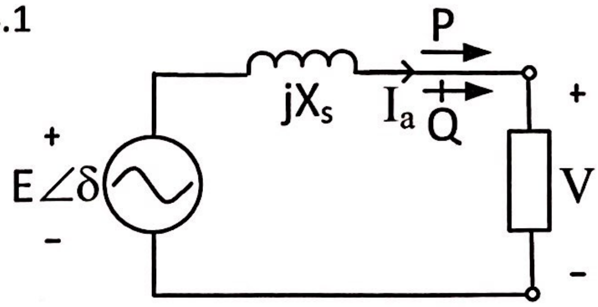
EE3015 Tutorial #4

4.1



S_b = 24 MVA, V_b = 17.32 kV

$Z_b = 17.32^2/24 = 12.5\ \Omega$

$X_s = 5/12.5 = 0.4$ pu

$I_b = S_b/(\sqrt{3}\times V_b) = 0.8$ kA

(i) $V = 17.32/V_b = 1\angle 0^\circ$ pu; Ref angle

$$S = \frac{\text{Rated MVA}}{S_b}\angle 36.87^\circ = \frac{24}{24}\angle 36.87^\circ = 1\angle 36.87^\circ \text{ pu}$$

$I_a = (S/V)^* = 1\angle -36.87^\circ$ pu

$E = V + jX_s I_a = 1\angle 0^\circ + 0.4\angle 90^\circ \times 1\angle -36.87^\circ = 1.2806\angle 14.47^\circ$ pu

Internal emf per phase = $|E_p| = 1.2806 \times V_b/\sqrt{3} = 12.806$ kV
Power angle of the generator = $\delta = 14.47^\circ$

(ii) $|E| = 13.4 \times \sqrt{3}/V_b = 1.34$ pu, $|V| = 10 \times \sqrt{3}/V_b = 1$ pu

$$P_{max} = \frac{EV}{X_s}\text{Sin}\delta\Big|_{\delta=90^\circ} = \frac{1.34\text{x}1}{0.4} = 3.35 \text{ pu}$$

Actual P_{max} = 3.35 x 24 = 80.4 MW

$$\text{Q at Pmax or } Q = \frac{V}{X_s}(E\text{Cos}\delta - V)\Big|_{\delta=90^\circ} = -\frac{V^2}{X_s} = -\frac{1}{0.4} = -2.5 \text{ pu}$$

Actual Q = −2.5 x 24 = −60 Mvar or 60 Mvar absorbed by the generator

$S = 3.35 - j2.5 = 4.18\angle -36.73^\circ$ pu

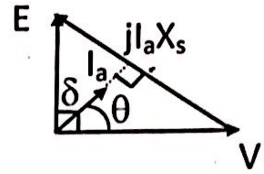
$$I_a = \left(\frac{S}{V}\right)^* = \left(\frac{4.18\angle -36.73^\circ}{1\angle 0^\circ}\right)^* = 4.18\angle 36.73^\circ \text{ pu}$$

Actual $|I_a| = 4.18 \times I_b = 4.18 \times 0.8 = 3.344$ kA

Alternative approach: When $\delta = 90^\circ$, E is perpendicular to V.

Using Pythagoras' theorem for a right-angled triangle:

$$I_a X_s = \sqrt{E^2 + V^2} = \sqrt{1.34^2 + 1^2} = 1.672 \text{ pu}$$



$$I_a = 1.672/0.4 = 4.18 \text{ pu}$$

4.2 $P_{fl1} = P_{fl2} = 3$ MW, $f_{fl1} = f_{fl2} = 49$ Hz, $f_{nl1} = 52$ Hz and $f_{nl2} = 51$ Hz

$$S_{p1} = \frac{P_{fl1}}{f_{nl1} - f_{fl1}} = \frac{3}{52-49} = 1 \text{ MW/Hz}$$

$$S_{p2} = \frac{P_{fl2}}{f_{nl2} - f_{fl2}} = \frac{3}{51-49} = 1.5 \text{ MW/Hz}$$

$P_{G1} = S_{p1}(f_{nl1} - f_{sys})$

$P_{G2} = S_{p2}(f_{nl2} - f_{sys})$

(a) $P_{Load} = P_{G1} + P_{G2} \rightarrow 4 = 1(52 - f_{sys}) + 1.5(51 - f_{sys})$

$f_{sys} = (128.5 - 4)/2.5 = 49.8$ Hz

$P_{G1} = 1(52 - f_{sys}) = 52 - 49.8 = 2.2$ MW

$P_{G2} = 1(51 - f_{sys}) = 51 - 49.8 = 1.8$ MW

(b) $S_{Load} = \frac{P_{Load}}{pf_{Load}} \angle \cos^{-1} 0.8 = \frac{4}{0.8} \angle 36.87^\circ = 5 \angle 36.87^\circ$ MVA

