6.3| 3φ, \( f = 60 \text{Hz} \), \( V_a = \frac{550}{\sqrt{3}} \), \( P = 250 \text{KW (at rated voltage)} \)
\[ |E_a| = 460 \text{V/phase}, \ x = 1.2 - j2 \]

a) \( S = ? \) **Synchronous generator**

\[ \overline{I_a} = \frac{\overline{E_a} - \overline{V_a}}{jx} \]

\[ P_T = 3 \text{Re} \left[ \overline{V_a} \overline{I_a}^* \right] \]

\[ = 3 \text{Re} \left[ \frac{\overline{V_a} \overline{E_a}^* - \overline{V_a^2}}{-jx} \right] \]

\[ = 3 \text{Re} \left[ \frac{\overline{V_a} \overline{E_a} (\cos(\theta) + j \sin(\theta)) - \overline{V_a^2}}{-jx} \right] \]

\[ = 3 \text{Re} \left[ \frac{\overline{V_a} \overline{E_a} \cos(\theta) + \text{Im} \left( \frac{\overline{V_a} \overline{E_a}}{x} \right) - \overline{V_a^2}}{-jx} \right] \]

\[ P_T = 3 \frac{\overline{V_a} \overline{E_a} \sin \theta}{x} = 250 \text{KW} = 3 \left( \frac{550}{\sqrt{3}} \right) (460) \sin \theta \]

\[ S = 43.2^\circ \]
b) $I_a = ?$

\[ I_a = \frac{\bar{E}_{ar} - \bar{V}_a}{jX_s} \]

\[ I_a = \frac{460 \angle 3.2^\circ \text{ V} - \frac{550 \angle 0^\circ \text{ V}}{\sqrt{3}}}{j1.2 \Omega} \]

\[ I_a = 262.8 \angle 3.2^\circ \text{ A} \]

pf = ?

\[ \text{pf} = \cos \theta \]

\[ \text{pf} = \cos (\theta_v - \theta_i) \]

\[ \text{pf} = \cos (0 + 3.2^\circ) \]

\[ \text{pf} = 0.998 \text{ lag} \]

G = ?

\[ S_t = \frac{P_t}{\text{pf}} \]

\[ Q_t = \sin \theta \cdot S_t \]

\[ Q_t = \sin (3.2^\circ) \cdot \frac{250 \text{ kw}}{0.998} \]

\[ Q_t = 14.11 \text{ kVAR} \]

C) for pf = 0.8 lag \( \rightarrow \delta = ? \)

\[ \bar{E}_{ar} = \bar{V}_a + jX_s \bar{I}_a \]

| \( I_a | = \frac{P_t}{3V_a \cos \theta} = \frac{250 \text{ kw}}{3 \times \left( \frac{550}{\sqrt{3}} \right) (0.8)} = 3.28 \text{, 04 A} \]

\[ \angle I_a = -\theta \]

\[ I_a = 3.28 \text{, 04 A} \angle -36.8^\circ \]

\[ \bar{E}_{ar} = \frac{550}{\sqrt{3}} \angle 0^\circ + j(1.2 \Omega) 3.28 \text{, 04 A} \angle -36.8^\circ \]

\[ \bar{E}_{ar} = \frac{550}{\sqrt{3}} + (1.2 \angle 90^\circ) (3.28 \text{, 04 A} \angle -36.8^\circ) \]

\[ \bar{E}_{ar} = 637.02 \angle 29.63^\circ \rightarrow \delta = 29.63^\circ \]
\[ S_T = 1000 \, \text{kVA} \]
\[ V_a = \frac{3300 \, \text{V}}{\sqrt{3}} \]
\[ f = 60 \, \text{Hz} \]
\[ X_s = 1.5 \, \Omega \]
\[ p_f = 0.8 \, \text{lag} \rightarrow \varphi = 36.87^\circ \]

\[ |S_T| = 3 |V_a| |I_a| \]

\[ |I_a| = \frac{1000 \, \text{kVA}}{(3) \frac{3300 \, \text{V}}{\sqrt{3}}} = 174.95 \, \text{A} \rightarrow \varphi_a = -\cos^{-1}(p_f) \]

\[ \varphi_a = -36.87^\circ \]

\[ I_a = 174.95 \angle -36.87^\circ \, \text{A} \]

\[ \bar{E}_{ar} = V_a + jX_s I_a \]

\[ = \frac{3300}{\sqrt{3}} + j(1)174.95 \angle -36.87^\circ \]

\[ \bar{E}_{ar} = 2015.09 \angle 3.98^\circ \, \text{V} \]

