

EE3124 Tutorial 6 (Solution)

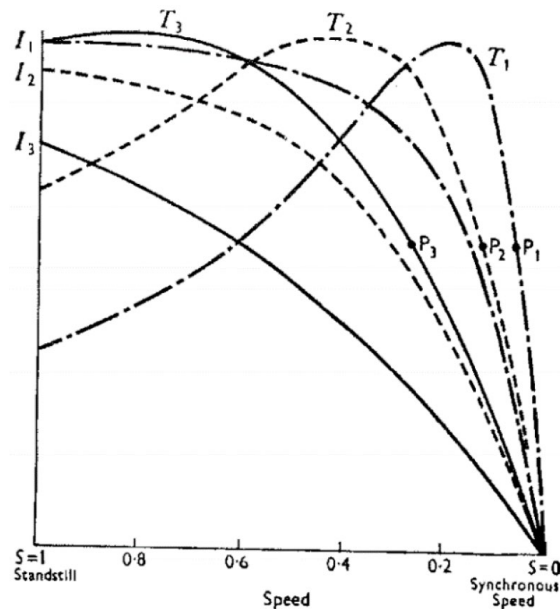
Induction Machine

Name:

Student No.:

Q1 - Sketch the torque-speed and current-speed characteristics of a three-phase wound-rotor induction motor when using external resistance control. Hence, explain why both high starting torque and low starting current can be achieved simultaneously.

Solution



The starting torque depends on the applied voltage, starting current and the corresponding power factor. When external resistance is properly added during the starting, the improvement in power factor is dominant to the reduction of starting current. Hence, both reduction of starting current and improvement of starting torque can be achieved simultaneously.

Q2 - A three-phase, 380 V, 50 Hz, 8-pole star-connected wound rotor induction motor has a stator impedance of $(0.1+j 0.55) \Omega$ per phase, and a rotor impedance of $(0.2+j 0.55) \Omega$ per phase referred to the stator side. Ignoring the magnetizing current ($I_{X_m} = 0$), determine the required external resistance (referred to the stator side) which should be inserted in each rotor phase to achieve the maximum starting torque. Hence, calculate this maximum starting torque.

Given:

$$\text{The air gap power } P_{AG} = \frac{3V_{TH}^2 R_2 / s}{(R_{TH} + R_2 / s)^2 + (X_{TH} + X_2)^2} \quad \text{The induced torque } \tau_{ind} = \frac{P_{AG}}{\omega_{sync}}$$

The maximum power transfer occurs when $\frac{R_2}{s} = \sqrt{R_{TH}^2 + (X_{TH} + X_2)^2}$

Solution

$$N_s = \frac{rpm}{60} = \frac{50 \times 60}{4} = \frac{750}{60} = 12.5 \text{ rps}$$

$$\text{In the per phase equivalent circuit, } V_\phi = \frac{V_{LL}}{\sqrt{3}} = \frac{380}{\sqrt{3}} = 219.4 \text{ V}$$

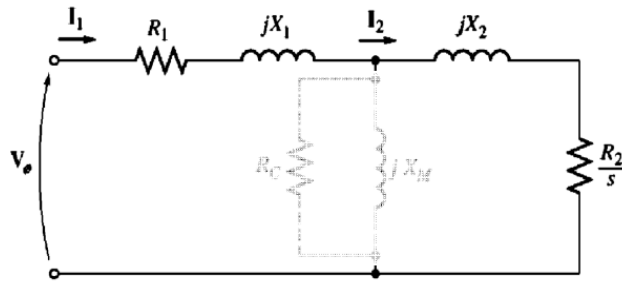
When the motor starts, slip $s=1$, $R_2' = \sqrt{R_1^2 + (X_1 + X_2)^2}$ and $R_2' = R_2 + R_e$

where R_e is the external rotor resistance.

$$R_2 + R_e = \sqrt{0.1^2 + (0.55 + 0.55)^2}$$

$$0.2 + R_e = 1.1045$$

$$R_e = 0.9045$$



$$\tau_{ind} = \frac{P_{AG}}{\omega_{sync}} = \frac{3V_{TH}^2 R_2 / s}{(2\pi N_s) \left[(R_{TH} + R_2 / s)^2 + (X_{TH} + X_2)^2 \right]}$$

$$= \frac{3 \times (219.4)^2 \times 1.1045}{(2\pi N_s) \times [(0.1 + 1.1045)^2 + (0.55 + 0.55)^2]}$$

$$= \frac{159499.8289}{(78.5398) \times [(1.4508) + (1.21)]}$$

$$= 763.2348 \text{ N} \cdot \text{m}$$

Q3 - A 220-V three-phase six-pole 50-Hz induction motor is running at a slip of 3.5 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

$$n_{\text{sync}} = \frac{120f_{se}}{P} = \frac{120(50 \text{ Hz})}{6} = 1000 \text{ r/min}$$

- (b) The speed of the rotor is

$$n_m = (1 - s) n_{\text{sync}} = (1 - 0.035)(1000 \text{ r/min}) = 965 \text{ r/min}$$

- (c) The slip speed of the rotor is

$$n_{\text{slip}} = sn_{\text{sync}} = (0.035)(1000 \text{ r/min}) = 35 \text{ r/min}$$

- (d) The rotor frequency is

$$f_{re} = \frac{n_{\text{slip}}P}{120} = \frac{(35 \text{ r/min})(6)}{120} = 1.75 \text{ Hz}$$

Q4 - A two-pole, 50-Hz induction motor supplies 15 kW to a load at a speed of 2950 r/min.

- (a) What is the motor's slip?
- (b) What is the induced torque in the motor in N • m under these conditions?
- (c) What will the operating speed of the motor be if its torque is doubled?
- (d) How much power will be supplied by the motor when the torque is doubled?

Solution

- (a) The synchronous speed of this motor is

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

Therefore, the motor's slip is

$$\begin{aligned}s &= \frac{n_{\text{sync}} - n_m}{n_{\text{sync}}} (\times 100\%) \\&= \frac{3000 \text{ r/min} - 2950 \text{ r/min}}{3000 \text{ r/min}} (\times 100\%) \\&= 0.0167 \text{ or } 1.67\%\end{aligned}$$

- (b) The induced torque in the motor must be assumed equal to the load torque, and P_{conv} must be assumed equal to P_{load} , since no value was given for mechanical losses. The torque is thus

$$\begin{aligned}\tau_{\text{ind}} &= \frac{P_{\text{conv}}}{\omega_m} \\&= \frac{15 \text{ kW}}{(2950 \text{ r/min})(2\pi \text{ rad/r})(1 \text{ min}/60 \text{ s})} \\&= 48.6 \text{ N} \cdot \text{m}\end{aligned}$$

- (c) In the low-slip region, the torque–speed curve is linear, and the induced torque is directly proportional to slip. Therefore, if the torque doubles, then the new slip will be 3.33 percent. The operating speed of the motor is thus

$$n_m = (1 - s)n_{\text{sync}} = (1 - 0.0333)(3000 \text{ r/min}) = 2900 \text{ r/min}$$

Q5 - 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

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