Effect of slip on rotor frequency

- Frequency of the voltage induced in the rotor, f_r
- $f_r = P*n_{slip}/120$,

where

P = The number of stator poles

n_{slip} = The slip speed (r/min)

f_r = Rotor frequency (Hz) = $P(n_s - n_r)/120$

$f_r = P(sn_s)/120 => s(Pn_s/120)$

Thus, found that proportional to s.

“Blocked rotor” condition (nr=0)

- $s = (n_s – n_r)/n_s$
  $=(n_s-0)/n_s$
  $= 1$
- $f_r = s(Pn_s/120)$
  $= Pn_s/120$
  = same as source

Alternately,

- $f_r = f_{BR} = f_{stator}$
- In general, $f_r = sf_{BR}$

Effect of slip on rotor voltage

- For a squirrel-cage rotor,
  - --->$E_r = 4.44Nf_r\Phi_{max} = 4.44N*sf_{BR}\Phi_{max}$
- at blocked rotor, s=1
  - --->$EBR = 4.44Nf_{BR}\Phi max$ => $Er = sE_{BR}$

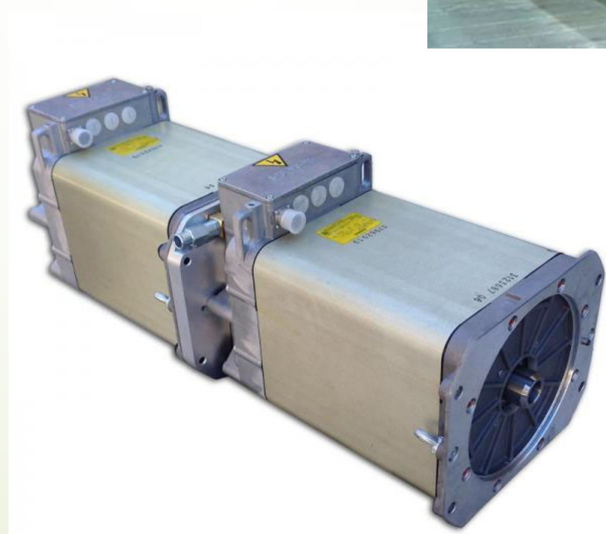
Induction Motor : Applications

- Conveyer line (belt) drives
- Roller table

Induction Motor : Applications

- Paper mills

- Electric vehicle



Induction Motor : Applications

- Elevators

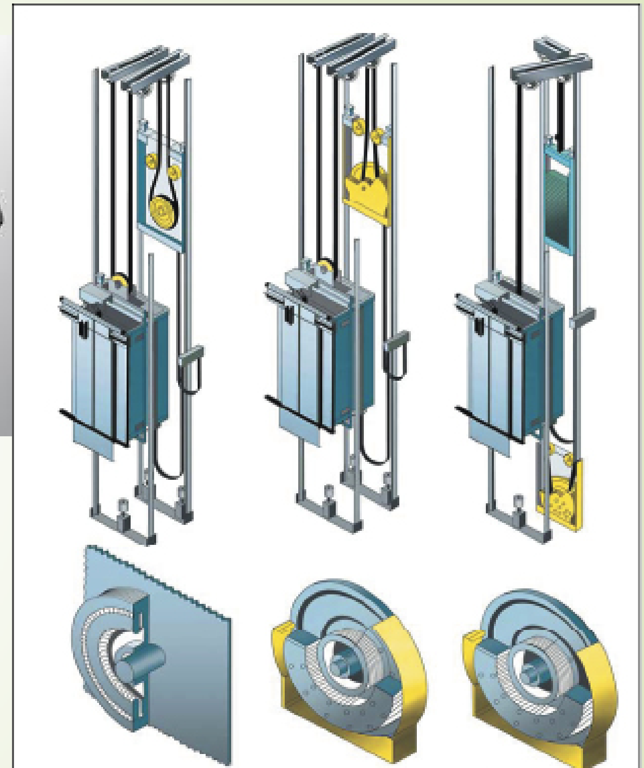


Illustration 3: Development phases of the machine.

