Chapter 12

Induction Motor Drives: Speed Control

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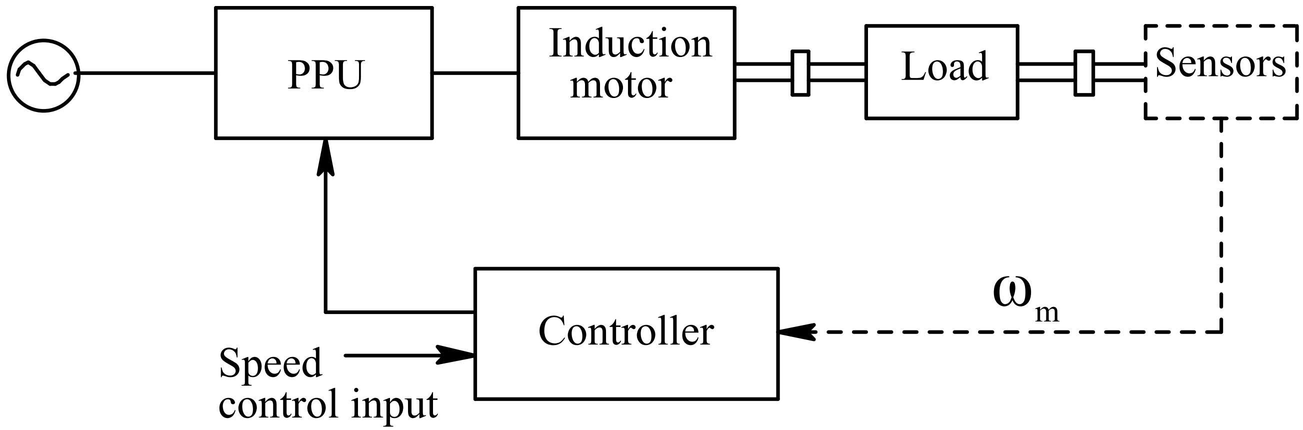


- ❑ Efficient speed control over a wide range
  - Reduced voltage control (inefficient)
  - Frequency control (efficient)
- ❑ PPU drives induction motor with variable frequency to maintain low slip
- ❑ As frequency decreases, voltage must also decrease to avoid magnetic saturation

Rotor Losses

Power crossing air gap to rotor:

$$P_r = T_{em}\,\omega_{syn}$$

Power delivered through rotor to load:

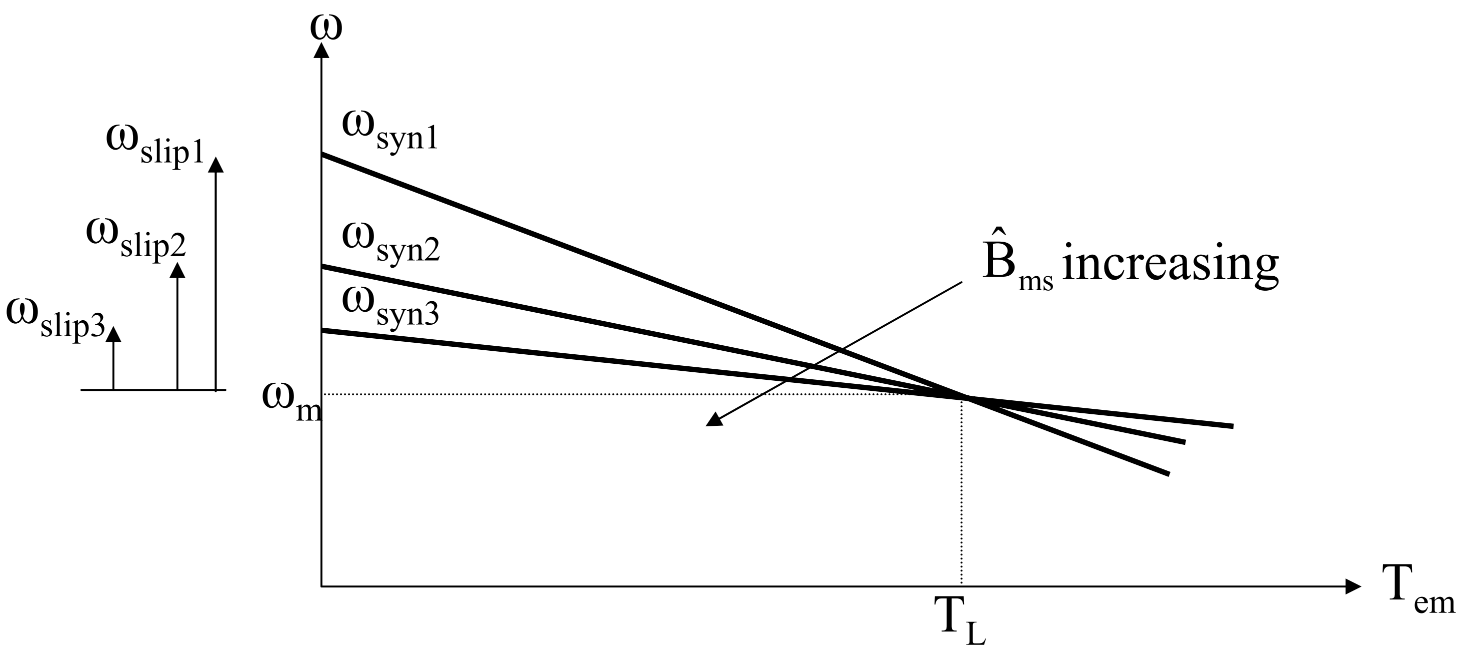
$$P_{em} = T_{em}\,\omega_m$$

Power lost in rotor:

$$P_{r,loss} = P_r - P_{em} = T_{em}\,(\omega_{syn} - \omega_m) = T_{em}\,\omega_{slip}$$

