Example 5 - 4: Induction Machine Correction Correction Correction

Dummy unit: $\Omega \equiv 1$ $\text{rpm} \equiv 1$ $V \equiv 1$ $A \equiv 1$ $\text{Hz} \equiv 1$ $\text{kW} \equiv 10^3$ $\text{Nm} \equiv 1$ $W \equiv 1$ $k \equiv 10^3$

Y-connected Induction Machine:

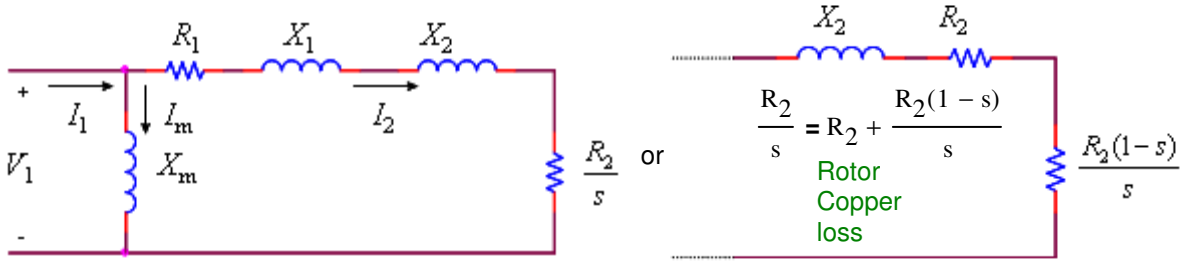
$V_{3\phi} := 460V$ $N_r := 1740\text{rpm}$ $f := 60\text{Hz}$

$R_1 := 0.25\Omega$ $R_2 := 0.2\Omega$ $p := 4$

$X_1 := 0.5$ $X_2 := 0.5$ $X_m := 30\Omega$

$V_1 := \frac{V_{3\phi}}{\sqrt{3}}$ $V_1 = 265.581$ $N_s := \frac{120 \cdot f}{p}$ $N_s = 1.8 \times 10^3$

We use approximate equivalent circuit for all analysis and calculations.



(a) (i) Starting current when started direct on full voltage

At start $s := 1$ $R_2 \cdot \frac{(1-s)}{s} = 0$

$V_1 := \frac{V_{3\phi}}{\sqrt{3}}$ $V_1 = 265.581\ V$

$I_2 := \frac{V_1}{R_1 + \frac{R_2}{s} + j \cdot (X_1 + X_2)}$ $I_2 = 99.386 - 220.857i$ $|I_2| = 242.189\ A$ $\arg(I_2) = -65.772\ \text{deg}$

$I_m := \frac{V_1}{j \cdot X_m}$ $I_m = -8.853i$ $|I_m| = 8.853$ $\arg(I_m) = -90\ \text{deg}$

$I_1 := I_m + I_2$ $I_1 = 99.386 - 229.71i$ $|I_1| = 250.288$ $\arg(I_1) = -66.604\ \text{deg}$

Starting current, $I_{start} := |I_1|$ $I_{start} = 250.288\ A$

(ii) Starting torque

Air gap power, $P_{ag} := \frac{3(|I_2|)^2 \cdot R_2}{s}$ $P_{ag} = 35.193\ \text{kW}$

$\omega_s := \frac{N_s}{60} \cdot 2\pi$ $T := \frac{P_{ag}}{\omega_s}$ $T = 186.707\ \text{Nm}$

(b) (i) Full load slip

$$s := \frac{N_s - N_r}{N_s} \qquad s = 0.033$$

(ii) Full load current

$$I_2 := \frac{V_1}{R_1 + \frac{R_2}{s} + j \cdot (X_1 + X_2)} \qquad I_2 = 41.432 - 6.629i \qquad |I_2| = 41.959\,A \qquad \arg(I_2) = -9.09\,deg$$

$$I_m := \frac{V_1}{j \cdot X_m} \qquad I_m = -8.853i \qquad |I_m| = 8.853 \qquad \arg(I_m) = -90\,deg$$

$$I_1 := I_m + I_2 \qquad I_1 = 41.432 - 15.482i \qquad |I_1| = 44.23 \qquad \arg(I_1) = -20.489\,deg$$

Full load current, $I_{FL} := |I_1|$ $I_{FL} = 44.23\,A$

(iii) Ratio of starting current to full-load current

$$\frac{I_{start}}{I_{FL}} = 5.659$$

(iv) Full-load power factor

$\theta := \arg(I_1)$ $\theta = -20.489\,deg$ $pf := \cos(\theta)$ $pf = 0.937$ lagging

(v) Full-load torque

Air gap power, $P_{ag} := \frac{3(|I_2|)^2 \cdot R_2}{s}$ $P_{ag} = 31.69\,kW$

$\omega_s := \frac{N_s}{60} \cdot 2\pi$ $T := \frac{P_{ag}}{\omega_s}$ $T_{FL} := T$ $T_{FL} = 168.123\,Nm$

(vi) Internal Efficiency

$P_{rot} := 1700W$ rotational losses (windage plus friction)

Rotor Copper loss: $P_2 := s \cdot P_{ag}$ $P_2 = 1.056 \times 10^3$

Mechanical power: $P_m := (1 - s) \cdot P_{ag}$ $P_m = 30.634\,kW$

Output power: $P_{out} := P_m - P_{rot}$ $P_{out} = 28.934\,kW$

Input power: $P_{input} := 3 \left|V_1\right| \cdot \left|I_1\right| \cdot pf$ $P_{input} = 33.011\,kW$

Motor efficiency, $Eff_{motor} := \frac{P_{out}}{P_{input}} \cdot 100$ $Eff_{motor} = 87.65$

Internal efficiency, $Eff_{internal} := \frac{P_m}{P_{ag}} \cdot 100$ $Eff_{internal} = 96.667$

(c) (i) Slip at which maximum torque is developed

$$s_{Tmax} := \frac{R_2}{\sqrt{R_1^{\,2} + (X_1 + X_2)^2}} \qquad s_{Tmax} = 0.194$$

(ii) Maximum torque developed

$s := s_{Tmax}$

$$I_2 := \frac{V_1}{R_1 + \frac{R_2}{s} + j \cdot (X_1 + X_2)} \qquad I_2 = 128.826 - 100.584i \quad \left|I_2\right| = 163.442\,A \quad \arg(I_2) = -37.982\,deg$$

Air gap power, $P_{ag} := \frac{3\left(\left|I_2\right|\right)^2 \cdot R_2}{s}$ $P_{ag} = 82.606\,kW$

$\omega_s := \frac{N_s}{60} \cdot 2\pi$ $T := \frac{P_{ag}}{\omega_s}$ $T_{max} := T$ $T_{max} = 438.239\,Nm$

$T_{FL} = 168.123\,Nm$ $\frac{T_{max}}{T_{FL}} = 2.607$

(d) How much external resistance per phase should be connected in the rotor circuit so that maximum torque occurs at start.

At start, $s = 1$

S_{Tmax} occurs at start. Therefore, $s_{Tmax} := 1$

$R_{ext} := 1$ (Guess value required by mathcad)

Given $s_{Tmax} = \frac{R_2 + R_{ext}}{\sqrt{R_1^{\,2} + (X_1 + X_2)^2}}$ $R_{ext} := Find(R_{ext})$ $R_{ext} = 0.831\,\Omega$