Potenza meccanica

$$T_{em}\,\omega = K_T \phi_f i_a \omega$$

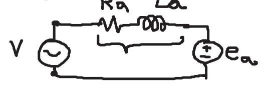
Potenza elettrica

$$e_a i_a = K_e \phi_f \omega i_a$$

in assenza di perdite $K_e = K_T$

" presenza " " $K_e > K_T$

avvolgimento di armatura



$$V(s) = (R_a + L_a s) I_a + E_a$$

$$T_{em} = \underset{\text{meccanica}}{T_W} + \underset{\text{momento d'inerzia}}{J}\dot{\omega} + \underbrace{B\omega}_{\text{attrito}}$$

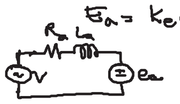
Condizioni stazionarie

29 May 2014 09:05

ϕ_f COSTANTE [MAGNETE PERMANENTE]

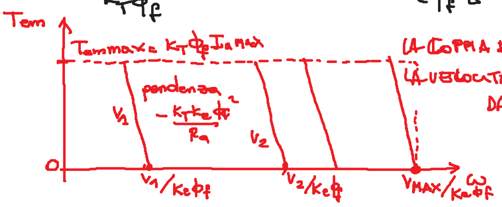
$$T_{em} = k_T \phi_f I_a$$

$$E_a = k_e \phi_f \omega$$



$$V = (R_a + \underbrace{jL_a\omega}_{\text{trascuriamo}}) I_a + E_a$$

$$V = \frac{R_a T_{em}}{k_T \phi_f} + k_e \phi_f \omega \rightarrow \omega = \frac{1}{k_e \phi_f}\left[V - \frac{R_a \overset{T_W}{T_{em}}}{k_T \phi_f}\right]$$



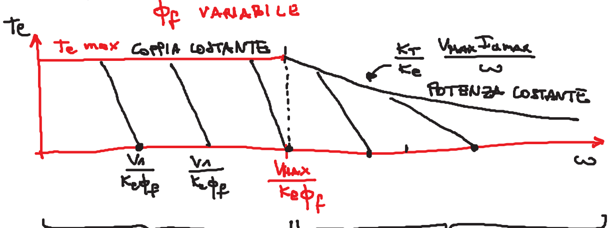
LA COPPIA DIPENDE DA I_a

LA VELOCITÀ DIPENDE DA VA

Macchina con eccitazione indipendente

29 May 2014 09:17

ϕ_f VARIABILE



ϕ_f cost e massimo — Potenza max costante

$$\omega = \frac{V_{max}}{k_e \phi_f} \rightarrow \phi_f = \frac{V_{max}}{K_e \omega}$$

$$T_{e\,max} = k_T \phi_f I_{a\,max} = \frac{K_T}{K_e}\frac{V_{max} I_{a\,max}}{\omega}$$

Modello del motore in continua

29 May 2014 09:23

$$V = E_a + (R_a + L_a s) I_a$$

$$T_{em} = K_T \phi_f I_a = T_W + J s \omega + B\omega$$

$$E_a = K_e \phi_f \omega$$

$$I_a = \frac{V - E_a}{R_a + L_a s} = \frac{T_{em}}{K_T \phi_f} = \frac{T_W + (Js + B)\omega}{K_T \phi_f}$$

$$[V - K_e \phi_f \omega] K_T \phi_f = [T_W + (Js + B)\omega][R_a + L_a s]$$

$$\omega\left[(Js + B)(R_a + L_a s) + K_e K_T \phi_f^2\right] = V K_T \phi_f - T_W (R_a + L_a s)$$

Funzione di trasferimento

29 May 2014 09:31

$$G = \frac{\omega}{V} = \frac{K_T \phi_f / J L_a}{s^2 + \left[\frac{R_a J + B L_a}{J L_a}\right] s + \left[\frac{K_T K_e \phi_f^2 + B R_a}{J L_a}\right]}$$

Hp 2 poli molto diversi: $|s_m| << |s_e|$

den: $(s - s_m)(s - s_e)$

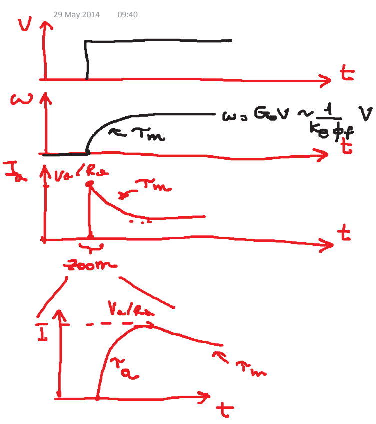
$$s^2 - \underbrace{(s_m + s_e)}_{\simeq s_e} s + s_m s_e$$

$$s_e = -\left(\frac{R_a}{L_a} + \frac{B}{J}\right) \qquad s_m = -\left[\frac{K_T K_e \phi_f^2 + B R_a}{R_a J + B L_a}\right]$$

se trascuriamo B:

$$s_e = -\frac{R_a}{L_a} = -\frac{1}{\tau_a} \qquad s_m = -\frac{K_T K_e \phi_f^2}{R_a J} = -\frac{1}{\tau_m}$$

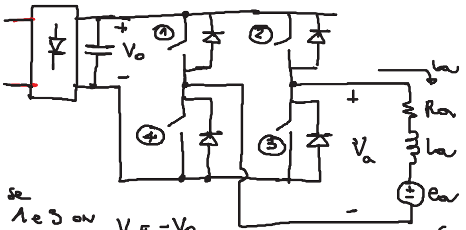
29 May 2014 09:40



Convertitore a 4 quadranti

29 May 2014 09:46

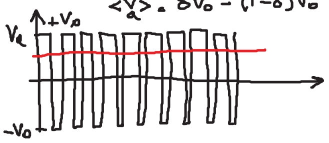
$V_a \gtrless 0$
$I_a \gtrless 0$



se
1 e 3 ON
2 e 4 OFF $V_a = -V_o$

$\langle V_a \rangle = \delta V_o - (1-\delta) V_o$

se
1 e 3 OFF $V_a + V_o$
2 e 4 ON



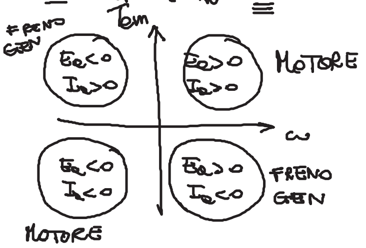
IN FRENATA
(comportamento da generatore)

29 May 2014 09:52

$V = R_a I_a + E_a$
(ω)

$T_{em} = k_T \phi_p I_a = T_w + J\dot{\omega} + B\omega$

$T_{em}\,\omega = E_a I_a$



29 May 2014 10:00

T_{CONV}

$V = (R_a + L_a s) I_a + E_a$

$v(t) = L_a \frac{di_a}{dt} + e_a(t)$

$\langle V \rangle + v_a(t) = L_a \frac{di_a}{dt} + E_a$

caso peggiore in un semiperiodo

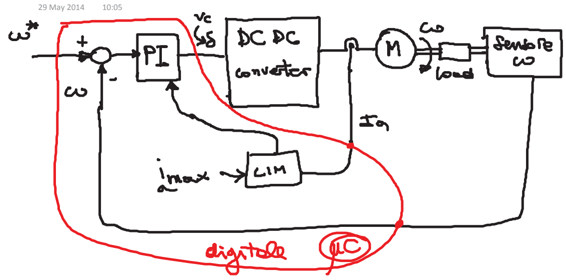
$2V_o = L_a \frac{\Delta i_a}{T/2}$

$\Delta i_a = \frac{V_o}{f L_a} \rightarrow \Delta T = k_T \phi_p \Delta i_a$

aumentando f il ripple si riduce

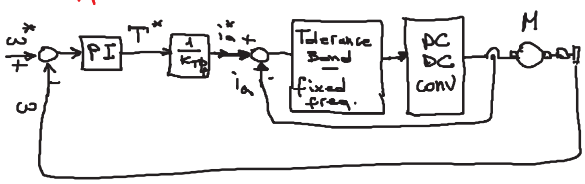
Controllo di motore in continua

29 May 2014 10:05

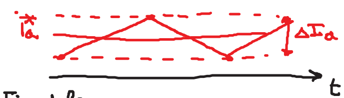


Doppio loop con controllo di corrente

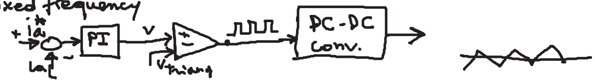
29 May 2014 10:13



Tolerance band



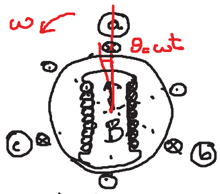
Fixed frequency



Motore Sincrono

29 May 2014 14:45

- servomotori
- motori a velocità variabile



statore a 1 polo

Rotore
- magnete permanente ($<$ kW)
  Brushless
- avvolgimento di campo ($>$ kW)

