Speed Control of 3-Phase Induction Motors

$$N = (1 - s) N_s = (1 - s) \frac{120 f}{P}$$

- The speed of induction motor (N) can be varied by changing:
  - (i) Supply frequency, f.
  - (ii) No. of stator poles, P.
  - (iii) The slip, s.

The change of f is generally not possible because the commercial supplies have constant frequency. Therefore, the practical methods of speed control are either to change P or s.

Speed Control of 3-Phase Induction Motors …

1. Squirrel Cage Motors

Its speed changed by changing number of stator poles (only two or four speeds are possible by this method). Two-speed motor has one stator winding provides two speeds (For instance, the winding may be connected for either 4 or 8 poles, giving N_s of 1500 or 750r.p.m. Four-speed motors are equipped with two separate stator windings each of which provides two speeds.

2. Wound rotor motors

The speed of wound rotor motors is changed by changing the motor slip. This can be achieved by;

- Varying the stator line voltage.
- Varying the resistance of the rotor circuit.

Power Stages (Power Flow) in an Induction Motor

- The input electric power fed to the stator of the motor is converted into mechanical power at the shaft of the motor. The various losses during the energy conversion are:

  1- Fixed losses:

  (i) Stator iron loss

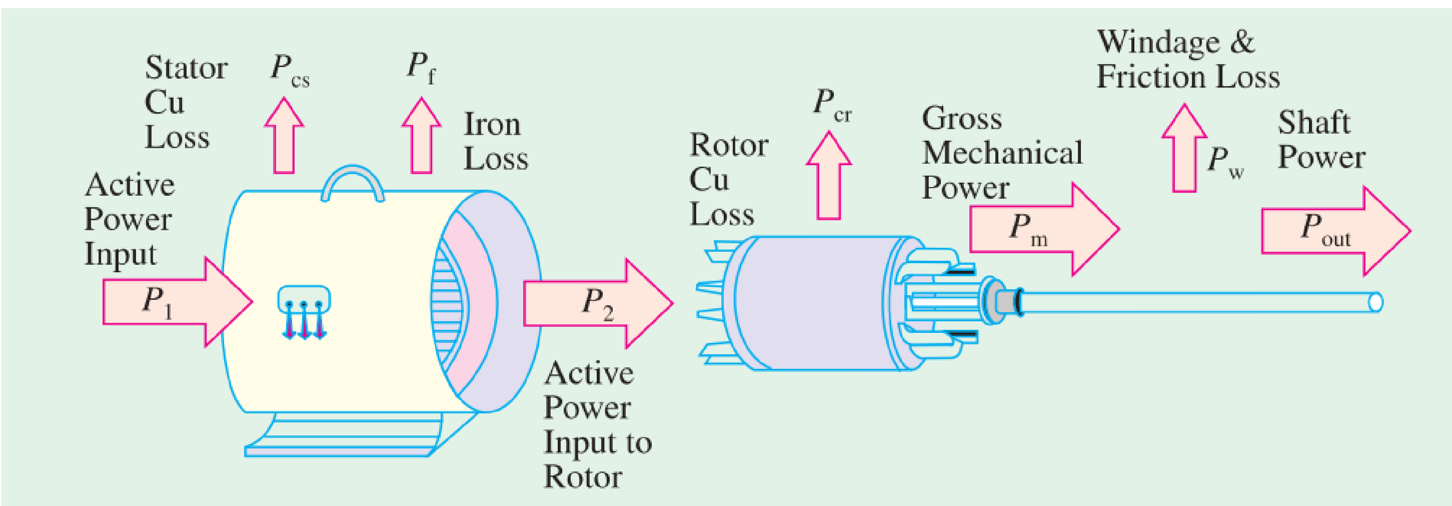
  (ii) Rotor iron loss is negligible (because $f^{\backslash}$ is small)

