Electric Drives
Laboratory
DII - UniPD

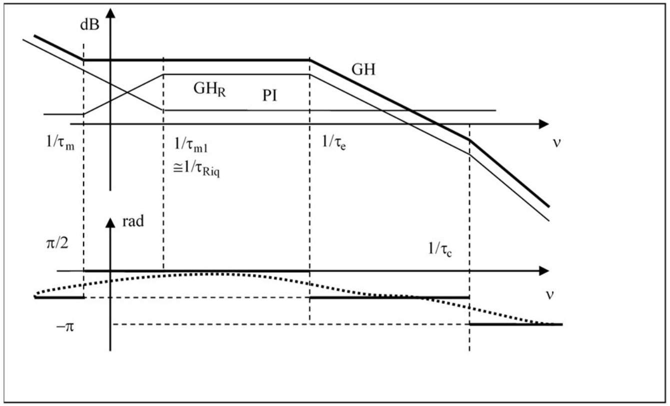
Azionamenti Elettrici

Lezioni a.a. 2018-2019

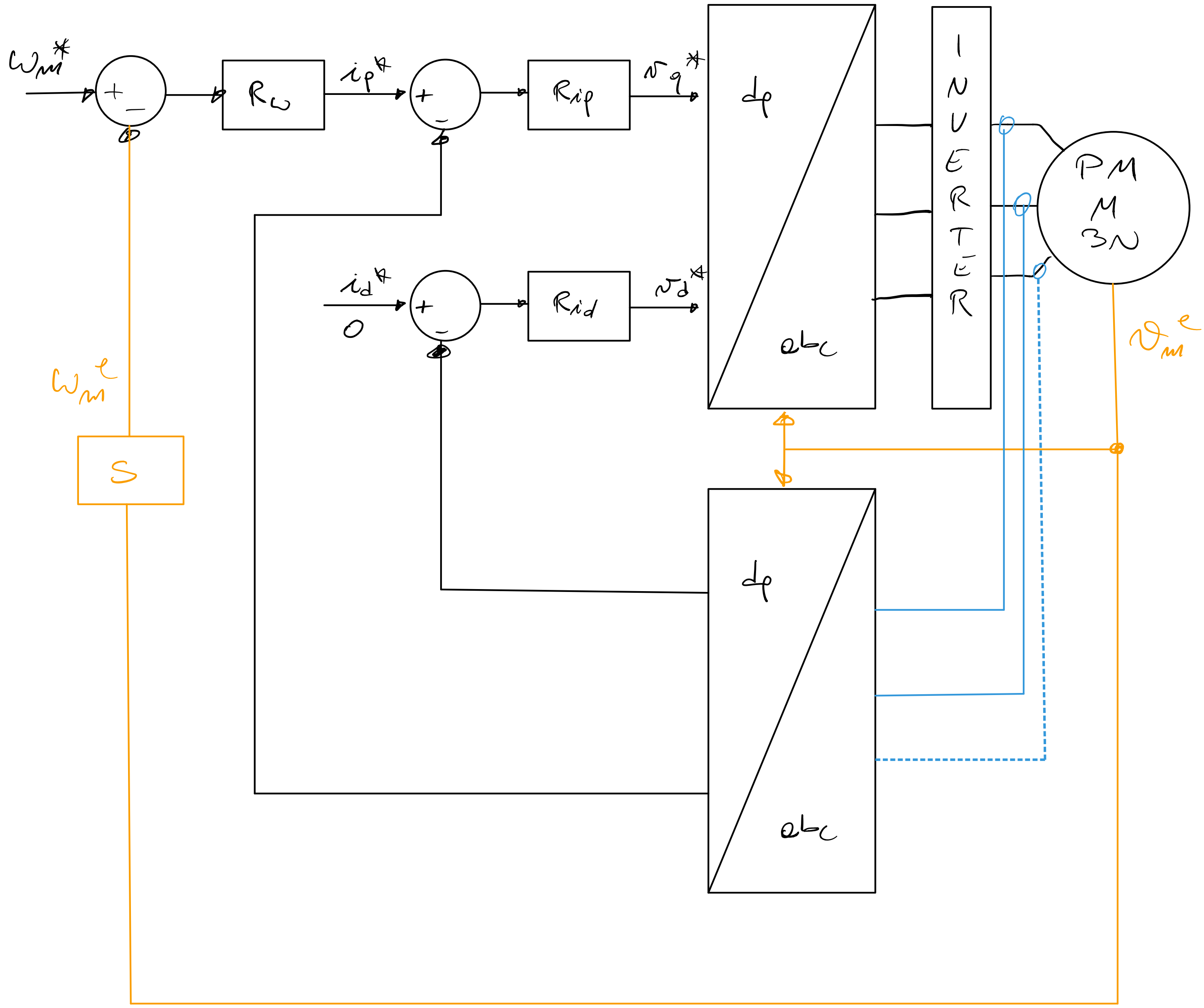
prof. Silverio Bolognani

PARTE III

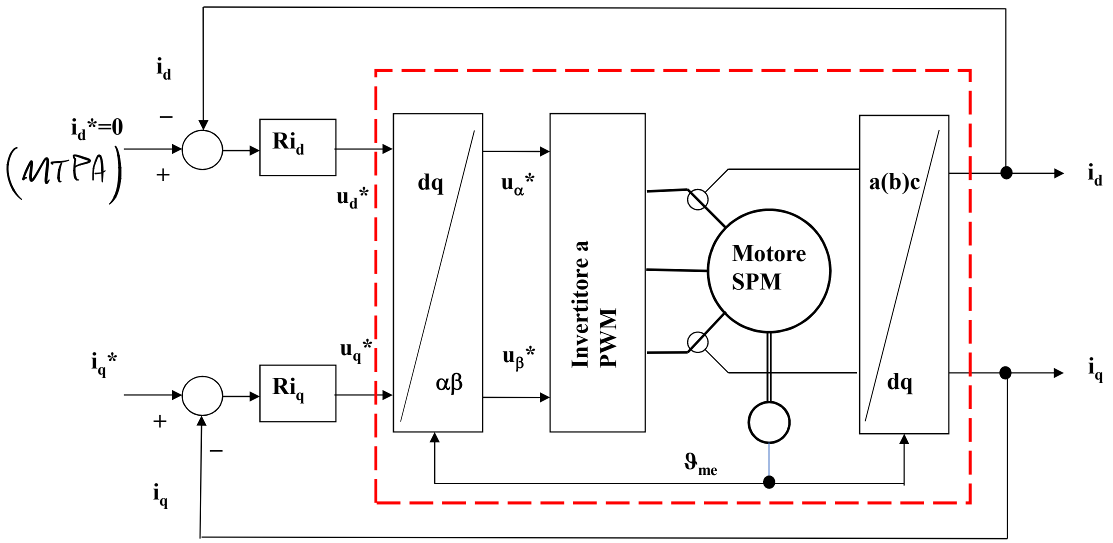
Controllo di corrente «PID sincrono» in azionamenti con motore sincrono



