Lecture No. 59
Single Phase Induction Motor (Characteristics)

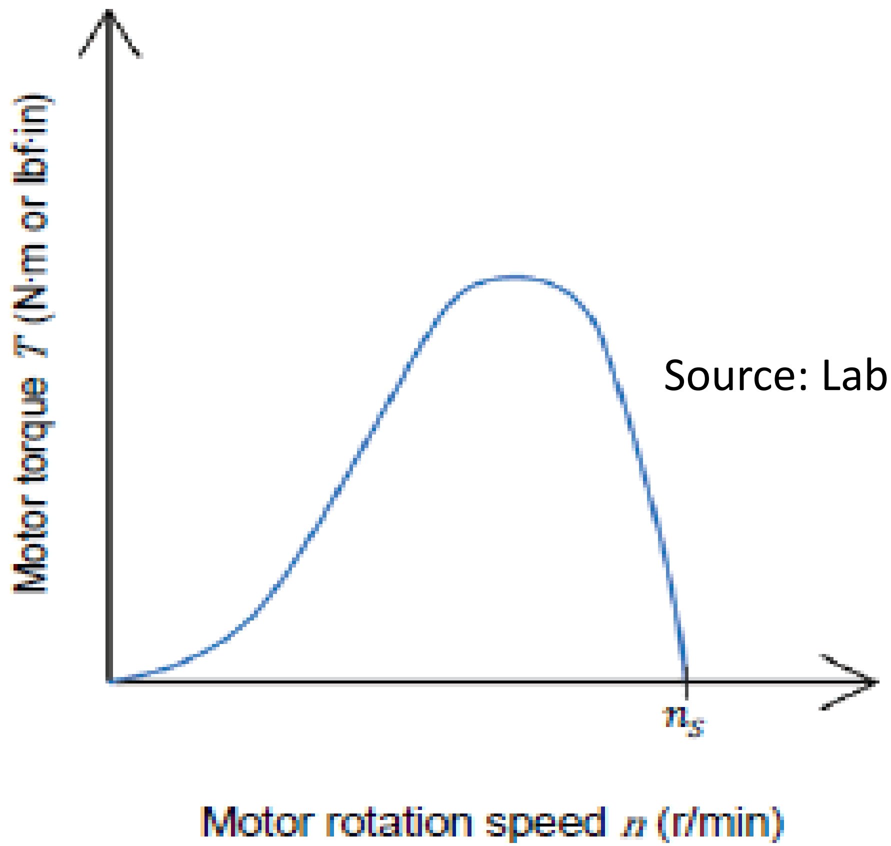
Lecture delivered by:

Objectives

At the end of this lecture, student will be able to:

- Explain the Torque-Speed Characteristics
- Classify Single Phase Induction Motors based on construction and operation
- Discuss the need for Auxiliary winding

