ESEMPIO 1 : Dato il seguente motore

$2p = 4$
$R = 2\Omega$
$L_d = 10\,mH$
$L_q = 40\,mH$

$\left.\begin{matrix} L_d = 10\,mH \\ L_q = 40\,mH \end{matrix}\right\} \xi = \dfrac{L_q}{L_d} = 4$

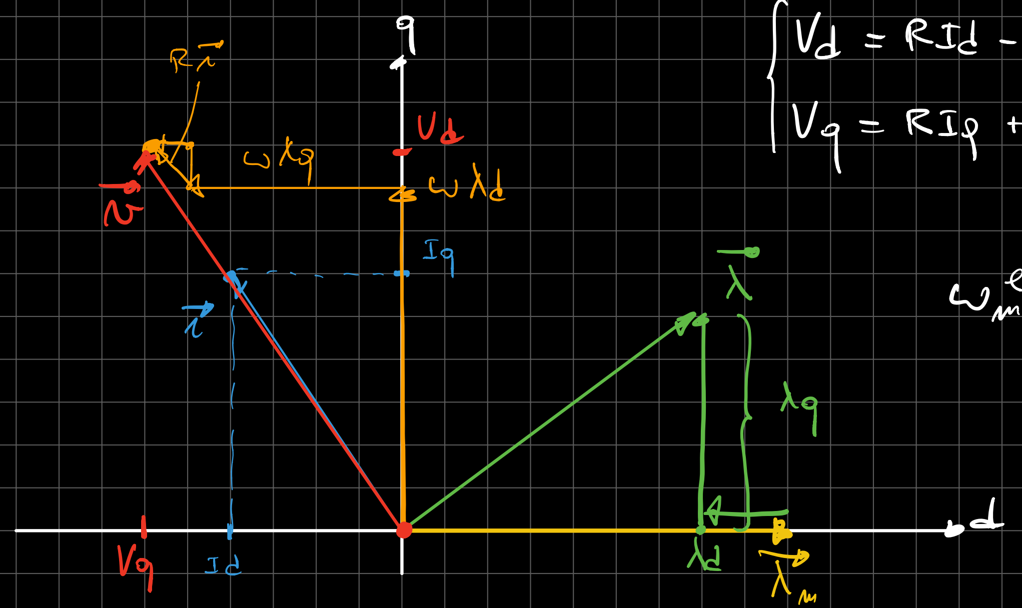
$\omega_m = 150 \ \dfrac{rad}{s}$

$\left.\begin{matrix} I_d = -8{,}5\,A \\ I_q = 12\,A \end{matrix}\right\}$ picco

$\lambda_m = 0{,}6\ Vs$ (picco)

? Calcolare tensione necessaria, bilancio delle potenze

$$\begin{cases} V_d = R I_d - \omega_m^e \underbrace{L_q I_q}_{\lambda_q = 0{,}48} \\ V_q = R I_q + \omega_m^e \underbrace{(\lambda_m + L_d I_d)}_{\lambda_d = 0{,}515\,V_s} \end{cases}$$



$$\omega_m^e = \omega_m \cdot p = 150 \cdot 2 = 300 \ \frac{rad}{s}$$

$$\begin{cases} \lambda_d = \lambda_m + L_d I_d = 0{,}6 - 0{,}01 \cdot 8{,}5 = 0{,}515\ V_s \\ \lambda_q = L_q I_q = 0{,}04 \cdot 12 = 0{,}48\ V_s \end{cases}$$

$$\left.\begin{cases} V_d = \ldots = 2(-8{,}5) - 300 \cdot 0{,}48 = -161\ V \\ V_q = \ldots = 2 \cdot 12 + 300\ 0{,}515 = 178{,}5\ V \end{cases}\right\} \vec{v} = 240{,}4\ e^{j132^\circ}$$

Coppia : $m = \frac{3}{2} p \left[\lambda_m I_q + (L_d - L_q) I_d I_q\right]$

$= \frac{3}{2} \cdot 2 \left[0{,}6 \cdot 12 + (10-40) \cdot 10^{-3} (-8{,}5)\, 12\right]$

