KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

ELECTRICAL ENGINEERING DEPARTMENT

EE 306 – Term 171

HW # 6: Induction Machines

Due Date:

UT Classes: December 26, 2017

MW Classes: December 27, 2017

Problem 1

A 480-V three-phase two-pole 60-Hz induction motor is running at a slip of 2.5 percent. Find:

(a) The speed of the magnetic fields in revolutions per minute

(b) The speed of the rotor in revolutions per minute

(c) The slip speed of the rotor

(d) The rotor frequency in hertz

Solution

(a) The speed of the magnetic fields is

$$n_{\text{sync}} = \frac{120 f_{se}}{P} = \frac{120(60\text{ Hz})}{2} = 3600\text{ r/min}$$

(b) The speed of the rotor is

$$n_m = (1-s)\ n_{\text{sync}} = (1-0.025)(3600\text{ r/min}) = 3510\text{ r/min}$$

(c) The slip speed of the rotor is

$$n_{\text{slip}} = s n_{\text{sync}} = (0.025)(3600\text{ r/min}) = 90\text{ r/min}$$

(d) The rotor frequency is

$$f_{re} = \frac{n_{\text{slip}} P}{120} = \frac{(90\text{ r/min})(2)}{120} = 1.5\text{ Hz}$$

Problem 2

A 50-kW, 460-V, 50-Hz, two-pole induction motor has a slip of 5 percent when operating a full-load conditions. At full-load conditions, the friction and windage losses are 700 W, and the core losses are 600 W. Find the following values for full-load conditions:

(a) The shaft speed n_m

(b) The output power in watts

(c) The load torque τ_{load} in newton-meters

(d) The induced torque τ_{ind} in newton-meters

(e) The rotor frequency in hertz

Solution

(a) The synchronous speed of this machine is

$$n_{\text{sync}} = \frac{120 f_{se}}{P} = \frac{120(50\text{ Hz})}{2} = 3000\text{ r/min}$$

Therefore, the shaft speed is

$$n_m = (1-s)\ n_{\text{sync}} = (1-0.05)(3000\text{ r/min}) = 2850\text{ r/min}$$

(b) The output power in watts is 50 kW (stated in the problem).

(c) The load torque is

$$\tau_{\text{load}} = \frac{P_{\text{OUT}}}{\omega_m} = \frac{50\text{ kW}}{(2850\text{ r/min})\left(\frac{2\pi\text{ rad}}{1\text{ r}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)} = 167.5\text{ N}\cdot\text{m}$$

(d) The induced torque can be found as follows:

$$P_{\text{conv}} = P_{\text{OUT}} + P_{\text{F\&W}} + P_{\text{core}} + P_{\text{misc}} = 50\text{ kW} + 700\text{ W} + 600\text{ W} + 0\text{ W} = 51.3\text{ kW}$$

$$\tau_{\text{ind}} = \frac{P_{\text{conv}}}{\omega_m} = \frac{51.3 \text{ kW}}{(2850 \text{ r/min})\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right)} = 171.9 \text{ N}\cdot\text{m}$$

(e) The rotor frequency is

$$f_r = sf_e = (0.05)(50 \text{ Hz}) = 2.5 \text{ Hz}$$

Problem 3

The power crossing the air gap of a 60 Hz, four-pole induction motor is 25 kW, and the power converted from electrical to mechanical form in the motor is 23.2 kW.

(a) What is the slip of the motor at this time?

(b) What is the induced torque in this motor?

(c) Assuming that the mechanical losses are 300 W at this slip, what is the load torque of this motor?

Solution

(a) The synchronous speed of this motor is

$$n_{\text{sync}} = \frac{120 f_{se}}{P} = \frac{120(60 \text{ Hz})}{4} = 1800 \text{ r/min}$$

The power converted from electrical to mechanical form is

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

so

$$s = 1 - \frac{P_{\text{conv}}}{P_{\text{AG}}} = 1 - \frac{23.4 \text{ kW}}{25 \text{ kW}} = 0.064$$

or 6.4%.

