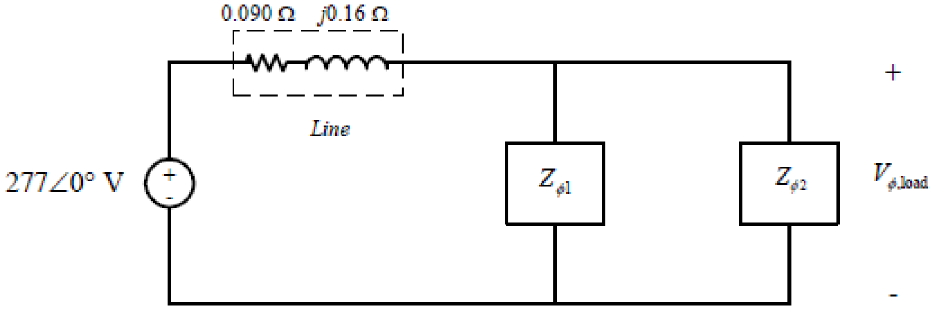
Q1)

SOLUTION To solve this problem, first convert the delta-connected load 2 to an equivalent wye (by dividing the impedance by 3), and get the per-phase equivalent circuit.



$Z_{\phi 1} = 2.5\angle 36.87°\ \Omega$

$Z_{\phi 2} = 1.67\angle -20°\ \Omega$

(a) The phase voltage of the equivalent Y-loads can be found by nodal analysis.

$$\frac{\mathbf{V}_{\phi,\text{load}} - 277\angle 0°\ \text{V}}{0.09 + j0.16\ \Omega} + \frac{\mathbf{V}_{\phi,\text{load}}}{2.5\angle 36.87°\ \Omega} + \frac{\mathbf{V}_{\phi,\text{load}}}{1.67\angle -20°\ \Omega} = 0$$

$$(5.443\angle -60.6°)\ \left(\mathbf{V}_{\phi,\text{load}} - 277\angle 0°\ \text{V}\right) + (0.4\angle -36.87°)\mathbf{V}_{\phi,\text{load}} + (0.6\angle 20°)\mathbf{V}_{\phi,\text{load}} = 0$$

$$(5.955\angle -53.34°)\ \mathbf{V}_{\phi,\text{load}} = 1508\angle -60.6°$$

$$\mathbf{V}_{\phi,\text{load}} = 253.2\angle -7.3°\ \text{V}$$

Therefore, the line voltage at the loads is $V_L\sqrt{3}\ V_\phi = 439\ \text{V}$.

(b) The voltage drop in the transmission lines is

$$\Delta\mathbf{V}_{\text{line}} = \mathbf{V}_{\phi,\text{gen}} - \mathbf{V}_{\phi,\text{load}} = 277\angle 0°\ \text{V} - 253.2\angle -7.3° = 41.3\angle 52°\ \text{V}$$

(c) The real and reactive power of each load is

$$P_1 = 3\frac{V_\phi^2}{Z}\cos\theta = 3\frac{(253.2\ \text{V})^2}{2.5\ \Omega}\cos\ 36.87° = 61.6\ \text{kW}$$

$$Q_1 = 3\frac{V_\phi^2}{Z}\sin\theta = 3\frac{(253.2\ \text{V})^2}{2.5\ \Omega}\sin 36.87° = 46.2\ \text{kvar}$$

$$P_2 = 3\frac{V_\phi^2}{Z}\cos\theta = 3\frac{(253.2\ \text{V})^2}{1.67\ \Omega}\cos\ (-20°) = 108.4\ \text{kW}$$

$$Q_2 = 3\frac{V_\phi^2}{Z}\sin\theta = 3\frac{(253.2\ \text{V})^2}{1.67\ \Omega}\sin\ (-20°) = -39.5\ \text{kvar}$$

(d) The line current is

$$\mathbf{I}_{\text{line}} = \frac{\Delta\mathbf{V}_{\text{line}}}{Z_{\text{line}}} = \frac{41.3\angle 52°\ \text{V}}{0.09 + j0.16\ \Omega} = 225\angle -8.6°\text{A}$$

Therefore, the loses in the transmission line are

$$P_{\text{line}} = 3I_{\text{line}}{}^2 R_{\text{line}} = 3\ (225\ \text{A})^2 (0.09\ \Omega) = 13.7\ \text{kW}$$

$$Q_{\text{line}} = 3I_{\text{line}}{}^2 X_{\text{line}} = 3\ (225\ \text{A})^2 (0.16\ \Omega) = 24.3\ \text{kvar}$$