MACCHINA ISOTROPA MTPA



Schema a blocchi del controllo di corrente dq di un motore SPM



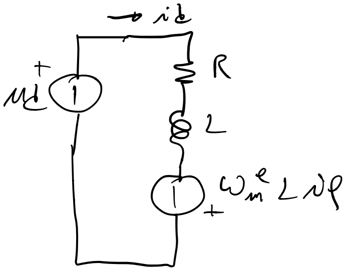
Modello in dq del sistema invertitore-motore.

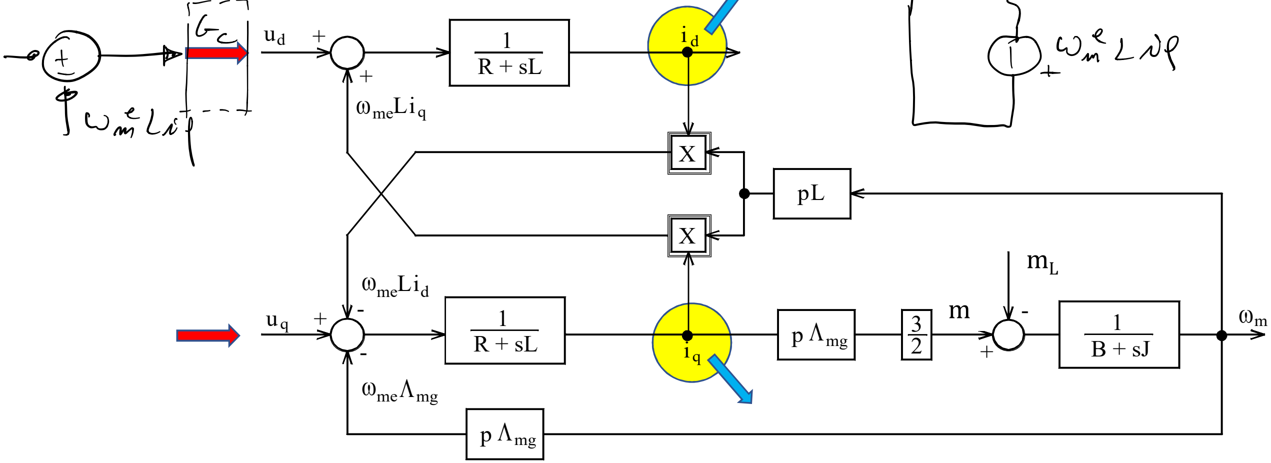
Ingressi: tensioni dqdi riferimento (+coppia di disturbo)