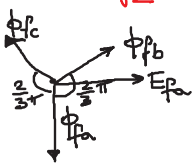
ϕ_{fa} flusso del campo magnetico del rotore concatenato con una spira dell'avvolgimento a dello statore $\phi_{fa} = \phi_f \sin(\omega t)$

29 May 2014 14:57

e_{fa} forza elettromotrice indotta sull'avvolgimento ⓐ

$$e_{fa}(t) = N_s \frac{d\phi_{fa}}{dt}(t) = N_s \phi_f \omega \cos(\omega t)$$

$$E_{fa} = \frac{N_s \phi_f \omega}{\sqrt{2}}$$ Valore efficace



$$\phi_{fb} = \phi_f \sin\left(\omega t + \frac{2}{3}\pi\right)$$

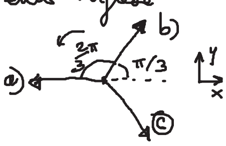
$$\phi_{fc} = \phi_f \sin\left(\omega t - \frac{2}{3}\pi\right)$$

Campo magnetico rotante generato dallo statore

29 May 2014 15:02

→ alimentato da una terna di correnti trifase

$$i_a = \sqrt{2} I_a \sin(\omega t + \delta)$$
$$i_b = \sqrt{2} I_a \sin\left(\omega t + \frac{2}{3}\pi + \delta\right)$$
$$i_c = \sqrt{2} I_a \sin\left(\omega t - \frac{2}{3}\pi + \delta\right)$$



COMPONENTE X del campo magnetico

$$\underbrace{-B\sin(\omega t + \delta)}_{a} + \underbrace{\frac{B}{2}\sin\left(\omega t + \frac{2}{3}\pi + \delta\right)}_{b} + \underbrace{\frac{B}{2}\sin\left(\omega t - \frac{2}{3}\pi + \delta\right)}_{c}$$

$$= -B\sin(\omega t+\delta) + \frac{B}{2}\sin(\omega t+\delta)\cos\left(\frac{2}{3}\pi\right) + \cancel{\frac{B}{2}\cos(\omega t+\delta)\sin\frac{2}{3}\pi}$$
$$+ \frac{B}{2}\sin(\omega t+\delta)\cos\left(-\frac{2}{3}\pi\right) + \cancel{\frac{B}{2}\cos(\omega t+\delta)\sin\left(-\frac{2}{3}\pi\right)} =$$
$$-\frac{3}{2}B\sin(\omega t+\delta)$$

29 May 2014 15:12

COMPONENTE Y

$$\underbrace{B\sin\left(\omega t+\delta+\frac{2}{3}\pi\right)\sin\left(\frac{\pi}{3}\right)}_{b} + \underbrace{B\sin\left(\omega t+\delta-\frac{2}{3}\pi\right)\sin\left(-\frac{\pi}{3}\right)}_{c}$$

$$\frac{\sqrt{3}}{2}B\left[\cancel{\sin(\omega t+\delta)\cos\left(\frac{2}{3}\pi\right)} + \cos(\omega t+\delta)\sin\left(\frac{2}{3}\pi\right)\right] +$$

$$-\frac{\sqrt{3}}{2}B\left[\cancel{\sin(\omega t+\delta)\cos\left(-\frac{2}{3}\pi\right)} + \cos(\omega t+\delta)\sin\left(-\frac{2}{3}\pi\right)\right] =$$

$$= \frac{3}{2}B\cos(\omega t+\delta)$$

Campo magnetico rotante di ampiezza costante $\frac{3}{2}B$, velocità angolare ω

29 May 2014 15:18

ϕ_{sa} flusso del campo magnetico di statore concatenato con l'avvolgimento ⓐ [una spira]

