20-Induction Motors

ECEGR 3500

Text: 12.2

Electrical Energy Systems

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Overview

- Introduction
- Applications
- Three-Phase Induction Motor Rotation
- Slip Speed

Introduction

- Practical three-phase induction motor invented by Nikola Tesla in 1883
- Induction machines do not require brushes or slip rings
- Induction motors are very common
  - 1/3 of electrical energy consumption
  - Induction generators often used in wind turbine
- "singly-fed" machine (only stator is connected to power)
  - Induction generators may be "doubly fed"

Applications

- Large range of power ratings
  - Several watts to 40,000 hp
- Can be single phase, two phase, three phase…
  - >5 hp usually three phase
- Typical applications:
  - Washers, dryers, blenders, electric vehicles, fans, pumps

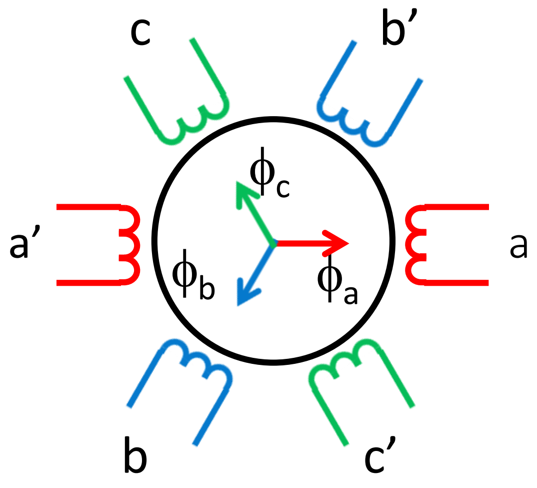
Applications

- Advantages:
  - Low cost
  - Simple and rugged construction
  - Low maintenance
  - Appealing torque-speed characteristics
- Disadvantages:
  - consumes reactive power (lagging)
  - speed cannot be easily controlled if connected to fixed-frequency AC source

Applications

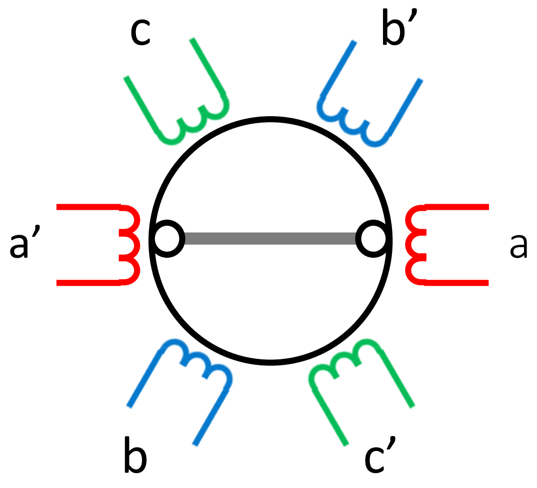
Induction Motor

Recall: revolving magnetic field established by connecting armature (stator) windings to three-phase AC source