Torque-Versus-Rotation Speed Curve of a Single-Phase Induction Motor



Source: Lab volt systems

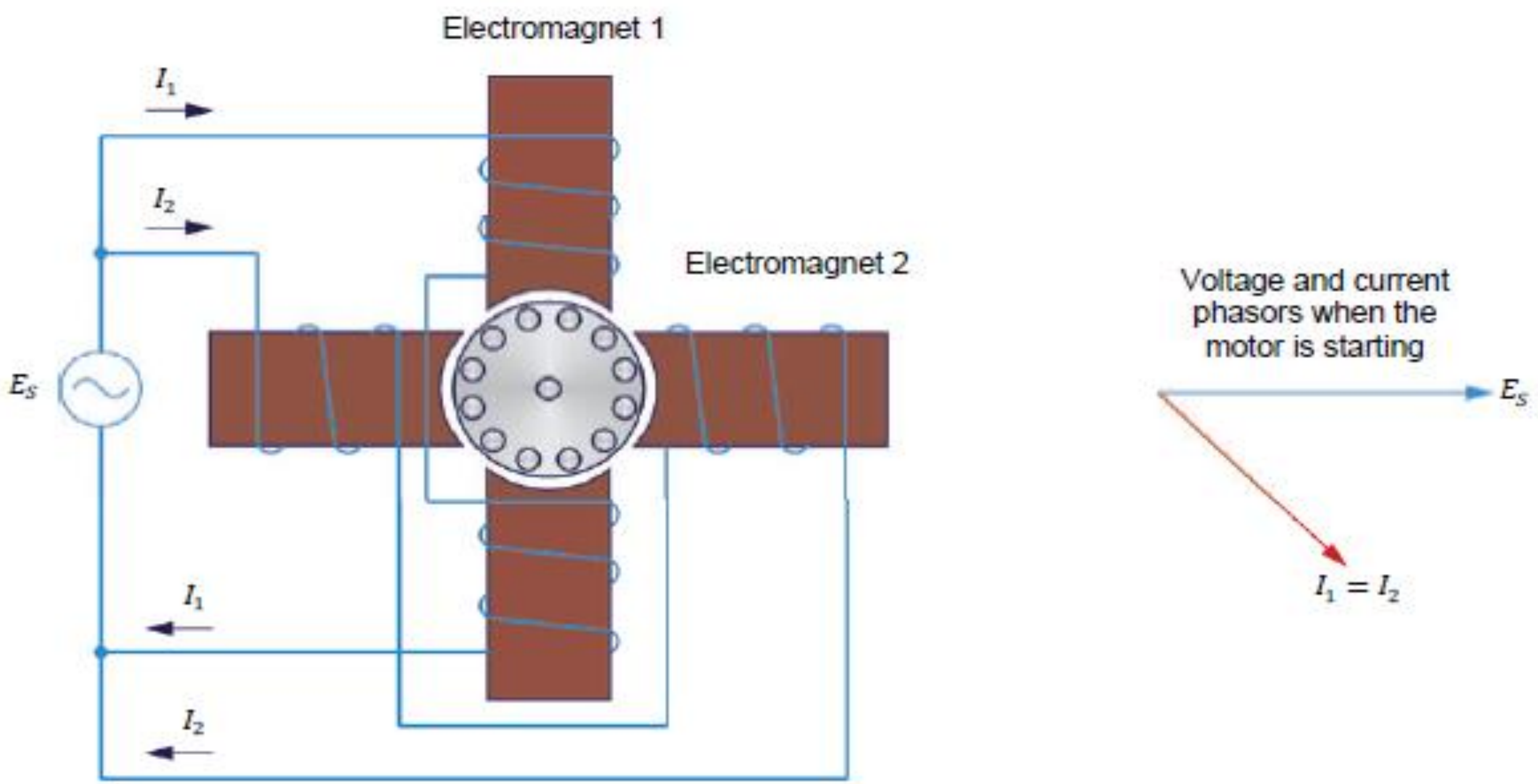
Why low torque at low speeds?

- Forces created due to R.M.F cancel each other and the resulting force acting on the rotor is weak. Thus, single-phase induction motor must be started manually.
- When motor is starting , low torque is obtained at low speeds.

