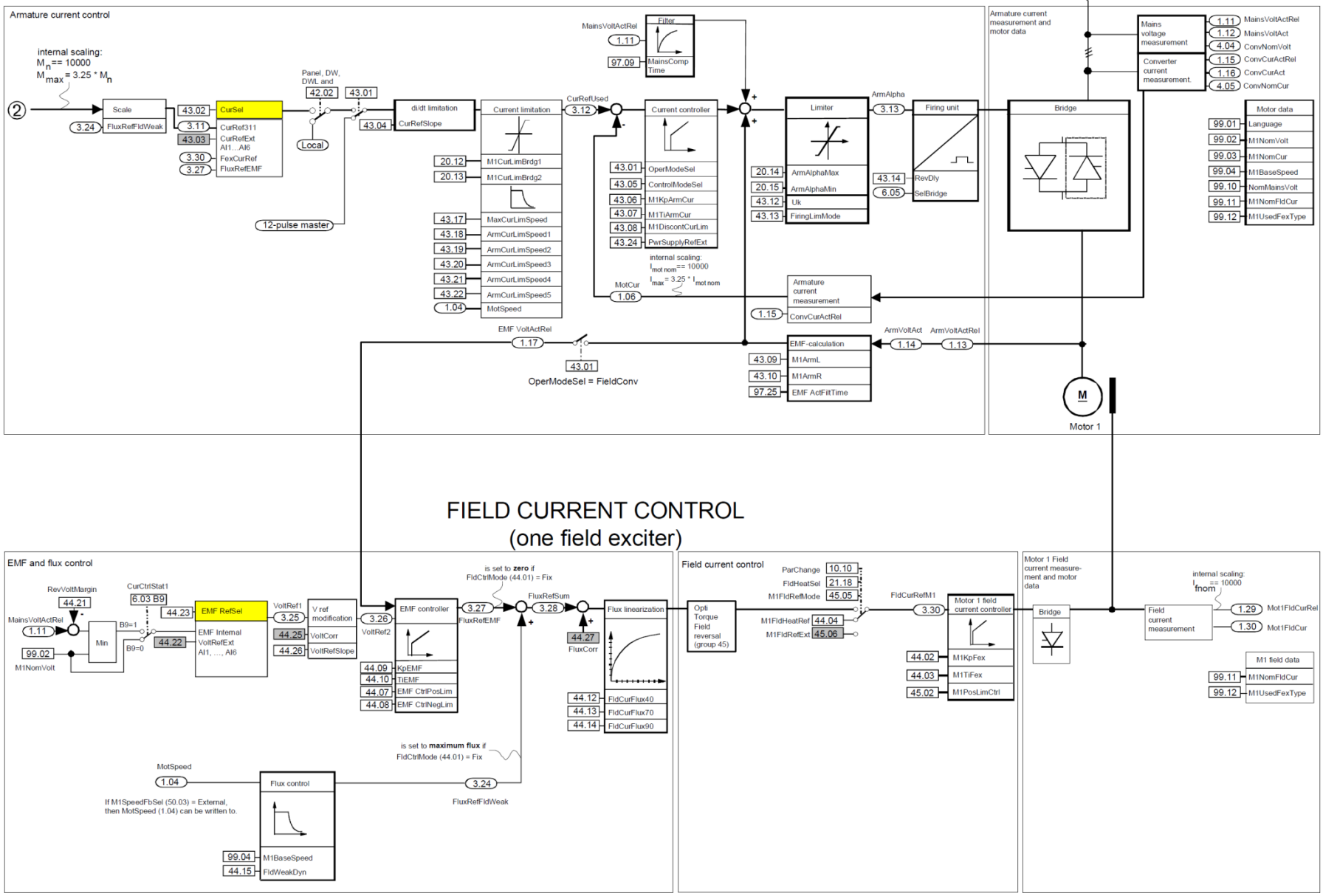
SIMOREG blok dijagram





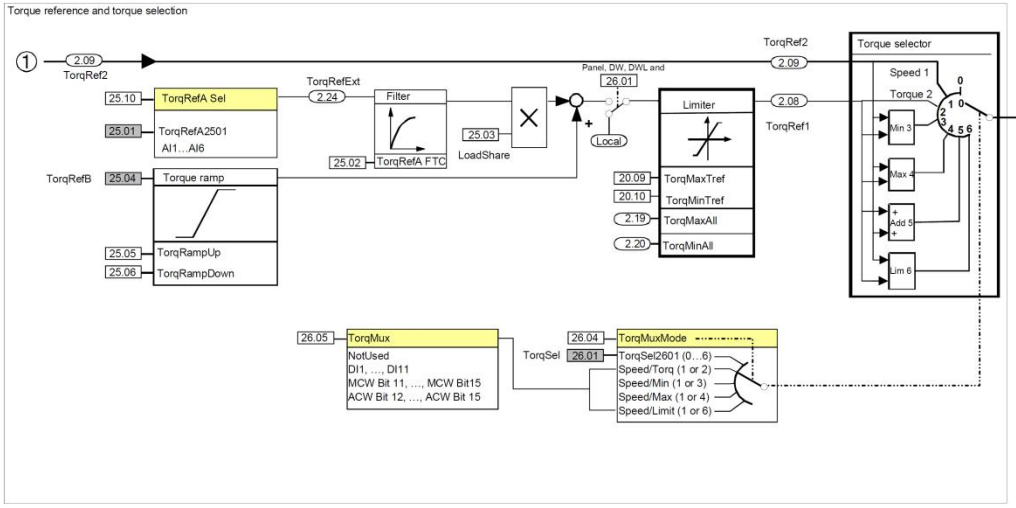


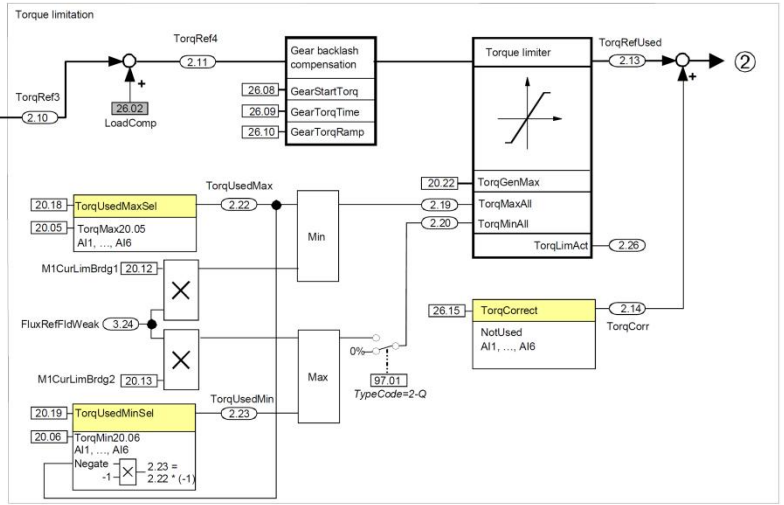
DCS 800 Blok dijagram – regulacija struje