  (iii) Friction and windage loss

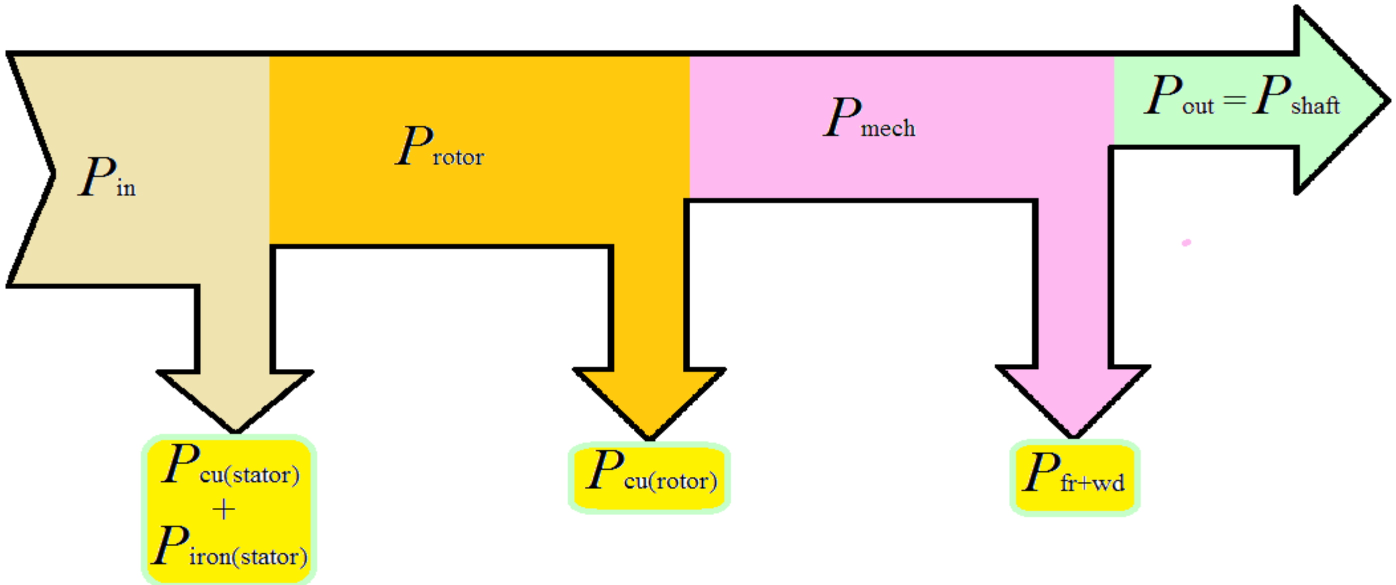
  2- Variable losses:

  (i) Stator copper loss

  (ii) Rotor copper loss



Power Stages (Power Flow) in an Induction Motor …



P_{in} input power to the motor or to the stator (Watt)

$P_{cu(stator)}$ stator copper losses (Watt)

$P_{iron(stator)}$ stator iron losses (Watt)

P_{rotor} input power to the rotor (Watt)

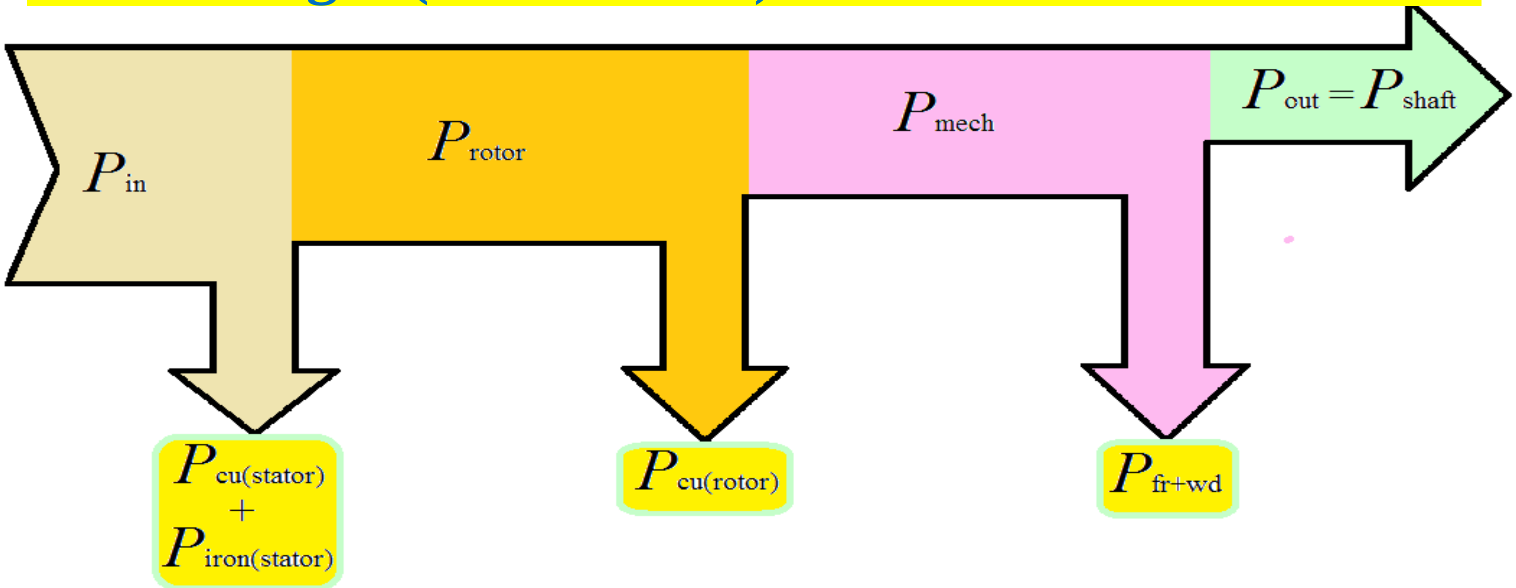
$P_{cu(rotor)}$ rotor copper losses (Watt)

