Problem 1

EE 360

Problem Session #5

Induction Motor

$P_{cu1} = 1033\ W$

$P_{cu2} = 1299\ W$

$P_{core} = 485\ W$

$P_{F\&W} = 540\ W$

(1) $V_1 = 220/\sqrt{3} = 127\ V$

$P_{in} = 3V_1 I_1 \cos\varphi_{V_1 I_1} = 3 \times 127 \times 77 \times 0.88$

$\boxed{P_{in} = 25.8\ KW}$

$P_g = P_{in} - P_{cu1} - P_{core} = 25.8 \times 10^3 - 1033 - 485$

(a) $\boxed{P_g = 24.3\ KW}$

(b) $T_d = \frac{P_g}{\omega_s}$, $\omega_s = \frac{2\pi n_s}{60}$, $n_s = \frac{120 \times f}{P} = \frac{120 \times 60}{4} = 1800\ rpm$

$\omega_s = \frac{2\pi \times 1800}{60} = 188.5\ rad/sec$

$T_d = \frac{24.3 \times 10^3}{188.5}$

$\boxed{T_d = 128.9\ N\text{-}m}$

(c) $S = \frac{P_{cu2}}{P_g} = \frac{1299}{24.3 \times 10^3} \Rightarrow S = 0.0534$

$\boxed{S = 5.34\%}$

(d) $P_d = (1-S) \times P_g = (1 - 0.0534) \times 24.3 \times 10^3$

$\boxed{P_d = 23.0\ KW}$

(e) $P_o = P_d - P_{F\&W} = 23 \times 10^3 - 540 = 22.46\ KW$

$P_o = \frac{22.46 \times 10^3}{746} \Rightarrow \boxed{P_o = 30\ hp}$

(f) $n_m = (1-S) \times n_s = (1 - 0.0534) \times 1800 \Rightarrow \boxed{n_s = 1704\ rpm}$

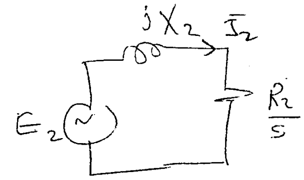
(g) $T_o = \frac{P_o}{\omega} = \frac{22.46 \times 10^3}{\ldots \times 1704} \Rightarrow \boxed{T_o = 126\ N\text{-}m}$ (h) $\eta = \frac{P_o}{P_{in}} = \frac{22.46}{25.8}$

Problem 2

$n = 1425$ rpm, $n_s = \frac{120 \times f}{P} = \frac{120 \times 50}{4} = 1500$ rpm

$S = \frac{n_s - n}{n_s} = \frac{1500 - 1425}{1500} = 0.05$

$\boxed{S = 5\%}$



(i) at full-load condition $S = 0.05$

$\bar{Z}_2 = \frac{R_2}{s} + jX_2 = \frac{0.4}{0.05} + j4 = 8 + j4\ \Omega$

$\boxed{\bar{Z}_2 = 8.94 \angle 26.6^\circ\ \Omega}$

$\bar{I}_2 = \frac{\bar{E}_2}{\bar{Z}_2} = \frac{203 \angle 0}{8.94 \angle 26.6^\circ} \Rightarrow \bar{I}_2 = 22.67 \angle -26.6^\circ$ A

$P_g = 3 I_2^2 \frac{R_2}{S} = 3(22.67)^2 * (\frac{0.4}{0.05})$

$\boxed{P_g = 12.36 \text{ KW}} \Rightarrow T_d = \frac{P_g}{\omega_s}$; $\omega_s = \frac{2\pi n_s}{60} = 157$ rad/s

$T_d = \frac{12.36 * 10^3}{157} \Rightarrow \boxed{T_d = 78.7 \text{ N-m}}$

or $T_d = \frac{P_d}{\omega_m}$, $P_d = 3 I_2^2 \frac{R_2(1-s)}{s}$, $\omega_m = \frac{2\pi n}{60}$