(e) The real and reactive power supplied by the generator is

$$P_{\text{gen}} = P_{\text{line}} + P_1 + P_2 = 13.7\ \text{kW} + 61.6\ \text{kW} + 108.4\ \text{kW} = 183.7\ \text{kW}$$

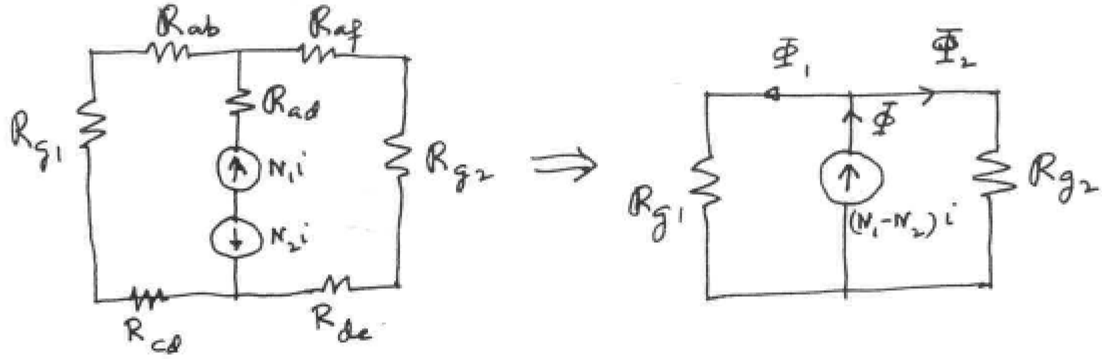
$$Q_{\text{gen}} = Q_{\text{line}} + Q_1 + Q_2 = 24.3\ \text{kvar} + 46.2\ \text{kvar} - 39.5\ \text{kvar} = 31\ \text{kvar}$$

The power factor of the generator is

$$\text{PF} = \cos\left[\tan^{-1}\frac{Q_{\text{gen}}}{P_{\text{gen}}}\right] = \cos\left[\tan^{-1}\frac{31\ \text{kvar}}{183.7\ \text{kW}}\right] = 0.986\ \text{lagging}$$

Q2)

$\boxed{1.5}$ MMFs of the two coils oppose each other.



$$A_{g1} = A_{g2} = 2.5 \times 2.5 \times 10^{-4} = 6.25 \times 10^{-4}\ m^2$$

$$\mathcal{R}_{g1} = \frac{0.05 \times 10^{-2}}{4\pi 10^{-7} \times 6.25 \times 10^{-4}} = 0.637 \times 10^{6}\ At/Wb.$$

$$\mathcal{R}_{g2} = \frac{0.1 \times 10^{-2}}{4\pi 10^{-7} \times 6.25 \times 10^{-4}} = 1.274 \times 10^{6}\ At/Wb$$

$$\Phi_1 = \frac{(700 - 200)\ 0.5}{0.637 \times 10^{6}} = 0.392 \times 10^{-3}\ Wb.$$

$$\Phi_2 = \frac{500 \times 0.5}{1.274 \times 10^{6}} = 0.196 \times 10^{-3}\ Wb$$

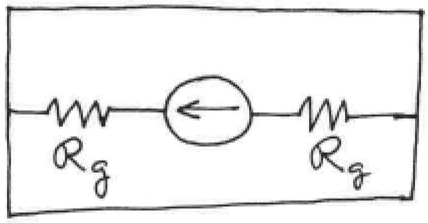
$$\Phi = \Phi_1 + \Phi_2 = 0.588 \times 10^{-3}\ Wb$$

$$B_{g1} = \frac{0.392 \times 10^{-3}}{6.25 \times 10^{-4}} = 0.627\ Wb/m^2$$

$$B_{g2} = \frac{0.196 \times 10^{-3}}{6.25 \times 10^{-4}} = 0.3135\ Wb/m^2$$

Q3)

$\boxed{1.7}$ (a)



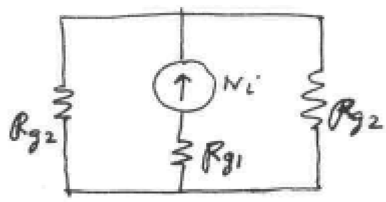
(b) $R_g = \dfrac{l_g}{\mu_0 A_g} = \dfrac{0.25 \times 10^{-3}}{4\pi 10^{-7} \times 500 \times 10^{-4}} = 39.7886 \times 10^{3}$ At/Wb.