Since:

\[ \omega_s = \frac{p \omega_m}{Z} \]

\[ \omega_m = \frac{2 \omega_s}{P} = \frac{2 \left( \frac{2\pi}{60} \right)}{4} \]

\[ \omega_m = 188.50 = 60 \pi \, \text{rad/s} = \omega_m = \text{synchronous mech. speed} \]

\[ T_e = \frac{P_T}{\omega_m} = \frac{1000 \, \text{kVA} \times 0.8}{60 \pi} \]

\[ T_e = 4244 \, \text{Nm} \]
\[ S_I = 25 \text{ kVA} \]
\[ \bar{V}_a = \frac{230 \text{ v}}{\sqrt{3}} \]
\[ \text{pf} = 0.8 \rightarrow \theta = 36.87^\circ \]
\[ f = 60 \text{ Hz} \]
\[ X_s = 1.5 \Omega \]

\[ \bar{E}_r = \bar{V}_a + jX_s \bar{I}_a \]

\[ \Rightarrow |S_I| = 3|V_a||I_a| \]
\[ |I_a| = 62.84 \]
\[ \theta_i = -\cos^\circ(\text{pf}) = -36.87^\circ \]
\[ \bar{I}_a = 62.8 \angle -36.87^\circ \]

\[ \bar{E}_r = \frac{230 \angle 60^\circ + j(0.5) 62.8 \angle -36.87^\circ}{\sqrt{3}} \]

\[ \bar{E}_r = 203.8 \angle 21.7^\circ \text{ V} \]

b) If increased by 20%:

\[ \bar{E}_r = \frac{\omega_s M \bar{I}_r \angle \delta}{\sqrt{2}} \rightarrow \therefore |\bar{E}_r|_{\text{new}} = 1.2 \times |\bar{E}_r|_{\text{old}} \]

\[ = 244.56 \text{ V} \]

Since the mechanical input is the same:

\[ P_{Tnew} = P_{Told} \]

\[ \frac{3\bar{V}_a \bar{E}_{rnew} \sin\delta_{new}}{X_s} = \frac{3\bar{V}_a \bar{E}_{rold} \sin\delta_{old}}{X_s} \]

\[ \bar{E}_{rnew} \sin\delta_{new} = \bar{E}_{rold} \sin\delta_{old} \]

\[ \frac{\sin\delta_{new}}{\sin\delta_{old}} = \frac{\bar{E}_{rold}}{\bar{E}_{rnew}} = \frac{1}{1.2} \]

\[ \therefore \delta_{new} = 17.95^\circ \]
\[ I_a = \frac{E_a - V_a}{jX_s} = \frac{(1.2)203.8 \angle 17.95^\circ - \frac{230}{\sqrt{3}} \angle 0^\circ}{j 1.5} \]

\[ I_a = 83.4 \angle -53^\circ \text{ A} \]

\[ \theta = +53^\circ \rightarrow \text{pf} = 0.60 \text{ Lag} \]

6.15 \[ p = 8 \quad \text{sync. motor} \]

\[ P_r = 45 \text{ kw} \]

\[ V_a = \frac{208}{\sqrt{3}} \text{ V} \]

\[ f = 60 \text{ Hz} \]

\[ \text{pf} = 0.8 \text{ lag} \]

\[ X_s = 0.652 \]

a) \[ E_a = ? \]

\[ P_r = 3V_a I_a \cos \theta \]

\[ 45 \text{ kw} = 3 \left( \frac{208}{\sqrt{3}} \right) I_a (0.8) \]

\[ I_a = 156.13 \text{ A} \rightarrow I_a = 156.13 \angle -36.8^\circ \text{ A} \]

\[ E_a = V_a - jX_s I_a \]

\[ = \frac{208}{\sqrt{3}} \angle 0^\circ - j(0.6) 156.13 \angle -36.8^\circ \text{ A} \]

\[ E_a = 98.47 \angle -49.6^\circ \text{ V} \]

b) \[ P_r = T_e \omega_m \]

\[ L_p T_e = \frac{3 E_a V_a \sin \delta}{X_s \omega_m} \]

\[ \omega_m = \frac{2\omega_s}{p} = \frac{2(2\pi 60)}{8} = 30\pi \text{ rad/s} \]

\[ = \frac{3 (98.47 \text{ V}) \left( \frac{208}{\sqrt{3}} \text{ V} \right) \sin \delta}{(0.652) (30\pi \text{ rad/s})} \]

\[ T_{e \text{ max}} = T_e |_{\delta = 90^\circ} = 627.34 \text{ Nm} = T_{e \text{ max}} \]