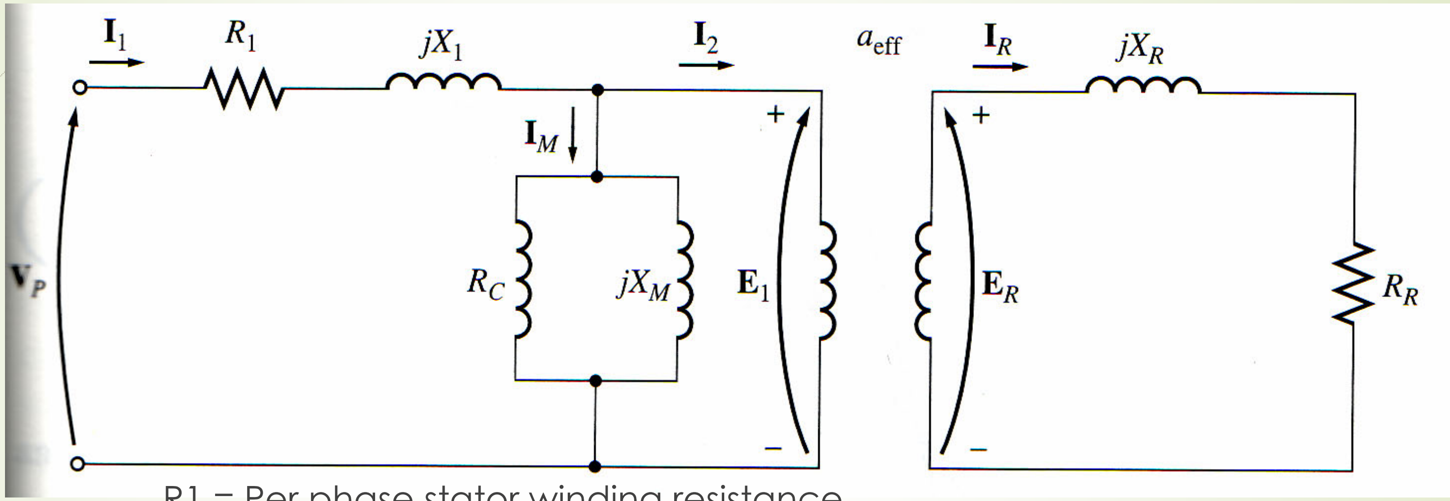
- Pulleys

Induction Motor : Applications

- Air conditioning

- Boiler feed pump

Induction Motor : Equivalent Circuit



R1 = Per phase stator winding resistance

jX1 = Per phase stator leakage reactance

VP = Per phase terminal voltage

RC = Core resistance

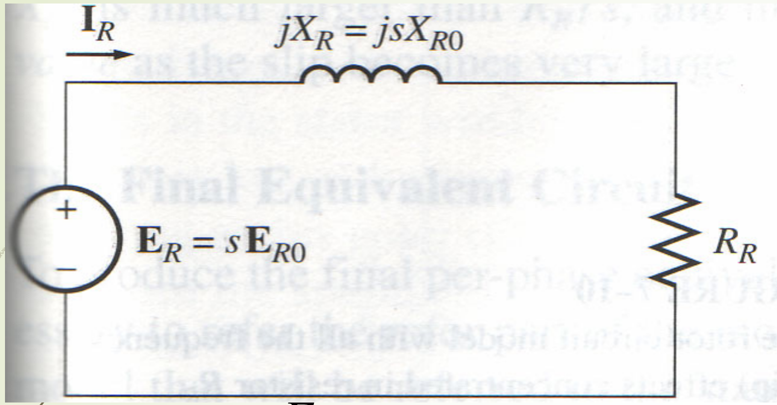
jXM = Magnetizing reactance

ER = Rotor voltage

RR = Rotor resistance

jXR = Per phase rotor leakage reactance

Induction Motor : Rotor Circuit Model



The greater the relative motion between rotor and the stator magnetic fields, the greater the resulting rotor voltage and rotor frequency. The largest relative motion occurs when the rotor is stationary. (locked rotor or blocked rotor condition)