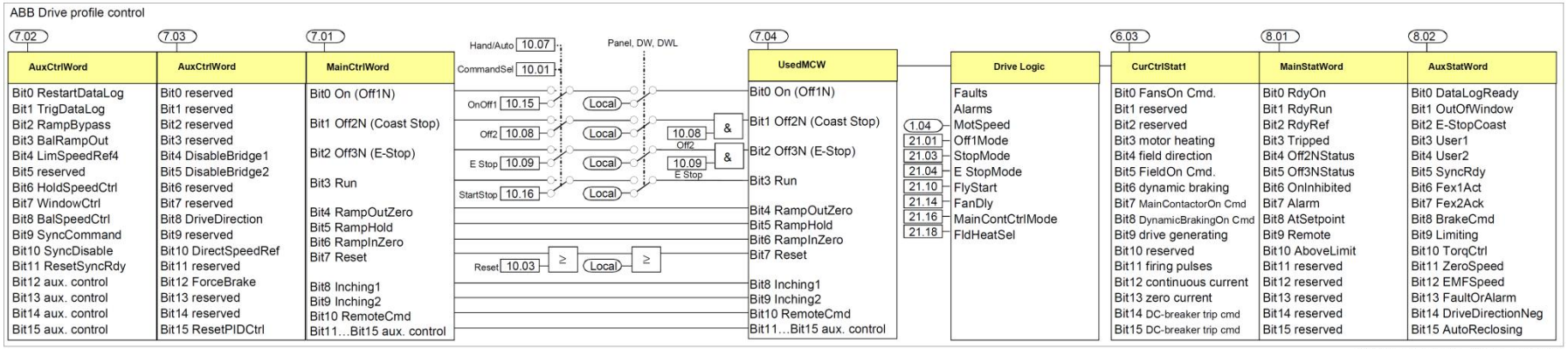


DCS800_FW_structure_diagram_rev_e.dsf

DCS 800 Blok dijagram – upravljanje momentom

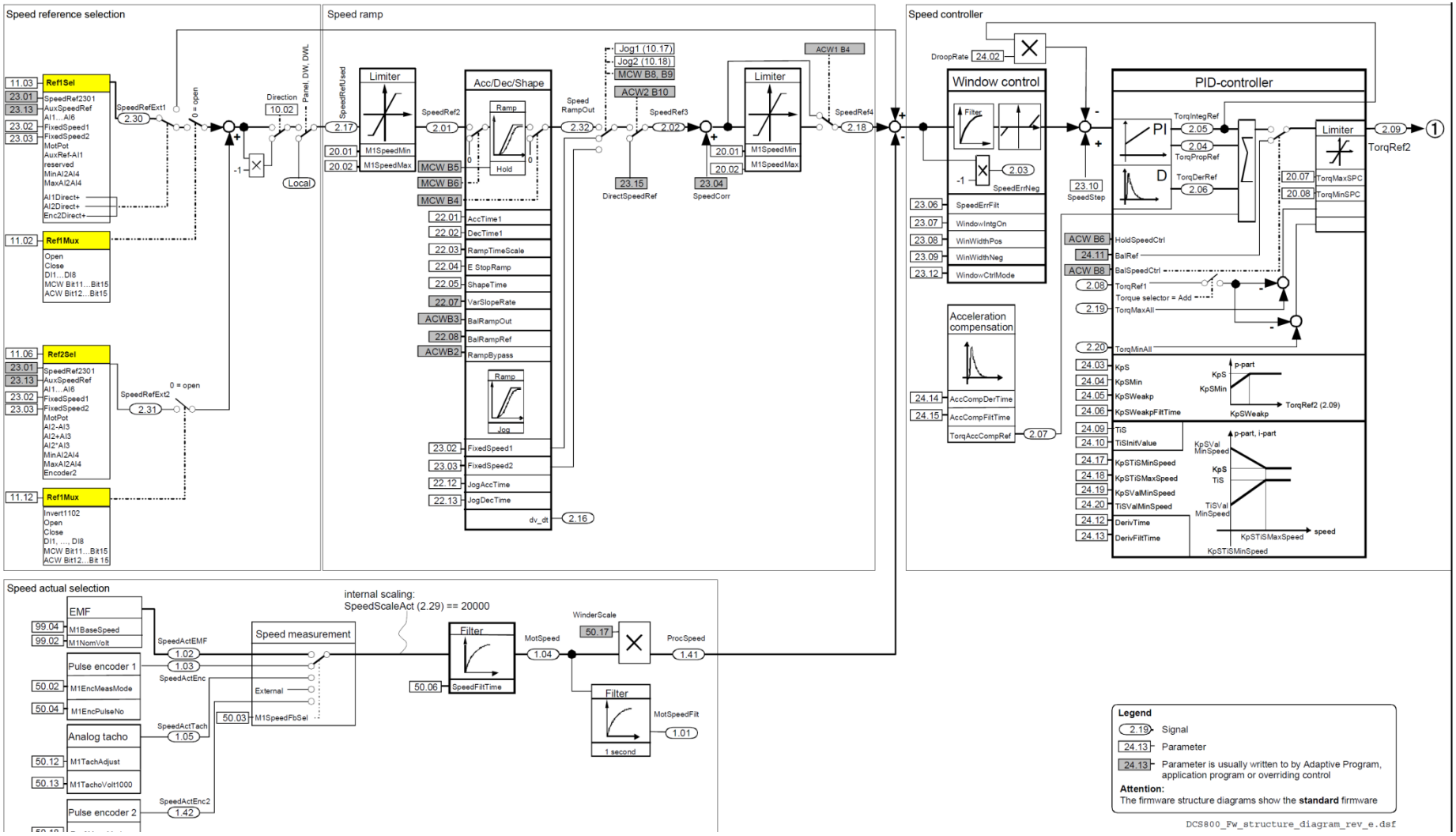




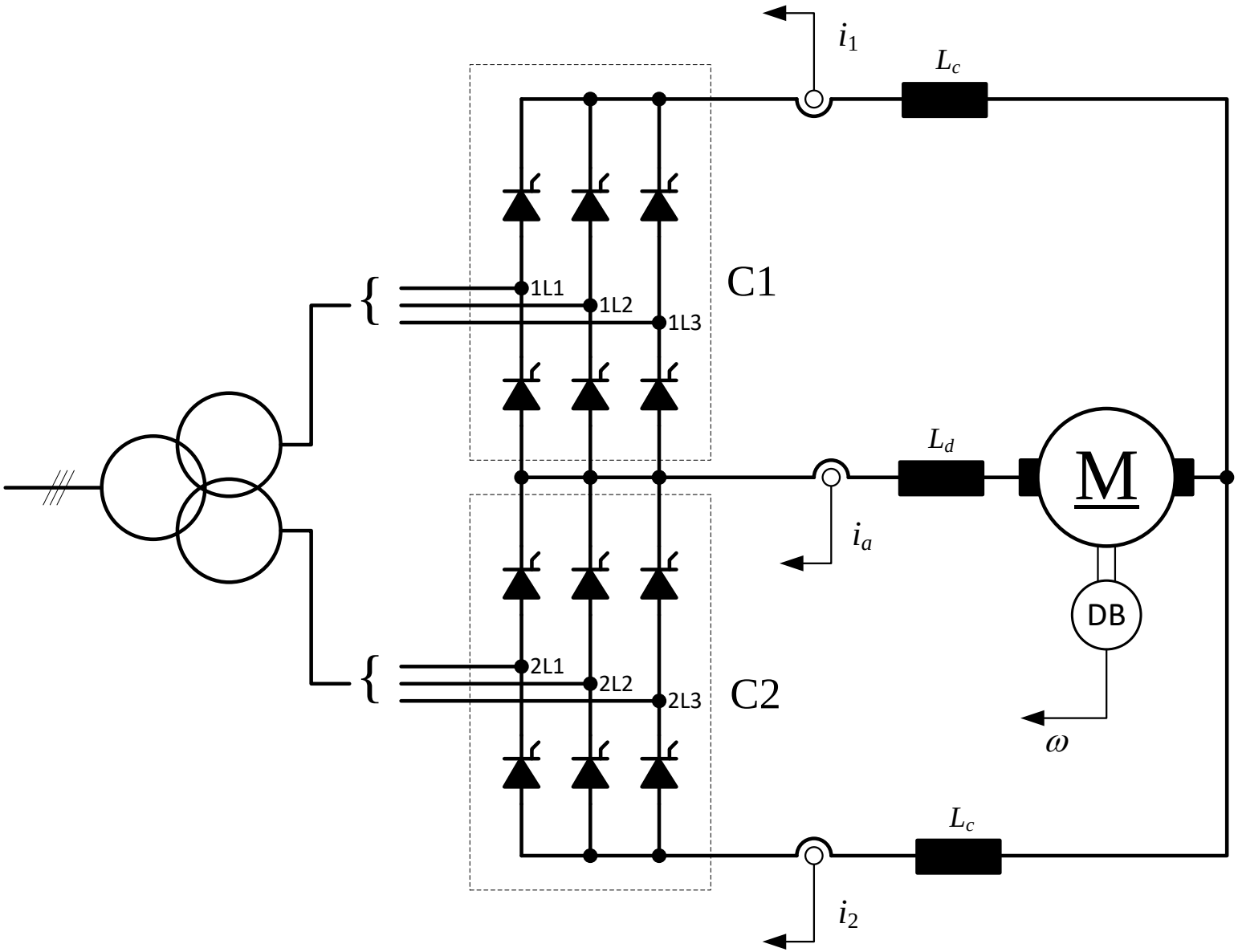


DCS800_Fw_structure_diagram_rev_e.dsf

DCS 800 Blok dijagram – regulacija brzine

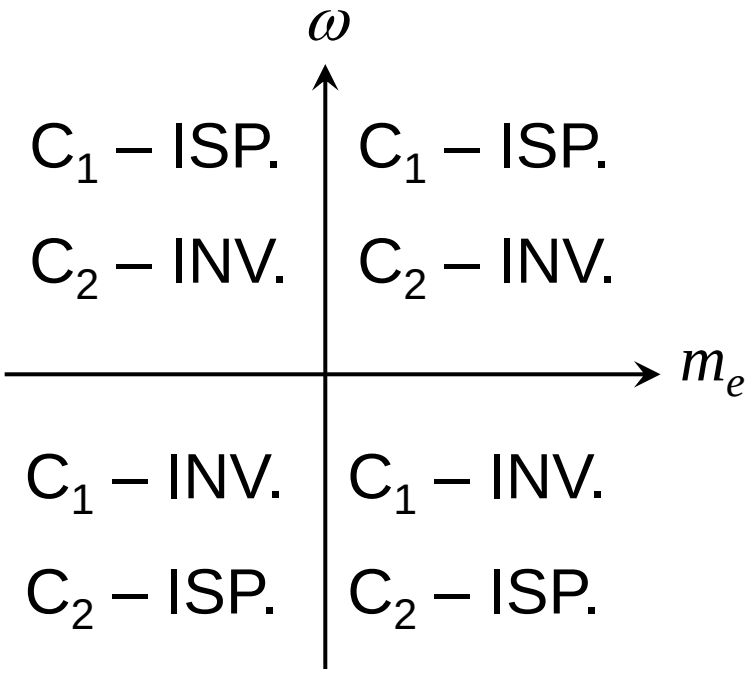


Četvoro-kvadrantni rad sa kružnom strujom



Četvoro-kvadrantni rad sa kružnom strujom (saglasno upravljanje)

Koristi se za ostvarivanje brzih reversa (promene znaka) momenta.