Therefore, to minimize rotor losses, ω_{slip} should be small

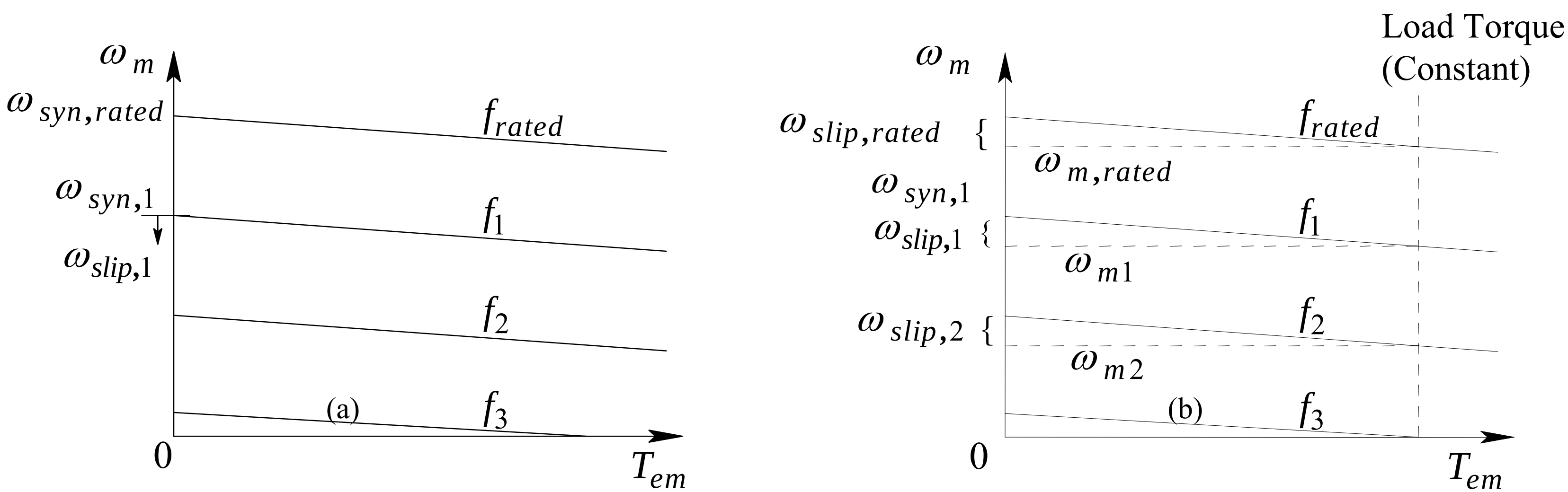
Minimizing ω_{slip} For A Given T_L and ω_m



- ❑ Large flux density allows low slip
- ❑ Keep $\hat{B}_{ms}$ as large as possible – maintain at $\hat{B}_{ms,rated}$