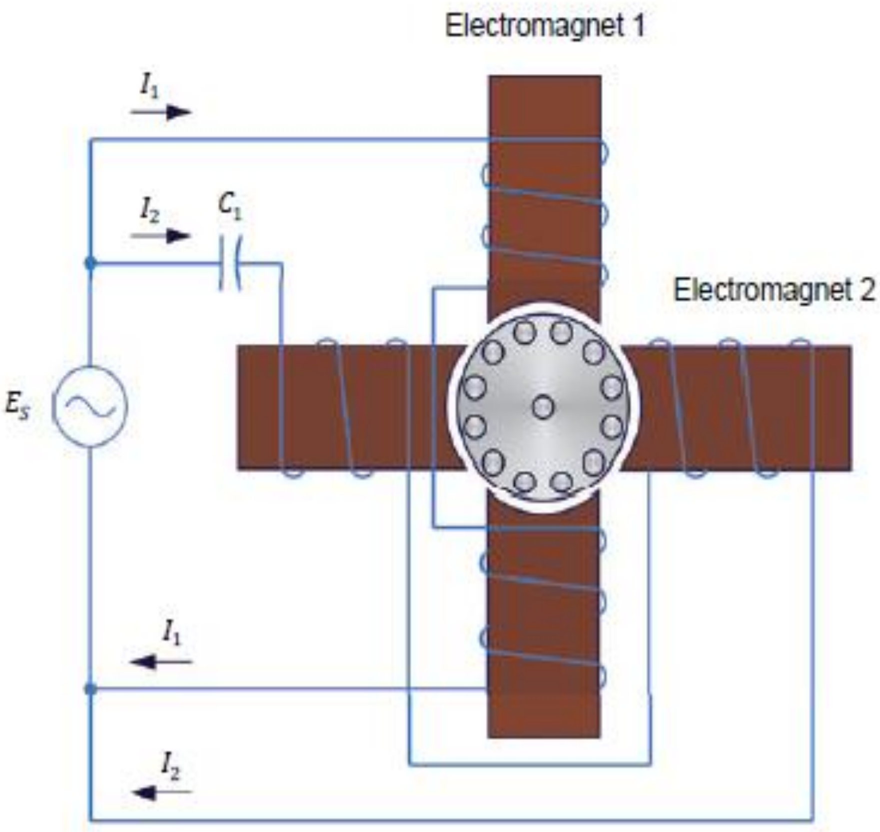
Types of Induction Motor starting

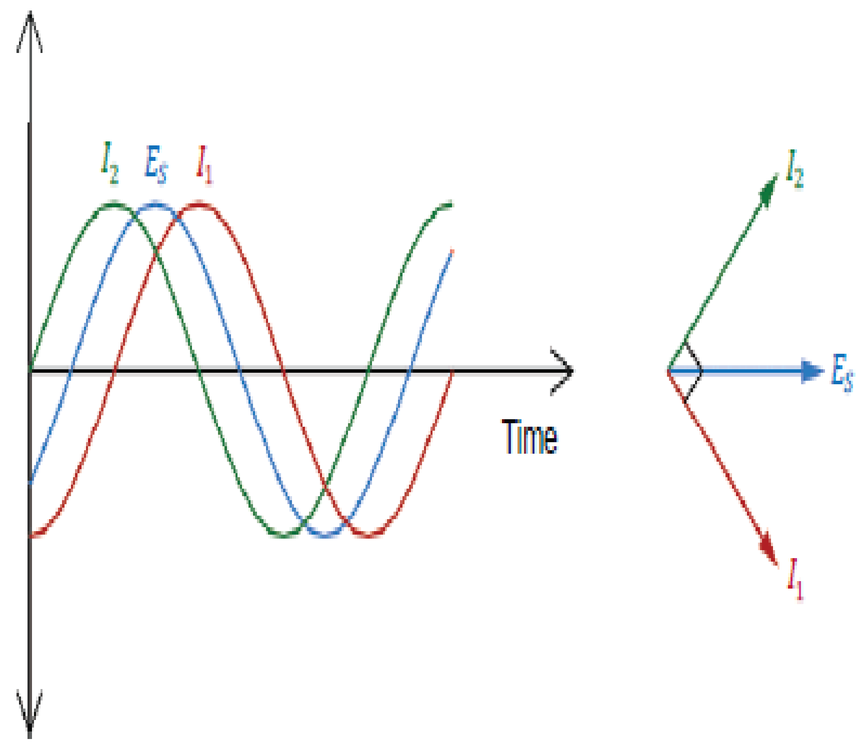
- Single-phase capacitor-start,
- Capacitor-run
- Split-phase and shaded-pole types
- Small poly-phase induction motors.

Single Phase Induction Motor with Two Electromagnets



Addition of Capacitance to Induction Motor





Waveforms and phasors when the motor is starting

Note: Adding capacitors develop starting torque

Parameters of Induction Motor

- Rotation rate of stator magnetic field, referred as synchronous speed is given by,

$$n_s = \frac{120 \times f}{p}$$

where ***f*** is the motor supply's frequency in Hertz and ***P*** is the number of magnetic poles

Parameters of Induction Motor

- Slip, is defined as the difference between synchronous speed and operating speed, at the same frequency, expressed in rpm or in percent or ratio of synchronous speed.