Uscite: correnti dq

$$u_d = R i_d + L \frac{di_d}{dt} - \omega_m^e L i_q$$

Dinamica del motore SPM (rotore isotropo)

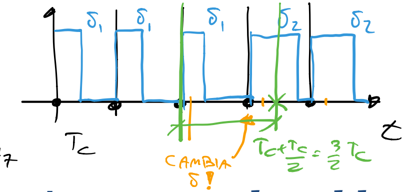




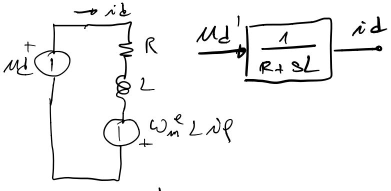
Nel sistema di riferimento dq la dinamica tensione-corrente del motore SPM è quella di un **sistema a due ingressi e due uscite**.

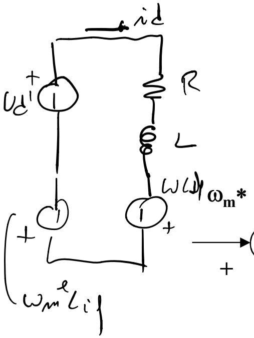
$$G_c = \frac{1}{1+s\tau_c} \qquad \tau_c = \frac{3}{2}T_c$$

es: $f_s = 100$ kHz, $\tau_c = 10\,\mu s$

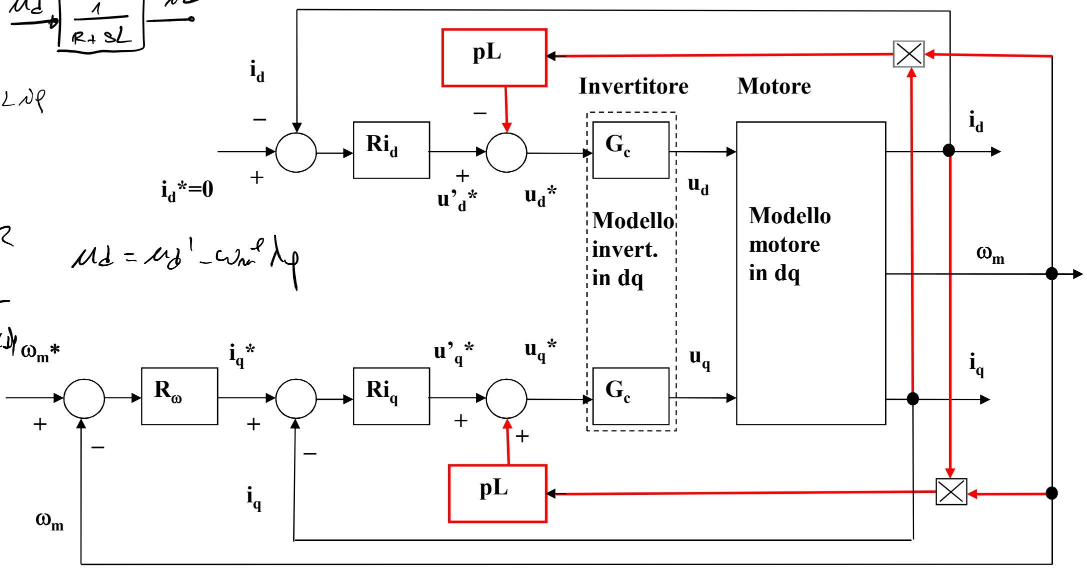


Schema a blocchi del controllo di un azionamento brushless isotropo (SPM)



