EE362 - HW #4 Solution

Q.1)

a) $N_{sync} = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000 \text{ rpm}$ //

b) $I_{rated} = \frac{S}{\sqrt{3}\, V_{l\text{-}l}} = \frac{40 \times 10^3}{400 \times \sqrt{3}} = 57.74 \text{ A}.$

$$\vec{E}_f = \vec{V}_t + j X_s \vec{I}_s \quad \ldots\ldots (1)$$

Take $\vec{V}_t$ as reference phasor.

Open circuit terminal voltage ; $|\vec{E}_f| = 231$ V/phase

φ : phase angle between $\vec{V}_t$ & $\vec{I}_s$

δ : " " " $\vec{V}_t$ & $\vec{E}_f$

From equation (1)

$|\vec{E}_f| \cos\delta = |\vec{V}_t| + X_s |\vec{I}_s| \sin\varphi \quad \ldots\ldots (2)$

$|\vec{E}_f| \sin\delta = X_s |\vec{I}_s| \cos\varphi \quad \ldots\ldots (3)$

b-i) $\vec{I}_s = 57.74 \angle 0^\circ$ (unity pf)

Using (3) : $\sin\delta = \frac{X_s |\vec{I}_s|}{|\vec{E}_f|} = \frac{1 \times 57.74}{231} = 0.25 \Rightarrow \delta = 14^\circ.48$

Using (2) : $|\vec{V}_t| = |\vec{E}_f| \cos\delta - X_s |\vec{I}_s| \cancel{\sin\varphi}_{0} = 231 \times 0.968 = 222.7$ V/phase

b-ii) $\vec{I}_s = 57.74 \angle -37^\circ$ (0.8 lagging pf)

Using (3) : $\sin\delta = \frac{X_s |\vec{I}_s| \cos\varphi}{|\vec{E}_f|} = \frac{1 \times 57.74 \times 0.8}{231} = 0.2 \Rightarrow \delta = 11^\circ.53$

Using (2) : $|\vec{V}_t| = |\vec{E}_f| \cos\delta - X_s |\vec{I}_s| \sin\varphi = 231 \times 0.98 - 1 \times 57.74 \times 0.6 = 191.7$ V/phase

b-iii) $\vec{I}_s = 57.74 \angle 37^\circ$ (0.8 leading pf)

Using (3) : $\sin\delta = \frac{1 \times 57.74 \times 0.8}{231} = 0.2 \Rightarrow \delta = 11^\circ.53$

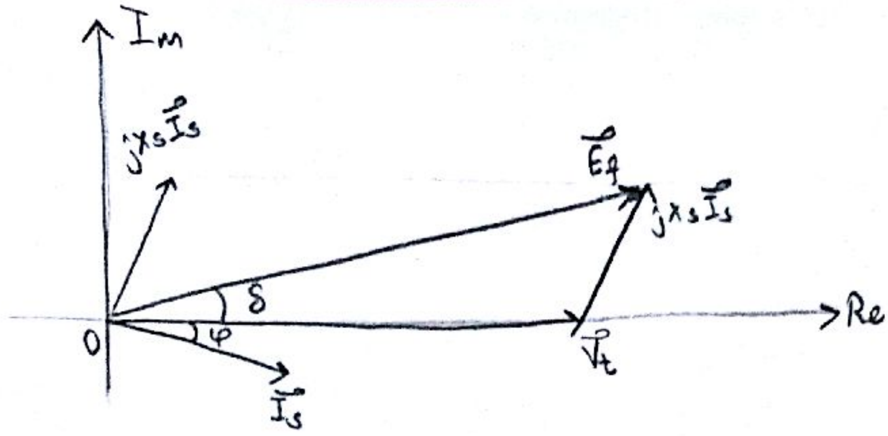
Using (2) : $|\vec{V}_t| = |\vec{E}_f| \cos\delta - X_s |\vec{I}_s| \sin\varphi = 231 \times 0.98 + 1 \times 57.74 \times 0.6 = 261$ V/phase

c) Total mechanical input power : $P_{in} = P_{f\&w} + V_t I_s$ (unity pf)

$\Rightarrow P_{in} = 1 + 38.6 = 39.6$ kW

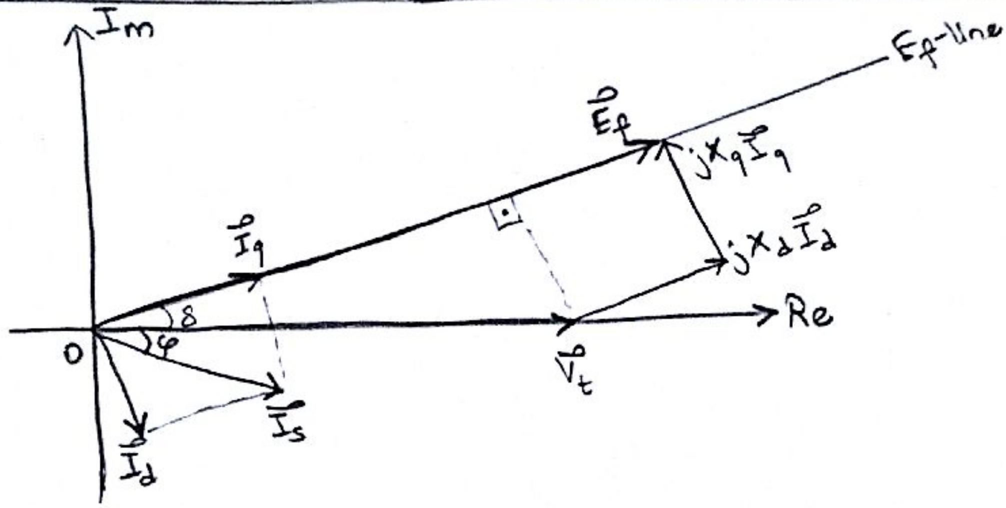
$\Rightarrow T_{in} = P_{in}/\omega = \frac{39.6 \times 10^3}{1000 \times \frac{2\pi}{60}} = 378.15$ Nm.