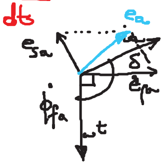
$$N_s \phi_{sa} = L_a i_a$$

↳ $\frac{3}{2}$ l'induttanza di ⓐ con b e c in c.a.

numero spire dell'aw di statore

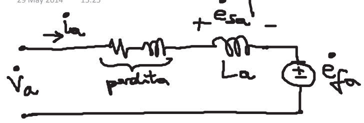
f.e.m. su ⓐ $\quad e_{sa}(t) = N_s \frac{d\phi_{sa}}{dt} = L_a \frac{di_a}{dt}$

$$i_a = \sqrt{2} I_a \sin(\omega t + \delta)$$
$$e_{sa} = \sqrt{2} I_a L_a \omega \cos(\omega t + \delta)$$



Circuito elettrico equivalente dell'aw. ⓐ

29 May 2014 15:25



$$P_{em} = i_a \cdot e_{fa} = I_a E_{fa} \cos\left(\delta - \frac{\pi}{2}\right) = \frac{I_a N_s \phi_f \omega}{\sqrt{2}} \cos\left(\delta - \frac{\pi}{2}\right)$$

· 3 avvolgimenti $\quad P_{em} = \frac{3}{\sqrt{2}} I_a N_s \phi_f \omega \sin\delta = T_{em}\omega$

la coppia

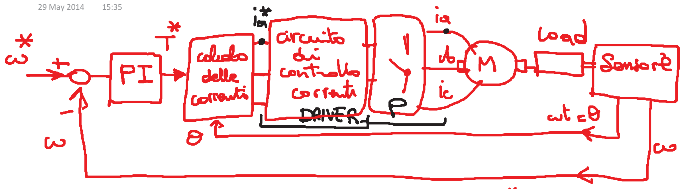
- NON dipende da ω
- è max se $\delta = \pi/2$

$$T_{em} = \frac{3}{\sqrt{2}} I_a N_s \phi_f \sin\delta$$

↳ la velocità angolare di rotazione del ROTORE è uguale alla pulsazione delle correnti di alim.

:) Eccitazione SINUSOIDALE

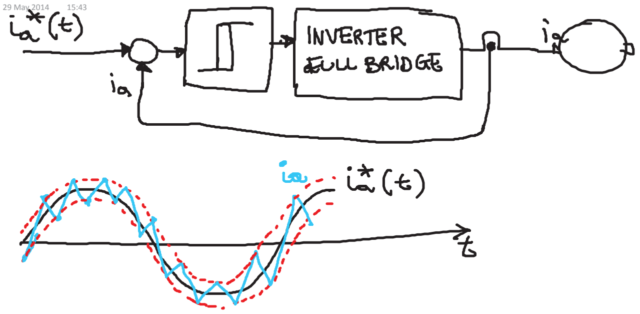
29 May 2014 15:35



$$T^* \Rightarrow I_s^* = \frac{T^* \sqrt{2}}{3 N_s \phi_f}$$

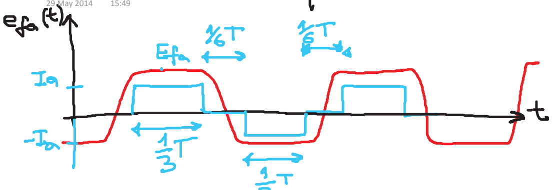
$$i_a^*(t) = I_s^* \sin\left(\omega t + \frac{\pi}{2}\right) = I_s^* \cos\theta$$
$$i_b^*(t) = I_s^* \sin\left(\omega t + \frac{2}{3}\pi + \frac{\pi}{2}\right) = I_s^* \cos\left(\theta + \frac{2}{3}\pi\right)$$
$$i_c^*(t) = I_s^* \cos\left(\theta - \frac{2}{3}\pi\right)$$

29 May 2014 15:43



2) Eccitazione trapezoidale

29 May 2014 15:49



$P_{em} = e_{fa}(t)\, i_a(t)$ → $E_{fa} \cdot I_a$ per $\frac{2}{3}$ del periodo

→ 0 per $\frac{1}{3}$ del periodo

SOMMANDO sulle 3 fasi

$\underline{\underline{P_{em} = 2E_{fa} I_a}}$ COSTANTE! — VANTAGGI