

Concordia University
Department of Electrical and
Computer Engineering

ELEC-331

Lecture 11

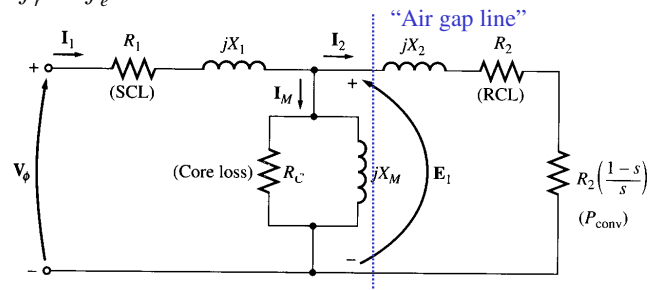
Induction Motors (7.6, 7.8-7.11)

Outline of the lecture

- Determining the circuit model parameters
- Torque x speed characteristics of an IM.
- Effects of the rotor resistance (R_2) on the characteristics of an induction machine.
- Speed control of induction motors.
- Solid-state (power electronics) induction motor drives.

Equivalent circuit of an induction motor

- Shows the power dissipated/converted at each point of the model.
- The magnitude of the currents in the rotor side can be calculated from this circuit but the frequency is still given by: $f_r = sf_e$

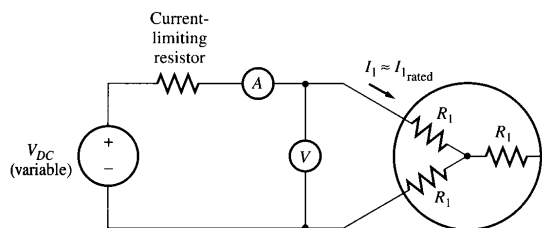


Determining the circuit model parameters

- The DC test for stator resistance (R_1). No induced voltage, no rotor current, no induced torque, no rotation

$$R_1 = \frac{V_{DC}}{2I_{DC}}$$

$$I_{DC} = \text{rated value}$$



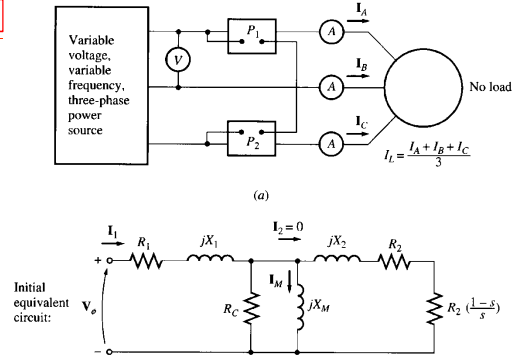
Same test as for the synchronous machine. Recall that the stators are identical...

Determining the circuit model parameters

- **No-load test:** Magnetization current and rotational losses.

$$P_{in} = P_{losses} \approx P_{SCL} + P_{core} + P_{RCL} + \underbrace{P_{F\&W}}_{\text{small...} \rightarrow \sim P_{conv}}$$

$$|Z_{eq}| = \frac{V_{\phi}}{I_{nl}} \approx X_1 + X_M$$



Determining the circuit model parameters

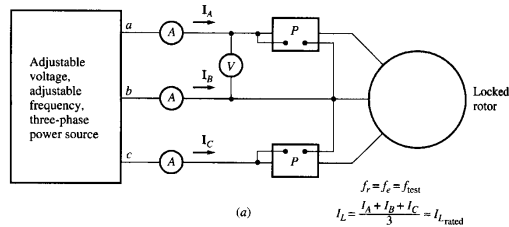
- **The locked-rotor test:** Stator and rotor impedances

$$P_F = \cos \theta = \frac{P_{in}}{\sqrt{3}V_T I_L}$$

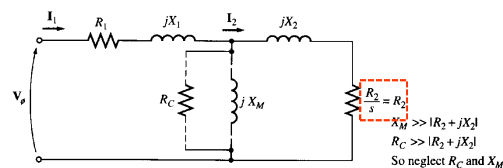
$$|Z_{LR}| = \frac{V_{\phi}}{I_1} = \frac{V_T}{\sqrt{3}I_L}$$

$$R_{LR} = |Z_{LR}| \cos \theta = R_1 + R_2$$

$$X_{LR} = |Z_{LR}| \sin \theta = X_1 + X_2$$



Rotor Design	X_1 and X_2 as functions of $X_{1,R}$	
	X_1	X_2
Wound rotor	$0.5 X_{1,R}$	$0.5 X_{1,R}$
Design A	$0.5 X_{1,R}$	$0.5 X_{1,R}$
Design B	$0.4 X_{1,R}$	$0.6 X_{1,R}$
Design C	$0.3 X_{1,R}$	$0.7 X_{1,R}$
Design D	$0.5 X_{1,R}$	$0.5 X_{1,R}$



Check Example 7-8 with the three tests.