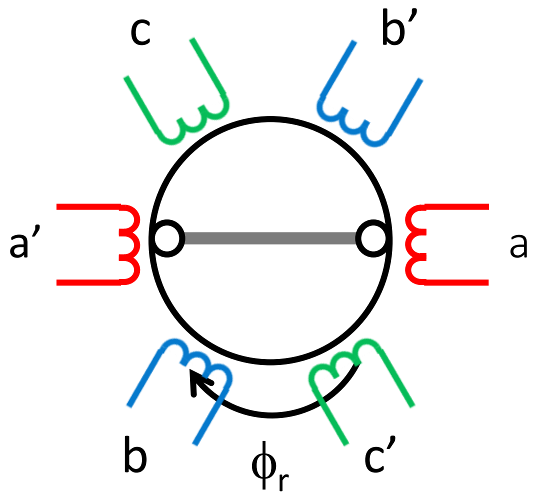
Induction Motor

Consider a single rotor coil with shorted terminals



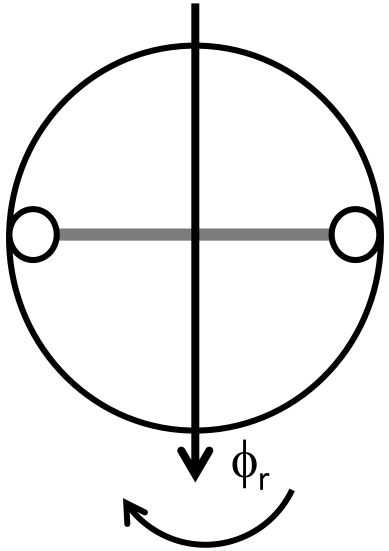
Induction Motor

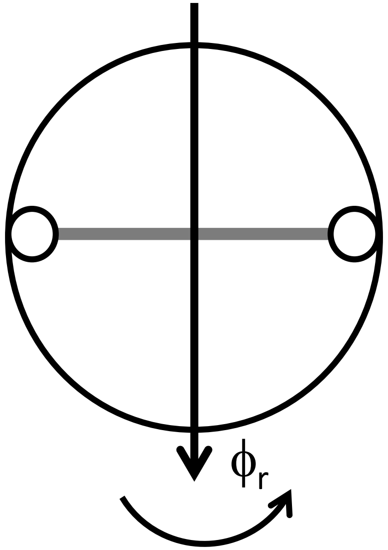
- Assume rotor is locked in place (cannot rotate)
- Net flux through the coil varies with time
  - Voltage induced in rotor, current flows



Induction Motor

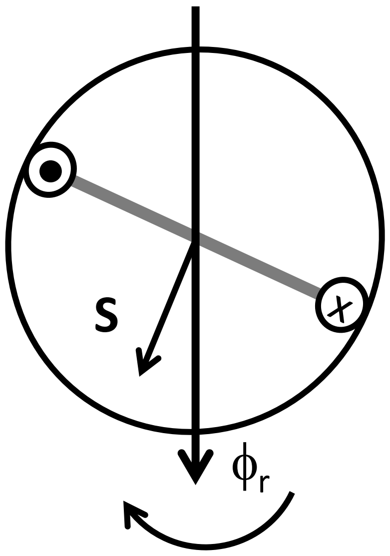
Determine the direction of the induced current for the shown rotational directions of flux.



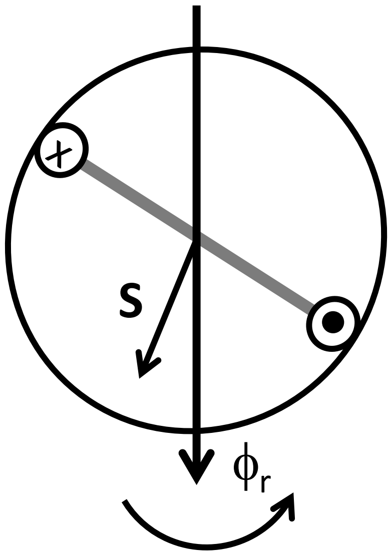


Induction Motor

Determine the direction of the torque on the conductors.



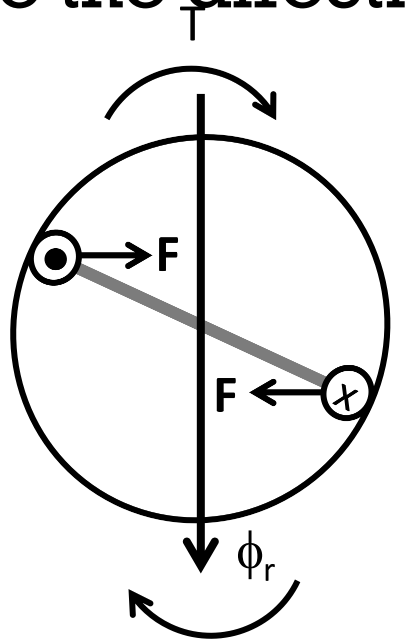
$\mathbf{S} \bullet \mathbf{B}$ increasing

