12.2 Induction Motors

Friday, 8 April 2022 3:42 PM

Q1 $n_r = (1-s) n_s$ $\quad s = \frac{n_s - n_r}{n_s}$

At rest: $n_r = 0$ $\quad s = 1$ if $n_r = 0$

$\Rightarrow 0 = (1-s) n_s$

$s = 1$ or 100%

Q2 3ϕ, 2 pole, 60 Hz, $n_r = 3502$ rpm

$P_{in} = 15.7$ kW, $I_1 = 22.6$ A

$r_1 = 0.2\,\Omega$/phase,

$P_{RCL} = ?$

$P_{core} = 0$ W

$P_{SCL} = 3 I_1^2 r_1$

$= 3 \times 22.6^2 \times 0.2$

$= 306.46$ W

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

$= 15.7\text{kW} - 0 - 306.46$

$= 15393.54$ W

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

$s \cdot P_{AG} = 3 I_2'^2 . R_2'$

$P_{in} = 3 V_1 I_1 \cos\theta$ $\quad P_{SCL} \rightarrow$ Stator copper loss

$\rightarrow P_{SCL} = 3 I_1^2 R_1$

$\rightarrow P_{core} = \frac{3 E_1^2}{R_c}$ $\quad 3 I_c^2 . R_c$

$P_{AG} \rightarrow P_{MECH} = P_{in} - P_{SCL} - P_{core}$.

$P_{AG} = 3 I_2'^2 . \frac{R_2'}{s}$ $\quad P_{RCL} \rightarrow$ Rotor copper loss

$\rightarrow P_{RCL} = 3 I_2'^2 . R_2'$

$P_{elec} = P_{AG} - P_{RCL} = 3 I_2'^2 \frac{R_2'}{s} - 3 I_2'^2 . R_2'$

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

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

$\rightarrow P_{mech\ losses} = P_{friction} + P_{windage}$.

$P_{out} = P_{elec} - P_{mech.loss}$

$P_{out} = \tau_m . \omega_m = P_{shaft}$

$\eta = \frac{P_{out}}{P_{in}}$

$n_s = \frac{120 \times 60}{2} = 3600$ rpm

$s = \frac{n_s - n_r}{n_s} = \frac{3600 - 3502}{3600}$

$= 0.027$ or 2.7%

$s . P_{AG} = 3 I_2'^2 . R_2' = P_{RCL}$

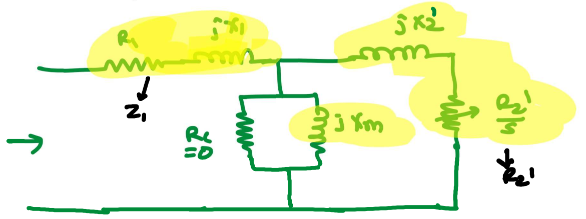
$P_{RCL} = 0.027 \times 15393.54$

$= 419$ W

3) 3ϕ, Y, 220V, 7.5kW, 60Hz, 6 pole

$R_1 = 0.1\,\Omega$, $R_2' = 0.1\,\Omega$, $X_1 = 0.2\,\Omega$, $X_2' = 0.2\,\Omega$

$X_m = 10\,\Omega$, $s = 0.01$



$n_s = \frac{120 f}{P} = \frac{120 \times 60}{6} = 1200$ rpm

$n_r = (1-s) n_s = (1 - 0.01) 1200$

$= 1188$ rpm

$\omega_r = 1188 \times \frac{2\pi}{60} = 124.4$ rad/s

$$\frac{R_2'}{s}+jX_2$$

$$Z_2' = \frac{0.1}{0.01} + j0.2 = 10 + j0.2\ \Omega$$

$$Z_2' \| jX_m = (10 + j0.2) \| (j10)$$
$$= \underline{4.9 + j5}\ \Omega$$

$$Z_{eq} = Z_1 + (Z_2' \| jX_m)$$
$$= (0.1 + 0.2j) + (4.9 + j5)\ \Omega$$
$$= 5 + j5.2\ \Omega$$

$$Z_{eq} = |Z_{eq}| \angle Z_{eq}$$
$\downarrow$
$\cos(\angle Z_{eq})$
$\downarrow$
P.F of the I.M.