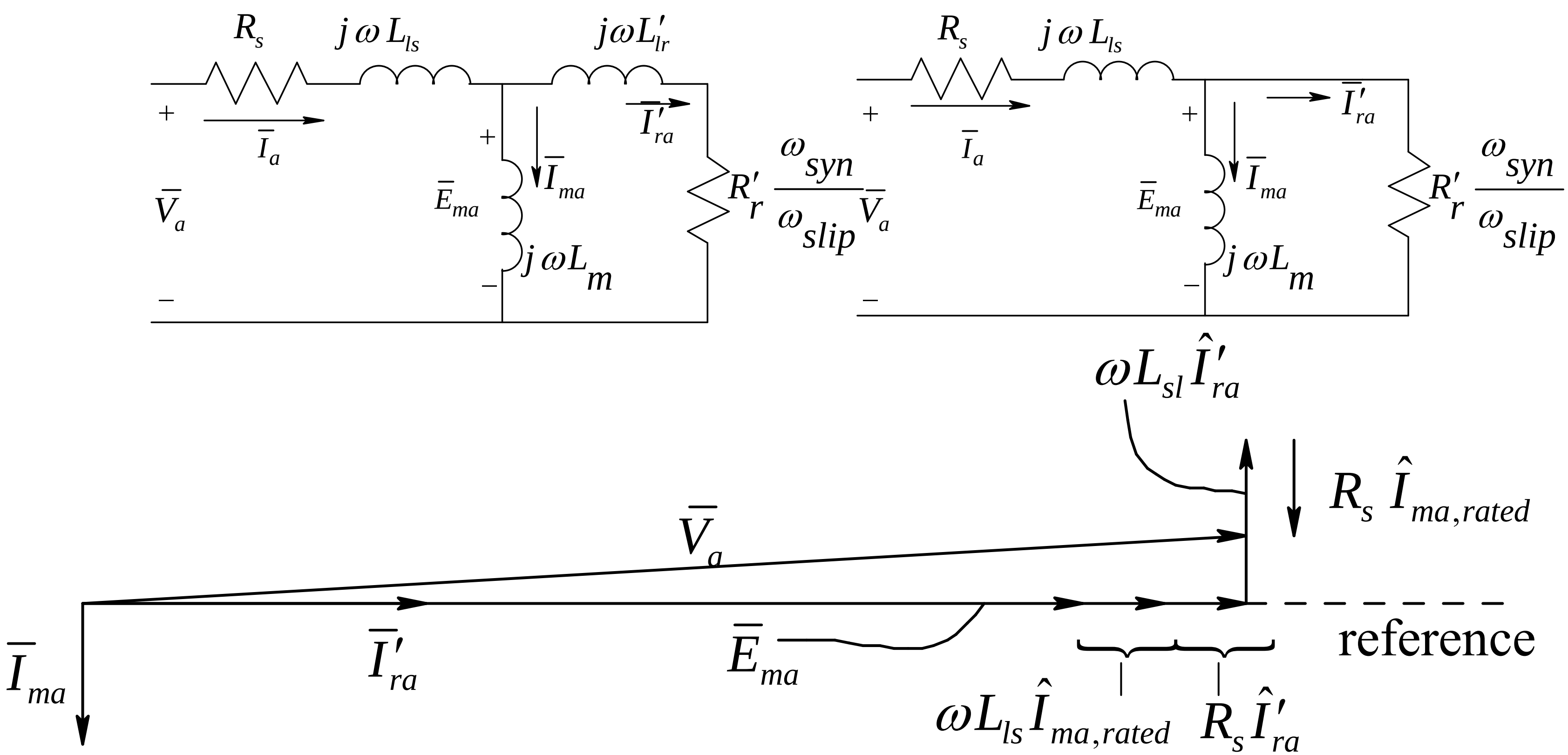
Operating Characteristics with

$$\hat{B}_{ms} = (\hat{B}_{ms})_{rated}$$



- If flux is kept constant, slope will be the same at every frequency
- Load torque and speed are met by adjusting frequency

Maintaining $\hat{B}_{ms,rated}$ Over Operating Frequencies and Current Levels by Adjusting Voltage



Maintaining $\hat{B}_{ms,rated}$ Over Operating Frequencies and Current Levels by Adjusting Voltage (cont…)

- Maintaining constant $\hat{B}_{ms}$ is equivalent to maintaining a constant $\hat{I}_{ma}$ (magnetizing current)
- Since $\hat{I}_{ma} = \dfrac{\hat{E}_{ma}}{\omega L_m}$, $\dfrac{\hat{E}_{ma}}{\omega}$ or $\dfrac{\hat{E}_{ma}}{f}$ should be kept constant
- Ignoring R_s and L_{ls}, this means that $\dfrac{V_a}{f}$ is a constant.

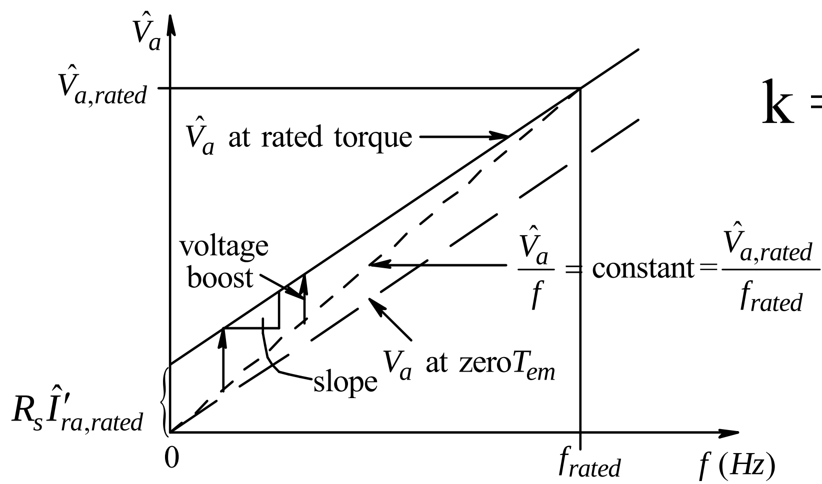
  As f decreases, so should V_a. Constant volts per hertz.
- This is a good first-order approximation

Adjusting Voltage – Stator Resistance Included

- Approximation: $\hat{V}_a = k;\cdot f$ $\quad k = \dfrac{\hat{V}_{a,rated}}{f_{rated}}$
- Including voltage drop across R_s:

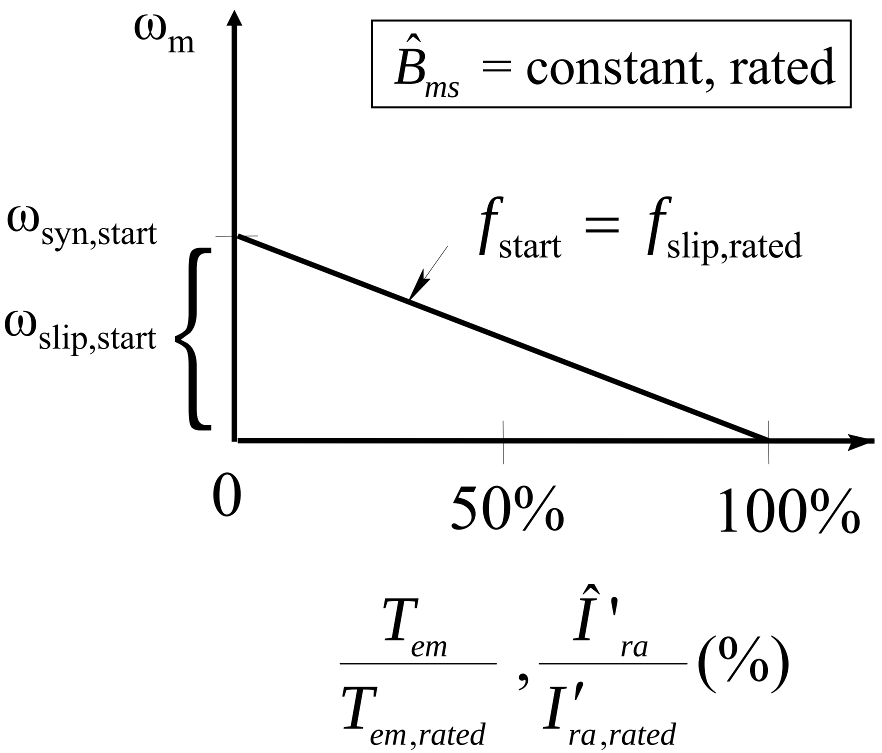
$$\hat{V}_a = k \cdot f + R_s \hat{I}'_{ra}$$

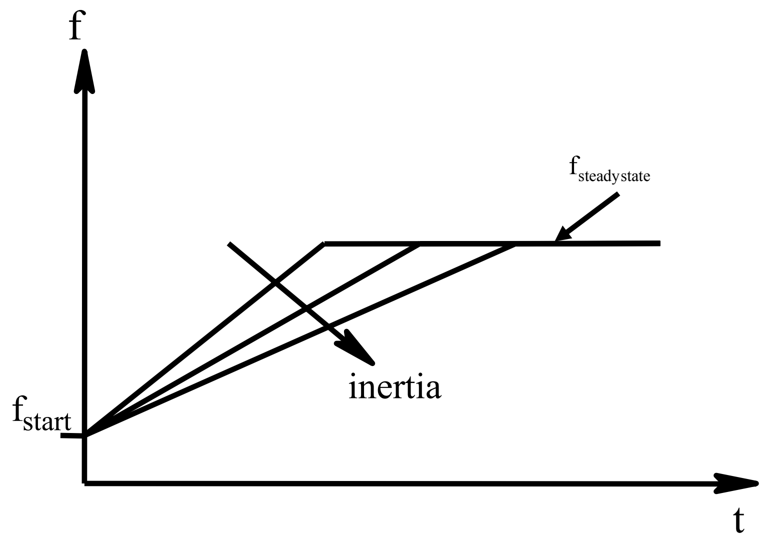
$$k = \frac{(\hat{V}_{a,rated} - R_s \hat{I}'_{ra,rated})}{f_{rated}}$$



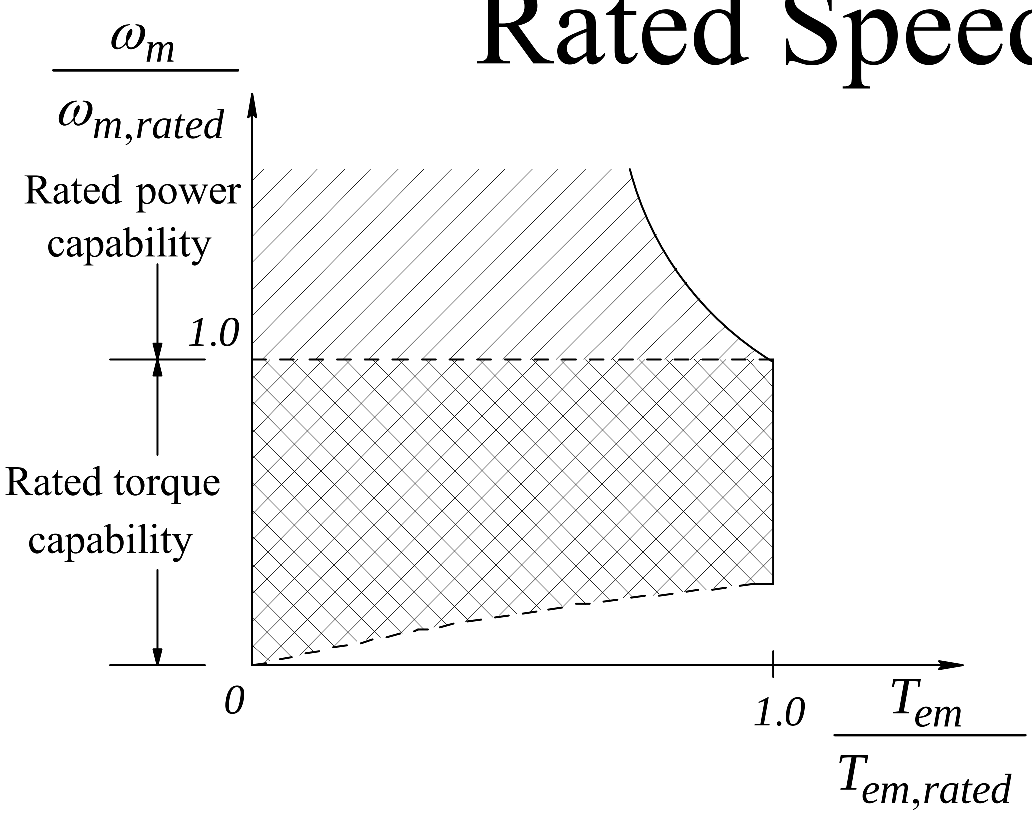
- For large torques, considerable voltage boost is needed at low frequencies. This is the $R_s \hat{I}'_{ra}$ term.