$= (1-s) P_g$

(ii) $I_2 = 22.67$ A ,

$PF_2 = \cos(26.6) \Rightarrow \boxed{PF_2 = 0.894 \text{ lagging}}$

(iii) $P_o = P_d - P_{F\&W}$

$P_d = (1-s) * P_g = (1 - 0.05) * 12.36$ K

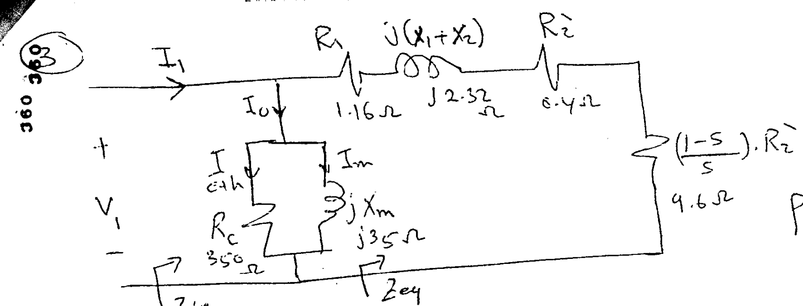
$P_d = 11.74$ Kw

$P_o = 11.74 * 10^3 - 500 \Rightarrow P_o = 11.24$ KW

$P_o = \frac{11.24 * 10^3}{...} \Rightarrow \boxed{P_o = 15 \text{ hp}}$

Problem 3

(3)



$P_{F\&W} = 350$ W

$n = 1440$ rpm

$V_1 = \frac{400}{\sqrt{3}} = 230$ V

$n_s = \frac{120 \times f}{P} = \frac{120 \times 50}{4} = 1500$ rpm

$s = \frac{n_s - n}{n_s} = \frac{1500-1440}{1500} = 0.04$

$\frac{1-s}{s} \cdot R_2' = \frac{1-0.04}{0.04} \times 0.4 = 9.6\ \Omega$

(a) $\Rightarrow$ $\bar{I}_2' = \frac{V_1}{Z_{eq}}$, $Z_{eq} = \left(R_1 + \frac{R_2'}{s}\right) + j(X_1 + X_2')$

$= 11.16 + j2.32 = 11.4 \angle 11.74°\ \Omega$

$\bar{I}_2' = \frac{230\angle 0}{11.4 \angle 11.74°} = 20.26 \angle -11.74°$ A

$\bar{I}_0 = \bar{I}_{c+h} + \bar{I}_m$, $\bar{I}_{c+h} = \frac{\bar{V}_1}{R_c} = \frac{230}{350} = 0.65 \angle 0$ A

$\bar{I}_m = \frac{\bar{V}_1}{X_m} = \frac{230}{35\angle 90} = 6.6 \angle -90°$ A

$\boxed{\bar{I}_0 = 0.65 - j\,6.6 \text{ A}}$

$\bar{I}_1 = \bar{I}_0 + \bar{I}_2' = 0.65 - j6.6 + 20.26 \angle -11.74°$

$\boxed{\bar{I}_1 = 23.1 \angle -27.6° \text{ A}}$ $\Rightarrow$ $\boxed{|I_1| = 23.1 \text{ A}}$

$PF = \cos(27.6)$

(a) ⟶ $\boxed{PF_1 = 0.886 \text{ lagging}}$

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

$P_{in} = 3 \times 230 \times 23.1 \times 0.886$

$P_{in} = 14.19$ kW

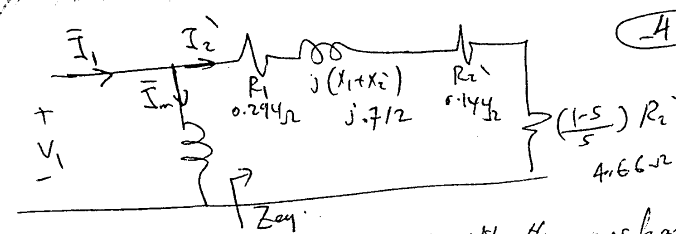
(b) $P_o = P_d - P_{F\&W}$

$P_d = 3 \times I_2'^2 \cdot R_2' \frac{(1-s)}{s} = 3(20.26)^2 \times \left(\frac{1-0.04}{0.04}\right)(0.4) = 11.82$ kW

