Control of Electrical Drives

Equation set & model salient PM?

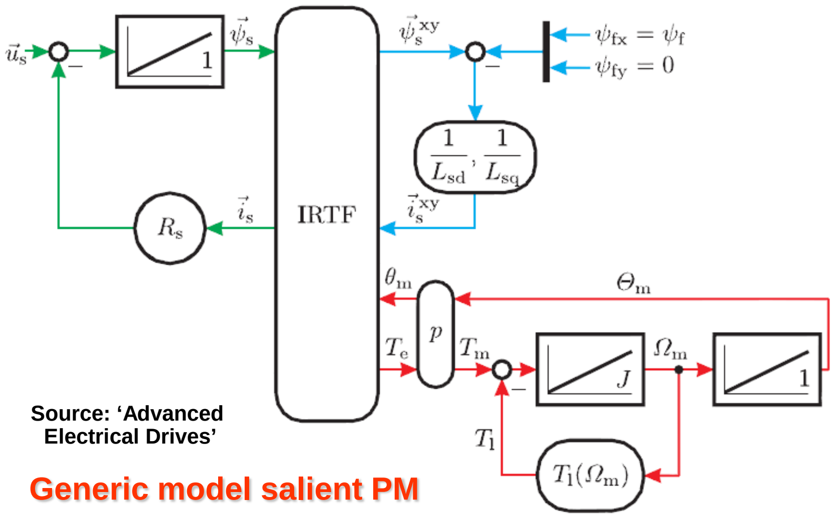
Equation set for 'p' pole pair machine :

- Terminal : $\vec{u}_s = \vec{i}_s R_s + \frac{d\vec{\psi}_s}{dt}$
- Flux (x): $\psi_{sx} = i_{sx} L_{sd} + \psi_f$
- Flux (y): $\psi_{sy} = i_{sy} L_{sq}$
- Torque : $T_e = \frac{3}{2}(\vec{\psi}_s \times \vec{i})$
- Mechanical: $T_m - T_l = J\frac{d\Omega_m}{dt}$
- Rotational: $\Omega_m = \frac{d\Theta_m}{dt}$
- Pole pair related: $T_m = pT_e, \ \theta_m = p\Theta_m$

With permanent magnet flux : ψ_f and mechanical shaft speed Ω_m

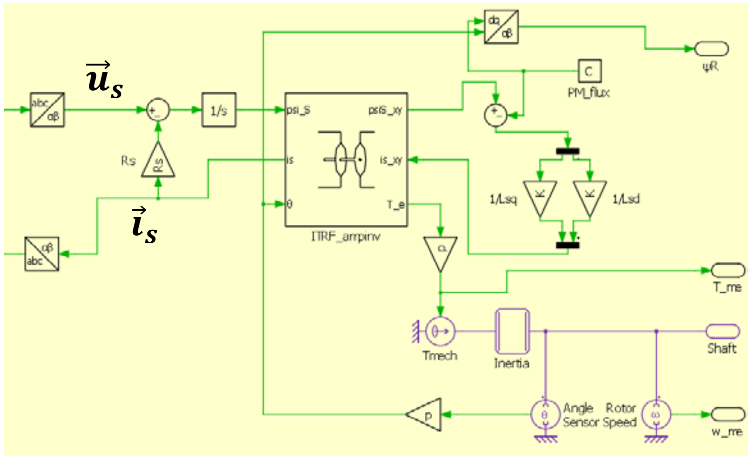
Generic model based on above equation set uses:

- Voltage vector as input
- Dynamic model of mechanical side
- IRTF model
- Load torque module: $T_l(\Omega_m)$



Source: 'Advanced Electrical Drives'

Generic model salient PM



Simulation model salient PM

Current controller?