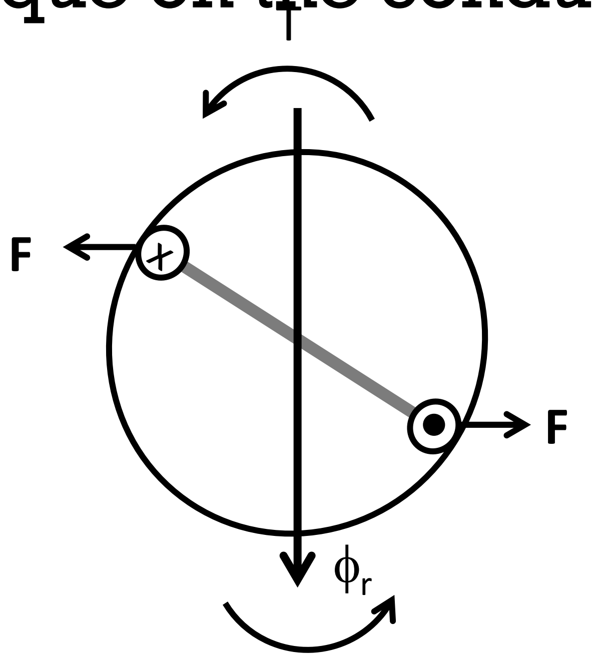


$\mathbf{S} \bullet \mathbf{B}$ decreasing

Induction Motor

Determine the direction of the torque on the conductors.

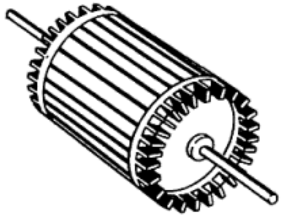




Torque is in the same direction as rotating field

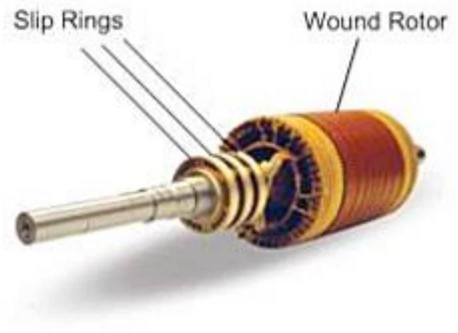
Squirrel Cage Induction Motors

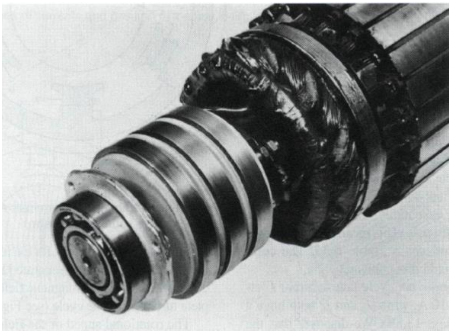
- Most common induction motor type
- Rotor made of solid conductors shorted through end rings
  - Low resistance
  - Promotes high current flow
  - No external connection



Wound Rotor Induction Motors

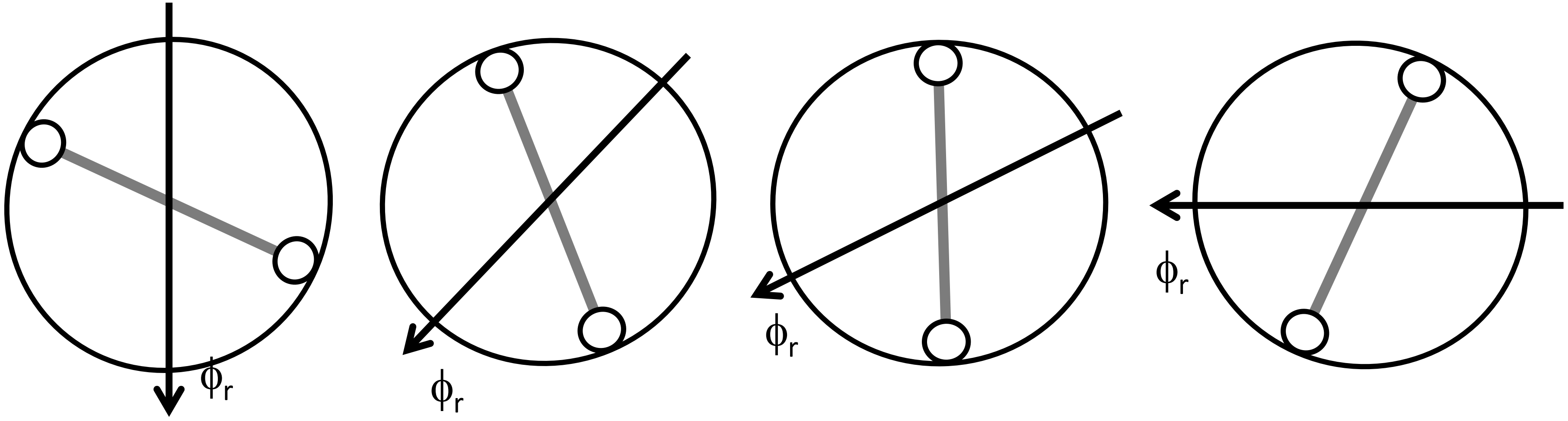
- Rotor wound with phases
- Slip rings used to connect rotor to external stationary circuit
- Greater control of motor
  - often used in induction generators