(c) $\eta = (P_o / P_{in}) \times 100$

$= 11.47$ [illegible]

Problem 4



-4-

$P_{Rot} = 403$ W

$n_s = 1200$ rpm

$V_1 = \frac{220}{\sqrt{3}} = 127$ V

Since the core loss is lumped with the mechanical losses, the core resistance will be removed from the equivalent circuit.

$$S = 0.03 \Rightarrow \frac{1-S}{S} \times R_2' = \frac{1-0.03}{0.03} \times 0.144 = 4.66\,\Omega$$

$$Z_{eq} = \left(R_1 + \frac{R_2'}{S}\right) + j(X_1 + X_2') = \left(0.294 + \frac{0.144}{0.03}\right) + j(0.503 + .209)$$

$$\boxed{Z_{eq} = 5.14 \angle 7.95^\circ\,\Omega}$$

$$V_1 = 220/\sqrt{3} = 127 \text{ V}$$

(a) $$I_2' = \frac{V_1}{Z_{eq}} = \frac{127\angle 0}{5.14\angle 7.95^\circ} \Rightarrow \boxed{I_2' = 24.7 \angle -7.95^\circ \text{ A}}$$

$$P_d = 3 I_2'^2 \left(\frac{1-S}{S}\right) R_2' = 3(24.7)^2(4.66) \Rightarrow P_d = 8.52 \text{ kW}$$

$$n = (1-S)\,n_s = (1-0.03) \times 1200 \Rightarrow n = 1164 \text{ rpm}$$

$$T_d = \frac{P_d}{\omega_m} = \frac{P_d}{\frac{2\pi n}{60}} = \frac{8.52 \times 10^3}{\frac{2\pi(1164)}{60}} \Rightarrow \boxed{T_d = 69.9 \text{ N-m}}$$

(b) $$T_{max} = \frac{3V_1^2}{2\omega_s} \cdot \frac{1}{\left[R_1 + \sqrt{R_1^2 + (X_1+X_2')^2}\right]} = \frac{3 \times (127)^2}{2\left(\frac{2\pi \times 1200}{60}\right)} \times \frac{1}{[0.294 + \sqrt{(0.294)^2 + \ldots}}$$

$$\boxed{T_{max} = 181 \text{ N-m}}$$

$$S_{max} = \frac{R_2'}{\sqrt{R_1^2 + (X_1+X_2')^2}} = \frac{0.144}{\sqrt{(0.294)^2 + (0.712)^2}} = 0.187$$

(c) $|\bar{I}_{2\,start}'| = \dfrac{V_1}{\sqrt{(R_1+R_2')^2+(X_1+X_2')^2}} = \dfrac{127}{\sqrt{(0.438)^2+(0.712)^2}}$

$\theta = \tan^{-1}\dfrac{(X_1+X_2')}{R_1+R_2'} = 58.5^\circ$

$$\bar{I}_{2\,start}' = 151.9\angle{-58.5^\circ}\ A$$

$$\bar{I}_m = \frac{\bar{V}_1}{jX_m} = \frac{127\angle 0}{13.25\angle 90} = -j9.6\ A$$

$$\bar{I}_{1\,start} = \bar{I}_m + \bar{I}_2' = 9.6\angle{-90} + 151.9\angle{-58.5^\circ}$$

$$\bar{I}_{1\,start} = 159.6\angle{-60.3^\circ}\ A$$

$$T_{d\,starting} = \frac{3 I_{2\,start}'^2 \cdot R_2'}{\omega_s} = \frac{3V_1^2}{\omega_s} \cdot \frac{R_2'}{(R_1+R_2')^2+(X_1+X_2')^2}$$

$$T_{d\,starting} = \frac{3(127)^2 \times (0.144)}{(0.438)^2+(0.712)^2} \times \frac{1}{\frac{2\pi \times 1200}{60}}$$

$$T_{d\,starting} = 79\ N\text{-}m$$

(d) $n_{T_{max}} = 900\ rpm \Rightarrow S_{max} = \dfrac{n_s - n}{n_s} = \dfrac{1200-900}{1200} = 0.25$