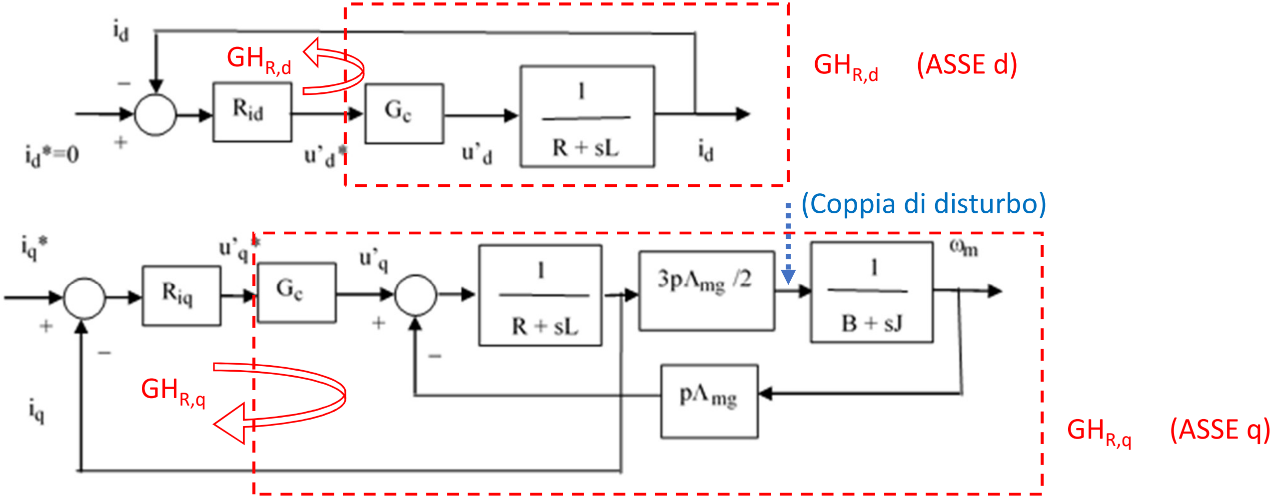


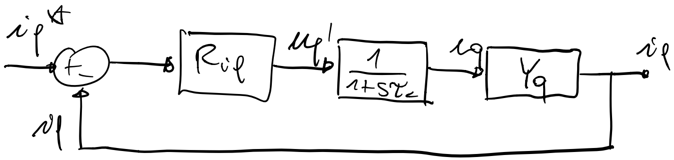
$u_d = u_d' - \omega_m^e \lambda_f$



In rosso le azioni di disaccoppiamento degli assi
per trasformare il sistema 2_IN/2_OUT in due sistemi 1_IN/1_OUT

Anelli di controllo delle correnti dq dopo disaccoppiamento degli assi





$$GH = \frac{1}{1+s\tau_c} Y_q = \frac{1}{1+s\tau_c} \frac{B+sJ}{\frac{3}{2}(p\Lambda_m)^2\left(1-\frac{s}{p_1}\right)\left(1-\frac{s}{p_2}\right)}$$

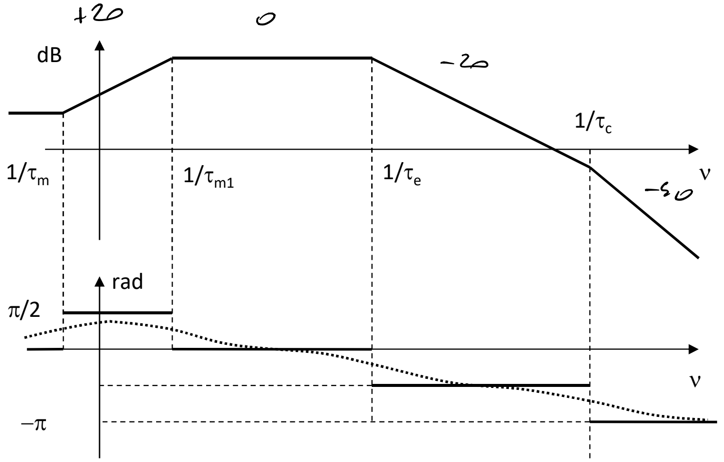
$$= \frac{B(1+s\tau_m)}{\frac{3}{2}(p\Lambda_m)^2(1+s\tau_c)(1+s\tau_e)(1+s\tau_{m1})}$$

$\tau_m = \frac{J}{B}$ $\quad \tau_e = \frac{L}{R}$ $\quad \tau_{m1} = \frac{JR}{\frac{3}{2}(p\Lambda_m)^2}$