d)



e) Already found: $\delta = 11^{\circ}.53$

Q2) a)



b) $\sin\delta = \dfrac{X_q |\vec{I}_q|}{|\vec{V}_t|}$, $\delta = 21^{\circ}.34$, $|\vec{V}_t| = 3464$ V/phase $\rightarrow$ infinite bus

$|\vec{I}_q| = |\vec{I}_s| \cos(\varphi + \delta)$ where $\varphi = 37^{\circ}$ (0.8 pf) and $|\vec{I}_s| = \dfrac{S}{V \times \sqrt{3}}$

$|\vec{I}_s| = \dfrac{2.6 \times 10^6}{\sqrt{3} \times 6 \times 10^3} = 250$ A.

$\Rightarrow |\vec{I}_q| = 131.3$ A $\Rightarrow X_q = \dfrac{3464 \times 0.36}{131.3} = 9.5$ Ω/phase.

c) $|\vec{E}_f| = |\vec{V}_t| \cos\delta + X_d |\vec{I}_d|$ where $|\vec{I}_d| = |\vec{I}_s| \sin(\varphi + \delta) = 212.8$ A

$\Rightarrow |\vec{E}_f| = 3464 \times 0.93 + 15 \times 212.8 = 6418$ V/phase //

d) All losses are neglected: $P_m = P_e$

$\Rightarrow P_m = S \cos\varphi = 2.6 \times 10^6 \times 0.8 = 2.08$ MW

$N_{sync} = \dfrac{120 f}{p} = \dfrac{120 \times 50}{8} = 750$ rpm $\Rightarrow \omega_m = 78.54$ rad/sec

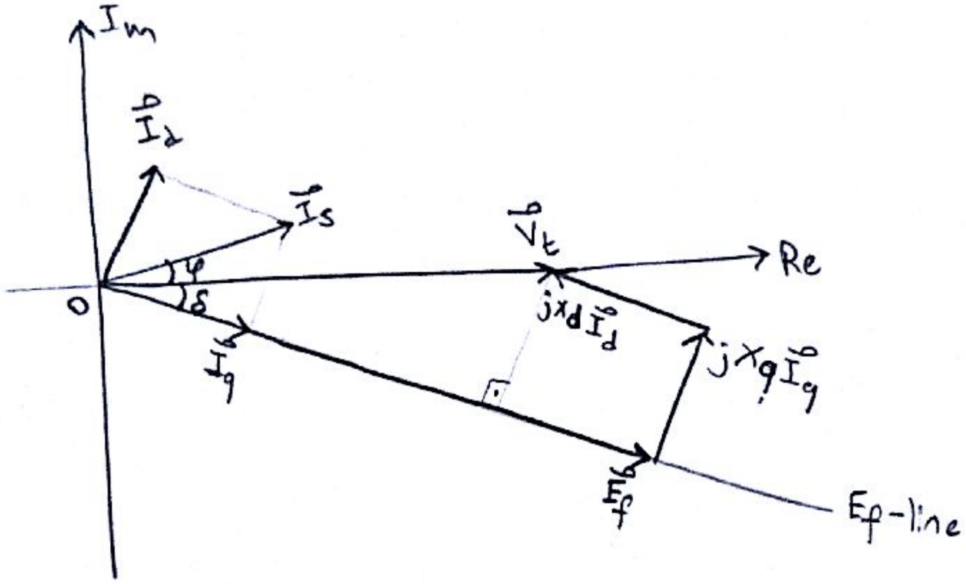
$\Rightarrow T_{em} = \dfrac{P_m}{\omega_m} = \dfrac{2.08 \times 10^6}{78.54} = 26.48$ kNm //

e) No losses : $P_m = P_e = 2\,MW$

$$pf = \frac{P}{\sqrt{P^2+Q^2}} = 0.8$$

Active power consumption : $P > 0$
Reactive power generation : $Q < 0$ } leading pf (acts as a capacitive load)

f)



g) $$\sin\delta = \frac{X_q|\vec{I}_q|}{|\vec{V}_t|}$$ where $|\vec{V}_t| = 3464\ V/_{phase}$ → rated voltage

$|\vec{I}_q| = |\vec{I}_s|\cos(\varphi+\delta)$ where $\varphi = 37^\circ$ (0.8 pf) and $|\vec{I}_s| = \frac{S}{V \times \sqrt{3}}$

$$|\vec{I}_s| = \frac{2.5\times10^6}{6\times10^3\times\sqrt{3}} = 240.6\ A$$

$$\Rightarrow \sin\delta = \frac{9.5\times240.6\times\cos(37+\delta)}{3464} = 0.66\cos(37+\delta)$$

$[\cos(a+b) = \cos a\cos b - \sin a\sin b]$

$\Rightarrow \sin\delta = 0.66[0.8\cos\delta - 0.6\sin\delta] \Rightarrow 1.396\sin\delta = 0.528\cos\delta$

$\Rightarrow \tan\delta = 0.378 \Rightarrow \delta = 20.7^\circ$