$\Rightarrow$ max. Torque $\Rightarrow S_{max} = \dfrac{R_{2\,new}'}{\sqrt{R_1^2+(X_1+X_2')^2}} = 0.25$

$$R_{2\,new}' = 0.25 \times \sqrt{[(0.294)^2+(0.712)^2]} = 0.193\,\Omega$$

$$R_{2\,added} = R_{2\,new}' - R_2' = 0.193 - 0.144$$

$$R_2\ added = 0.0486\ \Omega$$

$\Rightarrow T_{starting\,new} = 100\ N\text{-}m$

$T \ldots I_2'^2 \ldots R_{2\,new}'$

Problem 5

5) I-) No-Load test

$V_{o,L-L} = 400V$, $I_o = 7.5A$, $P_o = 700W$

$P_{core} = \frac{1}{3}(P_o - P_{F\&W}) = \frac{700-200}{3} \Rightarrow \boxed{P_{core} = 166.7W}$

$V_{o/ph} = \frac{400}{\sqrt{3}} = 230\ V$

$R_c = \frac{V_{o\,ph}^2}{P_{core}} = \frac{(230)^2}{166.7} \Rightarrow \boxed{R_c = 320\Omega\ /phase}$

$Q_o = \sqrt{S_o^2 - P_o^2} = \sqrt{V_o^2 I_o^2 - P_o^2} = \sqrt{(230)^2(7.5)^2 - (\frac{700}{3})^2}$

$Q_o = 1709\ VAR/phase = \frac{V_o^2/ph}{X_m} \Rightarrow X_m = \frac{(230)^2}{1709}$

$\boxed{X_m = 30.9\Omega}$

II- Blocked-Rotor Test

$V_{B,L-L} = 150V$, $I_B = 35A$, $P_B = 4000W$

$\boxed{V_{B\,ph} = \frac{150}{\sqrt{3}} = 86.6\ V}$, $P_{B/ph} = \frac{4000}{3} = 1333.3\ W$

$R_{eq} = R_1 + R_2' = \frac{P_{B/ph}}{I_B^2} = \frac{(1333.3)}{(35)^2} \Rightarrow \boxed{R_{eq} = 1.088\Omega/phase}$

Since $P_{cu1} = P_{cu2} \Rightarrow \boxed{R_1 = R_2' = \frac{R_{eq}}{2} = \frac{1.088}{2} = 0.544\Omega/phase}$

$Z_{ph} = \frac{V_B}{I_B} = \frac{86.6}{35} = 2.47\Omega = \sqrt{R_{eq}^2 + X_{eq}^2}$

$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2} = \sqrt{(2.47)^2 - (1.088)^2} = 2.22\Omega = X_1 + X_2'$

But X_1 , $X_1 = 2X_2' \rightarrow 2X_2' + X_2' = 2.22$

(b)

$S = 0.04$

$Z_{eq} = (R_1 + \frac{R_2'}{S}) + j(X_1 + X_2') = (0.544 + \frac{0.544}{0.04}) + j\,2.22$

$\boxed{Z_{eq} = 14.32 \angle 8.9^\circ \; \Omega}$

$I_2' = \frac{|V_1|}{|Z_{eq}|} = \frac{230}{14.32} \Rightarrow \boxed{I_2' = 16.13 \text{ A}}$

$P_d = 3 I_2'^2 (\frac{1-S}{S}) R_2' = 3 (16.13)^2 (\frac{1-0.04}{0.04})(0.544)$

$\boxed{P_d = 10.19 \text{ KW}}$

$P_o = P_d - P_{mech} = 10.19 \times 10^3 - 200$

$\boxed{P_o = 9.99 \text{ KW}}$

$T_o = \frac{P_o}{\omega_m} = \frac{P_o}{\frac{2\pi n}{60}}$, $n = (1-S) n_s$, $n_s = \frac{120 \times 50}{6} = 1000$ rpm

$n = (1-0.04) \times 1000 \Rightarrow n = 960$ rpm $\Rightarrow \omega_m = 100.5$ rad/sec

$T_o = \frac{9.99 \times 10^3}{100.5} \Rightarrow \boxed{T_o = 99.37 \text{ N-m}}$