$\Phi = \dfrac{Ni}{2 R_g} = \dfrac{500 \times 5}{2 \times 39.7886 \times 10^{3}} = 0.0314$ Wb.

$B_g = \dfrac{0.0314}{500 \times 10^{-4}} = 0.628$ T.

Q4)

$\boxed{1.8}$ $B = 1.4\,T$ throughout. $H_c = 0$.



$Ni = H_{g1} g_1 + H_{g2} g_2$

$H_{g1} = H_{g2} = \dfrac{B}{\mu_0}$

$g_1 = g_2 = g$

$Ni = 2 \dfrac{B}{\mu_0} g$

$g = \dfrac{\mu_0 Ni}{2B} = \dfrac{4\pi 10^{-7} \times 500 \times 20}{2 \times 1.4} \rightarrow 4.5$ mm

Q5)

For Constant B

$P_h \propto f$ i.e. $P_h = Af$ where A is Consta

$P_e \propto f^2$ i.e $P_e = Bf^2$ ~ B ~ ~

at 60 Hz

$$1800 = A * 60 + B * (60)^2 \longrightarrow (1)$$

at 90 Hz

$$3000 = A * 90 + B * (90)^2 \longrightarrow (2)$$

(1) by 3 and (2) by (2) and subtract

$$3 * 1800 - 2 * 3000 = 3B * (60)^2 - 2B * (90)^2$$

$$-600 = -5400 B$$

So, $B = 0.111$ sub. in (1)

$A = 23.333$

Hence; At 60 Hz $P_h = 23.333 * 60 = 1400$ W

$P_e = 0.111 * (60)^2 \doteq 400$ W

At 90 Hz $P_h = 23.333 * 90 = 2100$ W

$P_e = 0.111 * (90)^2 = 900$ W

Q6)

An air-gap flux density of 0.5 T requires a total flux of

$$\phi = BA_{\text{eff}} = (0.5\ \text{T})(0.05\ \text{m})(0.05\ \text{m})(1.05) = 0.00131\ \text{Wb}$$

This flux requires a flux density in the right-hand leg of

$$B_{\text{right}} = \frac{\phi}{A} = \frac{0.00131\ \text{Wb}}{(0.05\ \text{m})(0.05\ \text{m})} = 0.524\ \text{T}$$

The flux density in the other three legs of the core is

$$B_{\text{top}} = B_{\text{left}} = B_{\text{bottom}} = \frac{\phi}{A} = \frac{0.00131\ \text{Wb}}{(0.10\ \text{m})(0.05\ \text{m})} = 0.262\ \text{T}$$

The magnetizing intensity required to produce a flux density of 0.5 T in the air gap can be found from the equation $B_{\text{ag}} = \mu_o H_{\text{ag}}$:

$$H_{\text{ag}} = \frac{B_{\text{ag}}}{\mu_0} = \frac{0.5\ \text{T}}{4\pi \times 10^{-7}\ \text{H/m}} = 398\ \text{kA} \cdot \text{t/m}$$

The magnetizing intensity required to produce a flux density of 0.524 T in the right-hand leg of the core can be found from Figure P1-9 to be

$$H_{\text{right}} = 410\ \text{A} \cdot \text{t/m}$$

The magnetizing intensity required to produce a flux density of 0.262 T in the top, left, and bottom legs of the core can be found from Figure P1-9 to be

$$H_{\text{top}} = H_{\text{left}} = H_{\text{bottom}} = 240\ \text{A} \cdot \text{t/m}$$

The total MMF required to produce the flux is

$$\mathcal{F}_{\text{TOT}} = H_{\text{ag}}\ l_{\text{ag}} + H_{\text{right}}\ l_{\text{right}} + H_{\text{top}}\ l_{\text{top}} + H_{\text{left}}\ l_{\text{left}} + H_{\text{bottom}}\ l_{\text{bottom}}$$
$$\mathcal{F}_{\text{TOT}} = (398\ \text{kA} \cdot \text{t/m})(0.0005\ \text{m}) + (410\ \text{A} \cdot \text{t/m})(0.40\ \text{m}) + 3(240\ \text{A} \cdot \text{t/m})(0.40\ \text{m})$$
$$\mathcal{F}_{\text{TOT}} = 278.6 + 164 + 288 = 651\ \text{A} \cdot \text{t}$$

and the required current is

$$i = \frac{\mathcal{F}_{\text{TOT}}}{N} = \frac{651\ \text{A} \cdot \text{t}}{1000\ \text{t}} = 0.651\ \text{A}$$

The flux densities in the four sides of the core and the total flux present in the air gap were calculated above.