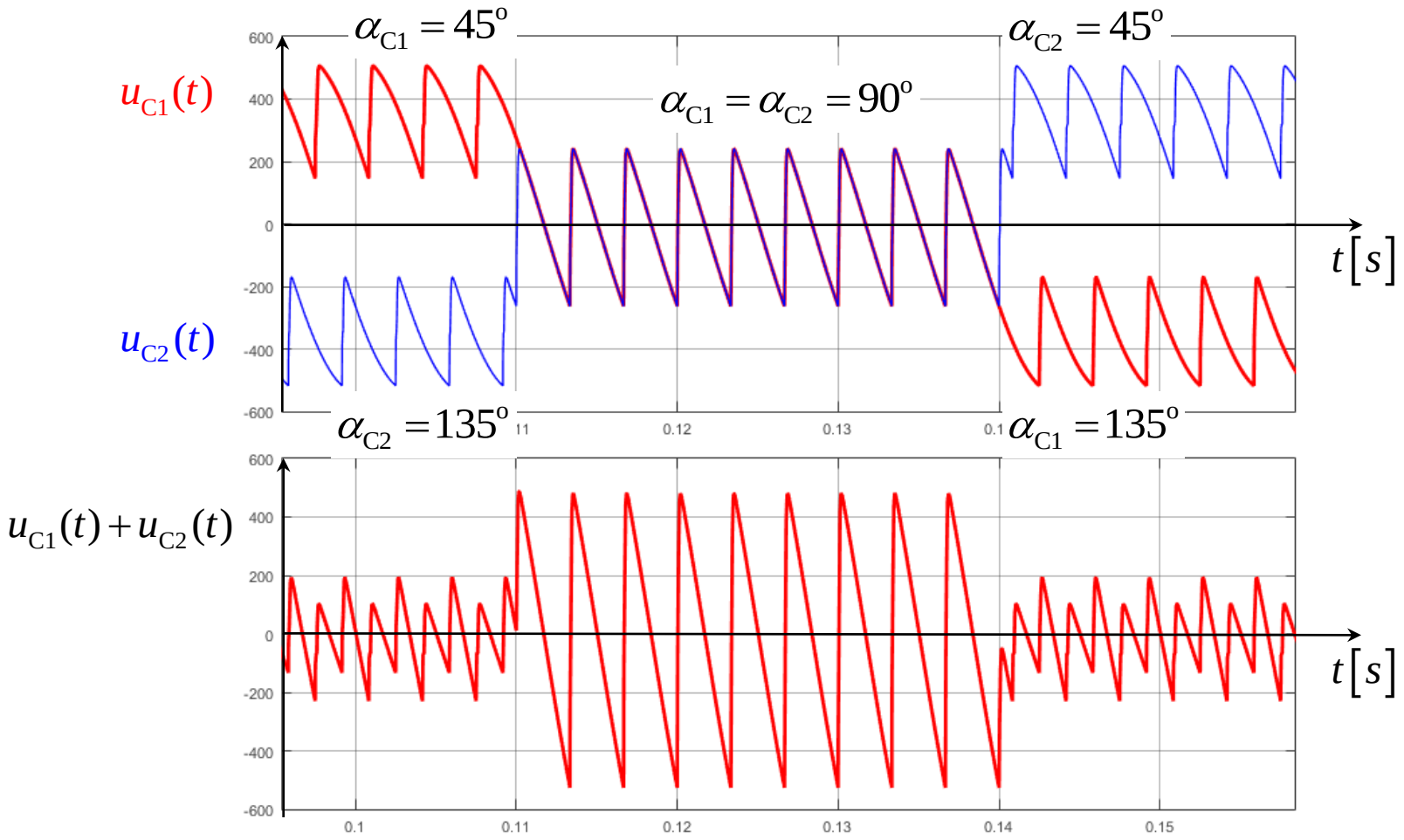


$$\alpha_1 + \alpha_2 = 180^{\circ}$$

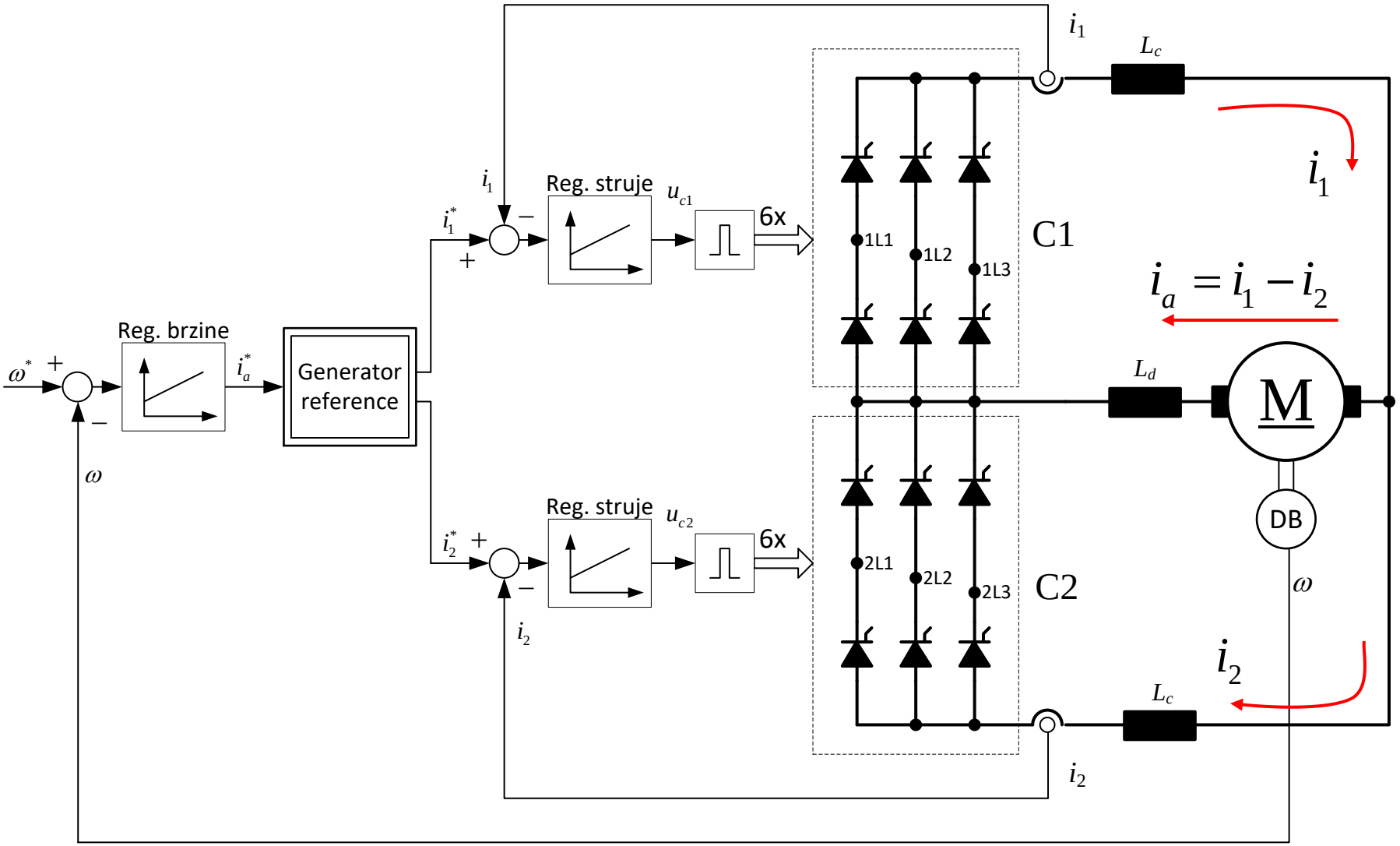
Dijagram trenutnih vrednosti napona

$|U_{C1}(\alpha_1)| = |U_{C2}(\alpha_2)|$ $\quad u_{C1}(t) \neq u_{C2}(t)$ ⟵ kružna struja

samo za $\alpha_{C1} = \alpha_{C2} = 90° \Rightarrow u_{C1}(t) = u_{C2}(t)$



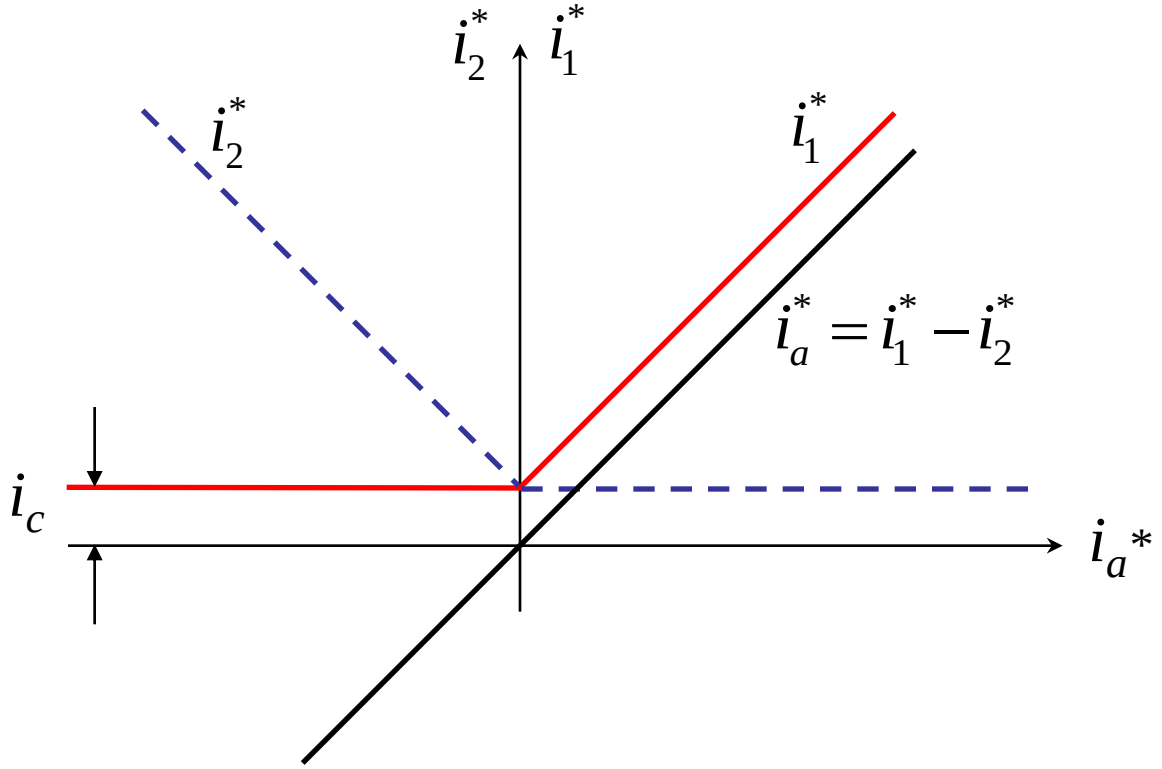
Kontrola kružne struje



Generator referentnih struja i_1* i i_2*

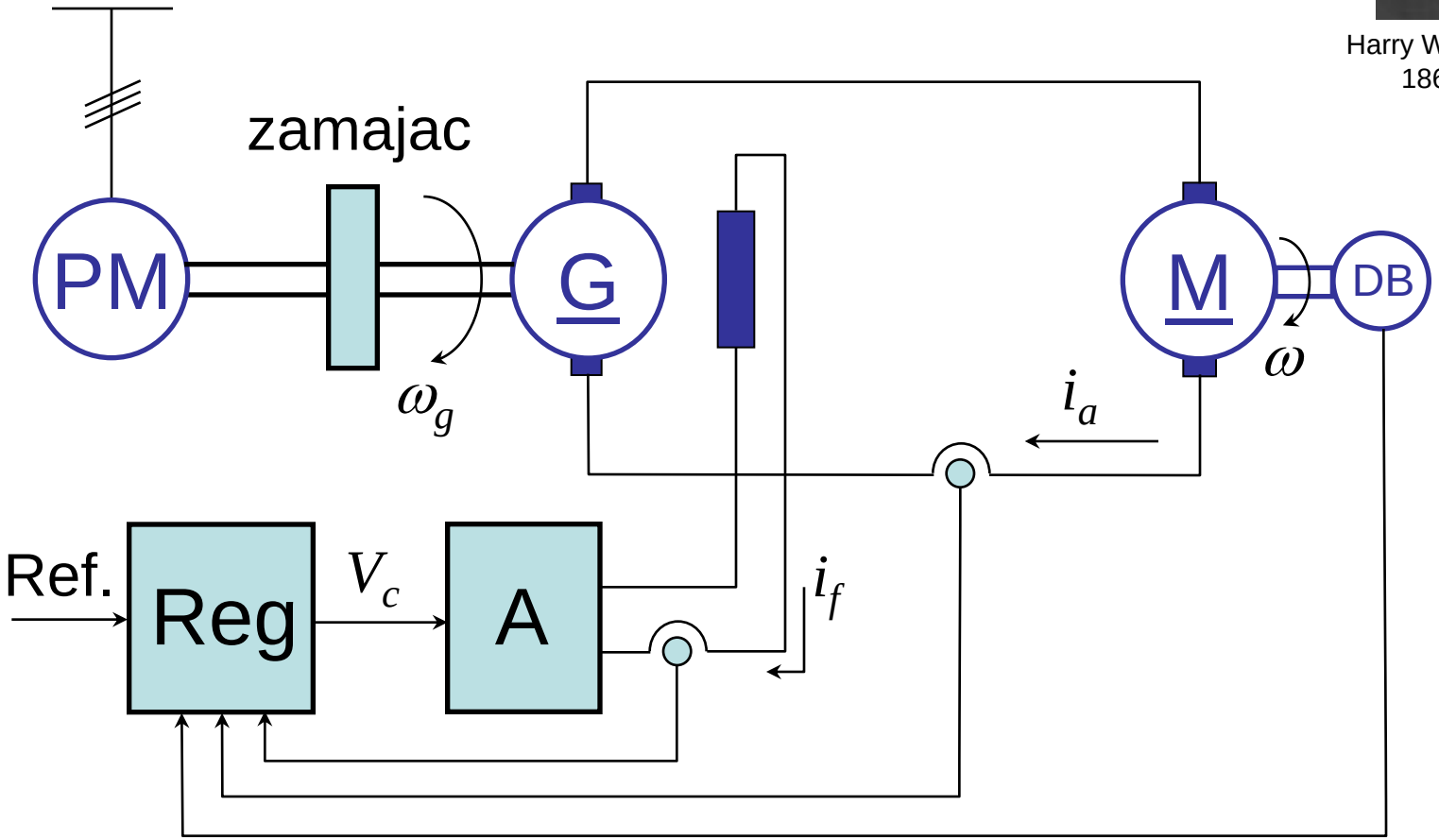
i_c – cirkulaciona (kružna) struja

Po vrednosti, kružna struja bi trebalo da bude minimalna, ali da se tiristori odgovarajućeg mosta održavaju u provodnom stanju.