$= 30{,}8\ Nm$

$P_m = m \cdot \omega_m = 30{,}8 \cdot 150 = 4617\ W$

$$P_J = \frac{3}{2} R I^2 = \frac{3}{2} \cdot 2 \cdot \left(I_d^2 + I_q^2\right) = 658{,}8 \text{ W}$$

$$P_{in} = P_m + P_J = 5617 + 658{,}8 = 5265 \text{ W}$$

$$= \frac{3}{2}\left(V_d I_d + V_q I_q\right) = \frac{3}{2}\left((-161)(-8{,}5) + 178{,}5 \cdot 12\right) = 5265 \text{ W}$$

$$\eta = \frac{P_m}{P_{in}} = \frac{5617}{5265} = 0{,}877 \qquad 87{,}7\,\%$$

ESEMPIO 2 Motore a Riluttanza

Dato il seguente motore:

$2p = 6$

$\lambda_m = 0$ (RSC)

$R \cong 0$ trascurabile

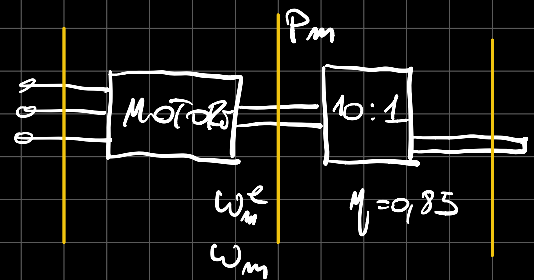
$L_d = 50$ mH

$L_q = 10$ mH

Sia connesso ad un carico meccanico con le seguenti caratteristiche

$P_L = 10$ kW e sia connesso al motore mediante riduttore di giri con rapporto $1:10$ $\eta = 0{,}85$

$n_L = 200$ rpm



$\vec{i}$ • V

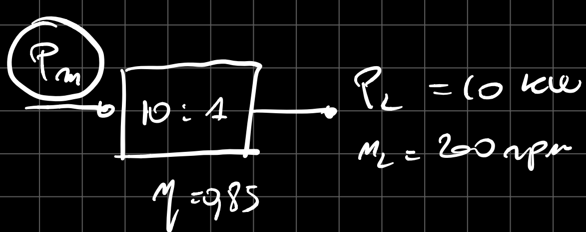
$\vec{v}$ • V

f • V

$$m = \frac{3}{2} p \left[\cancel{\lambda_m I_q} + (L_d - L_q) I_d I_q\right] = \frac{3}{2} p (L_d - L_q) I_d I_q \qquad L_d > L_q$$

$\lambda_m = 0$

$I_d, I_q > 0$ I° quadrante



$$P_m = \frac{P_L}{0{,}85} = \frac{10 \cdot 10^3}{0{,}85} = 11\,675 \text{ W}$$

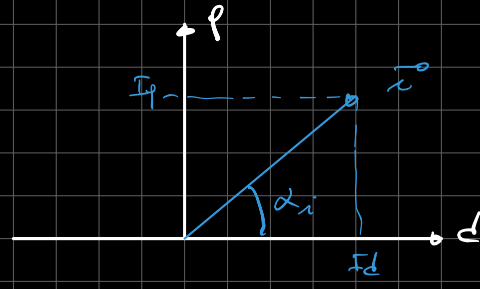
$n_m = 2000$ rpm

$$\omega_m = \frac{2\pi n_m}{60} = 209{,}3 \ \frac{\text{rad}}{\text{s}}$$

$$\omega_m^e = p \cdot \omega_m = 3 \cdot 209{,}3 = 628 \ \frac{\text{rad}}{\text{s}}$$

$f = \frac{\omega_m^e}{2\pi} = \frac{628}{2\pi} = 100\ Hz$ frequenza di alimentazione del motore

$P_m = m \cdot \omega_m \qquad m = \frac{P_m}{\omega_m} = \frac{11675}{209,3} = 55,78\ Nm$