Start-up Considerations



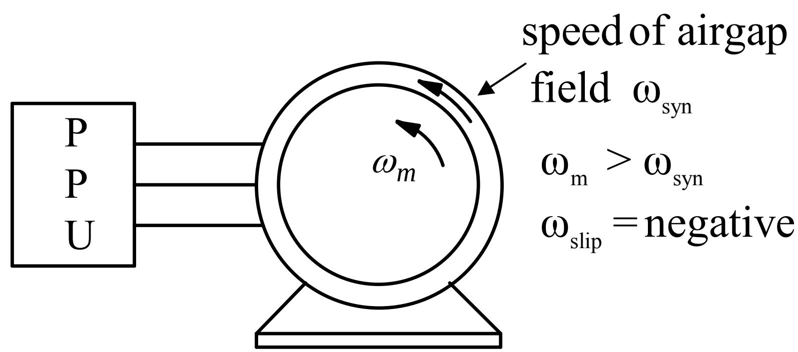


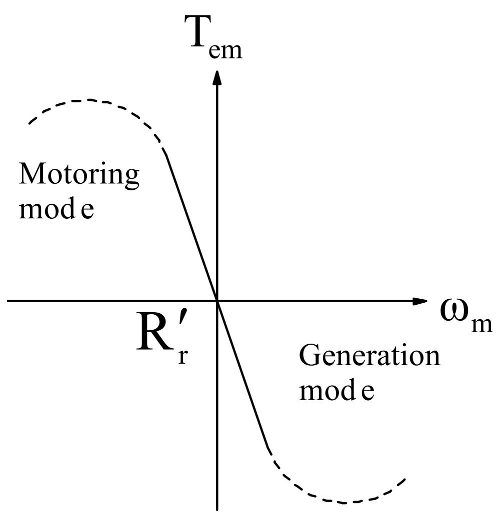
Capability Below and Above Rated Speed

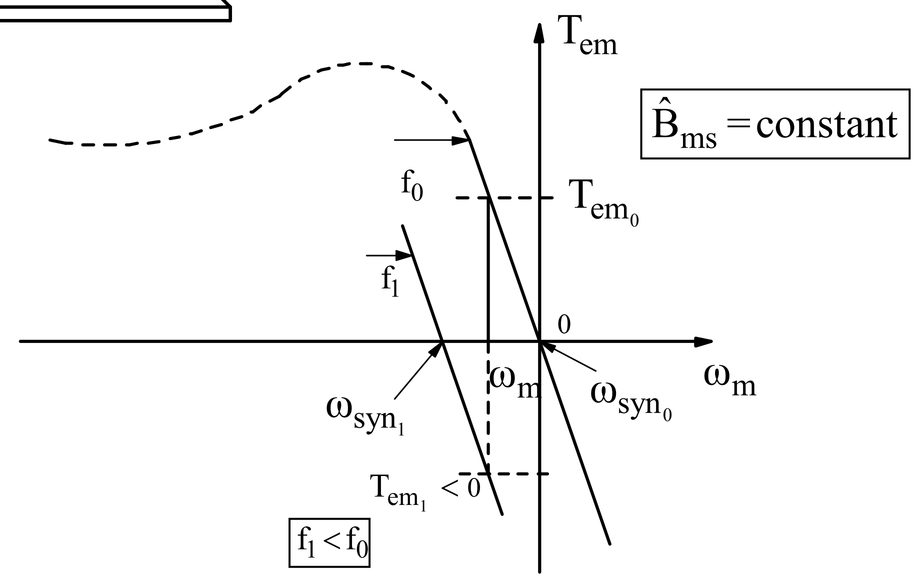


- Voltages limited to rated values, therefore $\hat{B}_{ms}$ must be reduced at higher speeds (Flux Weakening)
- Currents limited to rated values, therefore torque limited when $\hat{B}_{ms}$ is limited