Induction Motor

- Now assume rotor rotates at synchronous speed N_s (same speed as rotating field)
- Does any current flow?



Three-Phase Induction Motor

- The rotor must rotate at a <u>different speed than the synchronous speed</u>
  - rotor speed < synchronous (motor)
  - rotor speed > synchronous (generator)
- If it rotated at the same speed, the flux through the closed would be constant and no emf would be induced
- Rate of change of flux through coil is difference between field speed and mechanical speed
- For this reason, induction motors are known as <u>asynchronous motors</u>

Three-Phase Induction Motor

- The rotor speed is dependent on the load (torque)
- As load increases the rotor will start to slow down
- As it slows down, the rate of change of the flux through the closed loop increases, resulting in greater current and hence greater applied torque
- The rotor will speed up until the load torque equals the applied torque

Slip Speed

- Slip speed: difference in synchronous speed and rotor speed
  - Relative speed of the revolving flux ahead of the rotor

$$N_r = N_s - N_m$$

$$\omega_r = \omega_s - \omega_m$$

  - N_r: slip speed (rpm)
  - N_m: rotor speed (rpm)
  - ω_r: slip speed (rpm)
  - ω_m: rotor speed (rpm)

Slip

Slip of a motor is:

$$s = \frac{\omega_r}{\omega_s} = \frac{\omega_s - \omega_m}{\omega_s} = \frac{N_s - N_m}{N_s}$$

Note: slip is often expressed as a percent

0.5 slip = 50% slip

Three-Phase Induction Motor

Compute the synchronous speed of a 4-pole, 50 Hz three phase induction motor. What is the percent slip if the rotor rotates at 1200 RPM?

Three-Phase Induction Motor

Compute the synchronous speed of a 4-pole, 50 Hz three phase induction motor. What is the percent slip if the rotor rotates at 1200 RPM?

$$N_s = \frac{120f}{P} = \frac{120(50)}{4} = 1500 \text{ rpm}$$

$$s = 100 \times \frac{N_s - N_m}{N_s} = 20\%$$

Induced Voltage

- Voltage induced in rotor depends on rate of change of flux
- The closer to synchronous speed the rotor rotates, the smaller the change in flux
- Induced voltage in the rotor: $\mathbf{E}_r = s\mathbf{E}_b$
  - $\mathbf{E}_r$: induced voltage in the rotor (V)
  - $\mathbf{E}_b$: induced voltage in the rotor at standstill (V)
  - s: slip

Example

- A 2-pole induction motor is connected to a 60 Hz three phase AC supply. The maximum flux through the rotor is 0.1 Wb. Assume the rotor has a single, full-pitch coil with 10 turns.

▪ Compute the magnitude of the induced voltage if:
  - The rotor is locked in place
  - The rotor rotates at 3500 rpm
  - The rotor rotates at 3000 rpm