Field weakening control for non-salient PM machines

Moved from day 2

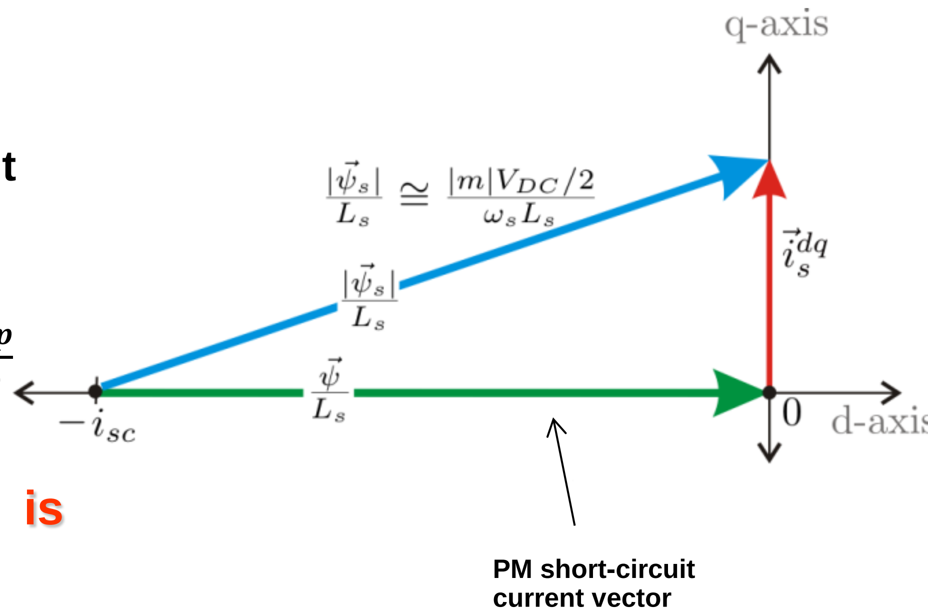
Recall basic motor equations:

$\vec{\psi}_s = \psi + L_s\vec{i}_s$,which can be written as: $\frac{\vec{\psi}_s}{L_s} = i_{sc} + \vec{i}_s$ with, $i_{sc} = \frac{\psi}{L_s}$; PM short-circuit current

$\vec{u}_s = j\omega_s\vec{\psi}_s + R_s\vec{i}_s$, if we ignore $R_s\vec{i}_s$ for simplicity, then the stator flux amplitude can be written as $\psi_s \sim \frac{m\, u_{DC}/2}{\omega_s}$, using $u_s = \frac{m\, u_{DC}}{2}$

Representation in d,q diagram

- Example given with $i_{sd} = 0$
- Modulation index |m| controlled by current controller, If speed increases, |m| must increase to maintain same stator flux value for given d,q current values
- Electrical speed is equal to $\omega_s = n_{shaft}\frac{2\pi p}{60}$



Absolute value of modulation index |m| is limited by current controller. We need to reduce length of stator flux vector if this condition is met and speed needs to be further increased

Field weakening control for PM

Moved from day 2

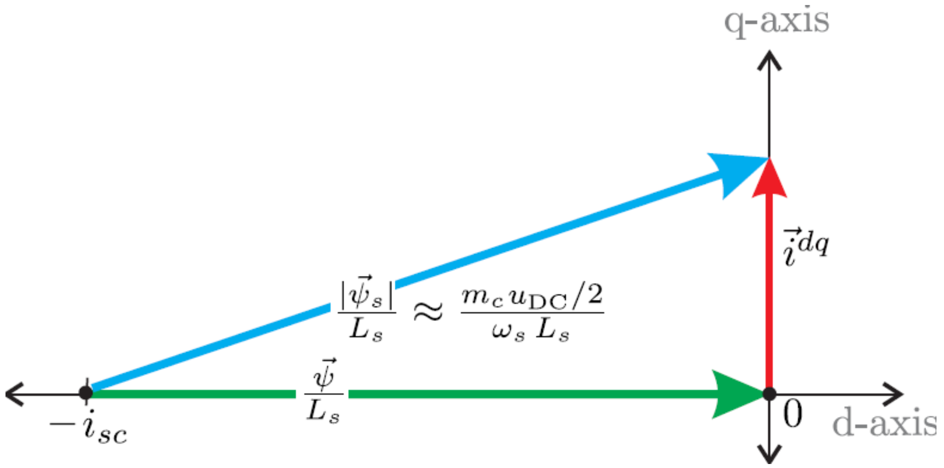
What is the operating speed which can be reached WITHOUT field weakening control?:

The estimate for the speed ω_{sLim} , with $i_{sd} = 0$, can be found using Pythagoras and the d,q diagram namely

$$\left(\frac{m_c \, {}^{u_{DC}}/_{2}}{\omega_{sLim} \, L_s}\right)^2 = (i_{sc})^2 + (i_{sq})^2$$

which gives

$$n_{shLim} = \left(\frac{15}{\pi p L_s}\right) \frac{m_c u_{DC}}{\sqrt{(i_{sc})^2 + (i_{sq})^2}}$$



- **A numerical example using the Teknic motor with : $i_{sc} = 35.7$ A, $i_{sq} = 2.6$ A, p $= 4$, $u_{DC} = 24$ V, $L_s = 180.0$ μH and current controller modulation index of m_c=1 gives a theoretical maximum achievable shaft speed (without field weakening) of $n_{shLim} = 4450$ rpm**

How can we extend this speed range?