P_{mech} gross/total/mechanical developed power (Watt)

P_{fr+wd} (friction & windage) or (rotational) or (mechanical) losses (Watt)

$P_{out} = P_{shaft}$ output/shaft/net power (Watt)

Power Stages (Power Flow) in an Induction Motor …



$$P_{in} = P_{rotor} + P_{cu(stator)} + P_{iron(stator)}$$

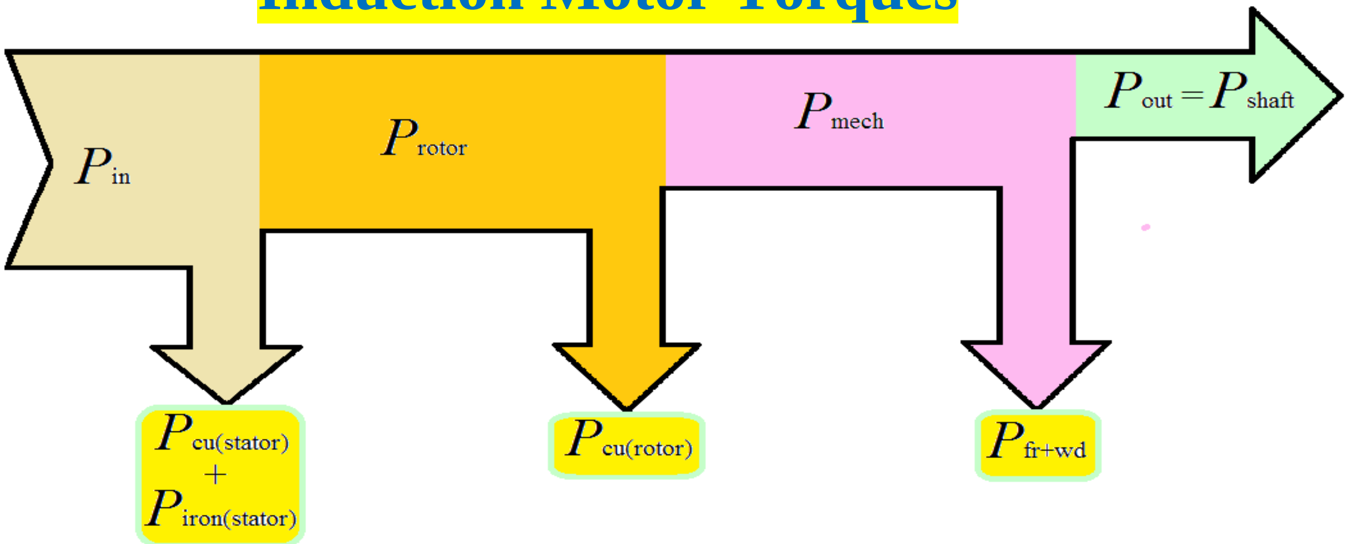
$$P_{rotor} = P_{mech} + P_{cu(rotor)} \qquad also \quad P_{cu(rotor)} = s\,P_{rotor}$$

$$P_{mech} = P_{out} + P_{fr+wd} \qquad or \quad P_{mech} = (1-s)P_{rotor}$$

$$\boxed{P_{out} = P_{in} - total\ losses} \qquad \boxed{P_{out} = P_{rotor} - (P_{cu(rotor)} + P_{fr+wd})}$$

$$\boxed{P_{out} = P_{mech} - P_{fr+wd}}$$

Induction Motor Torques



Developed/gross/total torque:

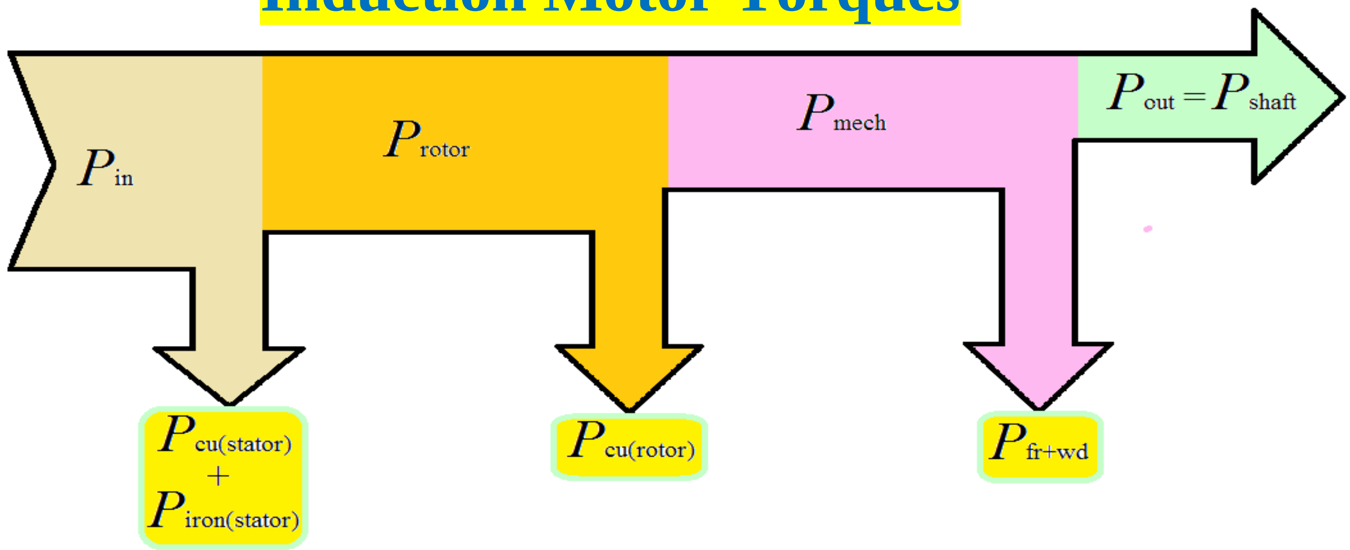
$$T_g = \frac{P_{rotor}}{\omega_s} = \frac{P_{rotor}}{2\pi \frac{N_s}{60}} = 9.55\frac{P_{rotor}}{N_s}$$

or

$$T_g = \frac{P_{mech}}{\omega} = \frac{P_{mech}}{2\pi \frac{N}{60}} = 9.55\frac{P_{mech}}{N}$$

… speeds (*rpm*) & torque (*Nm*) & power (Watt)

Induction Motor Torques



Shaft/net/output torque:

$$T_{shaft} = \frac{P_{shaft}}{\omega} = \frac{P_{shaft}}{2\pi \frac{N}{60}} = 9.55 \frac{P_{shaft}}{N}$$

… speed (*rpm*) & torque (*Nm*) & power (Watt)

Motor efficiency:

$$\%\eta = \frac{P_{out}}{P_{in}} \times 100$$

Example 34.27. *The power input to the rotor of 440 V, 50 Hz, 6-pole, 3-phase, induction motor is 80 kW. The rotor electromotive force is observed to make 100 complete alterations per minute. Calculate **(i)** the slip, **(ii)** the rotor speed, **(iii)** rotor copper losses per phase.* **[Madras University, 1997]**

(answer: (i) 0.0333 - (ii) 966.7rpm - (iii) 0.888kWatt)

Example 34.28. *A 440-V, 3-ϕ, 50-Hz, 4-pole, Y-connected induction motor has a full-load speed of 1425 rpm. The rotor has an impedance of (0.4 + J 4) ohm and rotor/stator turn ratio of 0.8. Calculate* ***(i)*** *full-load torque* ***(ii)*** *rotor current and full-load rotor Cu loss* ***(iii)*** *power output if windage and friction losses amount to 500 W* ***(iv)*** *maximum torque and the speed at which it occurs* ***(v)*** *starting current and* ***(vi)*** *starting torque.*

(answer: (i) 78.88Nm - (ii) 22.72A, 620Watt - (iii) 11271Watt -

(iv)98.6Nm, 1350rpm - (v) 50.56A - (vi) 19.5Nm)

Example 8: the input power of 500V, 50Hz, 6 pole, 3-phase induction motor at 975 rpm is 40kWatt. The stator losses are 1 kWatt and the total friction and windage losses is 2 kWatt. calculate:

(i) slip.
(ii) Rotor copper losses.
(iii) Shaft power
(iv) Motor efficiency

Answer

[Ans.: (i) 0.025 - (ii) 0.975 kWatt - (iii) 36.025kWatt - (iv) 90%]

Example 9: A 208 V, 10 hp, 4 poles, 60 Hz, Y-connected induction motor has a full-load slip of 5%. calculate:

(i) Synchronous speed.
(ii) Rotor speed at rated load.
(iii) Rotor frequency at rated load
(iv) Shaft torque at rated speed

Answer

[Ans.: (i) 1800rpm - (ii) 1710rpm - (iii) 3Hz - (iv) 41.7Nm]