7-3

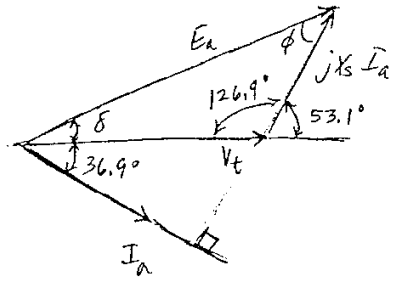
$$p = \frac{120f}{n} = \frac{(120)(60)}{900} = 8 \text{ poles}$$

7-8

$$V_t = \frac{2300}{\sqrt{3}} \angle 0^\circ = 1327.9 \angle 0^\circ \text{ V}$$

$$I_a = \frac{150{,}000}{\sqrt{3}\,(2300)} \angle -\cos^{-1} 0.8 = 37.65 \angle -36.9^\circ \text{ A}$$

$$|E_a| = \frac{3500}{\sqrt{3}} = 2020.7 \text{ V}$$



$$\frac{\sin\phi}{|V_t|} = \frac{\sin 126.9^\circ}{|E_a|} = \frac{\sin\delta}{|X_s I_a|}$$

$$\sin\phi = \frac{|V_t|}{|E_a|} \sin 126.9^\circ = \frac{1327.9}{2020.7} \sin 126.9^\circ = 0.5255$$

$$\phi = 31.7^\circ$$

$$\delta = 180^\circ - 126.9^\circ - 31.7^\circ = 21.4^\circ$$

$$X_s = \frac{|V_t|}{|I_a|} \frac{\sin\delta}{\sin\phi} = \frac{1327.9}{37.65} \frac{\sin 21.4^\circ}{\sin 31.7^\circ} = 24.5\ \Omega$$

7-10

(a) $V_t = \frac{230}{\sqrt{3}} \angle 0^\circ = 132.8 \angle 0^\circ \text{ V}$

$I_a = \frac{80{,}000}{\sqrt{3}(230)} \angle -\cos^{-1} 0.866 = 200.8 \angle -30^\circ \text{ A}$

(b) $E_R = V_t + (R_a + jX_s) I_a = 132.8 \angle 0^\circ + (0.1 + j0.5)(200.8 \angle -30^\circ)$

$= 214.64 \angle 21^\circ$

(c) $\delta = 21^\circ$

(d) $\omega_m = \frac{2}{p}(2\pi f) = \left(\frac{2}{6}\right)(2\pi)(60) = 125.66 \text{ rad/sec}$

$P = \frac{3 E_a V_t}{X_s} \sin\delta = \frac{(3)(214.64)(132.8)}{0.5} \sin 21^\circ = 61.29 \text{ kW}$

$T = \frac{P}{\omega_m} = \frac{61{,}290}{125.66} = 487.7 \text{ N-m}$

7-12

$S_b = 10\ MVA$

$V_b = 12\ kV$

$$Z_b = \frac{V_b^2}{S_b} = \frac{(12)^2}{10} = 14.4\ \Omega$$

(a) $$X_{c,unit} = \frac{15000/\sqrt{3}}{480} = 18.042\ \Omega \doteq 1.253\ pu$$

(b) $$X_{s,sat} = \frac{12000/\sqrt{3}}{480} = 14.43\ \Omega = 1.0\ pu$$

7-21

$S_b = 60\ MVA$

$V_b = 12\ kV \qquad I_b = \frac{60000}{\sqrt{3}(12)} = 2886.8\ A$

$E_a = V_t = 1.0\ pu$

(a) $P = \frac{E_a V_t}{X_d}\sin\delta + \frac{1}{2}V_t^2\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$

$= \frac{(1.0)(1.0)}{1.2}\sin\delta + \frac{1}{2}(1.0)^2\left(\frac{1}{0.6} - \frac{1}{1.2}\right)\sin 2\delta$

$= 0.833\sin\delta + 0.4167\sin 2\delta$

$\frac{dP}{d\delta} = 0.833\cos\delta + 0.833\cos 2\delta = 0$

$\cos 2\delta + \cos\delta = 0$

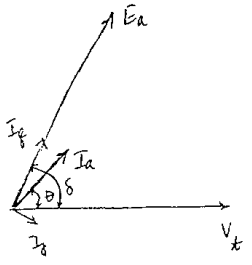
$2\cos^2\delta - 1 + \cos\delta = 0$

$2\cos^2\delta + \cos\delta - 1 = 0$

$(2\cos\delta - 1)(\cos\delta + 1) = 0$

$\cos\delta = +\frac{1}{2}, -1$

$\delta = 60°$



$P_{max} = 0.833\sin 60° + 0.4167\sin 2(60°) = 1.082\ pu = 65\ MVA$

(b) $Q = \frac{E_a V_t}{X_d}\cos\delta - V_t^2\left(\frac{\sin^2\delta}{X_q} + \frac{\cos^2\delta}{X_d}\right)$

$= \frac{(1.0)(1.0)}{1.2}\cos 60° - (1.0)^2\left(\frac{\sin^2 60}{0.6} + \frac{\cos^2 60}{1.2}\right) = -1.042\ pu = -62.5\ MVAR$