$\tau_m < \tau_{m1} < \tau_e < \tau_c$

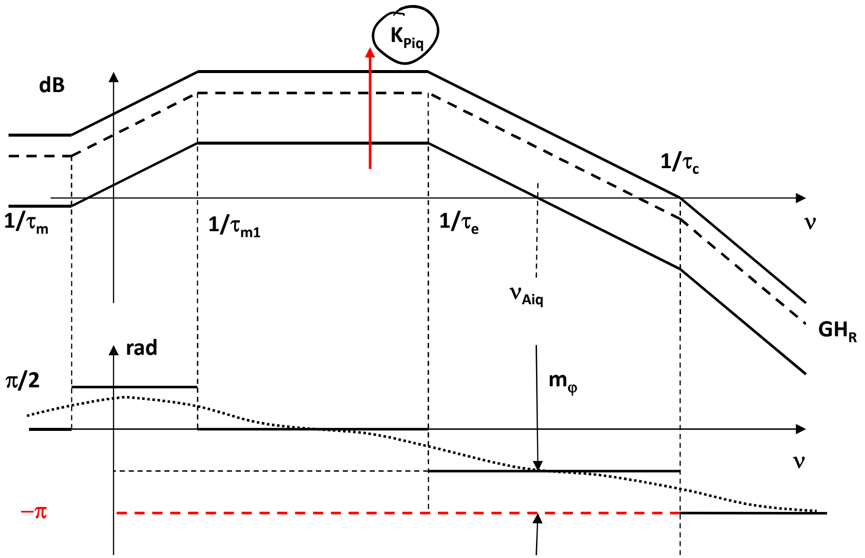
Diagrammi di Bode di $GH_{R(q)}(j\nu)$

$$GH = \frac{B(1+s\tau_m)}{\frac{3}{2}(p\lambda_m)^2(1+s\tau_c)(1+s\tau_e)(1+s\tau_{m1})}$$



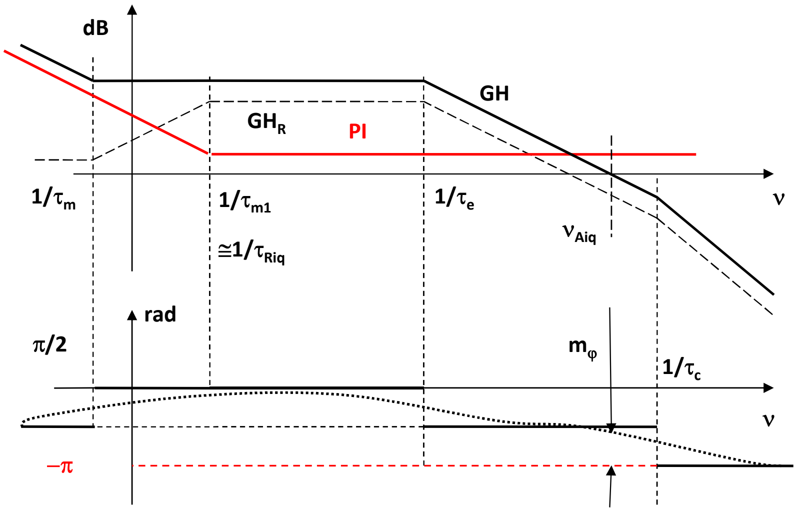
$R_{iq} = K_{Piq}$

Diagrammi di Bode di $GH_{(q)}(j\nu)$ con regolatore P



$$R_{iq} = k_P + \frac{k_I}{s} = k_I \frac{1+s\tau_{Riq}}{s} = k_P \frac{1+s\tau_{Riq}}{s\tau_{Riq}} \qquad \tau_{Riq} = \frac{k_P}{k_I}$$

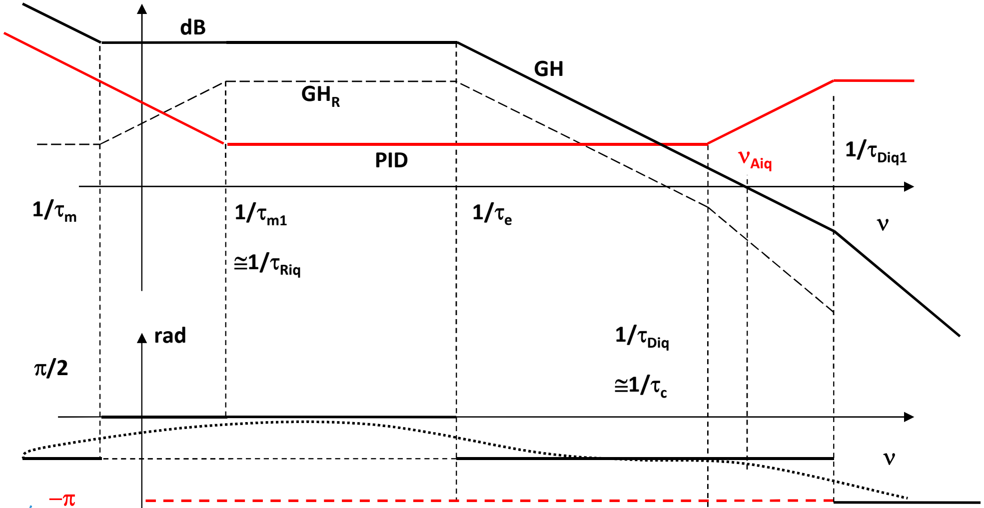
Diagrammi di Bode di $GH_{(q)}(j\nu)$ con regolatore PI



ERRORE A REGIME NULLO !

$$R_{\omega q} = k_p + \frac{k_i}{s} + s k_D = k_i \frac{(1+s\tau_{Riq})(1+s\tau_{Diq})}{s}$$