$$s = \frac{n_s - n_r}{n_s}$$

Where n_s is stator electrical speed, n_r is rotor mechanical speed

Parameters of Induction Motor

- **Power factor** of induction motors varies with load, typically from around 0.85 or 0.90 at full load to as low as 0.35 at no-load
- **Full load motor efficiency** varies from about 85 to 97%,

✓ Friction and windage, 5% – 15%

✓ Iron or core losses, 15% – 25%

✓ Stator losses, 25% – 40%

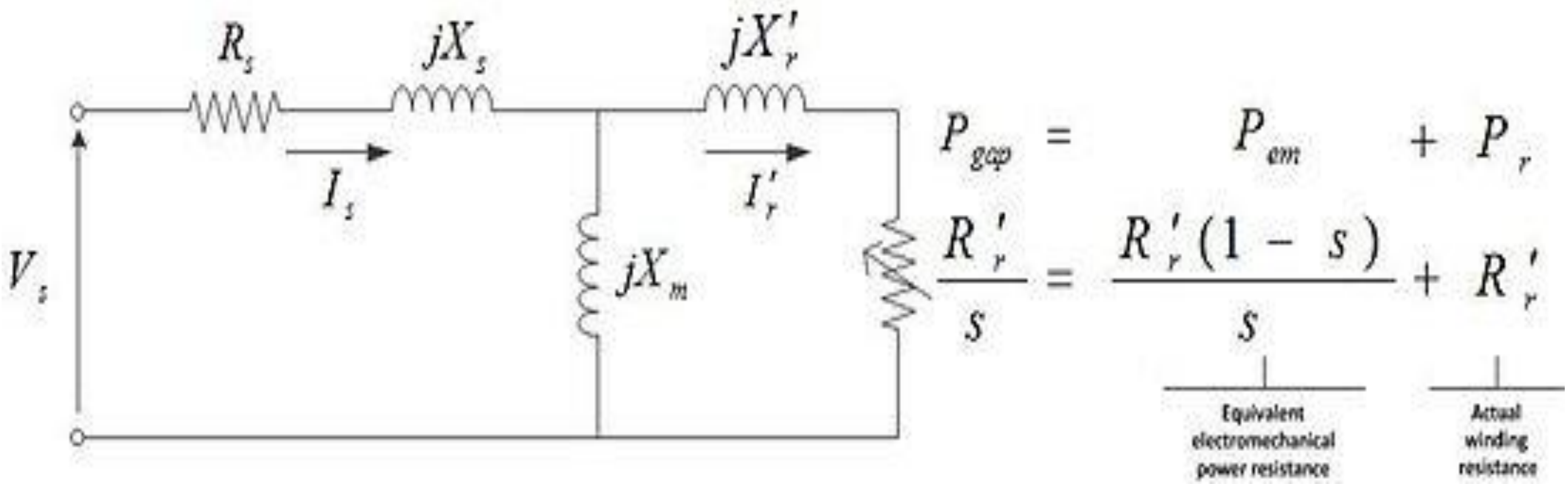
✓ Rotor losses, 15% – 25%

✓ Stray load losses, 10% – 20%.

Source:

1. Liang, Xiaodong; Ilochonwu, Obinna (Jan 2011). "Induction Motor Starting in Practical Industrial Applications". IEEE Transactions on Industry Applications 47 (1): 271–280.
2. U.S. DOE (2008). "Improving Motor and Drive System Performance: A Sourcebook for Industry"

Steinmetz Equivalent Circuit



- Stator resistance and leakage reactance(R_s ,X_s)
- Rotor resistance, leakage reactance, and slip (R_r' ,X_r' and s).
- Magnetizing reactance (X_m).

Source: Alger, Philip L. et al (1949). "'Induction Machines' sub-section of Sec. 7 - Alternating-Current Generators and Motors". In Knowlton, A.E. *Standard Handbook for Electrical Engineers* (8th ed.). McGraw-Hill. p. 705.