Example

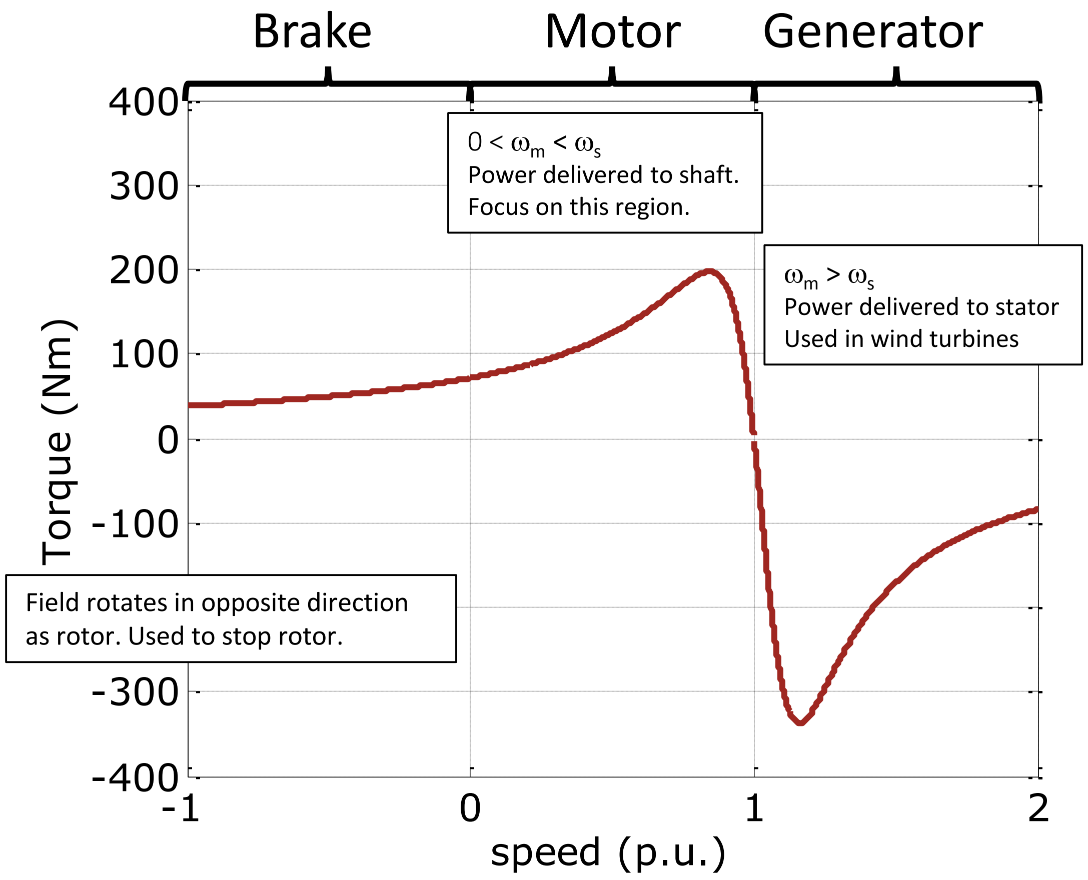
- A 2-pole induction motor is connected to a 60 Hz three phase AC supply. The maximum flux through the rotor is 0.1 Wb. Assume the rotor has a single, full-pitch coil with 10 turns.

$$|\mathbf{e}| = \frac{\omega_e \times \phi_p \times N_c \times s}{\sqrt{2}} = \frac{2\pi \times 60 \times 0.1 \times 10 \times 1}{\sqrt{2}} = 266.6V$$

$$|\mathbf{e}| = \frac{\omega_e \times \phi_p \times N_c \times s}{\sqrt{2}} = \frac{2\pi \times 60 \times 0.1 \times 10 \times 0.028}{\sqrt{2}} = 7.4V$$

$$|\mathbf{e}| = \frac{(\omega_e - \omega_m) \times \phi_p \times N_c \times s}{\sqrt{2}} = \frac{2\pi \times 60 \times 0.1 \times 10 \times 0.17}{\sqrt{2}} = 44.4V$$