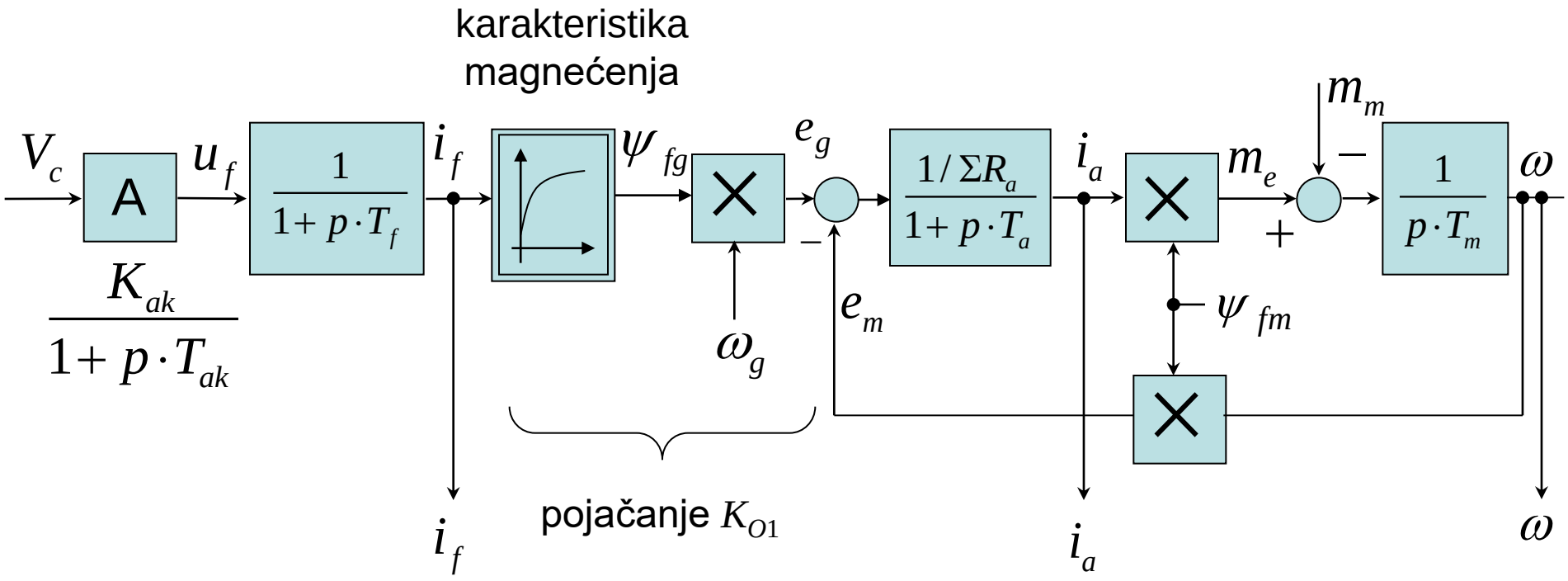


Vard Leonardova grupa

Harry Ward Leonard
1861-1915.

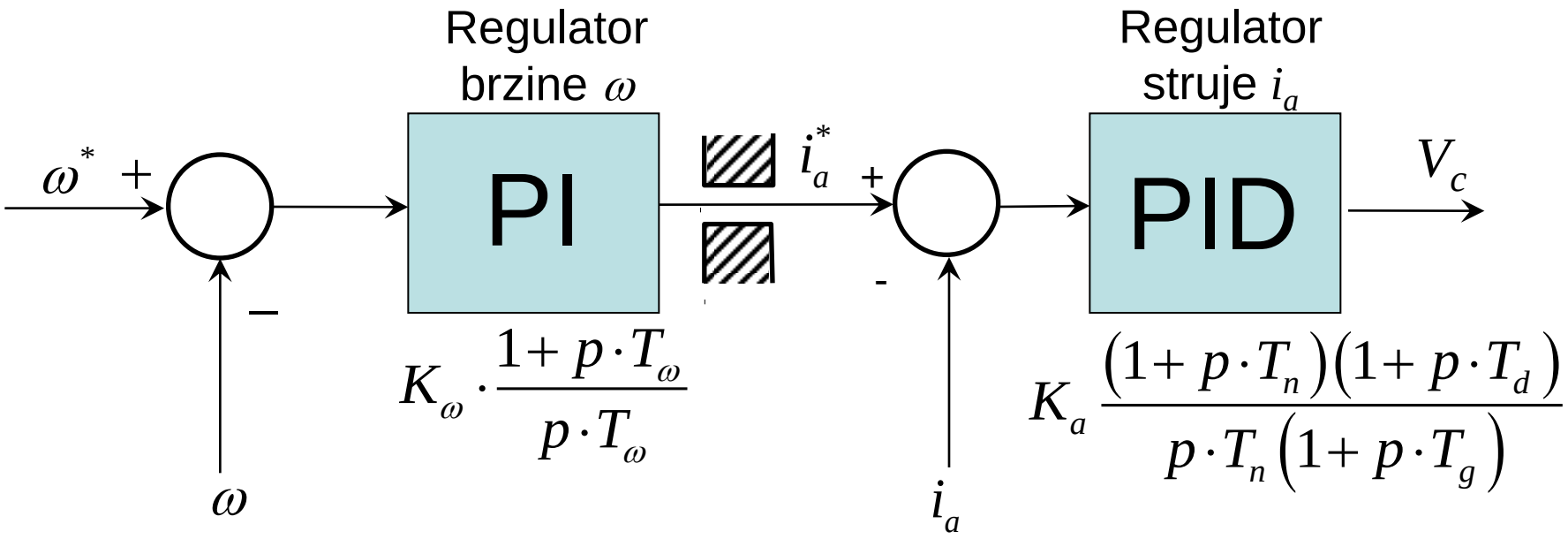


Vard Leonardova grupa (blok dijagram)



$$T_a = \frac{2\cdot L_a}{2\cdot R_a} \qquad T_f > T_a > T_{ak}$$

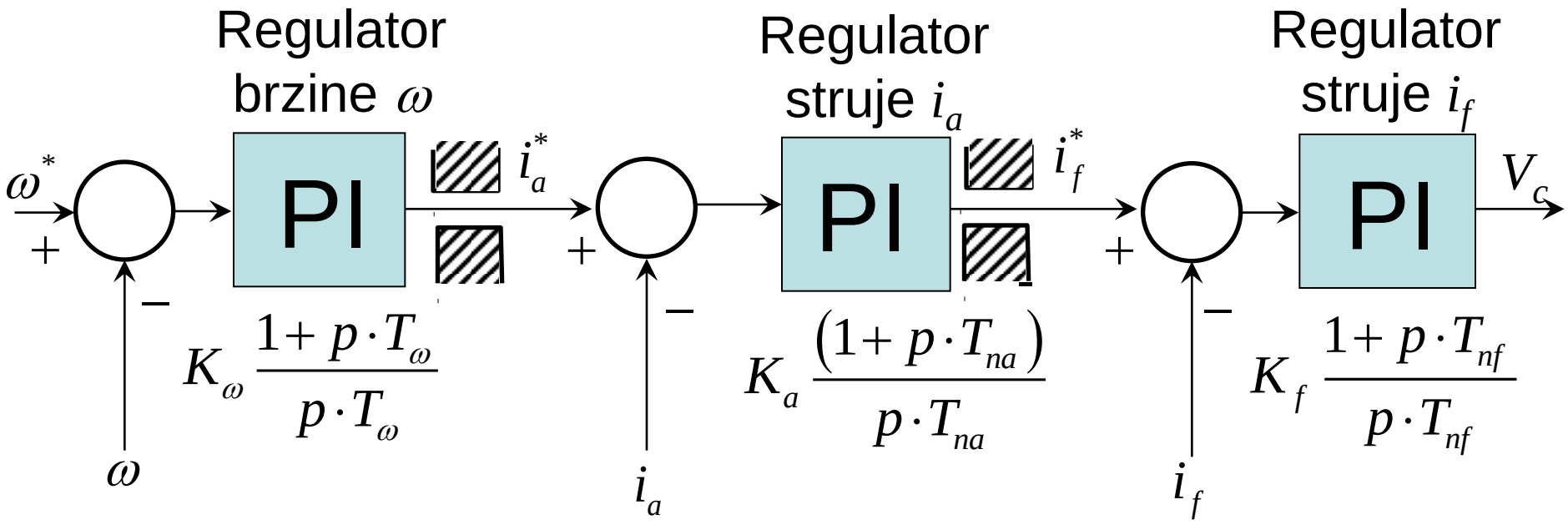
Vard Leonardova grupa
Regulator: PI + PID



REG i_a: $\left(T_n = T_f \quad T_d = T_a\right) \Rightarrow \left|F(j\omega)\right|$ drugog reda.

REG ω: $\Rightarrow \left|F(j\omega)\right|$ trećeg reda.

Vard Leonardova grupa regulator (PI + PI + PI)



REG i_f: $\left(T_{nf}=T_f\right)\Rightarrow\left|F(j\omega)\right|$ drugog reda.