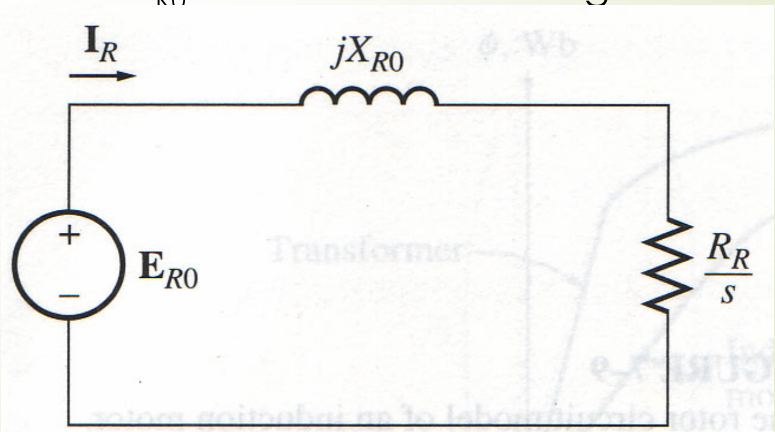
$$I_R = \frac{E_R}{R_R + jX_R}$$

jX_{R0} = blocked-rotor rotor resistance

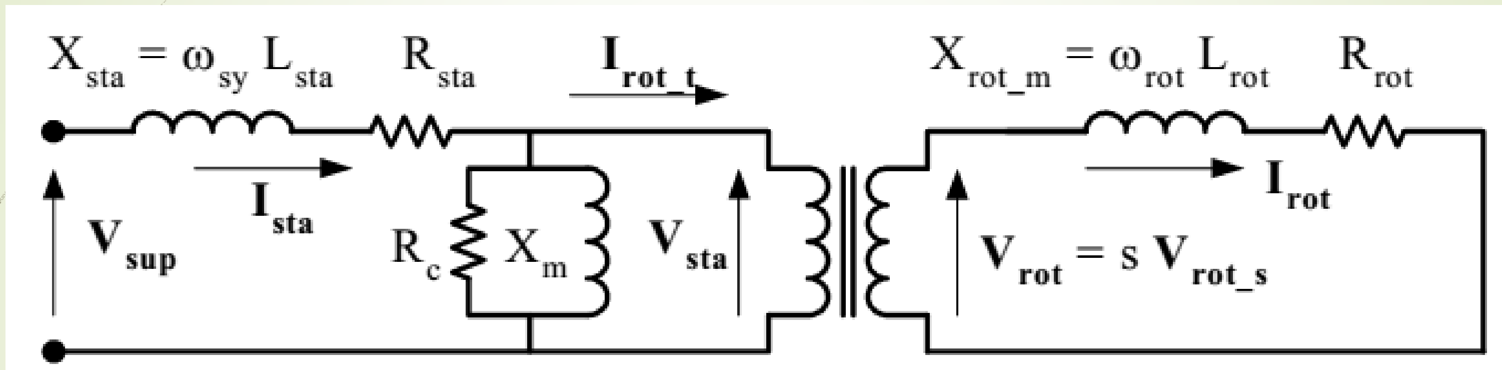
E_{R0} = Locked-rotor voltage

$$I_R = \frac{E_R}{R_R + jsX_{R0}}$$

$$I_R = \frac{E_{R0}}{\frac{R_R}{s} + jX_{R0}}$$



Induction Motor – Equivalent Circuit



Stator and Rotor as Coupled Circuits

- Same as a transformer
- Stator is connected to the AC source, and the rotor's voltage and current are produced by induction.
- The primary of the transformer corresponds to the stator of the machine, whereas the secondary corresponds to the rotor

Induction Motor : Final Equivalent Circuit

In an ordinary transformer, the voltages, currents, and impedances on the secondary of the device can be referred to the primary side by means of the turn ratio of the transformer:

$$V_P = V_S^{'} = aV_S \qquad I_P = I_S^{'} = \frac{I_S}{a} \qquad Z_S^{'} = a^2 Z_S$$