$S = P + jQ = 1.082 - j1.042 = 1.502\angle -43.9°\ pu = 90\ MVA$

$I_a = \frac{S^*}{V^*} = \frac{(1.502\angle -43.9)^*}{(1.0\angle 0°)^*} = 1.502\angle 43.9°\ pu = 4336\angle 43.9°\ A$

$PF = \cos 43.9° = 0.72$ leading

7-25

$$\cos\theta = \frac{P}{\sqrt{3}\,V_t\,I_a} = \frac{850{,}000}{\sqrt{3}\,(12{,}000)(48)} = 0.852$$

$$\theta = \cos^{-1} 0.852 = 31.6^\circ$$

$$E_a = V_t - jX_s I_a = \frac{12000}{\sqrt{3}}\angle 0^\circ - (j38)(48\angle -31.6^\circ) = \mathbf{6171\angle -14.6^\circ\ V_{LN}}$$

for lagging PF

or $$E_a = \frac{12000}{\sqrt{3}}\angle 0^\circ - (j38)(48\angle 31.6^\circ) = 8036\angle -11^\circ\ V_{LN}$$

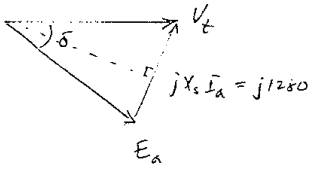
for leading PF

7-26

(a) $$V_t = \frac{2400}{\sqrt{3}}\angle 0^\circ = 1385.6\angle 0^\circ\ V$$

$$E_a = \frac{2400}{\sqrt{3}}\angle -\delta = 1385.6\angle -\delta\ V$$

$$X_s I_a = (16)(80) = 1280$$



$$V_t \sin\left(\frac{\delta}{2}\right) = \frac{1280}{2}$$

$$\sin\left(\frac{\delta}{2}\right) = \frac{1280/2}{1385.6} = 0.462$$

$$\frac{\delta}{2} = 27.5^\circ$$

$$\delta = 55^\circ$$

(b) $$I_a = \frac{V_t - E_a}{jX_s} = \frac{1385.6\angle 0^\circ - 1385.6\angle -55^\circ}{j16} = 80\angle -27.5^\circ\ A$$

$$P = \sqrt{3}\,V_t\,I_a\cos\theta = \sqrt{3}(2400)(80)\cos 27.5^\circ = 295\ kW$$

$$P = 3\frac{E_a V_t}{X_s}\sin\delta = \frac{3(1385.6)(1385.6)}{16}\sin 55^\circ = 295\ kW$$

(c) $$\omega_m = \left(\frac{2}{p}\right)(2\pi f) = \left(\frac{2}{4}\right)(2\pi)(60) = 188.5\ rad/sec$$

$$T = \frac{P}{\omega_m} = \frac{295\times 10^3}{188.5} = 1564\ N\text{-}m$$

7-33

$$I_a = \frac{20{,}000}{\sqrt{3}(480)} = 24.06\ A$$

$$P_{cu} = 3 I_a^2 R_a = (3)(24.06)^2(2.5) = 4340\ W = 4.34\ kW$$

$$P_{in} = \sqrt{3} V_t I_a \cos\theta = \sqrt{3}(480)(24.06)(0.8) = 16\ kW$$

$$P_{out} = P_{in} - P_{cu} - P_{rotational} = 16 - 4.34 - 1.5 = 10.16\ kW$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{10.16}{16} 100\% = 63.5\%$$

7-36

(a) $n = \frac{120f}{P} = \frac{(120)(60)}{6} = 1200$ rpm

$\omega_m = \frac{2\pi n}{60} = \frac{2\pi(1200)}{60} = 125.66$ rad/sec

$P_{out} = (2000)(0.746) = 1492$ kW

$T_{out} = \frac{P_{out}}{\omega_m} = \frac{1492}{125.66} = 11.87$ kN-m

(b) $P_{in} = \frac{P_{out}}{\eta} = \frac{1492}{0.94} = 1587.2$ kW

$I_a = \frac{P_{in}}{\sqrt{3}\,V_t\,(PF)} \angle +\cos^{-1}(PF) = \frac{1,587,200 \angle \cos^{-1} 0.85}{\sqrt{3}(13,200)(0.85)} = 81.67 \angle 31.8^\circ$ A

(c) $\bar{E}_a = \bar{V}_t - jX_s\bar{I}_a = \frac{13,200\angle 0^\circ}{\sqrt{3}} - (j32)(81.67\angle 31.8^\circ)$

$= 7621\angle 0^\circ - (j32)(81.67\angle 31.8^\circ) = 9268 \angle -13.9^\circ$

(d) $P_{max} = \frac{3E_aV_t}{X_s} = \frac{(3)(9268)(7621)}{32} = 6.62$ MW

$T_{pull\text{-}out} = T_{max} = \frac{P_{max}}{\omega_m} = \frac{6.62\times10^6}{125.66} = 52.7$ kN-m