$S_{G1} = \frac{P_{G1}}{pf_{G1}} \angle \cos^{-1} 0.85 = \frac{2.2}{0.85} \angle 31.788^\circ = 2.588 \angle 31.788^\circ$ MVA

$S_{Load} = S_{G1} + S_{G2} \rightarrow S_{G2} = S_{Load} - S_{G1} = 5\angle 36.87^\circ - 2.588\angle 31.788^\circ$

$S_{G2} = 2.433 \angle 42.28^\circ$

Power factor of Generator #2 = $\cos 42.28^\circ = 0.74$ lag (lag because S_{G2} has a positive angle)

(c) f_{nl2} = ? to bring the system frequency back to 50 Hz

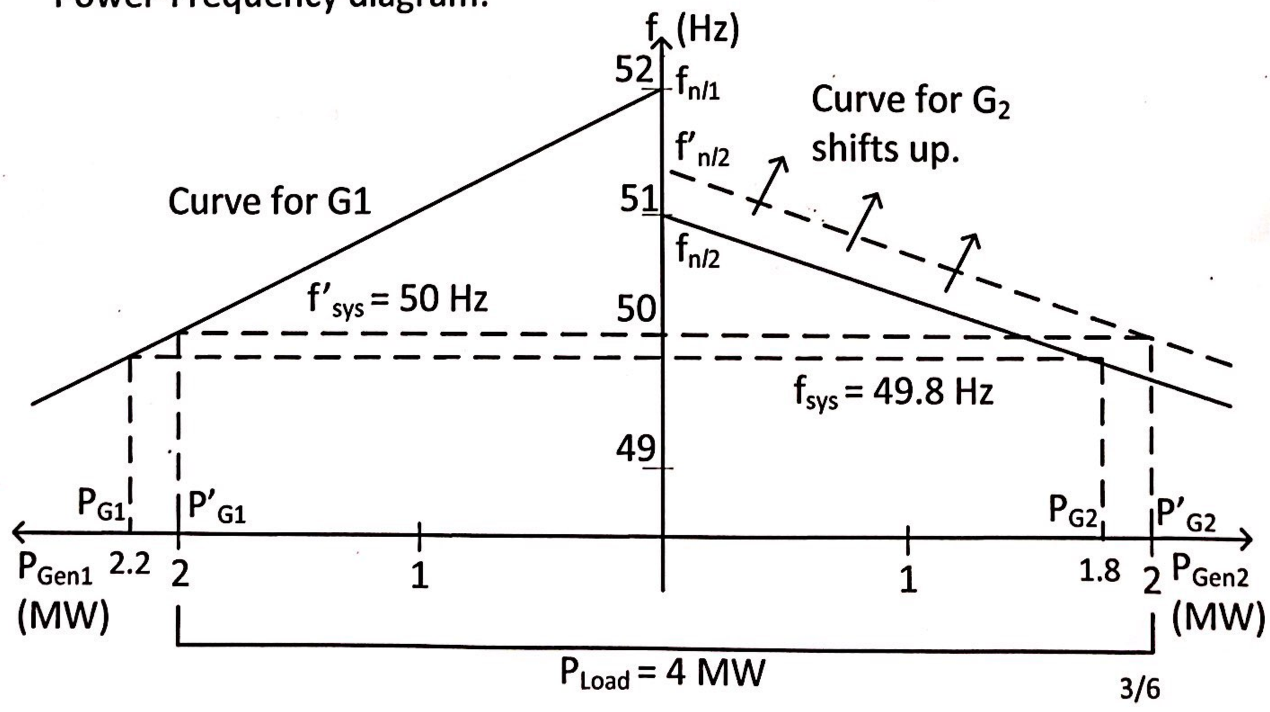
$P'_{G1} = S_{p1}(f'_{nl1} - f'_{sys}) = 1(52 - 50) = 2$ MW

$P'_{G2} = P_{Load} - P'_{G1} = 4 - 2 = 2$ MW

$2 = P'_{G2} = S_{p2}(f'_{nl2} - f'_{sys}) = 1.5(f'_{nl2} - 50) = 1.5 f'_{nl2} - 75$

$f'_{nl2} = (75 + 2)/1.5 = 77/1.5 = 51.33$ Hz

Power-Frequency diagram:



4.3 $n = \frac{120f}{p} \rightarrow f_{nl} = \frac{n_{nl} \text{ x } p}{120}$ and $f_{fl} = \frac{n_{fl} \text{ x } p}{120}$

$$f_{nl1} = \frac{n_{nl1} \text{ x } p_1}{120} = \frac{3040 \text{ x } 2}{120} = 50.67 \text{ Hz}$$

$$f_{fl1} = \frac{n_{fl1} \text{ x } p_1}{120} = \frac{2975 \text{ x } 2}{120} = 49.58 \text{ Hz}$$

$$f_{nl2} = \frac{n_{nl2} \text{ x } p_2}{120} = \frac{1500 \text{ x } 4}{120} = 50 \text{ Hz}$$

$$f_{fl2} = \frac{n_{fl2} \text{ x } p_2}{120} = \frac{1485 \text{ x } 4}{120} = 49.5 \text{ Hz}$$

