Three Phase Induction Motors – Torque-Slip Characteristics & Related Problems

Contents :

- Torque slip characteristics
- Power flow diagram
- Relationship between rotor power and losses
- Related Problems

1

Torque-Slip Characteristics

- The curve drawn between torque and slip from start (s=1) to Synchronous speed (s=0) is called torque slip characteristics of the induction motor

- Torque Equation

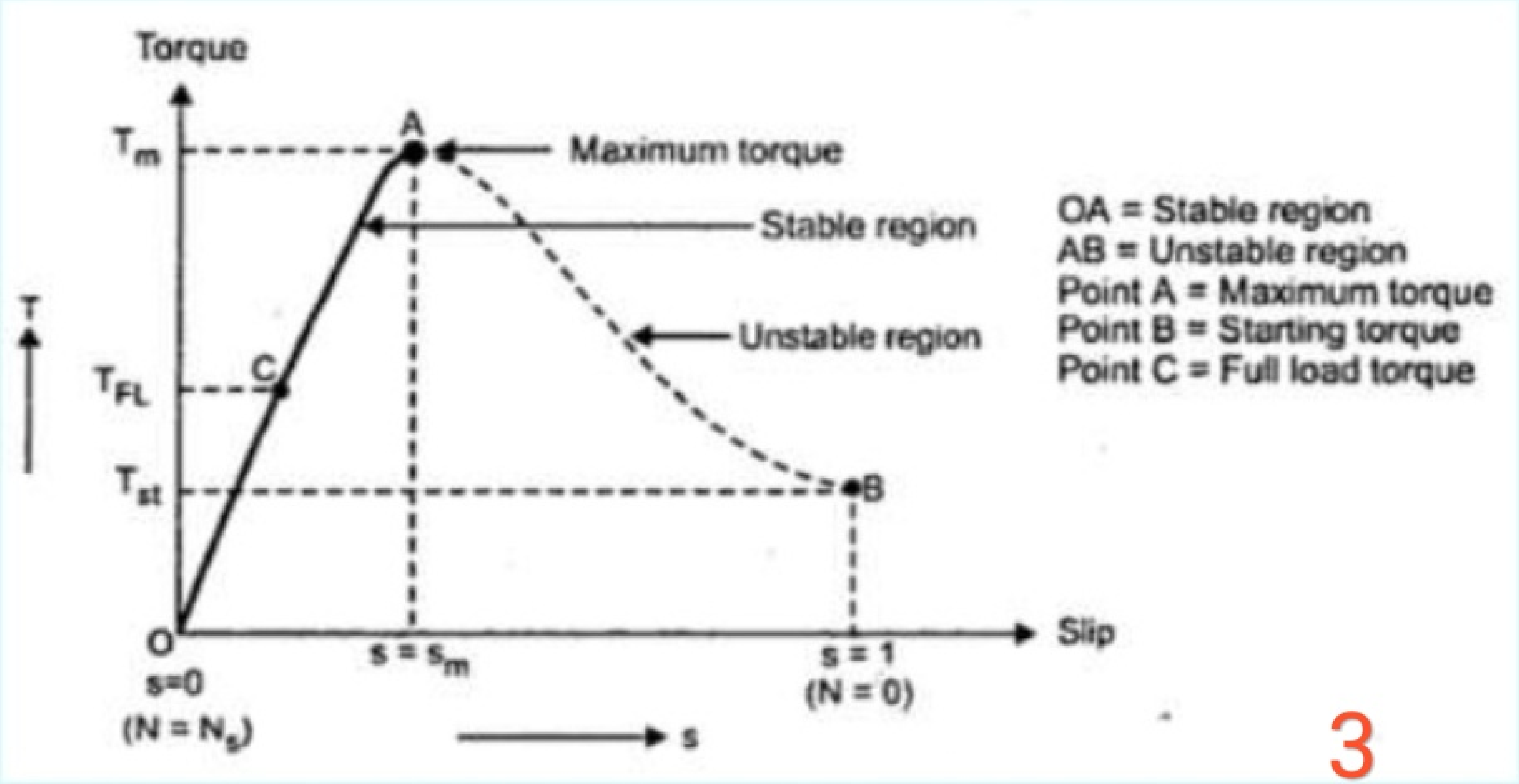
- Input voltage is constant (E_2=C)

$$T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

$$T \propto \frac{sR_2}{R_2^2 + (sX_2)^2}$$

2

Torque-Slip Characteristics



Torque-Slip Characteristics

- **Three Regions:**
  - **Stable operating region**
  - **Unstable operating region**
  - **Normal operating region**

