EE2029 – Introduction to Electrical Energy Systems
Tutorial # 4 Induction Motors

1. What is the slip of an induction motor when it is at rest/stationary?

(Answer: s = 1)

$P=2$ $\quad N_s = \frac{120f}{P} = \frac{120(60)}{2} = 3600rpm$ $\quad 1rpm = 1 \times \frac{2\pi}{60}$ rad/s $\quad N = 3502rpm$

2. A three-phase, two-pole, 60 Hz induction motor is observed to be operating at a speed of 3502 rpm. It has an input power of 15.7 kW, and a terminal current of 22.6 A. The winding resistance of the stator is 0.2 Ω per-phase. Find the heat dissipated in the rotor.
secondary

(Answer: P_{rotor} = 419 W)

3. A three-phase Wye-connected 220 V, 7.5 kW, 60 Hz, six-pole induction motor has the following parameter values in Ω per-phase referred to the stator:
primary

$$R_1 = 0.1 \mid R_2 = 0.1 \mid X_1 = 0.2 \mid X_2 = 0.2 \mid X_m = 10 \mid s = 0.01$$

What is the total impedance and the rotor speed of this induction motor?
Z_{eq} $\quad$ N

(Answer: Z_{eq} = 5+j5.2 Ω, 123.2 rad/s)

I_1 $\quad$ primary $\quad Z_{m//2} = 5.41 + j3.11\Omega$

4. Suppose the per-phase impedance presented to the stator by the magnetizing reactance and the rotor is 5.41 + j 3.11 Ω. The stator current of the three-phase induction motor rated at 7.5 kW is 18.8 A. The motor has a 2% slip and has a rotor speed of 123.2 rad/s. The total loss (friction + windage) is 403 W. Calculate the output (shaft) power and the output torque.
$P_{mLoss} = 403W$. $\quad N = 123.2 rad/s$

(Answer: P_{shaft} = 5220 W, T_{shaft} = 42.4 Nm)

$V_1 = V_{LN} = \frac{480}{\sqrt{3}} V$ $\quad 1hp = 745.7W$

5. A 480 V, 60 Hz, 50 hp, three-phase induction motor is drawing 60 A at 0.85 PF lagging. The stator conductance losses are 2 kW, and the rotor conductance losses are 700 W. The friction and windage losses are 600 W, the core losses are 1800 W, and the stray losses are negligible. Find the following quantities:
   (a) The air-gap power P_{AG}
   (b) The power converted P_{conv}
   (c) The output/shaft power P_{out}
   (d) The efficiency of the motor

$V_{LL} = \sqrt{3} V_{LN}$
$\Rightarrow V_{LN} = \frac{V_{LL}}{\sqrt{3}}$

$P_{3\phi} = 3 V_{LN} I_{LN} \cos\theta$
$= 3 \frac{V_{LL}}{\sqrt{3}} I_{LN} \cos\theta$
$= \sqrt{3} V_{LL} I_{LN} \cos\theta$

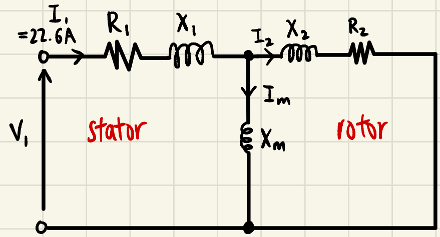
(Answer: P_{AG} = 38.6 kW, P_{conv} = 37.9 kW, P_{shaft} = 37.3 kW, n = 88%)

1. When motor is at rest, the rotor is at rest, $N = 0$.

$$s = \frac{N_s - \cancel{N}^{\,0}}{N_s} \times 100\%$$

$$= 100\%$$

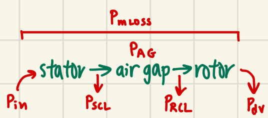
2.



$$\boxed{N_s = \frac{120f}{P}} = \frac{120(60)}{2} = 3600\,\text{rpm}$$

$$\boxed{s = \frac{N_s - N}{N_s} \times 100\%}$$

$$= \frac{3600 - 3502}{3600} \times 100\% = 2.72\%$$



$$\boxed{P_{AG} = P_{in} - P_{SCL} - \cancel{P_{core}}^{\,0}}$$

$$= P_{in} - I_1^2 R_1$$

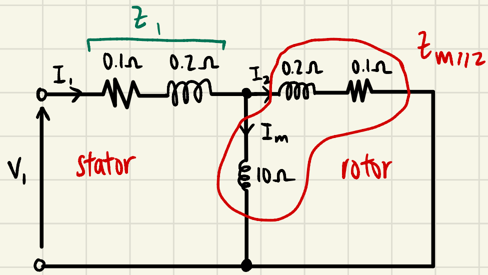
3-phase.

$$= (15.7 \times 10^3) - 22.6^2[3(0.2)] = 15.394\,\text{kW}$$

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

$$= \frac{2.72}{100}(15.394 \times 10^3) = 418.70\,\text{W}$$

3.