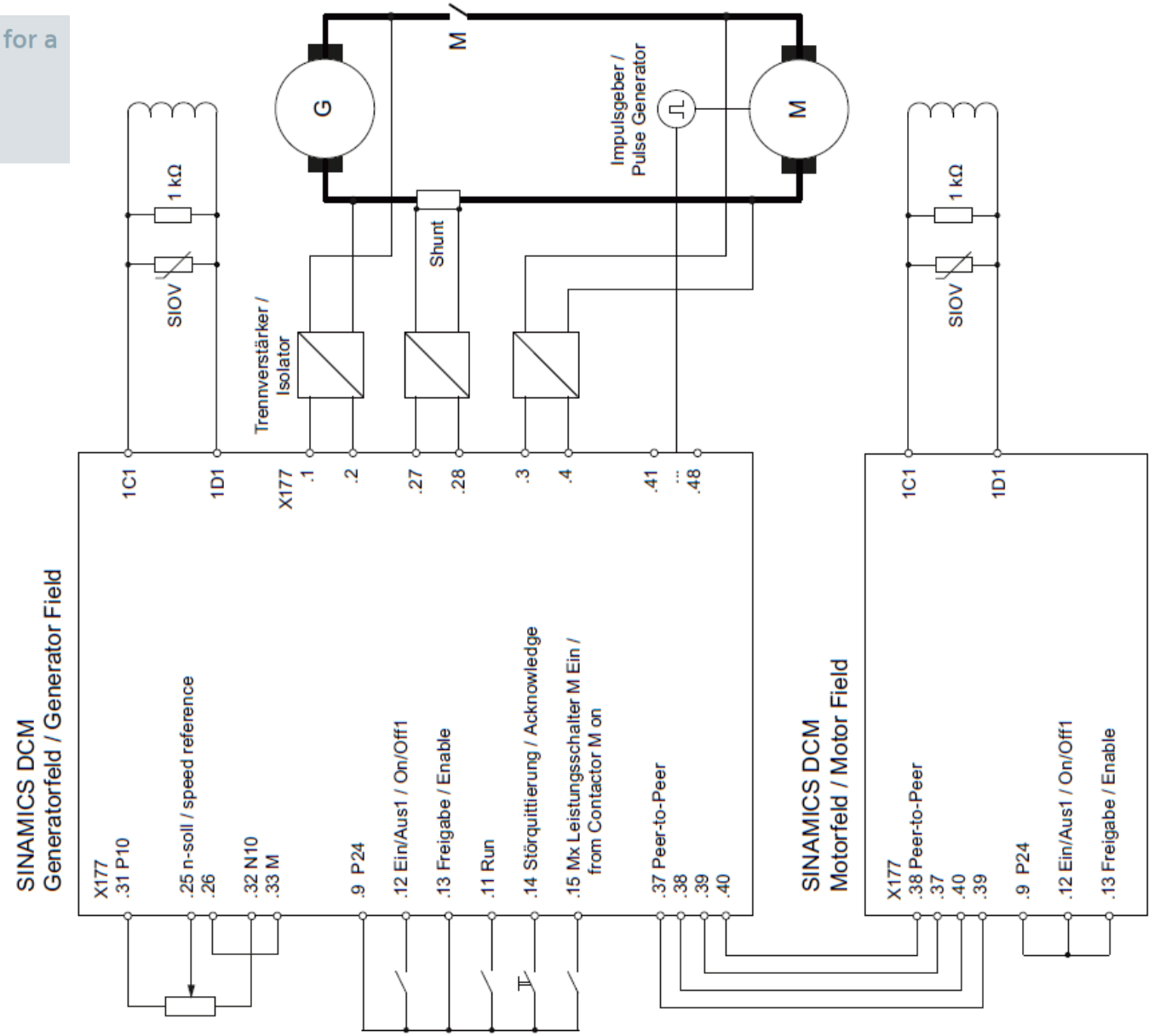
REG i_a: $\left(T_{na}=T_a\right)\Rightarrow\left|F(j\omega)\right|$ drugog reda.

REG ω: $\Rightarrow\left|F(j\omega)\right|$ trećeg reda.