(b) The speed of the motor is

$$n_m = (1-s) n_{\text{sync}} = (1-0.064)(1800 \text{ r/min}) = 1685 \text{ r/min}$$

The induced torque of the motor is

$$\tau_{\text{ind}} = \frac{P_{\text{conv}}}{\omega_m} = \frac{23.4 \text{ kW}}{(1685 \text{ r/min})\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right)} = 132.6 \text{ N}\cdot\text{m}$$

Alternately, the induced torque can be found as

$$\tau_{\text{ind}} = \frac{P_{\text{AG}}}{\omega_{\text{sync}}} = \frac{25.0 \text{ kW}}{(1800 \text{ r/min})\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right)} = 132.6 \text{ N}\cdot\text{m}$$

(c) The output power of this motor is

$$P_{\text{out}} = P_{\text{conv}} - P_{\text{mech}} = 23,400 \text{ W} - 300 \text{ W} = 23,100 \text{ W}$$

$$\tau_{\text{load}} = \frac{P_{\text{out}}}{\omega_m} = \frac{23.1 \text{ kW}}{(1685 \text{ r/min})\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right)} = 130.9 \text{ N}\cdot\text{m}$$

Problem 4

A 3ϕ, 280 V, 60 Hz, 20 hp, four-pole induction motor has the following equivalent circuit parameters.

$$R_1 = 0.12\ \Omega, \qquad R_2' = 0.1\ \Omega$$

$$X_1 = X_2' = 0.25\ \Omega$$

$$X_m = 10.0\ \Omega$$

The rotational loss is 400 W. For 5% slip, determine

(a) The motor speed in rpm and radians per sec.

(b) The motor current.

(c) The stator cu-loss.

(d) The air gap power.

(e) The rotor cu-loss.

(f) The shaft power.

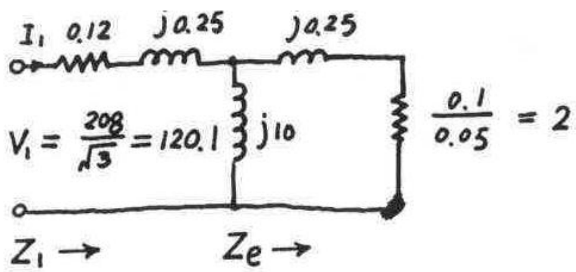
(g) The developed torque and the shaft torque.

(h) The efficiency.

Solution

(a) $n_s = \dfrac{120 \times 60}{4} = 1800 \text{ rpm} \qquad \omega_s = \dfrac{1800}{60} \times 2\pi = 188.5 \text{ rad/sec}$

(b)



$$Z_1 = 0.12 + j0.25 + R_e + jX_e = 0.12 + j0.25 + \frac{j10 \times (2 + j0.25)}{2 + j10.25}$$

$$= 0.12 + j0.25 + 1.9538 + j0.8517 = 2.1314 \angle 23.5533^\circ \Omega$$

$R_e = 1.9538, \; X_e = 0.8517$

$$I_1 = \frac{120.1}{2.1314 \angle 23.5533^\circ} = 56.3479 \angle -23.5533^\circ$$

(c) $P_1 = 3 \times (56.3479)^2 \times 0.12 = 1143.0309 \text{ W}$

(d) $P_s = 3 \times 120.1 \times 56.3479 \times \cos(-23.5533) = 18610.9794 \text{ W}$

$P_{ag} = P_s - P_1 = 17467.9485 \text{ W}$

(e) $P_2 = s P_{ag} = 0.05 \times 17467.9485 = 873.3974 \text{ W}$

(f) $P_{mech} = (1-S)\, P_{ag} = 16594.5511\,W$

$P_{shaft} = P_{mech} - P_{rotational} = 16194.5511\,W$

(g) $T = \dfrac{P_{ag}}{188.5} = \dfrac{17467.9485}{188.5} = 92.6682\ N.m$

$T_{shaft} = \dfrac{P_{shaft}}{188.5} = \dfrac{16194.5511}{188.5} = 85.9127\ N.m$

(h) $Eff = \dfrac{P_{shaft}}{P_s} = 0.8702 \times 100\% = 87.02\%$