$s = 0.01$

$$\boxed{Z_{eq} = Z_1 + Z_{m//2} = Z_1 + \left[\left(\frac{1}{jX_m}\right) + \left(\frac{1}{Z_2}\right)\right]^{-1}} \quad \text{—— (1)}$$

$$Z_1 = R_1 + jX_1 = 0.1 + j0.2\,\Omega$$

$$\boxed{Z_2 = \frac{R_2}{s} + jX_2} = \frac{0.1}{0.01} + j0.2$$

$$= 10 + j0.2\,\Omega$$

Since $R_m // Z_2$:

$$Z_{eq} = Z_1 + Z_{m//2} = Z_1 + \left[\left(\frac{1}{jX_m}\right) + \left(\frac{1}{Z_2}\right)\right]^{-1}$$

$$= 0.1 + j0.2 + \left[\left(\frac{1}{j10}\right) + \left(\frac{1}{10 + j0.2}\right)\right]^{-1}$$

$$= 5 + j5.20\,\Omega$$

$$\boxed{N_s = \frac{120f}{P}} = \frac{120(60)}{6} = 1200 \text{ rpm}$$

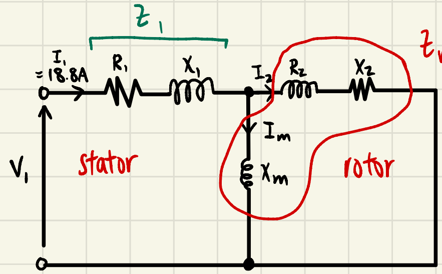
$$\boxed{N = (1-s)N_s}$$

$$= (1-0.01)[1200] = 1188 \text{rpm}$$

$1 \text{ rpm} = 1 \times \frac{2\pi}{60} \text{ rad/s}$

$$= 1188 \times \frac{2\pi}{60} = 124.41 \text{ rad/s}$$

4.



$Z_{m1/2} = 5.41 + j3.11\Omega$

Output / Shaft Power, P_{out}:

$$\boxed{\begin{aligned} P_{out} &= P_{dv} - P_{mLoss} = P_{AG}(1-s) - P_{mLoss} \\ &= n_{ph} I_2^2 R_{m1/2}(1-s) - P_{mLoss} \end{aligned}}$$

$$= 3I_2^2 R_{m1/2}(1-s) - P_{mLoss} \quad \text{—— (1)}$$

① $P_{out} = P_{shaft} = P_{dv} - P_{mLoss}$

② $P_{dv} = P_{AG}(1-s)$

③ $P_{AG} = 3I_2^2 R_{m1/2}$

$$Z_{m1/2} = R_{m1/2} + jX_{m1/2} = 5.41 + j3.11\Omega$$

$$\Rightarrow R_{m1/2} = 5.41\Omega \quad \text{—— (2)}$$

Sub. (2) into (1):

$$P_{out} = 3(18.8^2)(5.41)[1-0.02] - 403$$

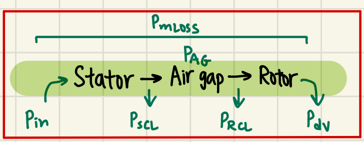
$$= 5218.60W$$

$$\boxed{P = \tau\omega}$$

$$\therefore \tau_{out} = \frac{P_{out}}{\omega_R} = \frac{5218.60}{123.2} = 42.36\ Nm$$

in rad/s.

5.



(a).

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

$$= 3I_1 V_{LN}\cos\theta - P_{SCL} - P_{core}$$

$$= 3(60)\left[\frac{480}{\sqrt{3}}\right](0.85) - [2\times10^3] - 1800$$

$$= 38.6kW$$

① $P_{in} = 3I_{LN}V_{LN}\cos\theta$

② $V_{LL} = \sqrt{3}V_{LN}$

(b).

$$\boxed{P_{conv} = P_{dv} = P_{AG} - P_{RCL}}$$

$$= (38.6 \times 10^3) - 700 = 37.9\text{kW}$$

(c).

$$\boxed{P_{shaft} = P_{conv} - P_{mLoss}}$$

$$= (37.9 \times 10^3) - 600 = 37.3\text{kW}$$

(d).

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

$$= \frac{P_{shaft}}{3I_1V_1\cos\theta} \times 100\%$$

$$= \frac{37.3 \times 10^3}{3(60)\left[\frac{480}{\sqrt{3}}\right](0.85)} \times 100\%$$

$$= 87.97\%$$