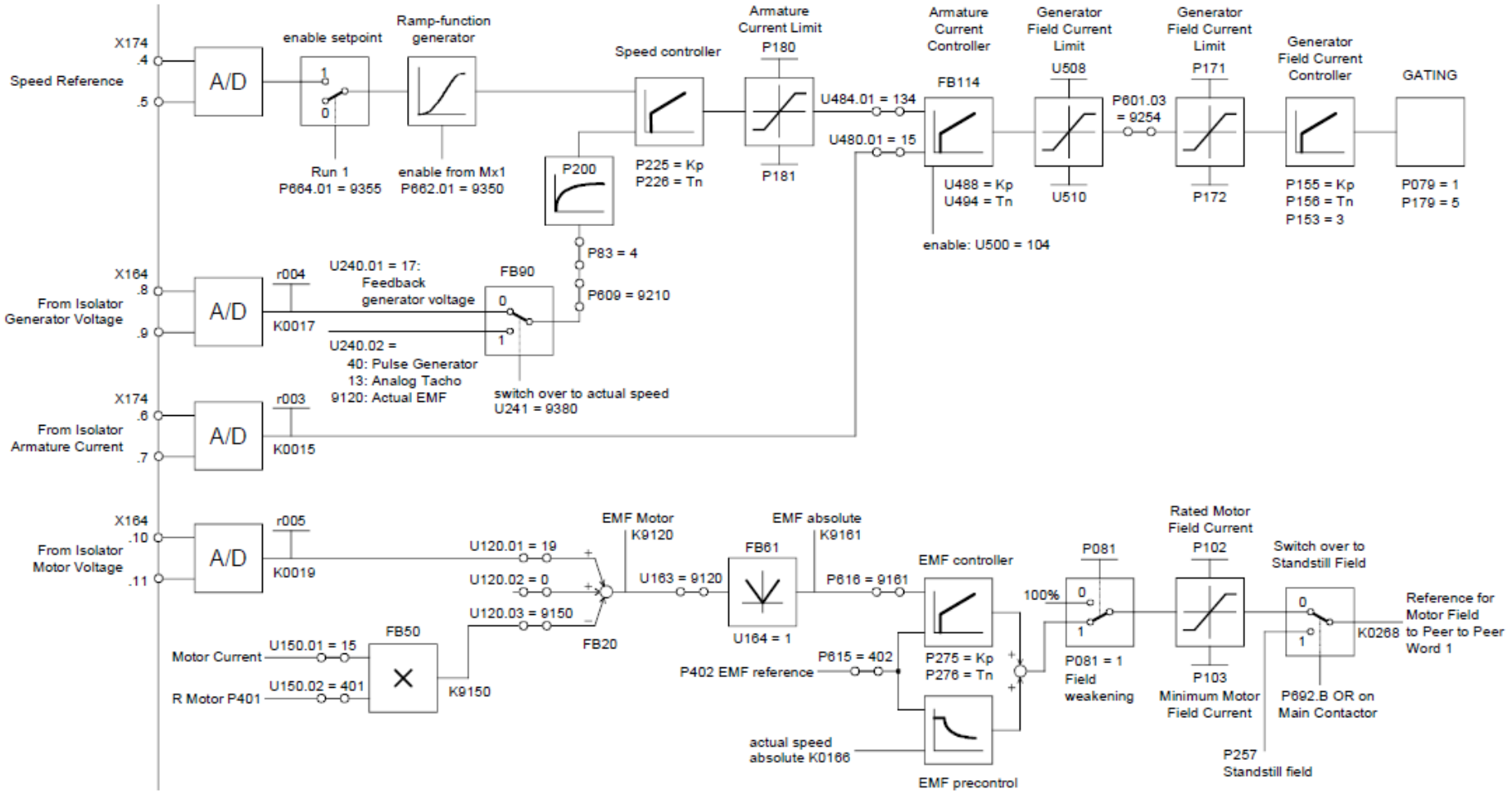
Vard Leonardova grupa

Closed-loop control application for a Ward-Leonard block

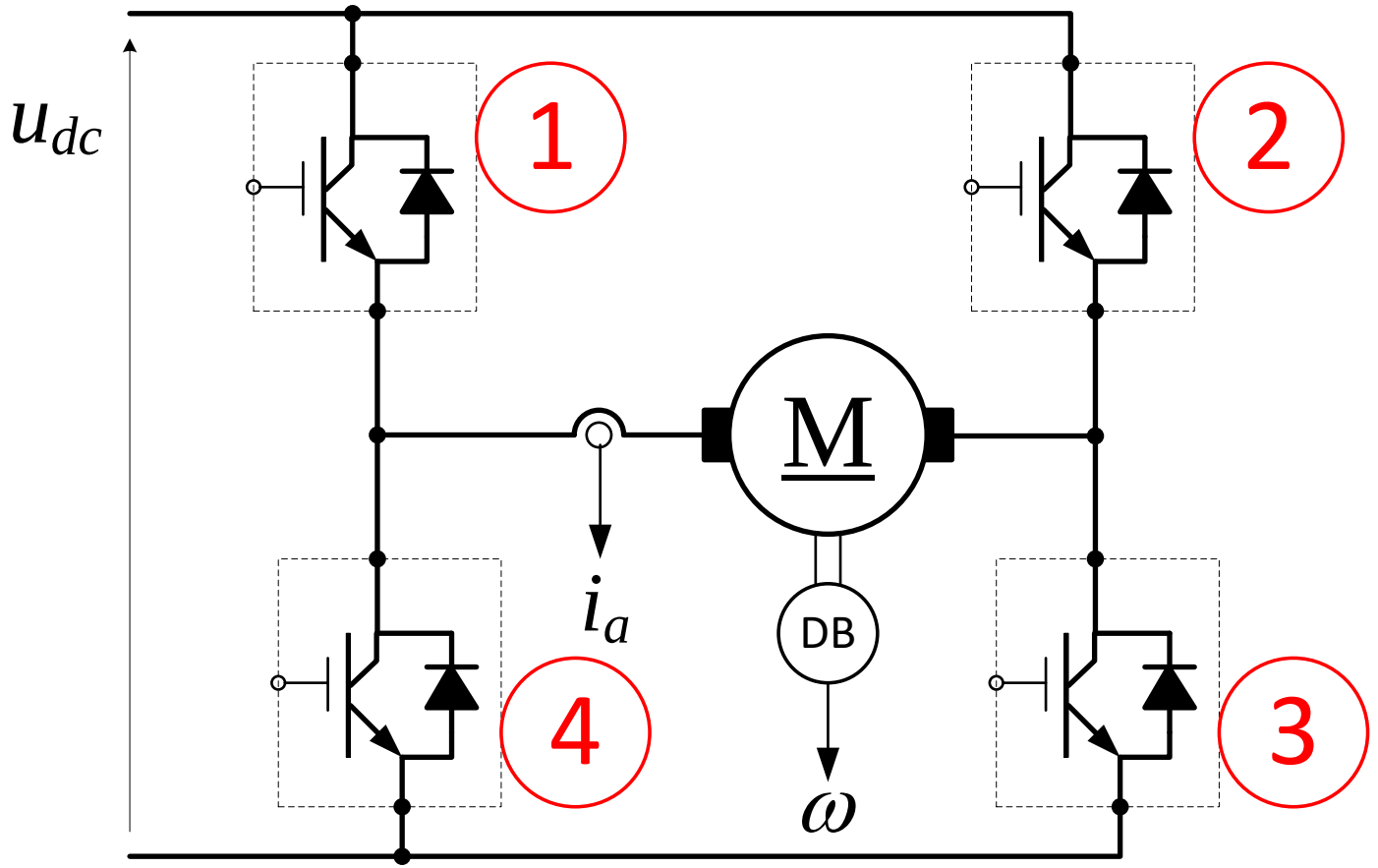
Edition 02 - 06/2013



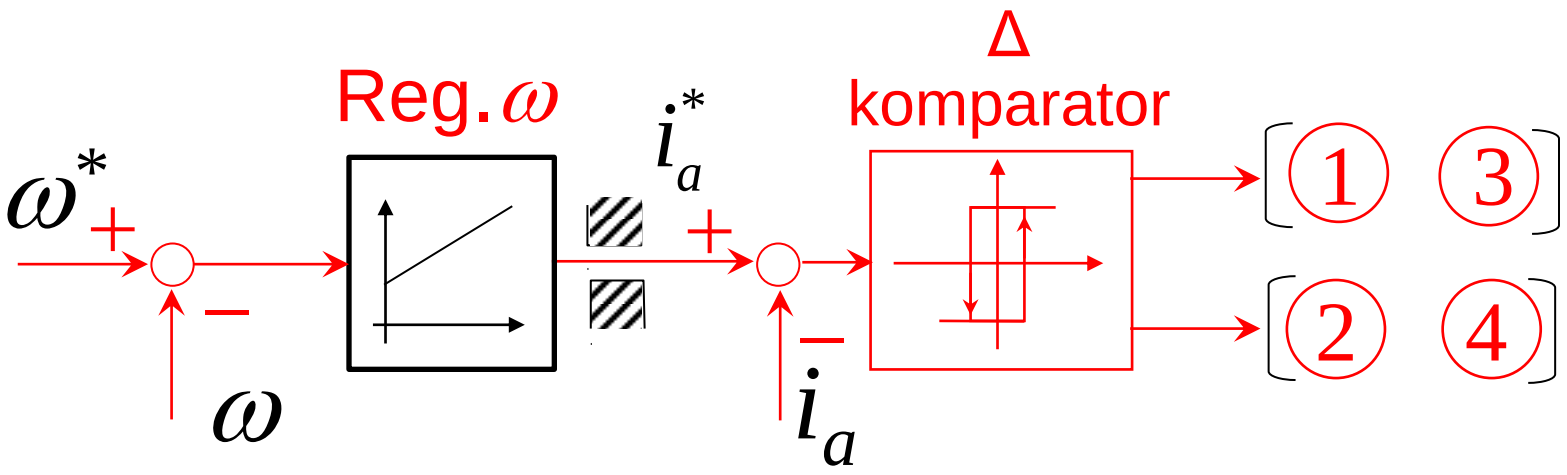
Vard Leonardova grupa



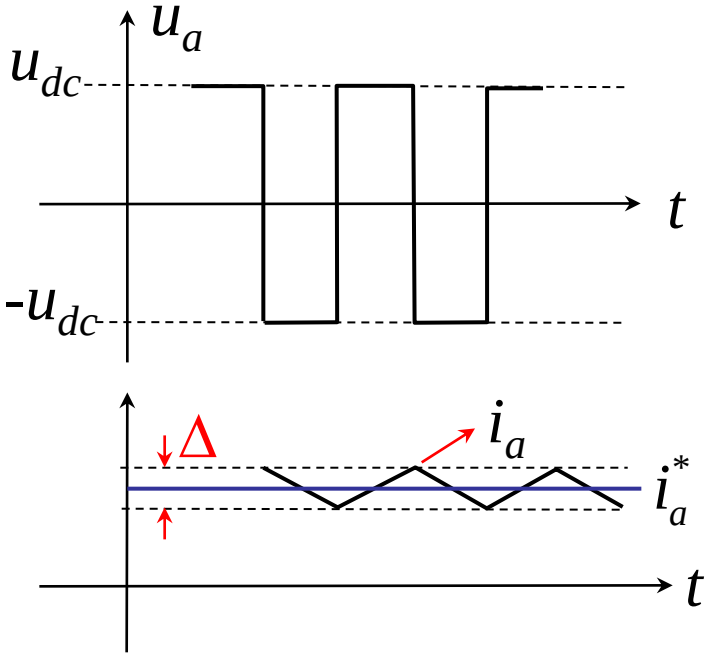
Četvoro-kvadrantni čoper



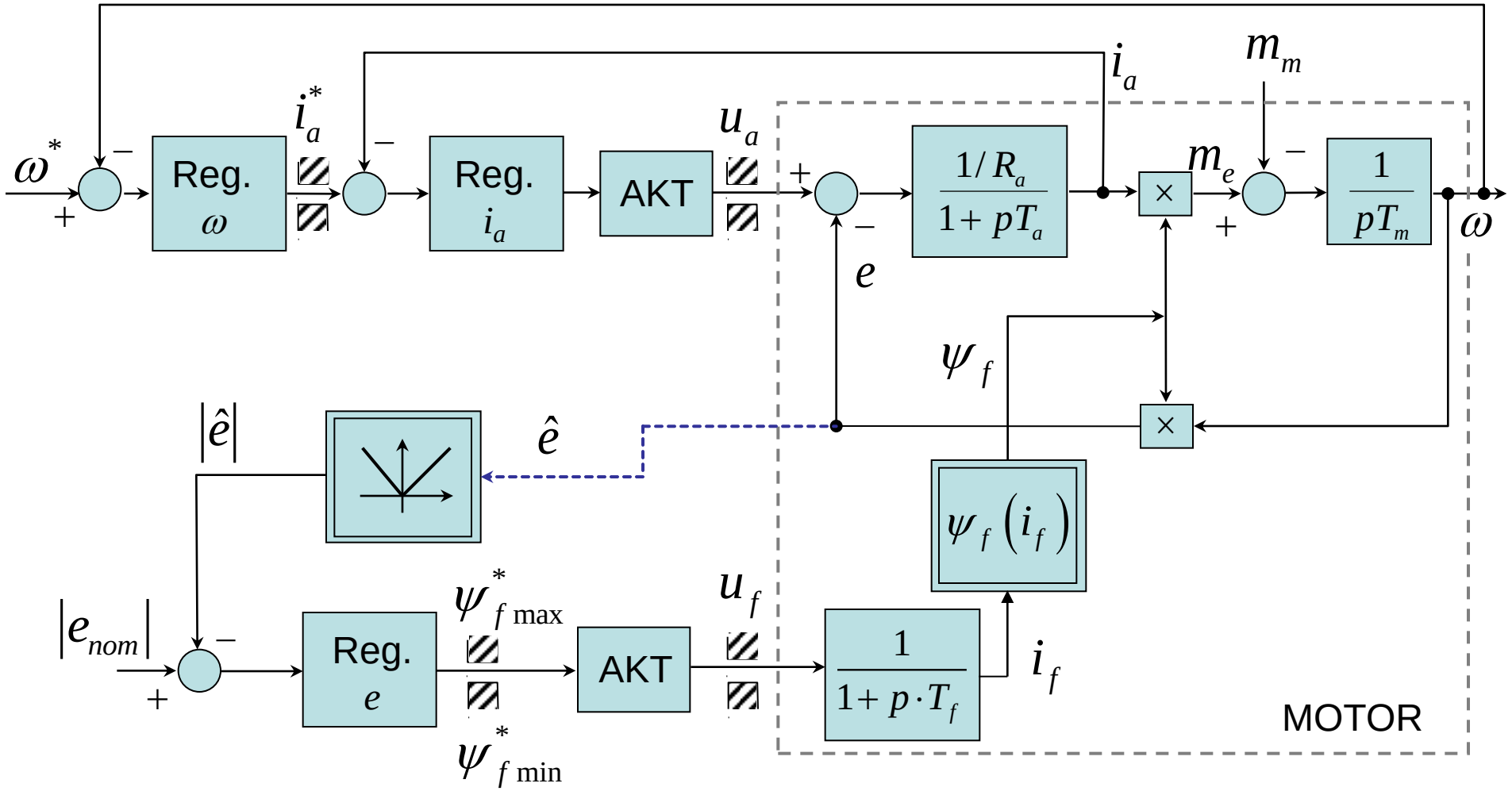
Struktura regulatora



Trenutne vrednosti napona i struje motora

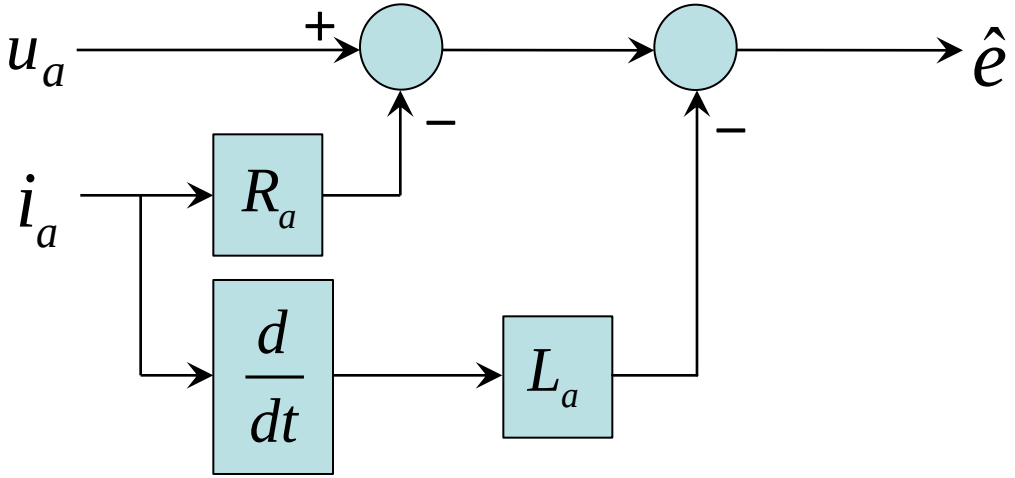