- ***Stable Region (AB)***
  - **'s' is very small (then, $(sX_2)^2$ <<< R_2^2), Hence $s^2X_2^2$ is neglected**

$$T \propto \frac{sR_2}{R_2^2} \propto s\ [as\ R_2 = Constant]$$

  - **in this region as load ↑, T↑, s↑**
  - **Characteristics is approximately straight line**

4

Torque-Slip Characteristics

- ***Unstable Region (BC)***
  - When s increases further from s_m the region is unstable region, s is high (between s_m and 1) , R_2^2 can be neglected as compared to $s_2X_2^2$

$$T \propto \frac{s}{(sX_2)^2} \propto \frac{1}{s} \; [as \; X_2 = Constant]$$

  - in this region as load ↑, s↑, T↓
  - Characteristics is approximately rectangular hyperbola.
  - When load further increases, N↓, s↑, leads motor to standstill condition, hence motor should not be operated at any point in this region.

5

Torque-Slip Characteristics

- ***Normal Region (AD)***
  - Low slip region, the motor can continuously operated in this region.

- ***Three torques:***
  - Starting torque (T_{st})
  - Maximum torque or pull out torque(T_m)
  - Full load torque(T_{fl})

- ***Starting Torque (Tst)***
  - The motor produces the torque when s=1 speed is zero.

- ***Maximum Torque or Pull out Torque(Tm)***
  - The torque produced at $s=s_m$ is called maximum torque.
  - S_m is slip at which maximum torque occurs.
  - Also called **breakdown torque of pull out torque**.

6

- ***Full Load Torque (Tfl)***
  - In the characteristics the torque corresponding to point D is called full load torque of motor. usually $T_{fl} < T_m$.

Torque-Slip Characteristics

Eddy Current Losses

- Occur due to flow of eddy current through body of the stator core.
- Can be minimized by using laminated construction of the stator core

- Two losses are depend on supply frequency ,
- $f_{stator} = f_{supply}$, hence iron loss for stator is more
- f_{rotor} <<, hence iron losses are also very small, neglected under running condition