If load change $\rightarrow$ s change $\rightarrow$ Z_2' change $\rightarrow$ Z_{eq} change $\rightarrow$ $\angle Z_{eq}$ changing $\rightarrow$ Power factor changing.

$$s = \frac{n_s - n_r}{n_s}$$

$$1(n_s) = n_s - n_r.$$
$$n_r = 0$$

4) $Z_2' = 5.41 + j3.1\ \Omega$, 7.5 kW

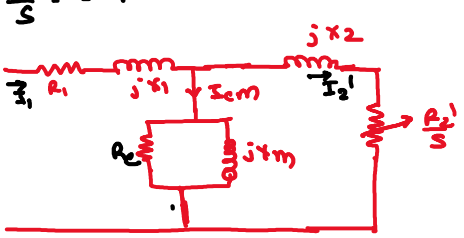
$I_1 = 18.8A$, $s = 2\%$, $\omega_r = 123.2$ rad/s

$P_{mech} = 240.8W$

$P_{shaft} = ?$

$T_{output} = ?$

$$Z_2' = 5.41 + j3.1$$
$$\frac{R_2'}{s} = 5.41$$



$$I_1 = I_2' + I_{em}$$
I_{em} = very small.
$$I_2' \approx I_1 = 18.8A$$

$$P_{AG} = 3 I_2'^2 \cdot \frac{R_2'}{s}$$
$$= 3 \times 18.8^2 \times 5.41$$
$$= 5736.3W$$

$$P_{elec} = P_{AG} - P_{RCL}$$
$$= P_{AG} - s \cdot P_{AG}$$
$$= 5736.3(1 - 0.02)$$
$$= 5621.6\ W$$

$P_{in} = 3V_1 I_1 \cos\theta$ — $P_{SCL} \rightarrow$ Stator copper loss

$\rightarrow P_{SCL} = 3 I_1^2 R_1$

$\rightarrow P_{core} = \frac{3 E_1^2}{R_c}$

$P_{AG} \rightarrow P_{Airgap} = P_{in} - P_{SCL} - P_{core}.$

$P_{AG} = 3 I_2'^2 \frac{R_2'}{s}$ — $P_{RCL} \rightarrow$ Rotor copper loss

$\rightarrow P_{RCL} = 3 I_2'^2 \cdot R_2'$
$$= s P_{AG}.$$

$$P_{elec} = P_{AG} - P_{RCL} = 3 I_2'^2 \frac{R_2'}{s} - 3 I_2'^2 \cdot R_2'$$
$$= 3 I_2'^2 R_2' \left(\frac{1}{s} - 1\right)$$
$$= 3 I_2'^2 R_2' \left(\frac{1-s}{s}\right)$$

$\rightarrow P_{mech\text{-}losses} = P_{friction} + P_{windage}$

$P_{shaft} = P_{out}$

$= P_{elec} - P_{mech\,loss}$

$= 5621.6 - 403$

$= 5218.6\,W$

$P_{out} = P_{elec} - P_{mech\,loss}$

$P_{out} = \tau_m \cdot \omega_m = P_{shaft}$ → rad/s

$\eta = \frac{P_{out}}{P_{in}}$

$\tau_m = \frac{P_{shaft}}{\omega} = \frac{5218.6}{123.2} = 42.4\,N.m$

5) 480V (Line voltage), 60Hz, 50 H.P, 3Φ, $I_1 = 60A$

$\cos\theta_1 = 0.85$ lag

$P_{SCL} = 2000W$, $P_{RCL} = 700W$

$P_{mech\text{-}loss} = 600W$, $P_{core} = 1800W$

$P_{in} = 3 V_{ph} I_{ph} \cos\theta$

$P_{in} = \sqrt{3} V_1 I_1 \cos\theta_1$

$= \sqrt{3} \times \frac{480}{\sqrt{3}} \times 60 \times 0.85$

$= 42400.6\,W$

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

$= 42400.6 - 2000 - 1800$

$= 38600.6\,W$

b) $P_{elec} = P_{conv} = P_{converted}$

$= P_{AG} - P_{RCL}$

$= 38600.6 - 700$

$= 37900.6\,W$

c) $P_{out} = P_{elec} - P_{mech\text{-}loss}$

$= 37900.6 - 600$

$= 37300.6\,W$

d) $\eta = \frac{P_{out}}{P_{in}} \times 100\%$

$= \frac{37300.6}{42400.6} \times 100\%$

$= 87.97\%$

$P_{in} = 3 V_1 I_1 \cos\theta$ — P_{SCL} → Stator copper loss

→ $P_{SCL} = 3 I_1^2 R_1$

→ $P_{core} = \frac{3E_1^2}{R_c}$

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

$P_{AG} = 3 I_2'^2 \frac{R_2'}{s}$ — P_{RCL} → Rotor copper loss

→ $P_{RCL} = 3 I_2'^2 \cdot R_2'$

$P_{elec} = P_{AG} - P_{RCL} = 3 I_2'^2 \frac{R_2'}{s} - 3 I_2'^2 \cdot R_2'$

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

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

→ $P_{mech\,losses} = P_{friction} + P_{windage}$

$P_{out} = P_{elec} - P_{mech\,loss}$

$P_{out} = \tau_m \cdot \omega_m = P_{shaft}$

$\eta = \frac{P_{out}}{P_{in}}$

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