Diagrammi di Bode di $GH_{(q)}(j\,\nu)$ con regolatore PID

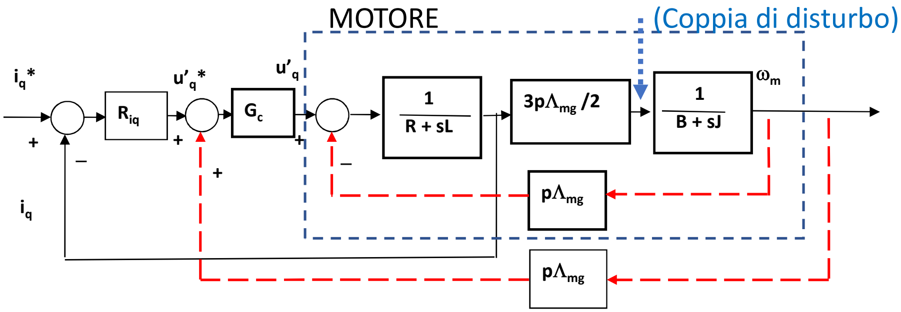


PI

D: Aumento banda passante

$$R_{\omega q} = k_i \underbrace{\frac{1+s\tau_{Riq}}{s}}_{PI} \; \frac{1+s\tau_{Diq}}{1+s\tau_{Diq1}}$$

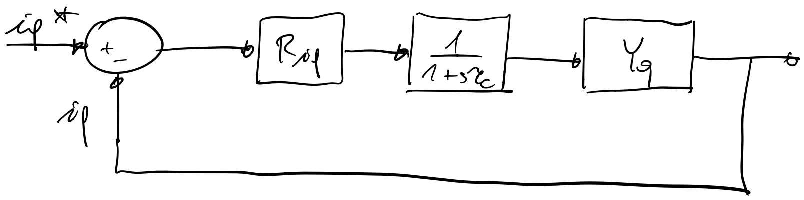
Schema a blocchi del controllo della corrente in quadratura dopo disaccoppiamento e compensazione della fem



In rosso l'azione di compensazione della fem

Le fdt dell'anello di asse q non risente del parametri meccanici e dell'effetto della coppia di disturbo.

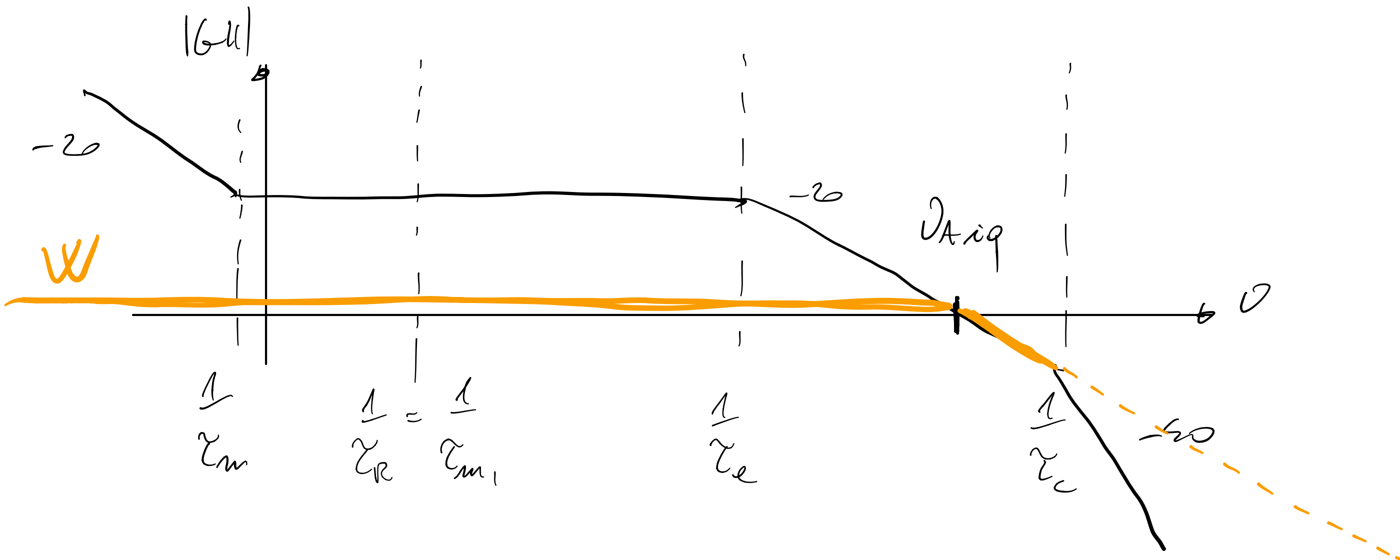
Con motore SPM diventa identica a quella dell'asse d.