Upravljanje motorom kod regulacije brzine u proširenom opsegu brzina (sa slabljenjem polja)

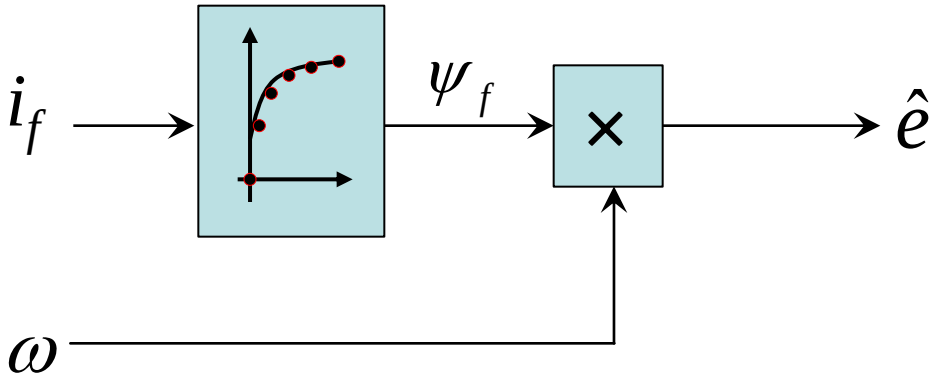


Merenje *elektromotorne sile nije moguće.*
Izračunava se na osnovu merenja dostupnih veličina.

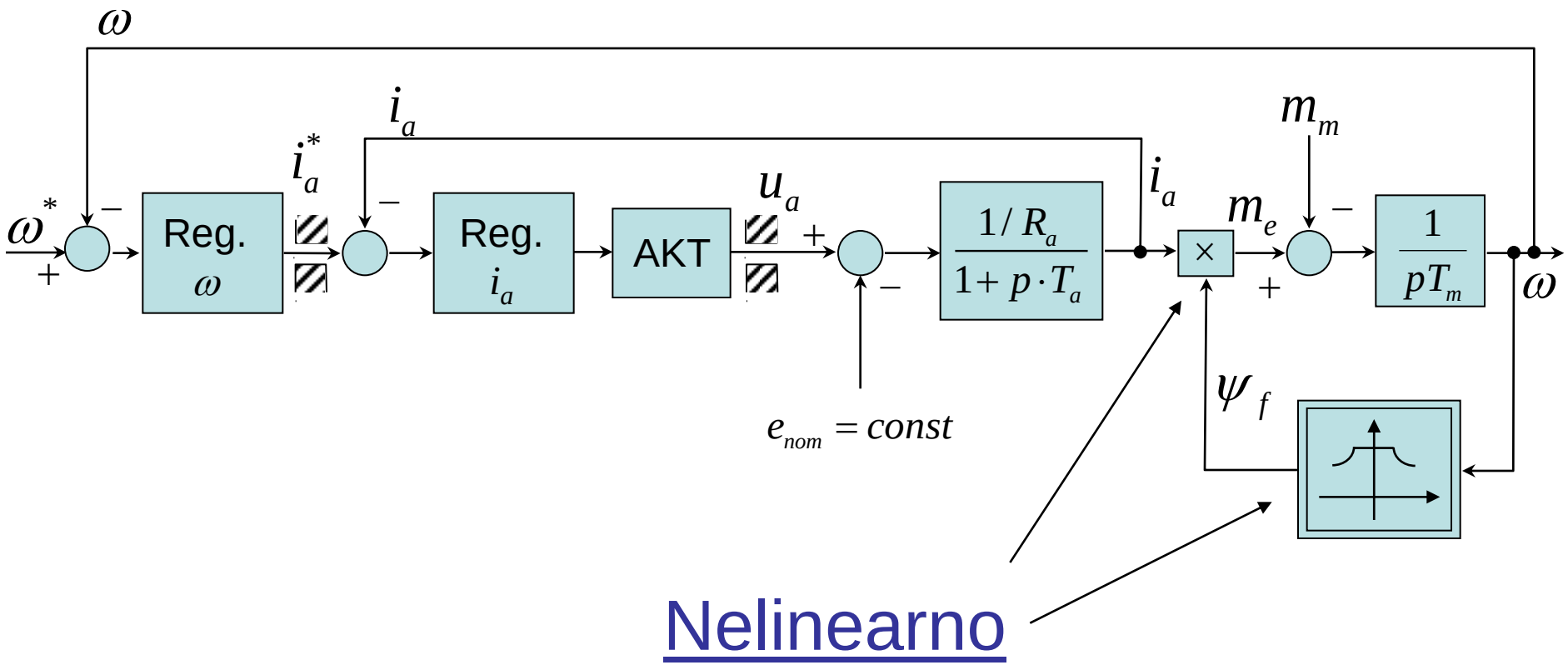
Prvi način: merenjem struje i napona indukta



Drugi način: merenjem struje pobude i brzine



Blok dijagram sistema pri brzini većoj od nominalne



Nelinearno