Mechanical Losses

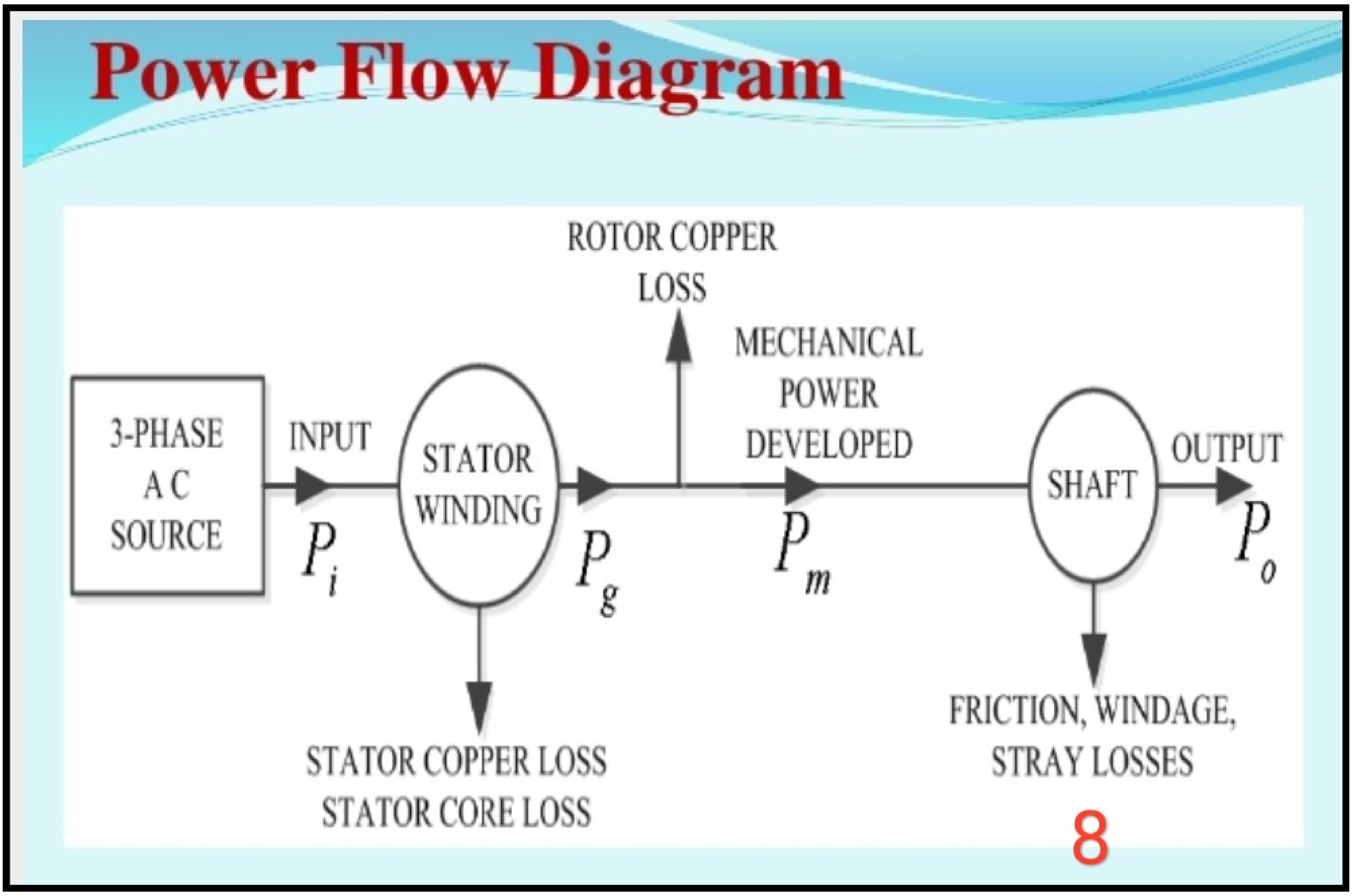
- Consists of frictional losses and windage losses
- Losses are <<< due to speed drop is very small
- Constant losses = Iron Losses + Mechanical Losses

Electrical Losses

- Due to resistance of stator and rotor winding. (stator and rotor copper losses)
- When load ↕ current ↕, so it is called variable losses

$$Rotor\ Copper\ Losses = 3I_2^2R_2$$

7


Power Flow Diagram
ROTOR COPPER
LOSS
MECHANICAL
POWER
DEVELOPED
3-PHASE
A C
SOURCE
INPUT
STATOR
WINDING
SHAFT
OUTPUT
P_i
P_g
P_m
P_o
FRICTION, WINDAGE,
STRAY LOSSES
STATOR COPPER LOSS
STATOR CORE LOSS
8

Power Flow Diagram

- Induction motor converts electrical power into mechanical power.
- 3ph supply is fed to stator, input power P_{in} is

$$P_{in} = \sqrt{3} V_L I_L \cos\varphi$$

- Losses occur in stator called stator losses (P_{SL})
- Remaining power is transferred to rotor magnetically,
- It is called output of the stator or input to the rotor(P_2)

$$P_2 = P_{in} - P_{SL}$$

- In rotor side, rotor copper losses occur (P_{cu}).
- Normally rotor iron losses are very small therefore it should be neglected.
- Remaining part is called mechanical power developed (P_m)

$$P_{cu} = 3 I_2^2 R_2$$

$$P_m = P_2 - P_{cu}$$

9

Power Flow Diagram

- Due to rotating part in motor **mechanical losses** (P_{mL}) occur.

$$P_{out} = P_m - P_{mL}$$

$$Rotor\ Efficiency = \frac{Rotor\ Output}{Rotor\ Input} = \frac{P_m}{P_2}$$

$$Motor\ Efficiency = \frac{Mechanical\ power\ Output\ at\ shaft}{Electrical\ power\ Input\ to\ the\ stator} = \frac{P_{out}}{P_{in}}$$

10