



Aalto University
School of Electrical
Engineering

Lecture 2: Scalar-Controlled Induction Motor Drive

ELEC-E8402 Control of Electric Drives and Power Converters

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Learning Outcomes

After this lecture and exercises you will be able to:

- ▶ Express the dynamic inverse- Γ model in synchronous coordinates
- ▶ Calculate steady-state operating points and draw the corresponding vector diagrams
- ▶ Explain the operating principle of the scalar control

Outline

Motor Model

Scalar Control

Model in Stator Coordinates

- ▶ Voltage equations

$$\underline{u}_s^s = R_s \underline{i}_s^s + \frac{d\underline{\psi}_s^s}{dt}$$

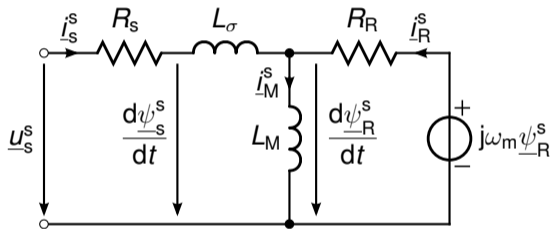
$$\underline{u}_R^s = R_R \underline{i}_R^s + \frac{d\underline{\psi}_R^s}{dt} - j\omega_m \underline{\psi}_R^s = 0$$

- ▶ Flux linkages

$$\underline{\psi}_s^s = L_\sigma \underline{i}_s^s + \underline{\psi}_R^s$$

$$\underline{\psi}_R^s = L_M (\underline{i}_s^s + \underline{i}_R^s)$$

- ▶ Steady state: $d/dt = j\omega_s$



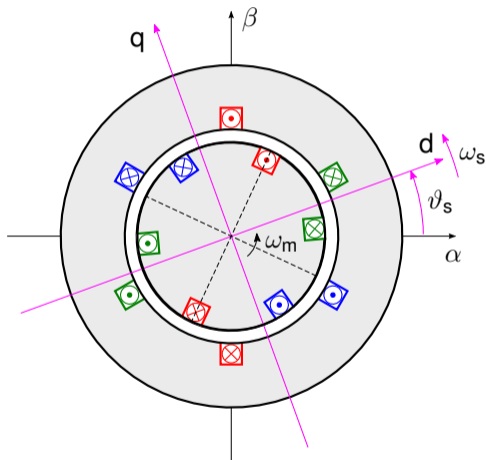
Model in Synchronous Coordinates

- ▶ Synchronous (dq) coordinates rotate at the angular speed ω_s
- ▶ Coordinate transformation $\underline{i}_s^s = \underline{i}_s e^{j\vartheta_s}$, where no superscript is used in synchronous coordinates
- ▶ Voltage equations become

$$\underline{u}_s = R_s \underline{i}_s + \frac{d\underline{\psi}_s}{dt} + j\omega_s \underline{\psi}_s$$

$$\underline{u}_R = R_R \underline{i}_R + \frac{d\underline{\psi}_R}{dt} + j\omega_r \underline{\psi}_R = 0$$

- ▶ Angular speed of the coordinate system
 - ▶ ω_s with respect to the stator
 - ▶ $\omega_r = \omega_s - \omega_m$ with respect to the rotor



Model in Synchronous Coordinates

- ▶ Voltage equations

$$\underline{u}_s = R_s \underline{i}_s + \frac{d\underline{\psi}_s}{dt} + j\omega_s \underline{\psi}_s$$

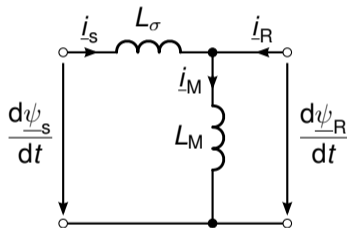
$$\underline{u}_R = R_R \underline{i}_R + \frac{d\underline{\psi}_R}{dt} + j\omega_r \underline{\psi}_R = 0$$

- ▶ Flux linkages

$$\underline{\psi}_s = L_\sigma \underline{i}_s + \underline{\psi}_R$$

$$\underline{\psi}_R = L_M (\underline{i}_s + \underline{i}_R)$$

- ▶ Steady state: $d/dt = 0$



Power Balance

$$\frac{3}{2} \operatorname{Re} \{ \underline{u}_s \underline{i}_s^* + \underline{u}_R \underline{i}_R^* \} = \frac{3}{2} R_s |\underline{i}_s|^2 + \frac{3}{2} R_R |\underline{i}_R|^2 + \frac{dW_f}{dt} + T_M \frac{\omega_m}{p}$$

- ▶ Electromagnetic torque

$$T_M = \frac{3p}{2} \operatorname{Im} \{ \underline{i}_s \underline{\psi}_s^* \}$$