$$GH = R_{iq}\frac{1}{1+s\tau_c}\,Y_q = R_{iq}\frac{1}{1+s\tau_c}\,\frac{1+s\tau_m}{(1+s\tau_e)(1+s\tau_m)}$$

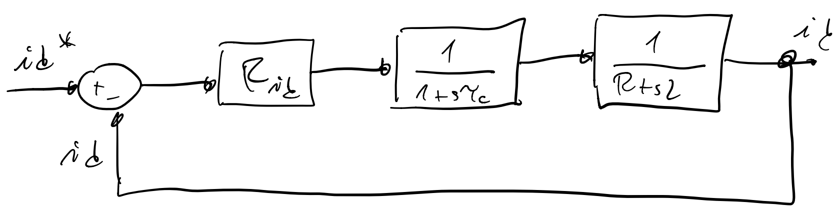
$$= \frac{1+s\tau_R}{s}\,\frac{1+s\tau_m}{(1+s\tau_c)(1+s\tau_e)(1+s\tau_m)}$$

$$W = \frac{G}{1+GH} = \begin{cases} \text{se } GH \gg 1 & W = 1 \\ \text{se } GH \ll 1 & W = G \end{cases}$$



$$W \cong \frac{1}{1+s\frac{1}{\omega_{A\,iq}}}$$

Similmente per l'asse d



ESEMPIO: DIMENSIONARE ANELLI DI CONTROLLO PER UN MOTORE SPM

$R_s = 1{,}5\,\Omega$

$\lambda_m = 0{,}067\ Vs$

$L = 5\,mH$

$I_n = 3{,}1\ A\ RMS$

$M_n = 1{,}77\ Nm$

$p = 4$

$J = 0{,}28 \cdot 10^{-3}\ kg\,m^2$

$B = 0{,}00112\ \frac{Nm}{rad/s}$

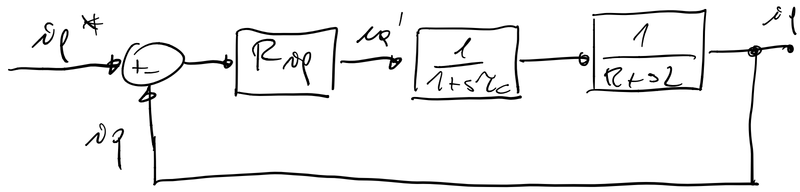
$V_n = 85\ V(RMS)$

$\omega_{mn} = 418\ \frac{rad}{s}$

$P_n = 750\,W$

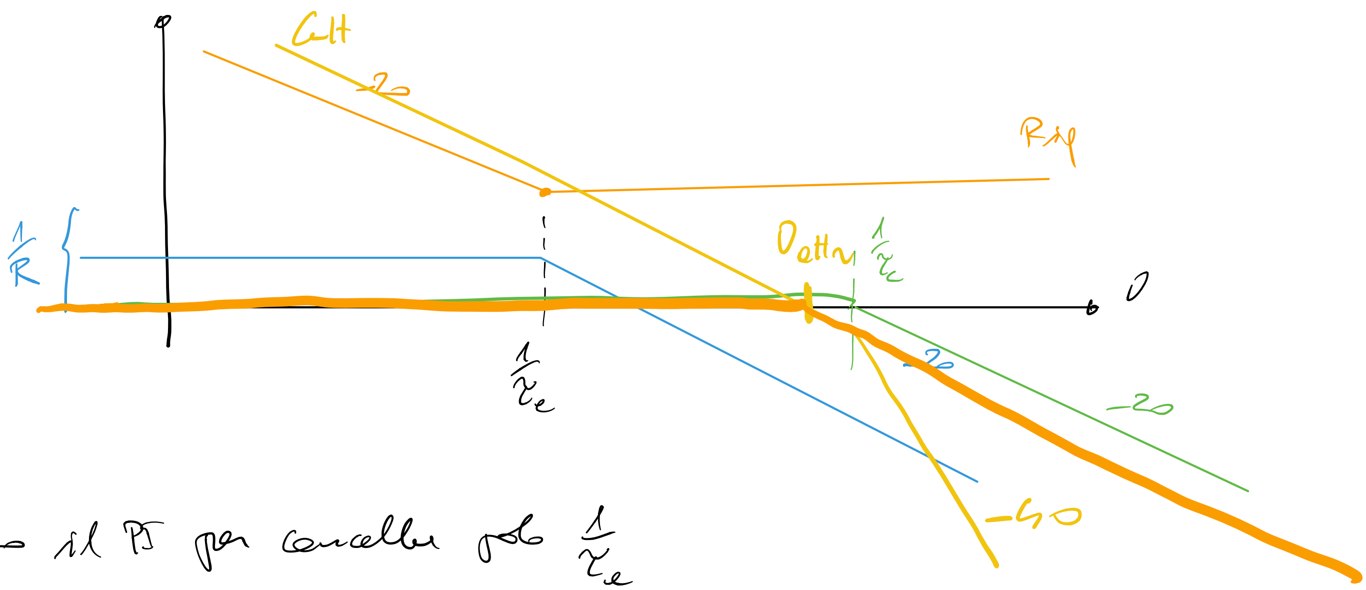
$T = 100\,\mu s$

USO DISACCOPPIAMENTO ASSI E COMPENSAZIONE F.C.E.M.