Braking in Induction Motor Drives

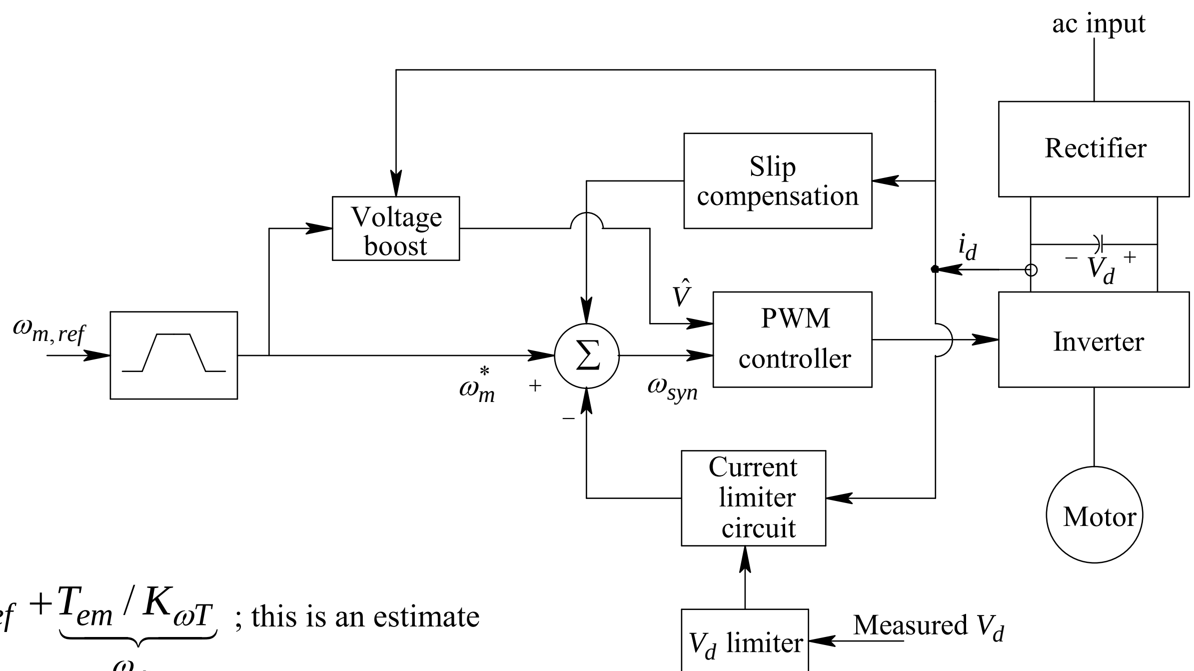






- To initiate braking, lower ω_{syn} to some value less than ω_m
- Braking torque can be adjusted by setting the negative slip frequency

Speed Control of Induction Motor Drives

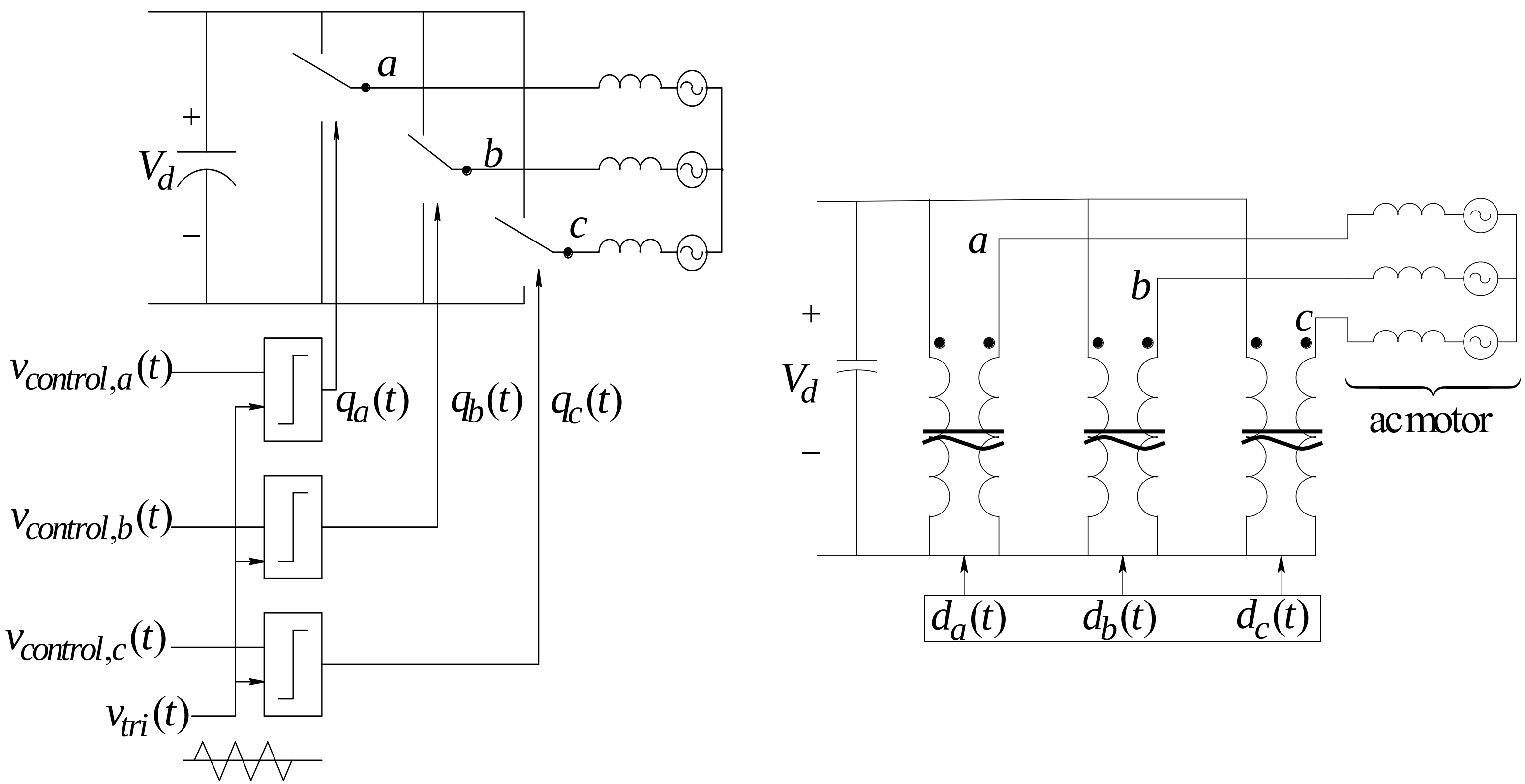


$$\omega_{syn} = \omega_{m,ref} + \underbrace{T_{em} / K_{\omega T}}_{\omega_{slip}}$$; this is an estimate