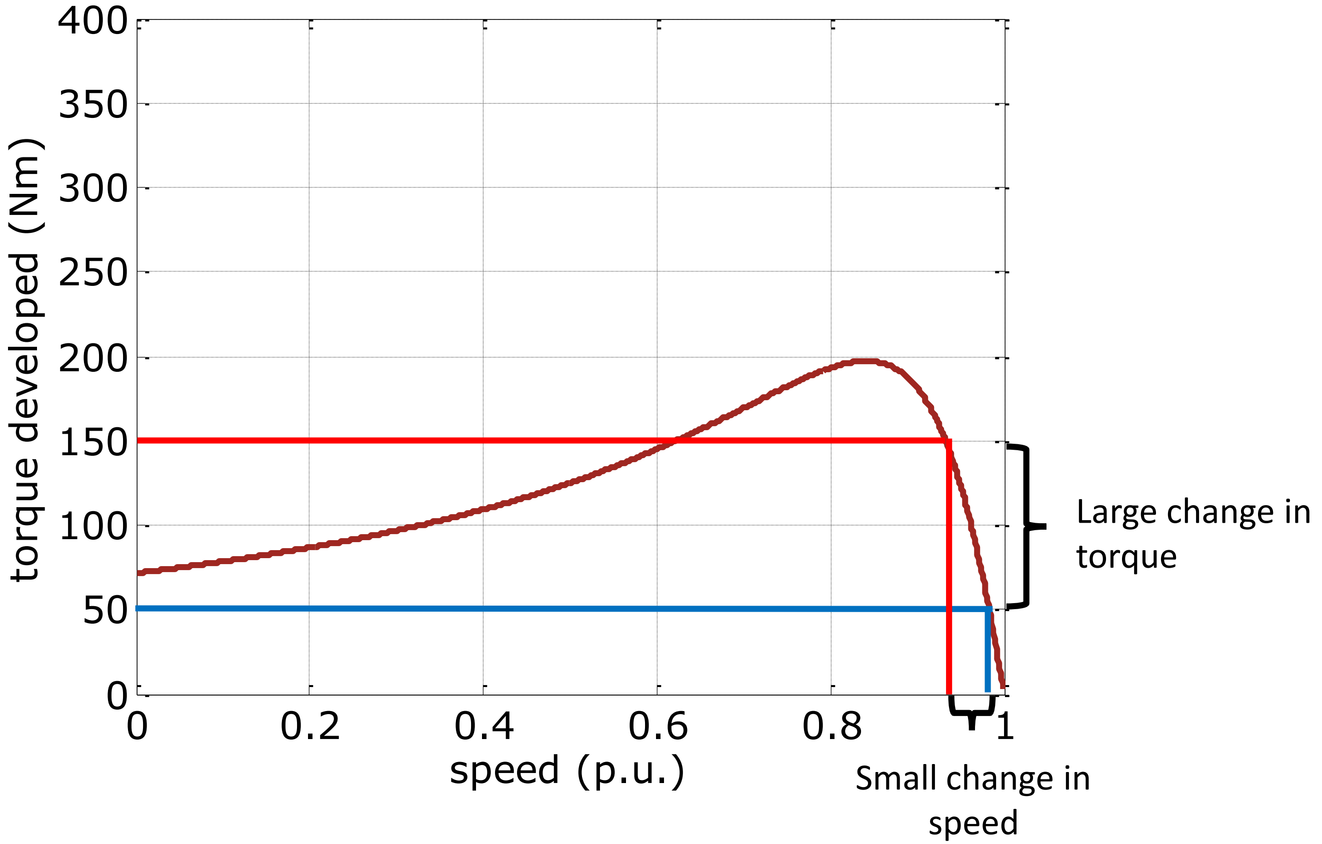
General Characteristics



General Characteristics

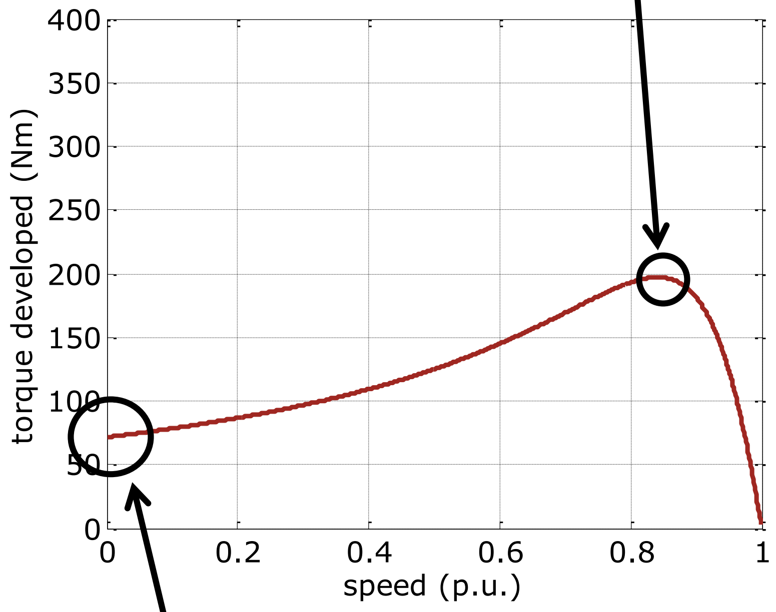
Slip is generally low < 5%

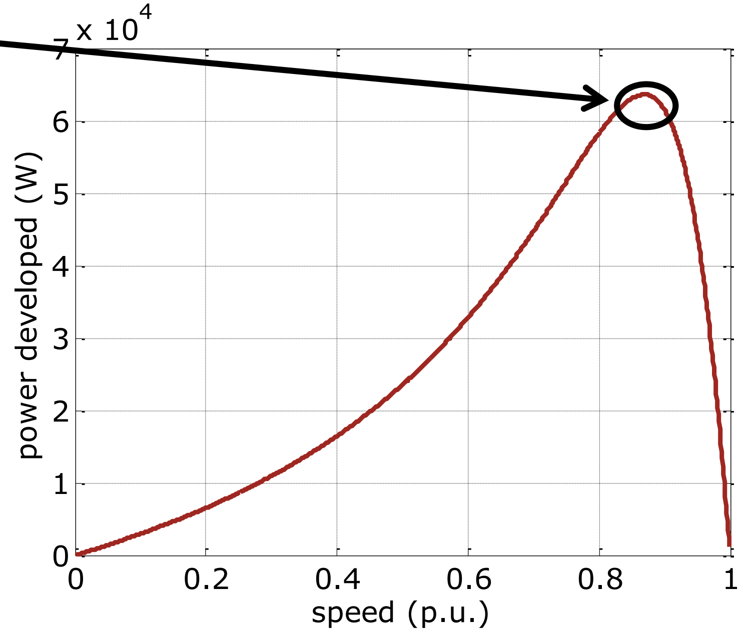
Induction motors are nearly *constant speed* in this region



General Characteristics

Unique maximum torque and
power operating points



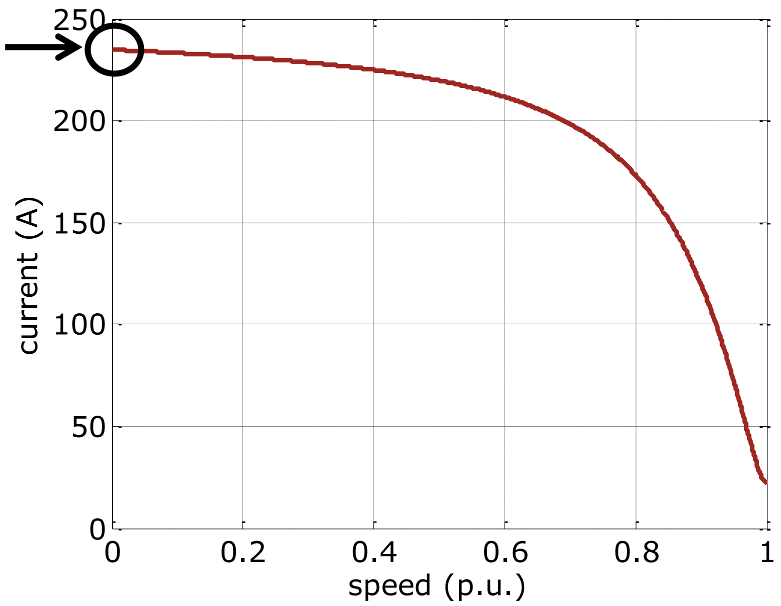


Non-zero
starting torque

Recall:
power = torque x speed

General Characteristics

High starting current



Summary

- Induction motors are the "workhorse" of the industry
- Synchronous revolving field induces current in rotor circuit
- Rotor rotates in direction of revolving field
- Rotor rotates at different speed than field
- Percent difference in speed is called "slip"
  - Higher the slip, the slower the rotation of the rotor