$$\frac{1}{R+sL} = \frac{1/R}{1+s\frac{L}{R}} = \frac{1/R}{1+s\tau_e} \qquad \tau_e = \frac{L}{R} = \frac{5\cdot 10^{-3}}{1{,}5} = 3{,}3\ ms$$

$$\tau_c = \frac{3}{2} T_c = 1{,}5 \cdot 100\mu = 150\,\mu s$$



Uso il PI per cancellare polo $\frac{1}{\tau_e}$

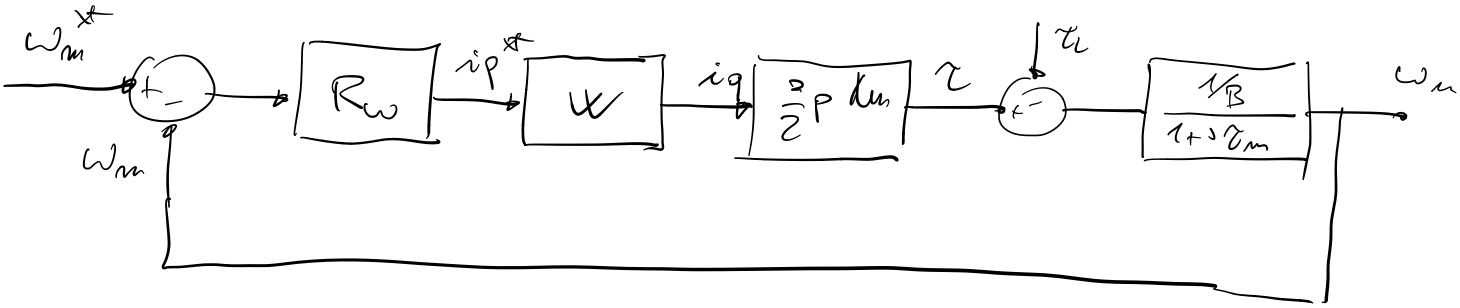
$$R_{iq} = K_p \frac{1+s\tau_{Riq}}{s\tau_{Riq}} \qquad \frac{1}{\tau_{Riq}} = \frac{1}{\tau_e} = \frac{1}{3{,}5\cdot 10^{-3}} = 285{,}7$$

Scelgo $m\varphi = 70° = 180 + \arg G_{lt}(j\omega_{ctr})$

$$\omega_{ctr} = \frac{\tan 20°}{150\cdot 10^{-6}} = 2426\ \frac{rad}{s} \qquad W = \frac{1}{1+s\frac{1}{\omega_{ctr}}} = \boxed{\frac{1}{1+s\cdot 4{,}12\cdot 10^{-5}}}$$

Calcolo K_p $\quad |G_{lt}(\nu_{attr})| = 1 \; \ldots \; K_p = 14{,}87 \; \frac{V}{A}$

$$R_{iq} = K_p \frac{1+s\,\tau_{Riq}}{s\,\tau_{Riq}} = \boxed{14{,}87 \frac{1+s \cdot 3{,}5 \cdot 10^{-3}}{s\; 3{,}5 \cdot 10^{-3}}}$$



$$R_\omega = k_{p\omega} \frac{1+s\,\tau_{i\omega}}{s\,\tau_{i\omega}}$$

$$\tau_{i\omega} = \tau_m = \frac{J}{B} = \frac{0{,}29 \cdot 10^{-3}}{0{,}00192} = 0{,}15 \text{ s}$$

Impongo $M\phi = 70° = 180 + \arg G_{lt}(\nu^{\omega}_{attr})$

$$\nu^{\omega}_{attr} = 631{,}5 \; \frac{rad}{s} \qquad \left(\nu_{attr} = 2626 \; \frac{rad}{s} \text{ ANELLO DI CORRENTE} \right)$$

Impongo $|G_{lt}(\nu^{\omega}_{attr})| = 1 \implies k_{p\omega} = 0{,}58$

$$R_\omega = 0{,}58 \; \frac{1 + 0{,}15 \cdot s}{s \cdot 0{,}15}$$

SIMULARE IN SIMULINK!