Derivation of the induced torque equation

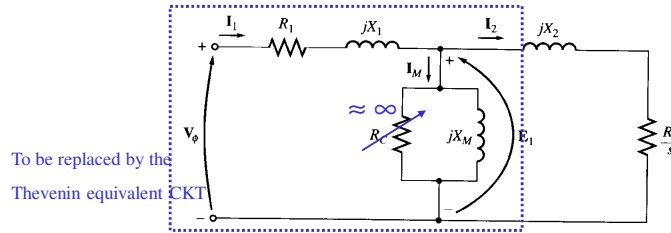


FIGURE 7-12

The per-phase equivalent circuit of an induction motor.

To be replaced by the
Thevenin equivalent CKT

$$\tau_{ind} = \frac{P_{AG}}{\omega_{sync}} \quad P_{AG} = 3I_2^2 \frac{R_2}{s} \quad I_2 = \frac{V_{TH}}{Z_{TH} + Z_2}$$

This is phasor, complex number!

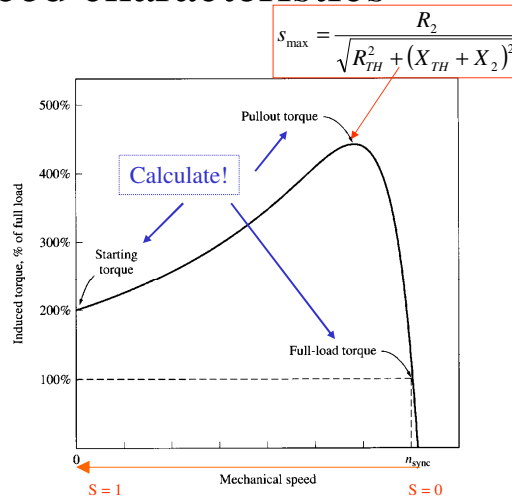
$$V_{TH} = \frac{X_M}{\sqrt{R_1^2 + (X_1 + X_M)^2}} V_\phi \quad Z_{TH} = \frac{jX_M(R_1 + jX_1)}{R_1 + j(X_1 + X_M)}$$

$$\tau_{ind} = \frac{3V_{TH}^2 R_2 / s}{\omega_{sync} [(R_{TH} + R_2 / s)^2 + (X_{TH} + X_2)^2]}$$

Torque x speed characteristics

- $\tau_{start} > \tau_{rated}$
- Maximum (pullout) torque.
- For load torques smaller than rated, **the slip varies linearly with the load torque!**

$$\frac{\tau_{Load_1}}{s_1} = \frac{\tau_{Load_2}}{s_2}$$

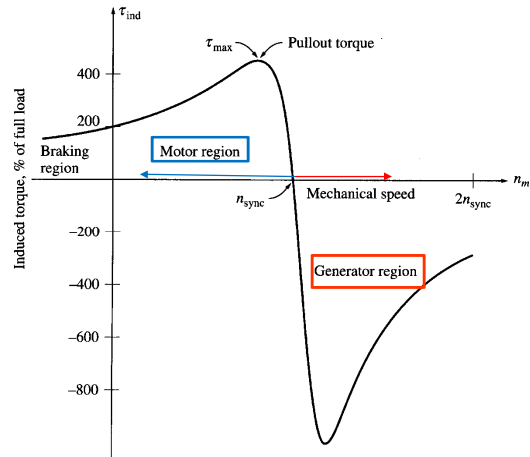


What is the rotor speed at no-load condition? Neglecting $P_{F\&W}$...

- $\tau_{ind} = 0$ for $n_m = n_{sync}$

Torque x speed characteristics

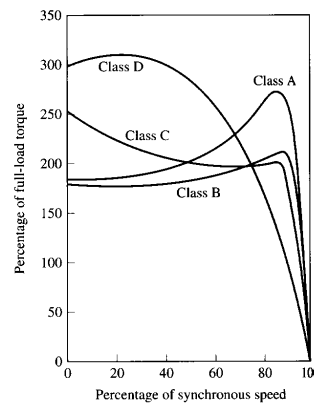
- The complete curve.



Recall that in linear dc machines, if the speed of the bar is higher than at no-load, the machine operates in the “generator mode!”

Obtaining different $\tau \times n$ characteristics

- Cage rotor design...
- Present different performance levels in terms of:
 - Starting torque (τ_{start})
 - Starting current
 - Full-load slip (s_{rated})
 - Efficiency (η)



- R_2 is high $\rightarrow \tau_{start}$ is high, s_{rated} is high, η_{rated} is low.

Start-up schemes

- Are based on the principle of applying a reduced voltage during the start-up and then full voltage.