Steinmetz Equivalent Circuit

- Basic Electrical Equations

✓ $$\omega_r = \frac{2\pi n_s}{60} = \frac{4\pi f_s}{p}$$

✓ Motor input equivalent impedance

$$Z_m = R_s + jX_s + \frac{(\frac{R_s}{s} + jX_r^{'})(jX_m)}{\frac{R_r'}{s} + j(X_r' + X_m)}$$

✓ Stator current

$$I_s = V_s/Z_m = V_s/(R_s + jX_s + \frac{(\frac{R_s}{s} + jX_r^{'})(jX_m)}{\frac{R_r'}{s} + j(X_r' + X_m)})$$

✓ Rotor current referred to the stator side in terms of stator current

$$I_r^{'} = \frac{jX_m}{\frac{R_r'}{s} + j(X_r' + X_m)} I_s$$

Steinmetz equivalent circuit

- From Steinmetz equivalent circuit, we have

$$\frac{R_r'}{s} = \frac{R_r'(1-s)}{s} + R_r'$$

- Air gap power is equal to electromechanical power output plus rotor copper losses

$$P_{gap} = P_{em} + P_r$$

$$P_r = 3R_r' I_r'^2$$

$$P_{gap} = \frac{3R_r' I_r'^2}{s}$$

$$P_{em} = \frac{3R_r' I_r'^2(1-s)}{s}$$

$$P_{em} = P_{gap}(1-s)$$

Power Equations

- Expressing electromechanical power output in terms of rotor speed

$$P_{em} = \frac{3R_r' I_r'^2 n_r}{s n_s}$$

$$P_{em} = \frac{3R_r' I_r'^2 n_r}{746 s n_s}$$

$$T_{em} = \frac{P_{em}}{\omega_r} = \frac{\frac{P_r}{s}}{\omega_r} = \frac{3I_r'^2 R_r'}{\omega_r s}$$

Thevenin Equivalent Circuit

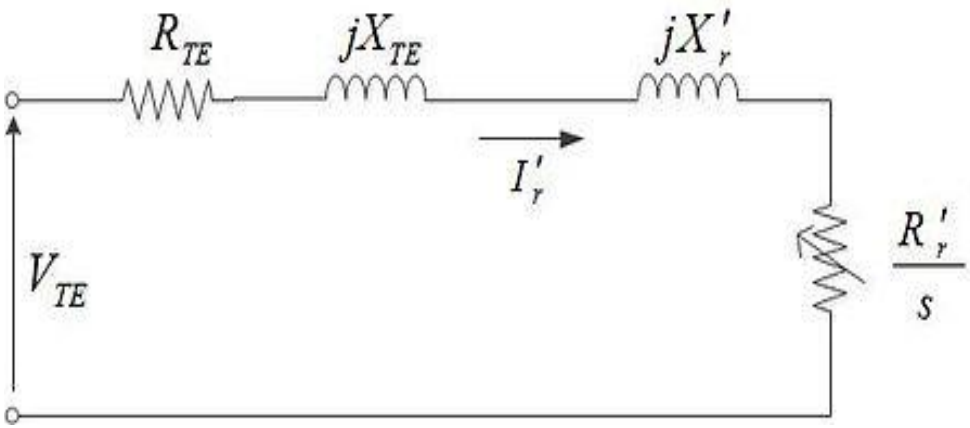
- Since, $R_s^2 \gg (X_s + X_m)^2$ $X_s \ll X_m$,

  and $K_{TE} = \dfrac{X_m}{X_s + X_m}$

$$V_{TE} \approx Z_{TE} V_s$$

$$Z_{TE} \approx K_{TE}^2 R_s + jX_s$$

$$T_{em} = \frac{3V_{TE}^2}{(R_{TE} + \frac{R_r'}{s})^2 + (R_{TE} + X_r')^2} \cdot \frac{R_r'}{s} \cdot \frac{1}{\omega_s} (N.m)$$



$$V_{TE} = \frac{X_m}{\sqrt{R_s^2 + (X_s + X_m)^2}} V_s$$

$$Z_{TE} = R_{TE} + jX_{TE} = \frac{jX_m(R_s + jX_s)}{R_s + j(X_s + X_m)}$$

Source: Özyurt, Ç.H. (2005). *Parameter and Speed Estimation of Induction Motors from Manufacturers Data and Measurements.* Middle East Technical University. pp. 33–34.

Summary

- Auxiliary windings are connected with capacitors in series
- Current in the auxiliary winding causes magnetic field to rotate thereby providing starting torque