The transformed rotor voltage becomes

$$E_1 = E_R^{'} = a_{eff} E_{R0}$$

The rotor current becomes

$$I_2 = \frac{I_R}{a_{eff}}$$

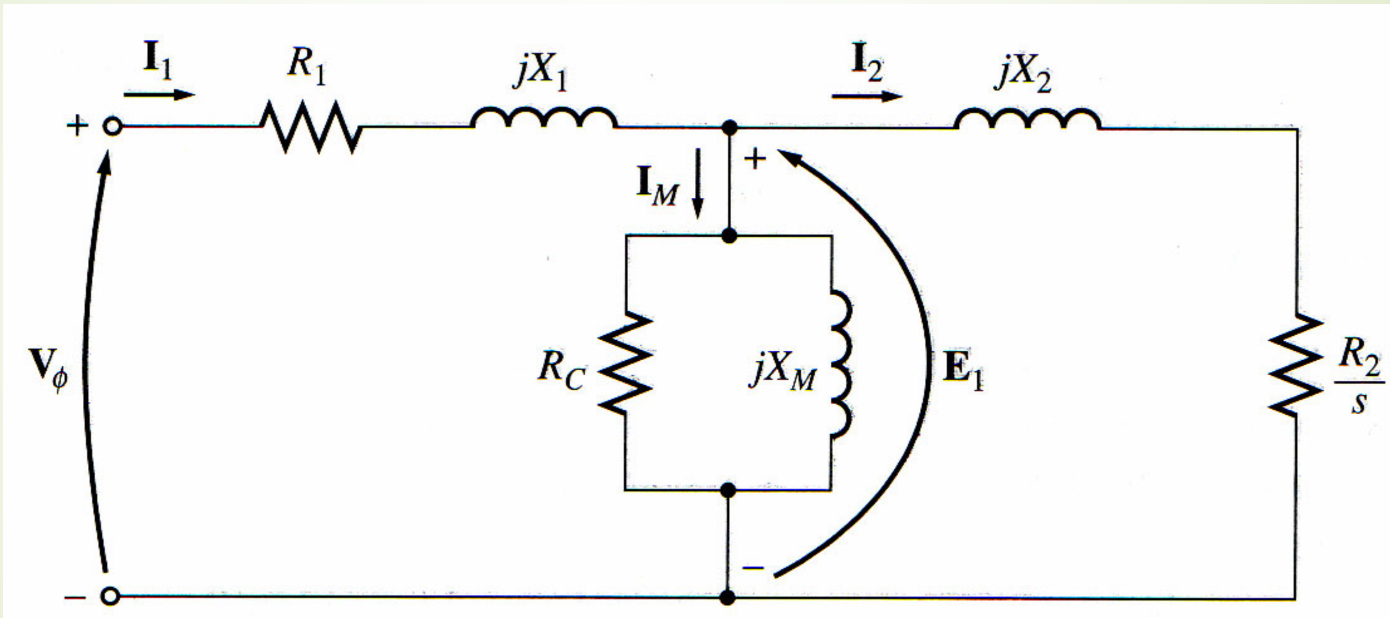
The rotor impedances becomes

$$Z_2 = a_{eff}^2 \left(\frac{R_R}{s} + jX_{R0} \right)$$

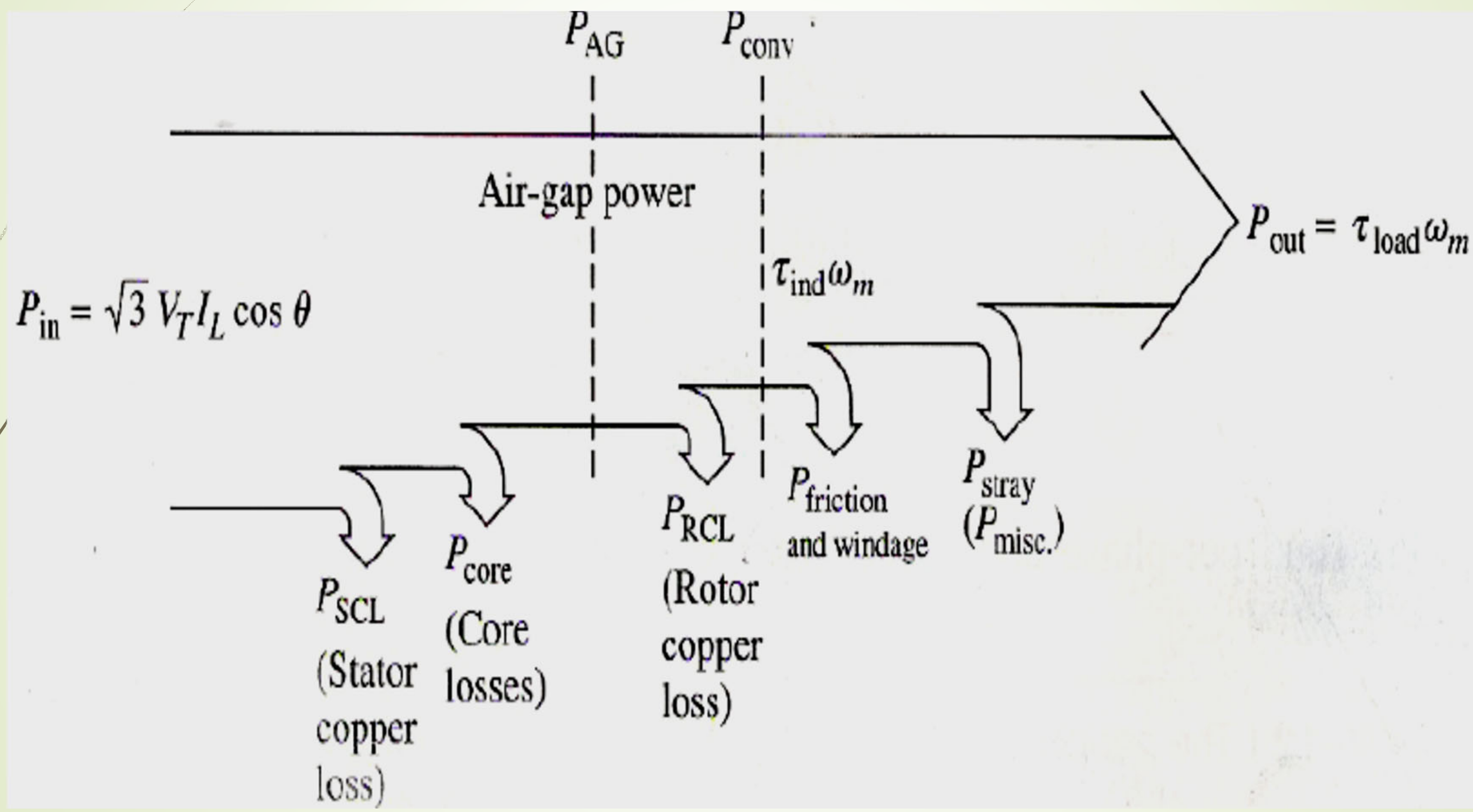
Referred rotor resistance and reactance

$$R_2 = a_{eff}^2 R_R \qquad X_2 = a_{eff}^2 X_{R0}$$

Induction Motor : Final Equivalent Circuit



