Chapter 14: Application of Induction Motors
Introduction

• When selecting a 3-phase induction motor for an application
  – several motor types can fill the need
  – manufactures often specify the motor class best suited to drive the load

• 3-phase induction motors under 500 hp are standardized
  – the frames have standard dimensions
    • a 25 hp, 1725 rpm, 60 Hz motor from one manufacture can be replaced by that of any other manufacturer without having to change the mounting holes, shaft height, or the type of coupling
  – limiting values for electrical, mechanical, and thermal characteristics are standardized
    • a motor must satisfy minimum requirements for starting torque, locked-rotor current, overload capacity, and temperature rise
Motor Classifications

- Environment
  - drip-proof motors
    - protected against dropping liquids and solids
  - splash-proof motors
    - best for wet locations
  - totally enclosed, nonventilated
    - no shaft-driven fan
    - best for very wet and dusty locations
  - totally enclosed, fan-cooled motors
    - fan blows cooling air over the ribbed motor frame
  - explosion-proof motor
    - highly inflammable or explosive surroundings
    - totally enclosed, long flanges
Motor Classifications

- Electrical and mechanical properties
  - standard locked-rotor torque
    - NEMA - B
    - most motor applications
    - locked rotor torque: 1.3 to 0.7 pu for 20 hp to 200 hp motors
    - locked rotor current: 6.4 pu maximum
  - high starting-torque motor
    - NEMA - C
    - locked rotor torque: 2 pu
    - locked rotor current: 6.4 pu maximum
    - pump and piston-type compressor applications

- high-slip motor
  - NEMA - D
  - slip at rated load lies between 5% and 15%
  - high-inertia loads; i.e., flywheels and centrifuges
Motor Speed

- The choice of motor speed is rather limited
  - depends on the power frequency and the number of poles
  - small variations due to slip
  - quantum jumps between speed ranges

- Use of large slip values for desired speed is inefficient
  - rotor losses are a function of slip
    \[ P_{\text{loss-rotor}} = s \, P_r \]
  - gear-box is often required to modify operating speed

- Low speed applications are often best served by using a high speed motor and a gear-box
  - for a given output power, a high-speed motor compared with a low-speed motor
    - costs less
    - is smaller sized
    - has higher efficiency and power factor

- Very high-speed applications (> 3600 rpm) always require the use of a gear-box
Motor Characteristics under Load

• Most of the time a motor runs close to synchronous speed
  – torque may vary from 0 to full-load torque $T_n$
  – this section of the torque-speed curve is essentially a straight line
    • the slope of the line depends mainly on the rotor resistance
  – at rated power frequency, the slip $s$, torque $T$, line voltage $E$, and rotor resistance $R$ are related by
    $$ s = k \frac{T R}{E^2} $$
    where $k$ is a motor construction dependent constant

  – by taking the ratio for two different operating conditions, we get the following expression
    $$ s_x = s_n \frac{T_x R_x}{T_n R_n} \left( \frac{E_n}{E_x} \right)^2 $$

[Diagram of motor characteristics with labels and equations]
Motor Characteristics under Load

- Example
  - a 3-phase, 208 V, 6-pole induction motor is connected to a 215 V supply and drives a constant torque load
    - the motor runs at 1140 rpm
  - calculate the speed when the supply voltage is raised to 240 V

- Example
  - a 3-phase, 460 V, 8-pole induction motor drives a compressor
    - just after starting the motor runs at 873 rpm with a cold rotor temperature of 23°C
    - after several hours of operation the speed drops to 864 rpm
  - calculate
    - the hot rotor resistance in terms of the cold resistance
    - the approximate hot temperature of the copper rotor bars
Starting an Induction Motor

- High-inertia load stains a motor by prolonging the starting period
  - the starting currents in both the rotor and stator are high during starting
  - overheating from $I^2R$ losses becomes a problem
  - prolonged starting of very large motors will overload the utility transmission network

- Induction motors are often started on reduced voltage
  - limits the current drawn by the motor
  - reduces the heating rate of the rotor
  - lengthens the starting period

- Heat dissipated in the rotor during starting, from zero speed to rated speed, is equal to the final kinetic energy stored in all the revolving components
Plugging an Induction Motor

- In some applications, the motor and its load must come to a quick stop
  - such braking action can be accomplished by interchanging two stator leads
  - the lead switching causes the revolving field to turn in the opposite direction
  - kinetic energy is absorbed from the mechanical load causing the speed to fall
  - the absorbed energy is dissipated as heat in the rotor circuit
  - the rotor also continues to receive power $P_r$ from the stator
    - plugging produces $I^2R$ losses that exceed the locked rotor losses
    - high rotor temperatures will result that may cause the rotor bars to overheat or even melt
  - the heat dissipated in the rotor during plugging, from initial speed to zero, is three times the original kinetic energy of all revolving parts, $P_{loss-rotor} = 3 \left( \frac{1}{2} J \omega^2 \right)$
Plugging an Induction Motor

• Example
  – a 100 kW, 60 Hz, 1175 rpm motor is coupled to a flywheel through a gearbox
    • the kinetic energy of the revolving components is 300 kJ at rated speed
  – the motor is plugged to a stop and allowed to run up to 1175 rpm in the reverse direction
    • calculate the energy dissipated in the rotor
DC Braking

• An induction motor with high-inertial load can also come to a quick stop by circulating dc current in the stator winding
  – any two stator terminals can be connected to a dc source
  – the dc current produces stationary N,S poles in the stator
    • the number of stationary poles are the same at the number of rotating poles normally produced with ac currents
  – as the rotor bars sweeps past the dc field, an ac rotor voltage is induced
    • the \( I^2R \) losses produced in the rotor circuit come at the expense of the kinetic energy stored in the revolving components
  – the motor comes to a rest by dissipating as heat all the kinetic energy

• The benefit of dc braking is the far less heat that is produced
  – dissipated rotor losses is equal to the kinetic energy of the revolving parts
  – energy dissipation is independent of the dc current magnitude
  – the braking torque is proportional to the square of the dc braking current
DC Braking

• Example
  – a 50 hp, 1760 rpm, 440 V, 3-phase induction motor drives a load with a total moment of inertia of 25 kg m²
    • dc resistance between two stator terminals is 0.32 ohms
    • rated motor current is 62 A
  – the motor is stopped by connecting a 24 V battery across two of the motor’s terminals

• calculate
  – the dc current in the stator
  – the energy dissipated in the rotor
  – the average braking torque if the motor stopping time is 4 minutes
Application of Induction Motors

• Homework
  – Problems: 14-10, 14-14, 14-16, and 14-22