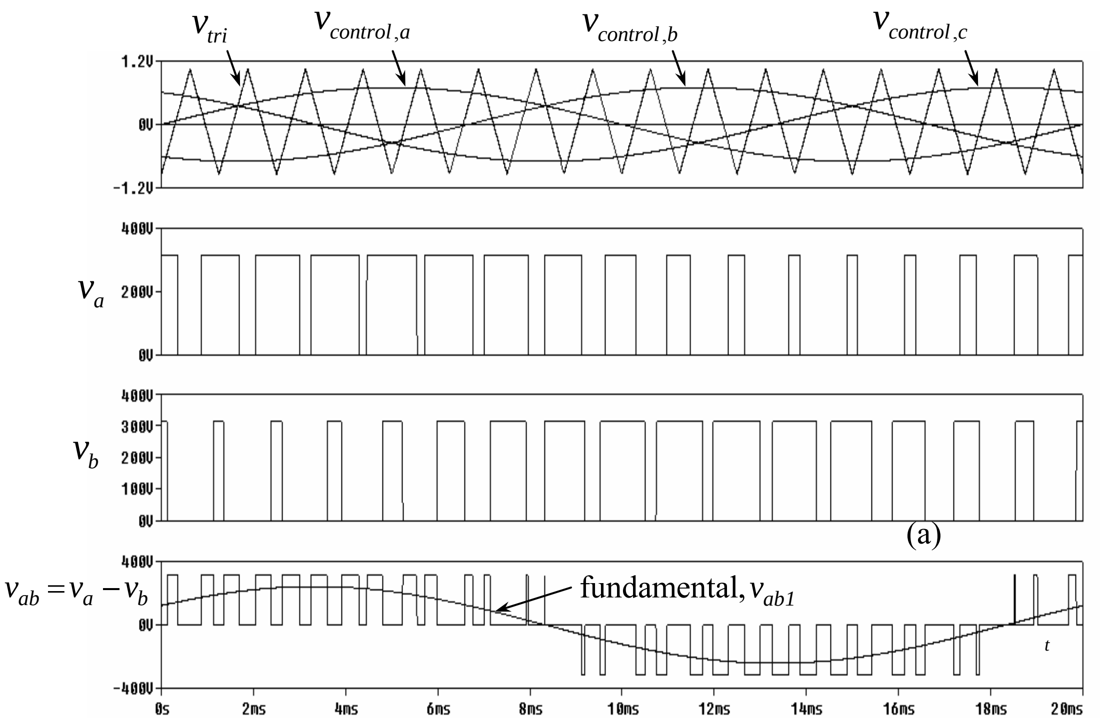
$$V_a = k_f \; f + k_{vT} \, T_{em}$$

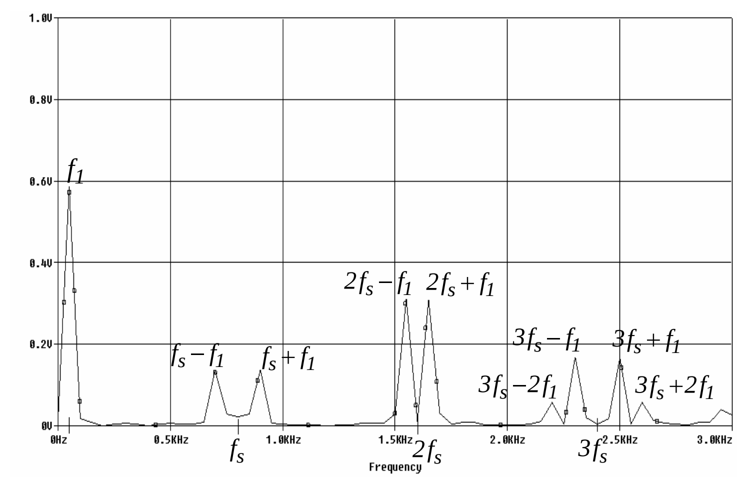
- $\omega_{m,ref}$ is passed through a rate limiter to avoid over driving the motor
- This method does not give precise speed control

Pulse-Width-Modulated Power Processing Unit



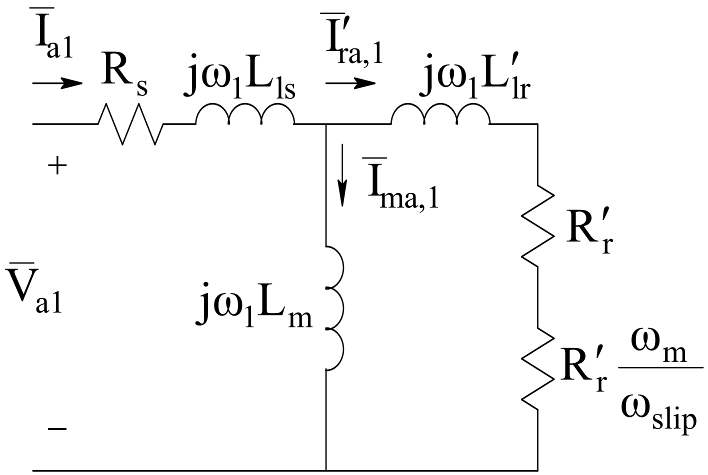
Harmonics in PPU



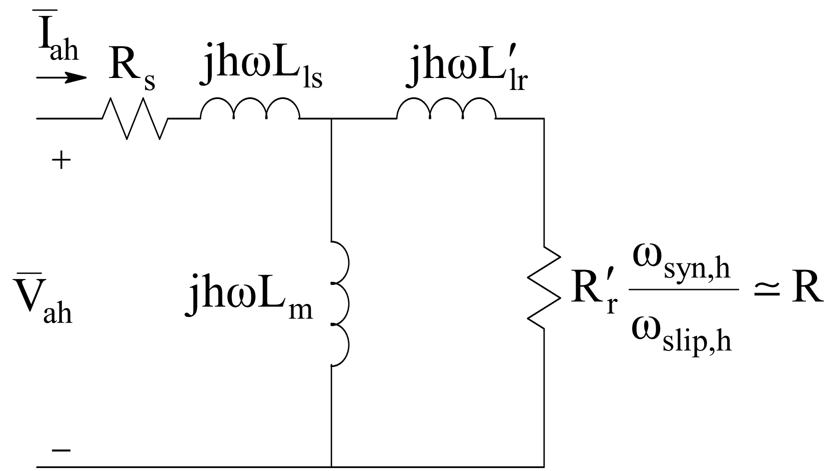


- PPU with switching frequency of 800 Hz generating a fundamental sine wave of 50 Hz
- Frequency spectrum shows large 50 Hz component and smaller components at higher frequencies due to switching
- These higher frequency components add to the losses in the motor

PPU – Supplied Induction Motor



Fundamental Frequency Model

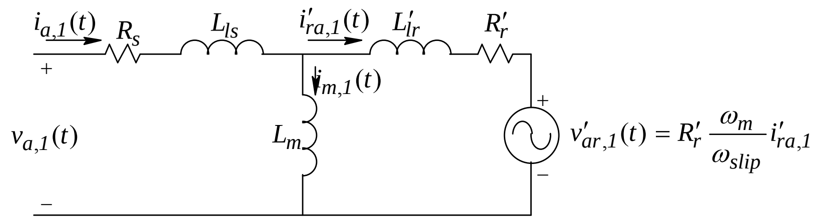


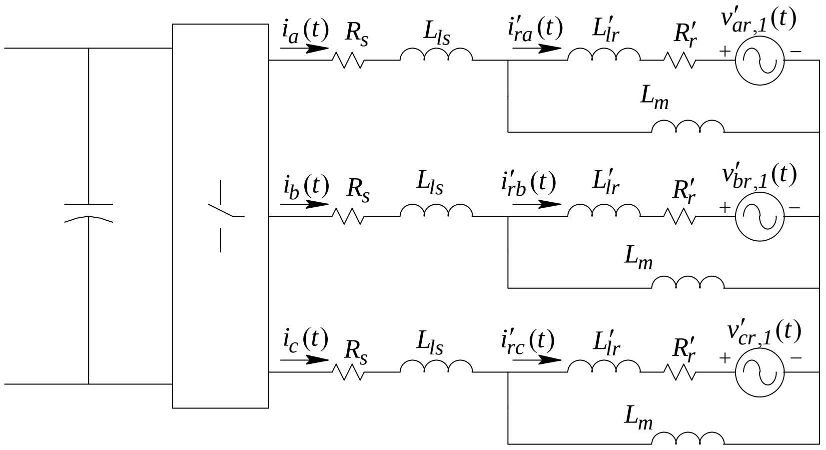
Harmonic Frequency Model

- At harmonic frequencies $R_{eq} \simeq R'_r$
  Magnetizing inductance can be ignored
  Harmonic currents controlled by leakage inductance

$$\hat{I}_{ah} \simeq \frac{\hat{V}_{ah}}{(X_{ls,h} + X'_{lr,h})}$$

PPU – Supplied Induction Motor Model





- Fundamental frequency drop across resistor replaced with AC voltage source
- Harmonic currents produce voltage across R'_r

Summary/Review

- What are the applications of adjustable-speed drives?
- Why are the thyristor-based, voltage reduction circuits for controlling induction-motor speed so inefficient?
- In operating below the rated speed (and not considering the core losses), why is it most efficient to keep the flux-density peak in the air gap at the rated value?
- Since an induction motor is operated at different values of frequency, hence different values of synchronous speed, how is the slip speed defined?
- Supplying a load that demands a constant torque independent of speed, what is the slip speed at various values of the frequency f of the applied voltages?

Summary/Review

- To keep the flux density peak in the air gap at the rated value, why do the voltage magnitudes, at a given frequency of operation, depend on the torque supplied by the motor?
- At start-up, why should small-frequency voltages be applied initially? What determines the rate at which the frequency can be ramped up?
- At speeds below the rated value, what is the limit on the torque that can be delivered, and why?
- At speeds above the rated values, what is the limit on the power that can be delivered, and why? What does it mean for the torque that can be delivered above the rated speed?