Induction Motor– Power and Torque



The power flow diagram

Example

Example 3

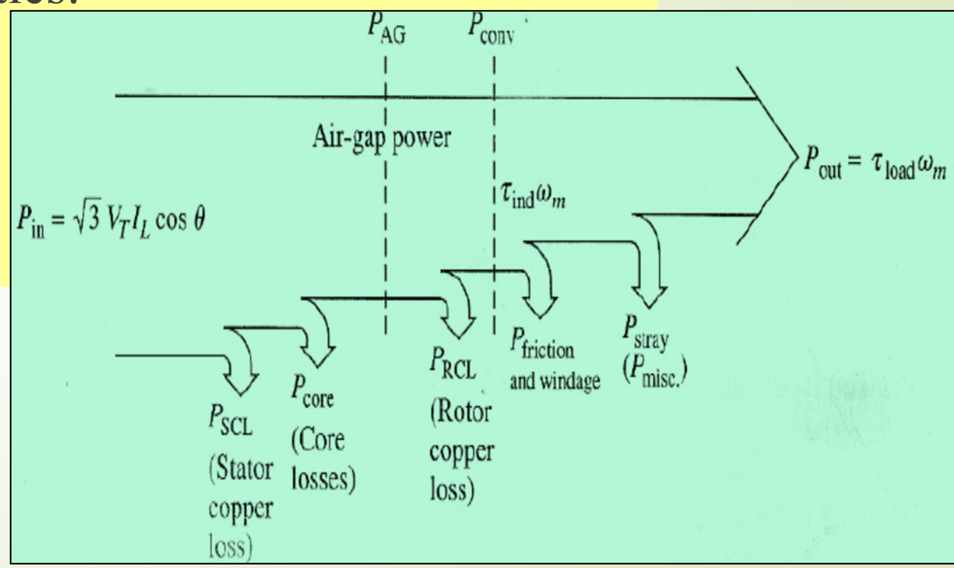
A 480-V, 50Hz, 50hp, three phase induction motor is drawing 60A at 0.80 PF lagging. The stator copper losses are 2 kW, and the rotor copper losses are 700W. The friction and windage losses are 600W, the core losses are 1800 W, and the stray losses are negligible. Fine the following quantities:

a. The air gap power PAG

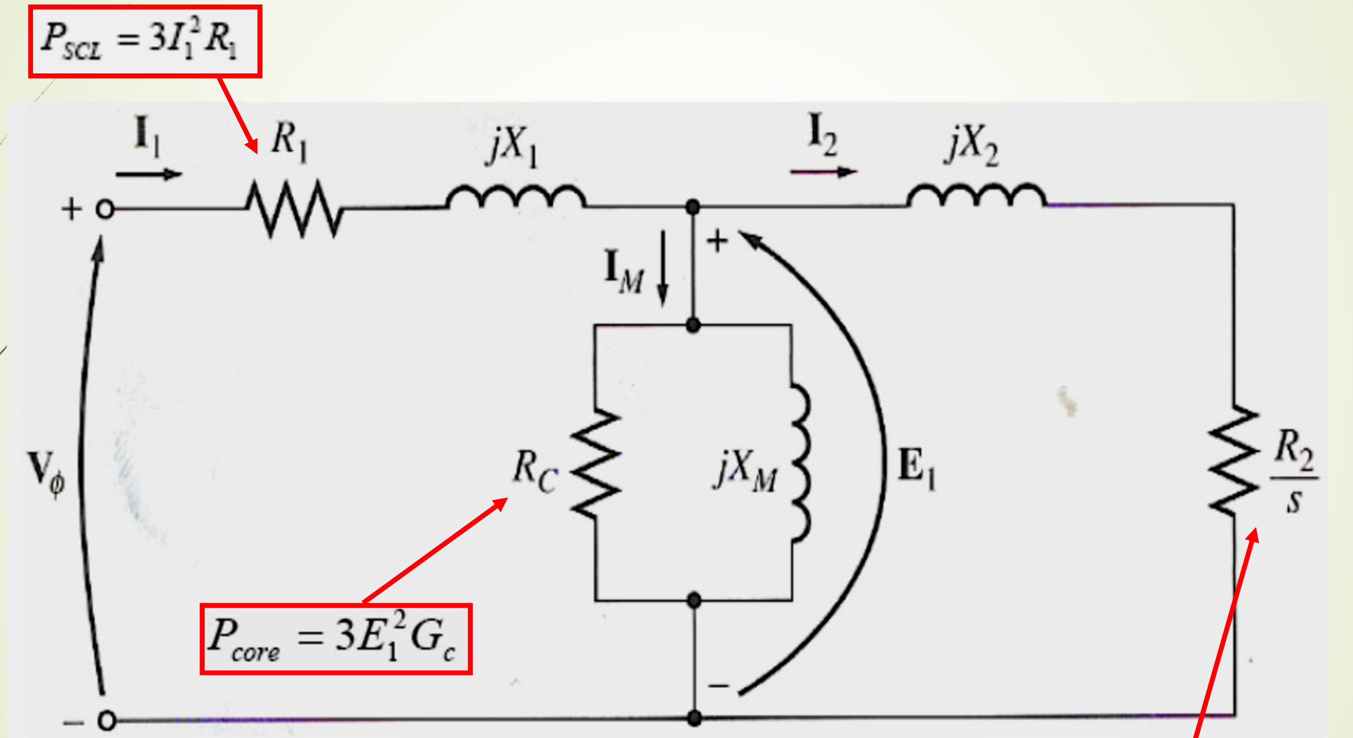
b. The power converted Pconv

c. The output power Pout

d. The efficiency of the motor



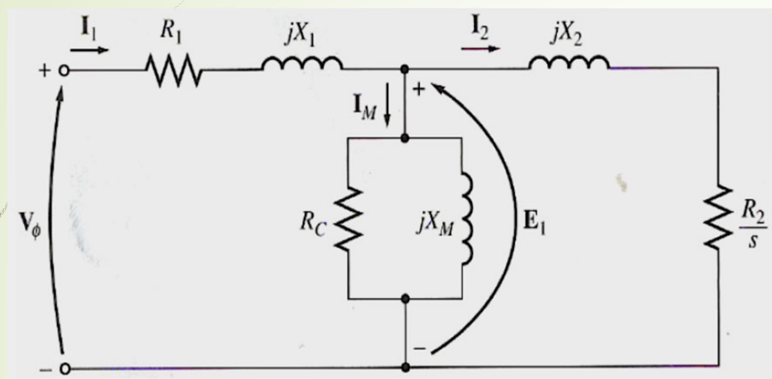
Induction Motor– Power and Torque

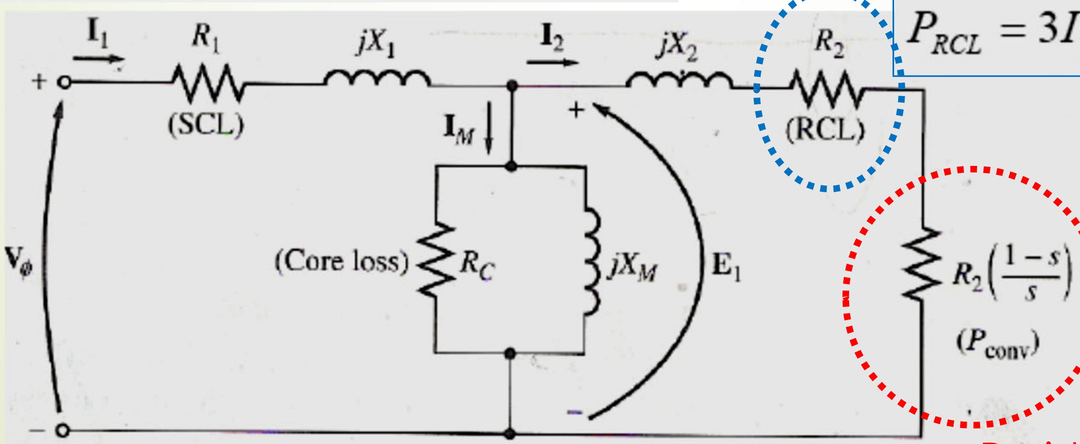


$$P_{AG} = P_{in} - P_{SCL} - P_{core}$$

$$P_{AG} = 3I_2^2 \frac{R_2}{s}$$

Induction Motor– Power and Torque





Actual rotor resistance

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

$$P_{conv} = 3I_2^2 R_2 \left(\frac{1-s}{s}\right)$$

Resistance equivalent to mechanical load

Induction Motor– Power and Torque

$$P_{RCL} = sP_{AG}$$

$$P_{conv} = (1 - s)P_{AG}$$

- The output power can be found as:

$$P_{out} = P_{conv} - P_{F\&W} - P_{misc}$$

- The induced torque or developed torque:

$$\tau_{ind} = \frac{P_{conv}}{\omega_m} \text{ or } \tau_{ind} = \frac{P_{AG}}{\omega_{sync}}$$

Induction Motor– Power and Torque

Example 4

A 460 V, 25-hp, 60Hz, four pole, Y-connected induction motor has the following impedances in ohms per phase referred to the stator circuit:

$R1 = 0.641\Omega$ $R2 = 0.332\Omega$

$X1 = 1.106\Omega$ $X2 = 0.464\Omega$ $Xm = 26.3\Omega$

The total rotational losses = 110 W, Rotor slip = 2.2% at rated voltage and frequency.

Find the motor's

i) Speed, ii) Stator Current, iii) Power factor, iv) Pconv, v) Pout vi) τ_{ind}, vii) τ_{load} and viii) Efficiency