(a) $S_{p1} = \frac{P_{fl1}}{f_{nl1} - f_{fl1}} = \frac{200}{50.67 - 49.58} = 185 \text{ kW/Hz}$

$$S_{p2} = \frac{P_{fl2}}{f_{nl2} - f_{fl2}} = \frac{150}{50 - 49.5} = 300 \text{ kW/Hz}$$

$$P_{Load} = P_{G1} + P_{G2} = S_{p1}(f_{nl1} - f_{sys}) + S_{p2}(f_{nl2} - f_{sys})$$

$$200 = 185(50.67 - f_{sys}) + 300(50 - f_{sys})$$

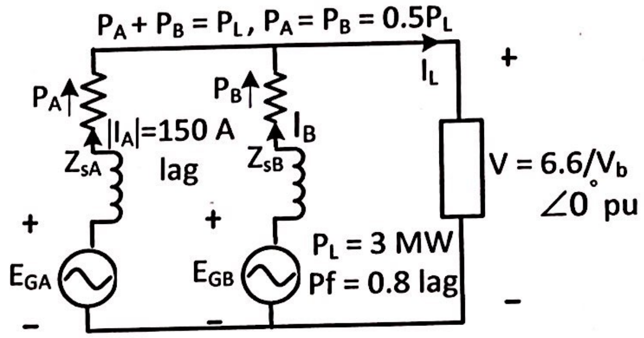
$$f_{sys} = (24{,}373.95 - 200)/485 = 49.843 \text{ Hz}$$

(b) $P_{G1} = S_{p1}(f_{nl1} - f_{sys}) = 185(50 - 49.843) = 153 \text{ kW}$

$$P_{G2} = P_{Load} - P_{G1} = 200 - 153 = 47 \text{ kW}$$

4.4 $S_b = 3/0.8 = 3.75$ MVA, $V_b = 6.6$ kV $\rightarrow Z_b = 6.6^2/3.75 = 11.616\ \Omega$
$I_b = S_b/(\sqrt{3}\,V_b) = 3.75/(\sqrt{3}\times 6.6) = 0.328$ kA

$V = 6.6/V_b = 1\angle 0^\circ$ pu, Ref



$$S_L = \frac{3/0.8}{S_b}\angle \cos^{-1}0.8$$

$$= \frac{3.75}{3.75}\angle 36.87^\circ = 1\angle 36.87^\circ \text{ pu}$$

$$I_L = \left(\frac{S_L}{V}\right)^* = \left(\frac{1\angle 36.87^\circ}{1\angle 0^\circ}\right)^* = 1\angle -36.87^\circ \text{ pu}$$

$$Z_{sA} = \frac{0.5 + j10}{11.616} = 0.862\angle 87.138^\circ \text{ pu}$$

$$Z_{sB} = \frac{0.4 + j12}{11.616} = 1.034\angle 88.091^\circ \text{ pu}$$

$I_A = 150$ A lag (Given)

Magnitude of $I_A = 150/328 = 0.4753$ pu
Phasor angle of I_A is solved as follows:

$$P_A = P_B = \frac{0.5P_L}{S_b} = \frac{1.5}{3.75} = 0.4 \text{ pu}$$

$P_A = |V||I_A|\cos\theta_A = 0.4 \rightarrow \cos\theta_A = P_A/(|V||I_A|) = 0.4/0.4753 = 0.8747$ lag
Note that lag is given by the problem and is not computed.

$\theta_A = \cos^{-1}0.8747 = 29^\circ$ lag $\rightarrow I_A = 0.4573\angle -29^\circ$ pu

$I_B = I_L - I_A = 1\angle -36.87^\circ - 0.4573\angle -29^\circ = 0.5506\angle -43.41^\circ$ pu

Actual $|I_B|$ = 0.5506 x I_b = 0.5506 x 328 = 180.63 A

Power factor of Gen B = Cos 43.41° = 0.7264 lag; lag because the phasor angle of I_B is negative with respect to that of the V phasor.

$E_{GA} = V + Z_{sA} I_A = 1\angle 0^\circ + 0.862\angle 87.138^\circ \times 0.4573\angle -29^\circ =$
$1.2536\angle 15.49^\circ$ pu

Actual $|E_{GA}|$ = 1.2536 x V_b = 1.2536 x 6.6 = 8.274 kV; δ_A = 15.49°

$E_{GB} = V + Z_{sB} I_B = 1\angle 0^\circ + 1.034\angle 88.091^\circ \times 0.5506\angle -43.41^\circ =$
$1.4605\angle 15.9^\circ$ pu

Actual $|E_{GB}|$ = 1.4605 x V_b = 1.4605 x 6.6 = 9.640 kV; δ_B = 15.9°

Phasor diagram: