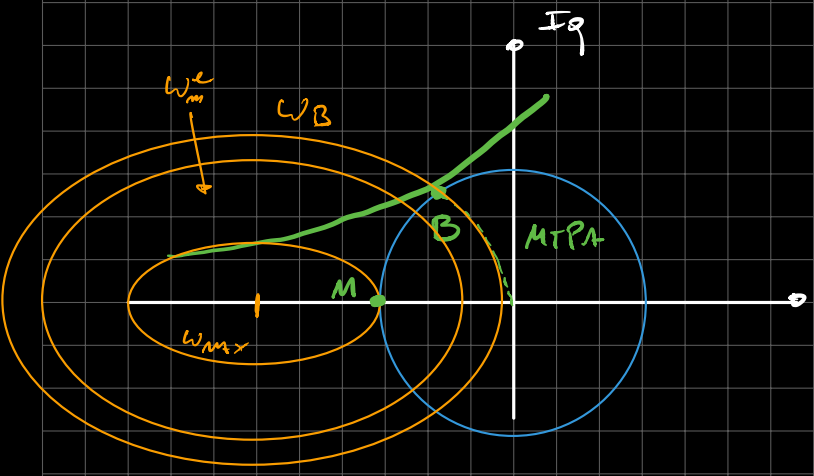
CALCOLO ω_B

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

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

$$(\omega_B L_q I_q)^2 + \omega_B^2 (\lambda_m + L_d I_d)^2 = V_m^2$$

$$\omega_B = \frac{V_m}{\sqrt{(\lambda_m + L_d I_d)^2 + (L_q I_q)^2}}$$

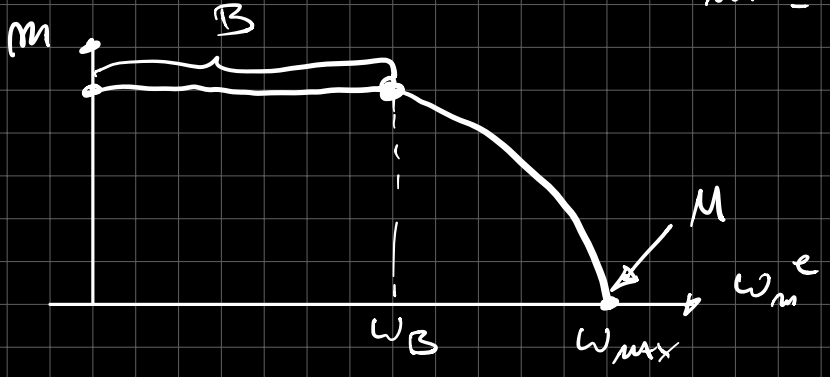


$\omega_m^e = \omega_{max}$ (Punto M)

$$\begin{cases} V_d = \omega_{max} \lambda_q \\ V_q = \omega_{max} \lambda_d \end{cases} \qquad \begin{cases} I_d = -I_m \\ I_q = 0 \end{cases}$$

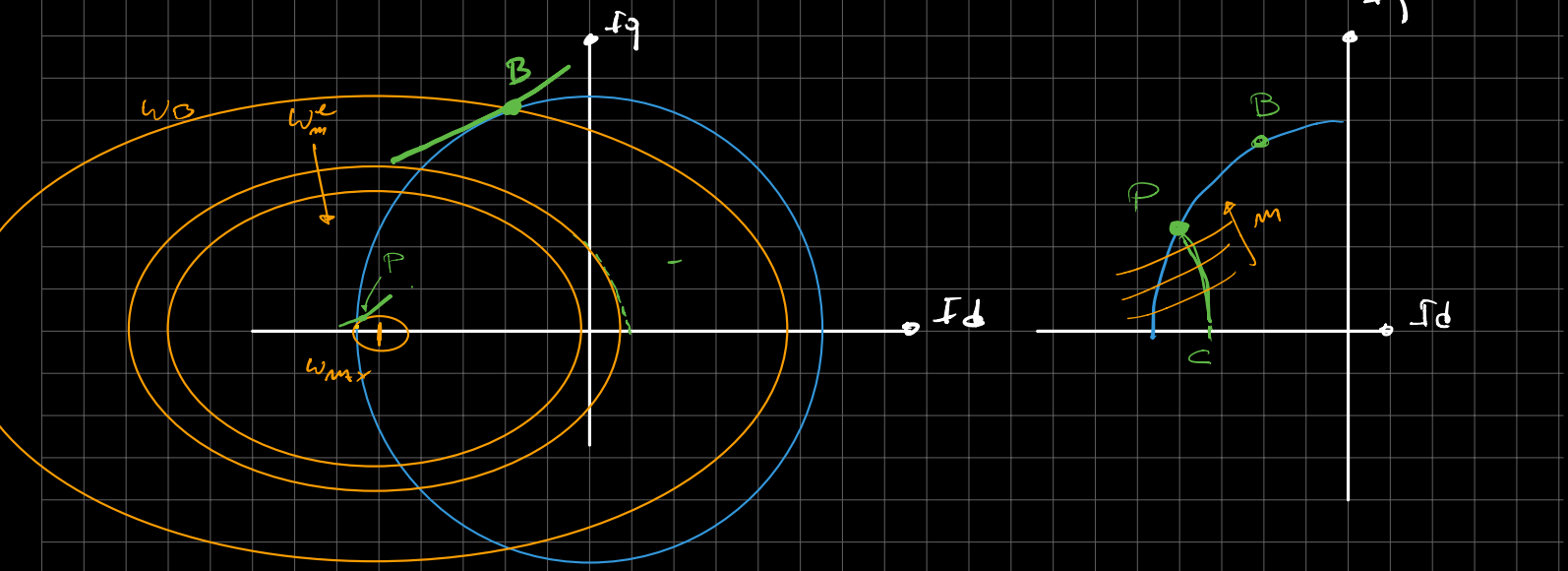
$$\begin{cases} V_d = 0 \\ V_q = \omega_{max} (\lambda_m - L_d I_m) \end{cases}$$

$$\omega_{max} = \frac{V_m}{\lambda_m - L_d I_m}$$

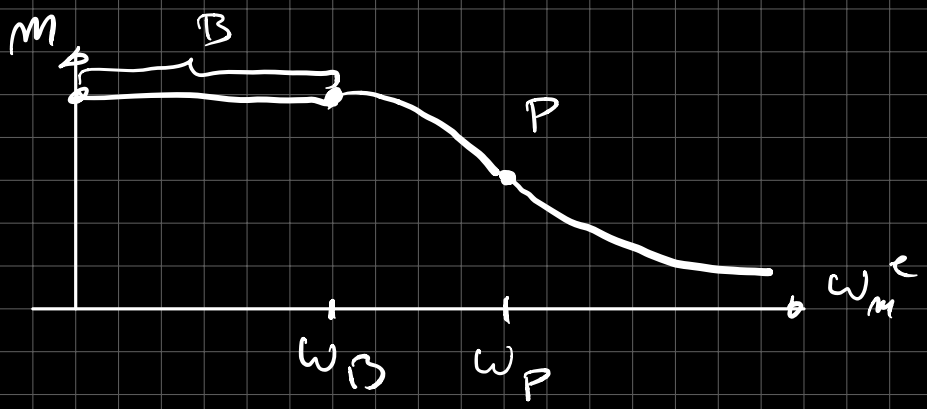


PUÒ SUCCEDERE SE $\frac{\lambda_m}{L_d} > I_m$

SE $I_{ch} < I_n$



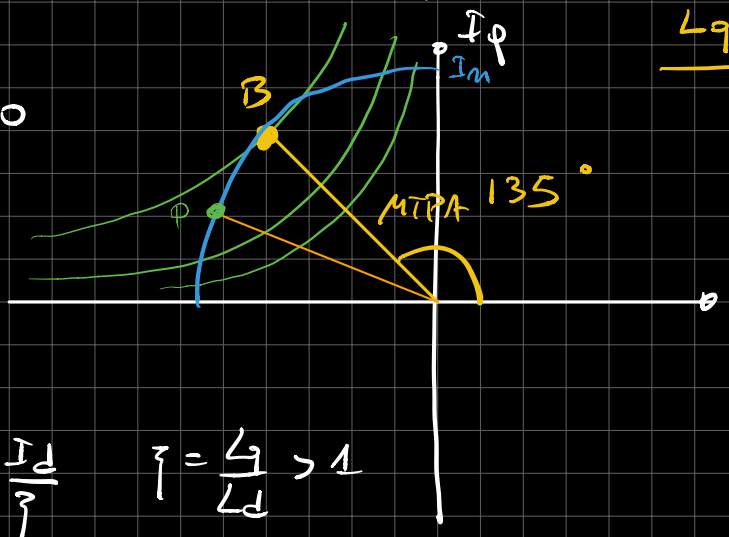
Per ω più elevate di ω_P segue MTPV



Si può dimostrare che il luogo MTPV risulta essere il seguente

$$I_q = \frac{L_d}{L_q}\sqrt{\frac{-\left(I_d+\frac{\Lambda_m}{L_d}\right)\left[\Lambda_m+(L_d-L_q)I_d\right]}{L_d-L_q}}$$

Nel caso REL $\Lambda_m = 0$



$L_q > L_d$

MTPA: $\alpha_i = 135°$

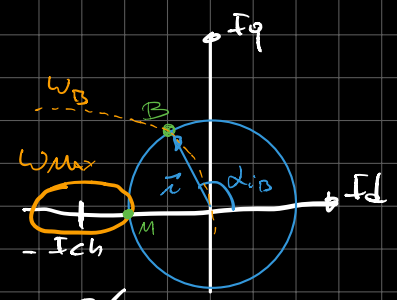
$$I_d = -I_q = -\frac{I}{\sqrt{2}}$$

MTPV: $I_q = -\frac{L_d}{L_q} I_d = -\frac{I_d}{\xi}$ $\quad \xi = \frac{L_q}{L_d} > 1$

ESEMPIO ① MOTORE IPM

$2p = 4$
$\lambda_m = 0{,}4\ Vs$
$L_d = 16\ mH$
$L_q = 26\ mH$
$R \cong 0$

$V_m = 210\ V$
$I_m = 20\ A$



$$I_{ch} = \frac{\lambda_m}{L_d} = \frac{0{,}4}{0{,}016} = 25\ A > I_m$$

a) Calcolare la massima coppia che il motore può sviluppare

$$\cos\alpha_{iB} = \frac{-\lambda_m + \sqrt{\lambda_m^2 + 8(L_d - L_q)^2 I_m^2}}{4(L_d - L_q) I_m}$$

$$= \dots = -0{,}186 \qquad \alpha_{iB} = 109{,}72°$$

$$\begin{cases} I_{dB} = I_m \cos\alpha_{iB} = -3{,}72\ A \\ I_{qB} = I_m \operatorname{sen}\alpha_{iB} = 19{,}65\ A \end{cases}$$

$$m_B = \frac{3}{2} p \left[\lambda_m I_{qB} + (L_d - L_q) I_{dB} I_{qB} \right]$$

$$= \dots = 24{,}55\ Nm$$

b) Calcolare la velocità base

$$V_d^2 + V_q^2 = V_m^2 \qquad \begin{cases} I_d = I_{dB} \\ I_q = I_{qB} \\ \omega_m^e = \omega_B \end{cases}$$

$$(\omega_B \lambda_q)^2 + (\omega_B \lambda_d)^2 = V_m^2$$

$$\omega_B^2 \left[(L_q I_{qB})^2 + (\lambda_m + L_d I_{dB})^2 \right] = V_m^2$$

$$\omega_B = \frac{V_m}{\sqrt{(L_q I_{qB})^2 + (\lambda_m + L_d I_{dB})^2}} = \frac{210}{\sqrt{(902 \cdot 19{,}65)^2 + (0{,}4 + 0{,}016 \cdot 3{,}72)^2}}$$

$$= 503{,}8\ \frac{rad}{s}$$

$$\omega_{Bm} = \frac{\omega_B}{p} = 201{,}9\ \frac{rad}{s} = 1929\ rpm$$

c) Calcolare la velocità massima ω_{max}

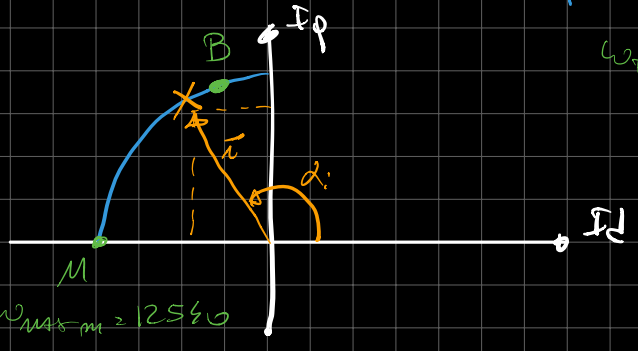
$$V_d^2 + V_q^2 = V_m^2$$

$\omega_m^e = \omega_{max}$
$I_q = 0$
$I_d = -I_m$

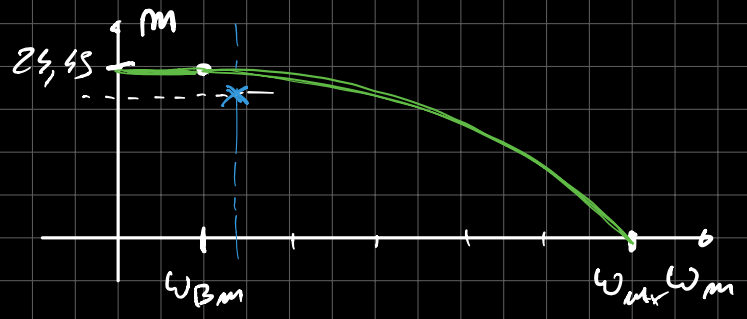
$$\omega_{max} = \frac{V_m}{\lambda_m - L_d I_m} = \frac{210}{0{,}5 - 0{,}016 \cdot 20} = 2625 \ \frac{rad}{s}$$

$$\omega_{max\,m} = \frac{\omega_{max}}{p} = 1312{,}5 \ \frac{rad}{s} = 12540 \ rpm$$

d) Calcolare la massima coppia che si può ottenere alla velocità di 2200 rpm



$\omega_{B\,m} = 1929$ rpm 25,55 Nm



Nel punto X posso scrivere:

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

$$\begin{cases} \omega_m^e = 560 \ \frac{rad}{s} = p \cdot \omega_m = p \cdot \frac{2\pi \cdot 2200}{60} \\ I_d = I_{dx} \\ I_q = I_{qx} \end{cases}$$

$$\left(\omega_m^e L_q I_{qx}\right)^2 + \omega_m^{e\,2}\left(\lambda_m + L_d I_{dx}\right)^2 = U_m^2$$

$$\left(L_q I_{qx}\right)^2 + \left(\lambda_m + L_d I_{dx}\right)^2 = \left(\frac{U_m}{\omega_m^e}\right)^2$$

$$\left(L_q I_m \sin\alpha_{ix}\right)^2 + \left(\lambda_m + L_d I_m \cos\alpha_{ix}\right)^2 = \left(\frac{U_m}{\omega_m^e}\right)^2$$

$$\left(0{,}5 \underbrace{\sin\alpha_{ix}}_{1-\cos\alpha_{ix}^2}\right)^2 + \left(0{,}5 + 0{,}32\cos\alpha_{ix}\right)^2 = 0{,}2085$$

$$-0{,}0576\,\cos^2\alpha_{ix} + 0{,}256\,\cos\alpha_{ix} + 0{,}1116 = 0$$

$$\cos\alpha_{ix} = \begin{cases} -0{,}4 \\ 4{,}85 \end{cases}$$

$$I_{dx} = I_M \cos\alpha_{ix} = 20\,(-0{,}4) = -8\,A$$

$$I_{qx} = \sqrt{20^2 - 8^2} = 18{,}33\,A$$

$$m_x = \frac{3}{2} p \left[\lambda_m I_{qx} + (L_d - L_q) I_{dx} I_{qx} \right]$$

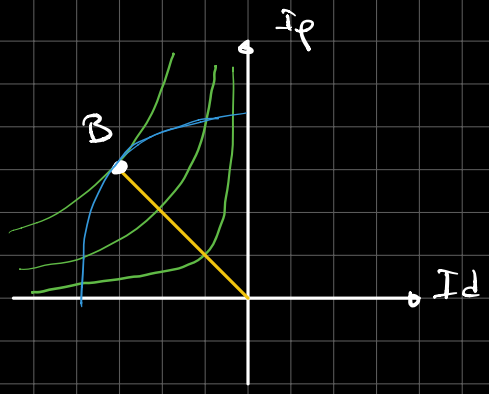
$$= 23{,}76\ Nm$$

ESEMPIO ② Motore REL

$\lambda_m = 0$
$L_d = 100\ mH$
$L_q = 500\ mH$
$2p = 4$

$U_M = 180\,V$

$I_M = 10{,}85\,A$



a+b: Determinare il punto base

MTPA: $\alpha_i = 45 + 90 = 135°$

$$I_{dB} = -I_M/\sqrt{2} = -10{,}85/\sqrt{2} = -7{,}67\,A$$

$$I_{qB} = I_M/\sqrt{2} = 10{,}85/\sqrt{2} = 7{,}67\,A$$

$$m_B = \frac{3}{2} p (L_d - L_q) I_d I_q = \frac{3}{2} \cdot 2 \cdot (0{,}1 - 0{,}5)(-7{,}67)\,7{,}67$$

$$= 70{,}59\ Nm$$

$$\lambda_d = L_d I_d = -0{,}767\ Vs$$

$$\lambda_q = L_q I_q = 0{,}5 \cdot 7{,}67 = 3{,}835\ Vs$$

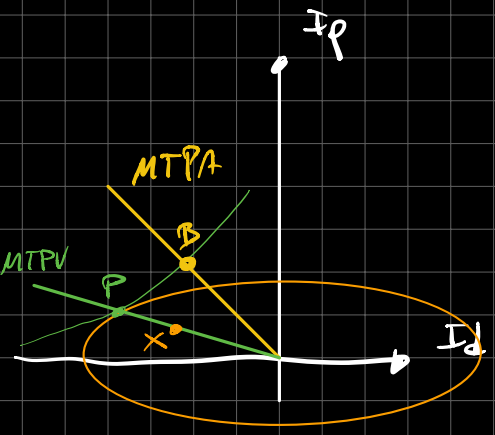
$$\omega_B = \frac{U_M}{\lambda} = \frac{U_M}{\sqrt{\lambda_d + \lambda_q}}$$

$$= \frac{180}{\sqrt{0{,}767^2 + 3{,}835^2}}$$

$$= 46{,}02\ \frac{rad}{s}$$

$$\omega_{BM} = 23 \frac{rad}{s} = 220 \text{ rpm}$$

c) Calcolare la traiettoria MTPV



$$I_d' = \frac{L_d}{L_q} I_d$$

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

$$(L_q I_q)^2 + (L_d I_d)^2 = \left(\frac{V_m}{\omega_m^e}\right)^2 \quad \text{ELLISSE}$$

$$(L_q I_q)^2 + \left(L_d \frac{L_q}{L_d} I_d'\right)^2 = \left(\frac{V_m}{\omega_m^e}\right)^2$$

$$(L_q I_q)^2 + (L_q I_d')^2 = \left(\frac{V_m}{\omega_m^e}\right)^2 \quad \text{CERCHIO } I_d' - I_q$$

$$M = \frac{3}{2} p (L_d - L_q) \frac{L_q}{L_d} I_d' I_q$$

MTPV $\quad I_d' = -I_q \quad \Leftrightarrow \quad \frac{L_d}{L_q} I_d = -I_q \quad \Rightarrow \quad I_d = -\frac{L_q}{L_d} I_q$

$$= -\gamma I_q$$

$$\tan \alpha_p = \frac{I_q}{I_d} = -\frac{1}{\gamma}$$

Nel nostro esempio $\tan \alpha_p = -\frac{1}{\gamma} = -\frac{1}{5} = -0{,}2$

$$\alpha_p = 168{,}7° \qquad I_{dp} = I_m \cos \alpha_p = -19{,}6\,5\,A$$

$$I_{qp} = I_m \sin \alpha_p = 2{,}13\,A$$

Le coppie in P vale: $M_p = \frac{3}{2} p (L_d - L_q) I_{dp} I_{qp}$

$$= \dots = 27{,}1\,5\ N_m$$

$$\omega_{mp}^e = \frac{V_m}{\sqrt{L_d^2 + L_q^2}} = \dots = 119{,}7 \frac{rad}{s}$$

$$\omega_{mp} = 5{,}1\,85 \frac{rad}{s} = 575 \text{ rpm}$$

d) Calcolare la massima coppia che si ottiene a 750 rpm

Poiché 750 rpm > ω_{mp} = 574 rpm mi muovo sul MTPV

$$\omega_{mH} = \frac{2\pi\, 750}{60} = 78{,}5 \ \frac{rad}{s}$$

$$\omega^e_{mH} = \omega_{mH} \cdot p = 2 \cdot 78{,}5 = 157 \ \frac{rad}{s}$$

$$\lambda_d^2 + \lambda_q^2 = \left(\frac{U_m}{\omega^e_{mH}}\right)^2 \qquad I_d = -3\, I_q \ \Big| = -\frac{L_q}{L_d} I_q$$

$$(L_d I_d)^2 + (\psi_f)^2 = \left(\frac{U_m}{\omega^e_{mH}}\right)^2$$

$$\left(\frac{L_d L_q}{L_d} I_q\right)^2 + (\psi_f I_q)^2 = \left(\frac{U_m}{\omega^e_{mH}}\right)^2$$

$$2(\psi_f I_q)^2 = \left(\frac{U_m}{\omega^e_{mH}}\right)^2 \Rightarrow \quad I_q = \frac{U_m}{\omega^e_{mH} L_q} \frac{1}{\sqrt{2}} = \dots = 1{,}62 \ A$$

$$I_d = -3\, I_q = -5 \cdot 1{,}62 = -8{,}1 \ A$$

$$I = \sqrt{I_d^2 + I_q^2} = 8{,}26 \ A \quad < I_m$$

$$m = \frac{3}{2} p (L_d - L_q) I_d I_q = \frac{3}{2} \cdot 2 \cdot 0{,}4 \cdot 1{,}62 \cdot 8{,}1 = 15{,}75 \ Nm$$