$m = \frac{3}{2} p (Ld - Lq)\, Id\, Iq = 55,78\ Nm$

$= \frac{3}{2} p (Ld - Lq)\, I \cos\alpha_i \, I \operatorname{sen}\alpha_i$

$= \frac{3}{2} p (Ld - Lq) \frac{I^2}{2} \operatorname{sen} 2\alpha_i$

$\vec{i} = Id + j\, Iq = I\, e^{j\alpha_i}$

$I^2 = Id^2 + Iq^2$

$Id = I \cos\alpha_i$

$Iq = I \operatorname{sen}\alpha_i$

$\operatorname{sen} 2\alpha_i = 1$ ho $|I|$ minore MTPA

$\alpha_i = 45°$ $\qquad Id = Iq = \frac{I}{\sqrt{2}}$

$m = \frac{3}{2} p (Ld - Lq) \frac{I^2}{2} = 55,78\ Nm$

$I = \sqrt{\frac{4\, m}{3\, p (Ld - Lq)}} = \sqrt{\frac{4 \cdot 55,78}{3 \cdot 3 (50 - 10) \cdot 10^{-3}}} = 24,9\ A$

$\vec{i} = 24,9\ e^{j45°} \qquad Id = Iq = \frac{24,9}{\sqrt{2}} = 17,6$

$$\begin{cases} Vd = \cancel{R Id} - \omega_m^e \lambda q = -\omega_m^e Lq Iq = -628 \cdot 10 \cdot 10^{-3} \cdot 17,6 = -110,5V \\ Vq = \cancel{R Iq} + \omega_m^e \lambda d = \omega_m^e Ld Id = 628 \cdot 50 \cdot 10^{-3}\ 17,6 = 550V \end{cases}$$

$\vec{v} = 561\ e^{j\,101,5°}$

Regioni limite di funzionamento

$I_m \qquad U_m \qquad \longrightarrow I_d \; I_q$

$|\vec{i}| \le I_m \qquad\qquad |\vec{v}| \le U_m$

$I_q^2 + I_d^2 \le I_m^2$

CERCHIO DI RAGGIO I_m

$$\begin{cases} U_d = \cancel{R I_d} - \omega_m^e L_q I_q \\ U_q = \cancel{R I_q} + \omega_m^e (\lambda_m + L_d I_d) \end{cases}$$

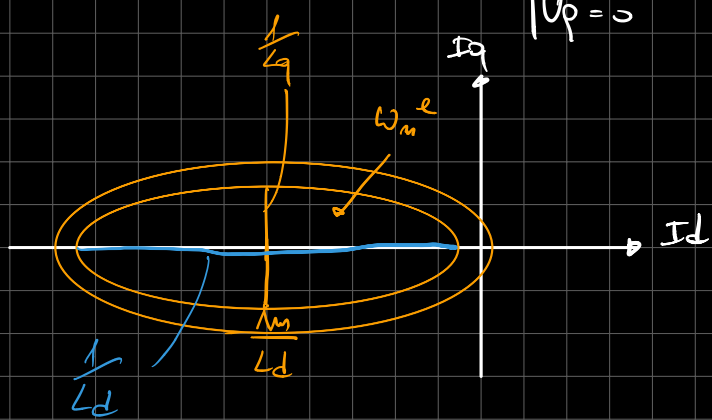
$$U_d^2 + U_q^2 \le U_m^2$$

$$\omega_m^{e\,2} (L_q I_q)^2 + \omega_m^{e\,2} (\lambda_m + L_d I_d)^2 \le U_m^2$$

$$(\lambda_m + L_d I_d)^2 + (L_q I_q)^2 \le \left(\frac{U_m}{\omega_m^e}\right)^2$$

$L_d \neq L_q$ ELLISSE DI TENSIONE

CENTRO $\begin{cases} U_d = 0 \\ U_q = 0 \end{cases} \qquad \begin{cases} I_q = 0 \\ I_d = -\dfrac{\lambda_m}{L_d} = I_{ch} \end{cases}$

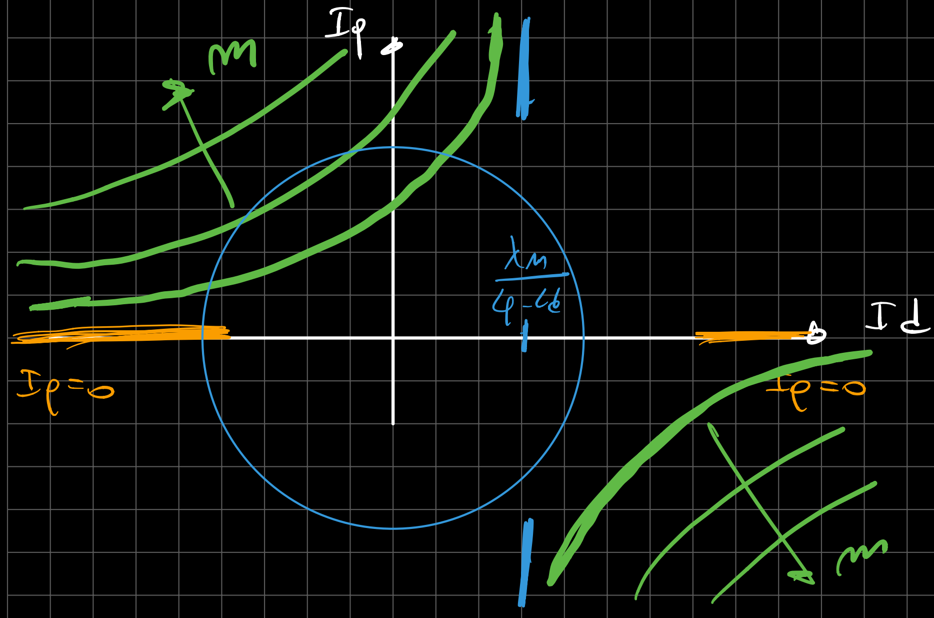


SALIENZA $= \dfrac{\frac{1}{L_d}}{\frac{1}{L_q}} = \dfrac{L_q}{L_d} = ?$

$$m = \frac{3}{2} p \left[\lambda_m I_q + (L_d - L_q) I_d I_q \right] = \frac{3}{2} p I_q \left[\lambda_m + (L_d - L_q) I_d \right]$$

$$I_q = \frac{2}{3} \frac{m}{p\left[\lambda_m + (L_d - L_q) I_d\right]}$$

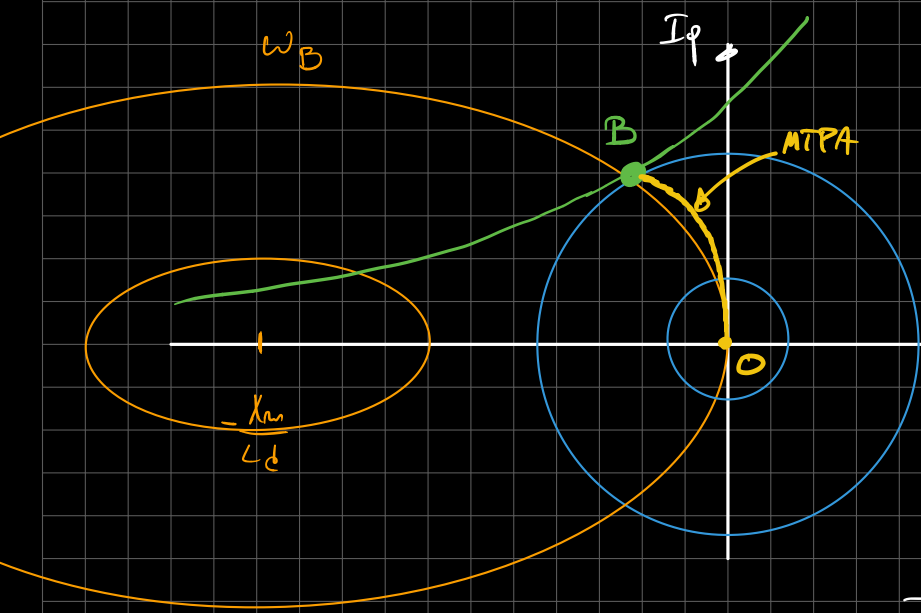
Iperbole con asintoti $\begin{cases} I_q = 0 \\ I_d = \dfrac{\lambda_m}{L_q - L_d} \end{cases}$

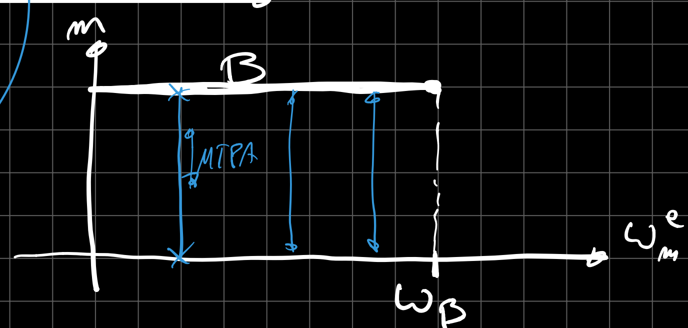


TRAIETTORIE DI CONTROLLO

B: punto base

$\overset{\frown}{OB}$ MTPA





① Impongo la tangenza fra isocoppia e cerchio di corrente

$I_d = I\cos\alpha_i$
$I_q = I\sin\alpha_i$

$$m = \frac{3}{2}p\left[\lambda_m I \sin\alpha_i + (L_d - L_q) I^2 \underbrace{\sin\alpha_i\cos\alpha_i}_{\frac{\sin 2\alpha_i}{2}}\right]$$

$$\frac{dm}{d\alpha_i} = 0 = \lambda_m I \cos\alpha_i + (L_d - L_q) I^2 \cos 2\alpha_i$$

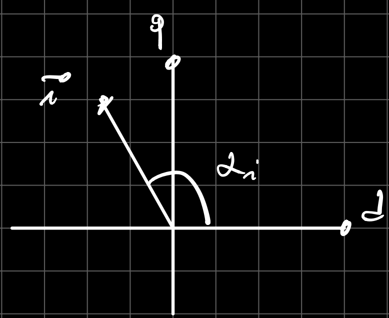
$$\overset{!}{=} \lambda_m \cos\alpha_i + (L_d - L_q) I \cos 2\alpha_i$$

$$\overset{!}{=} \lambda_m \cos\alpha_i + (L_d - L_q) I \left(2\cos^2\alpha_i - 1\right)$$

$$\underbrace{2(L_d - L_q) I}_{a} \cos^2\alpha_i + \underbrace{\lambda_m}_{b} \cos\alpha_i \underbrace{- (L_d - L_q) I}_{c} = 0$$

$$\cos\alpha_i = \frac{-\lambda_m \overset{+}{\cancel{-}} \sqrt{\lambda_m^2 + 8(L_d - L_q)^2 I^2}}{4(L_d - L_q) I}$$

$L_d < L_q$ $\quad < 0$



$\cos\alpha_i < 0$

$\alpha_i > \frac{\pi}{2}$

$L_d > L_q$

Noto si $\lambda_m = 0$ $\quad \cos\alpha_i = -\frac{\sqrt{8}}{4} = -\frac{\sqrt{2}}{2}$ $\quad 135^\circ = 45^\circ + 90$

$$I_d = I \cos\alpha_i = \frac{-\lambda_m + \sqrt{\lambda_m^2 + 8(L_d - L_q)^2 I^2}}{4(L_d - L_q)}$$

$$I_q = \sqrt{I^2 - I_d^2}$$

② $$m = \frac{3}{2} p \left[\lambda_m I_q + (L_d - L_q) I_d I_q\right]$$

$I_q = f(I_d)$ $\qquad I_q = \frac{2}{3} \frac{m}{p} \frac{1}{\lambda_m + (L_d - L_q) I_d}$

CALCOLO ω_B

$$\begin{cases} V_d = -\omega_B \lambda_q = -\omega_b L_q I_q \\ V_q = \omega_B(\lambda_m + L_d I_d) \end{cases}$$

$$V_d^2 + V_q^2 = V_m^2$$

$$\omega_B = \dots$$