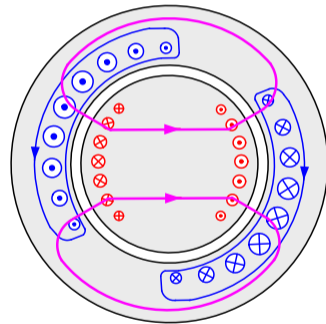
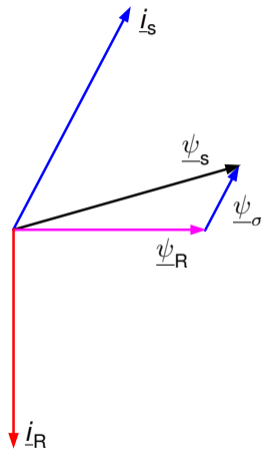
- ▶ Rate of change of the magnetic field energy

$$\frac{dW_f}{dt} = \frac{3}{2} \operatorname{Re} \left\{ \underline{i}_s^* \frac{d\underline{\psi}_s}{dt} + \underline{i}_R^* \frac{d\underline{\psi}_R}{dt} \right\} = \frac{3}{2} \frac{d}{dt} \left(\frac{1}{2} L_\sigma |\underline{i}_s|^2 + \frac{1}{2} L_M |\underline{i}_M|^2 \right)$$

is zero in the steady state

Vector Diagram: Currents and Flux Linkages

- ▶ Airgap and leakage flux paths are sketched
- ▶ All vectors are constant in synchronous coordinates in the steady state (but the rotor slips at $-\omega_r$)



Steady-State Torque

- ▶ Torque in the steady state

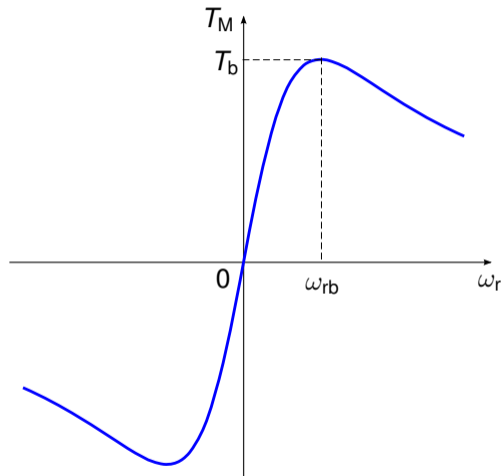
$$T_M = \frac{2T_b}{\omega_r/\omega_{rb} + \omega_{rb}/\omega_r}$$

- ▶ Breakdown torque

$$T_b = \frac{3p}{2} \frac{L_M}{L_\sigma + L_M} \frac{\psi_s^2}{2L_\sigma}$$

- ▶ Breakdown slip

$$\omega_{rb} = \frac{R_R}{\sigma L_M} \quad \text{where} \quad \sigma = \frac{L_\sigma}{L_M + L_\sigma}$$



Outline

Motor Model

Scalar Control

Stator Voltage vs. Stator Frequency

- ▶ Steady-state stator voltage

$$\underline{u}_s = R_s \underline{i}_s + j\omega_s \underline{\psi}_s$$

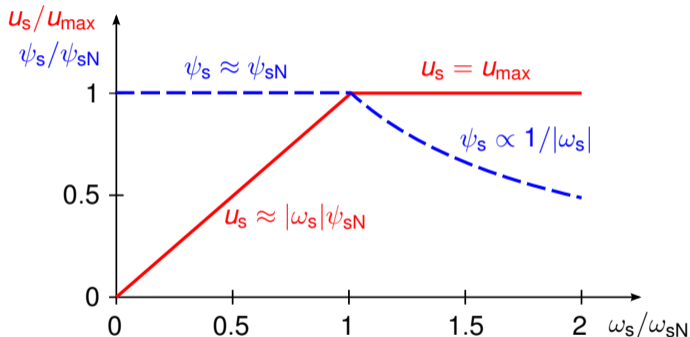
- ▶ Approximate magnitude

$$u_s = |\omega_s| \psi_s$$

where $u_s = |\underline{u}_s|$ and $\psi_s = |\underline{\psi}_s|$

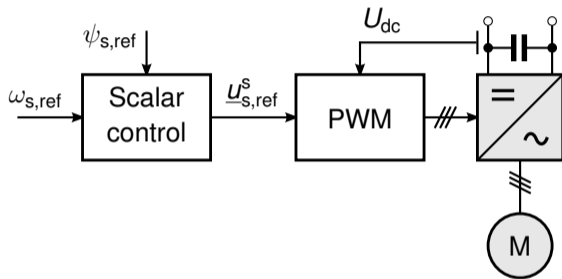
- ▶ Maximum voltage is limited

$$u_s < u_{\max}$$



Scalar Control or Constant-Volts-per-Hertz Control

- ▶ Based on the steady-state equations
- ▶ Supply frequency $\omega_{s,\text{ref}}$ corresponds to the desired rotor speed
- ▶ Some speed error due to the slip (can be partly compensated for)
- ▶ Slow or oscillating dynamics
- ▶ Torque cannot be controlled
- ▶ Current cannot be limited
- ▶ For simple applications



$$u_{s,\text{ref}} = \omega_{s,\text{ref}} \psi_{s,\text{ref}} (+ R_s i_s \text{ compensation})$$

$$\vartheta_s = \int \omega_{s,\text{ref}} dt$$

$$\underline{u}_{s,\text{ref}}^s = u_{s,\text{ref}} e^{j\vartheta_s}$$