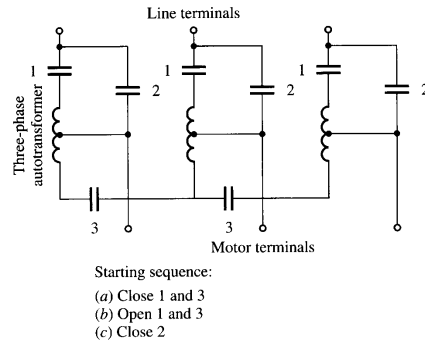


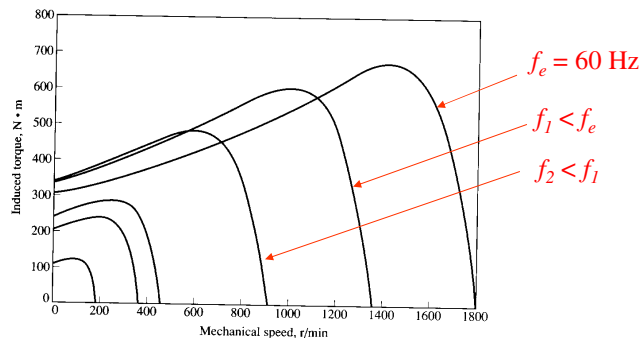
FIGURE 7-35
An autotransformer starter for an induction motor.

The starting current decreases proportionally to the voltage reduction but the starting torque decreases with the square of the voltage reduction.

- **Soft-starter based on SCRs. Power electronics...**

Speed control of induction motors

- **Line frequency variation:** $n_{sync} = \frac{120 f_e}{P}$ (rev/min) $n_m = (1-s)n_{sync}$
- To prevent saturation: V/f cte. $\phi(t) = -\frac{V_M}{\omega N_p} \cos(\omega t)$
- Power derating **needed, since I_L is fixed...** $P = \sqrt{3}V_L I_L \cos\theta$

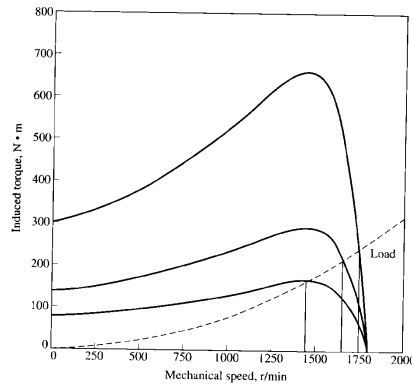


Speed control of induction motors

- Approach based on the T vs. n_m curve of an IM!
- Line voltage variation with rated frequency:

$$\tau_{ind} = \frac{3V_{TH}^2 R_2 / s}{\omega_{sync} [(R_{TH} + R_2 / s)^2 + (X_{TH} + X_2)^2]}$$

- $V = 0.5 V_{rated} \rightarrow \tau_{start} = 0.25 \tau_{start_rated}$
- Used for small motors only.

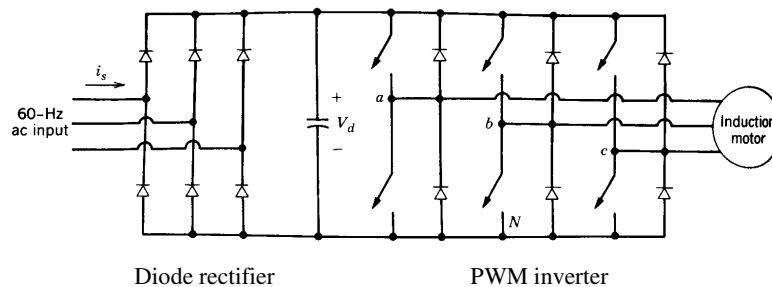


Slip (s) increases as V_t decreases!

$$n_{sync} = \frac{120 f_e}{P} \text{ (rev/min)} \quad n_m = (1 - s)n_{sync}$$

Solid-state induction motor drives

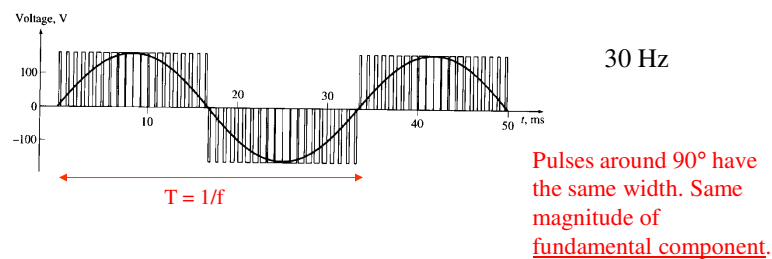
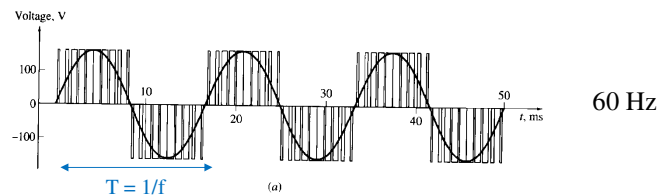
- Allows the control of the magnitude (0 – rated) and frequency(0 –120 Hz) of the voltage supplied to the IM.



- It also allows a motor to be *soft-started* (reduced voltage).

Solid-state induction motor drives

- Frequency control with constant magnitude (120 V) for the fundamental component.



Solid-state induction motor drives

- Control of the magnitude for the fundamental component (voltage) with constant frequency.

