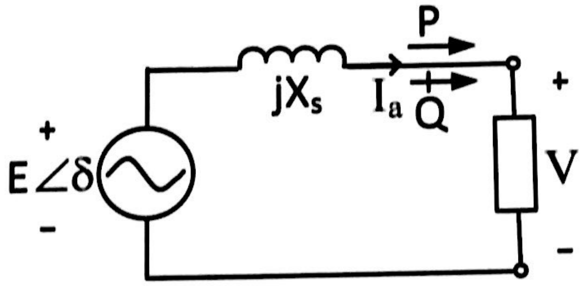
EE3015 Tutorial #3

3.1



$S_b = 125$ MVA, $V_b = 13.2$ kV

$Z_b = 13.2^2/125 = 1.3939\ \Omega$

$X_s = 1.7/1.3939 = 1.2196$ pu

(a) $V = 13.2/V_b = 1\angle 0^\circ$ pu; Ref

$$S = \frac{100}{125}\angle 0^\circ = 0.8\angle 0^\circ \text{ pu}$$

$I_{a1} = (S/V)^* = 0.8\angle 0^\circ$ pu

$$E_1 = V + jX_s I_{a1} = 1\angle 0^\circ + 1.2196\angle 90^\circ \times 0.8\angle 0^\circ = 1.3971\angle 44.295^\circ \text{ pu}$$

$|E_1| = 1.3971 \times V_b = 1.3971 \times 13.2 = 18.442$ kV; $\delta_1 = 44.295^\circ$

$Q_1 = 0$ due to unity pf.

(b) We assume that the generator has zero internal loss. Hence if the prime mover input to the generator is reduced by 50%:

$P_2 = P_1/2 = 100/2 = 50$ MW $\rightarrow P_2 = 50/S_b = 50/125 = 0.4$ pu

Without changing the excitation $\rightarrow |E_2| = |E_1|$ in part (a)

$$P_2 = \frac{E_2 V}{X_s}\text{Sin}\delta_2 \quad \rightarrow \quad 0.4 = \frac{1.3971\text{x}1}{1.2196}\text{Sin}\delta_2$$

$$\delta_2 = \text{Sin}^{-1}\frac{0.4\text{x}1.2196}{1.3971} = 20.437^\circ;\ |E_2| \text{ remains the same as before.}$$

$$Q_2 = \frac{V}{X_s}(E_2\text{Cos}\delta_2 - V) = \frac{1}{1.2196}(1.3971\text{Cos}20.437^\circ - 1) = 0.2535 \text{ pu}$$

$$Q_2 = 0.2535\text{x}S_b = 0.2535\text{x}125 = 31.687 \text{ Mvar (produced by the generator)}$$

(c) $P_3 = P_1 = 0.8$ pu = Constant power $\rightarrow E\,\text{Sin}\delta$ = Constant

This means that $E_3 \operatorname{Sin}\delta_3 = E_1 \operatorname{Sin}\delta_1$. However, we know E_1 and δ_1 but not E_3 and δ_3. Hence we are not able to solve E_3 and δ_3.

Applying the other constant power equation: $I_{a3} \operatorname{Cos}\theta_3 = I_{a1} \operatorname{Cos}\theta_1$. Therefore $I_{a3} \times 0.8 = 0.8 \times 1 \rightarrow I_{a3} = 1$ pu.

$I_{a3} = 1\angle 36.87^{\circ}$ pu; positive for leading angle (first quadrant).

Alternative approach: Form S_3 from 100 MW, 0.8 pf leading and S_b. Obtain I_{a3} from $I_{a3} = (S_3/V)^*$.

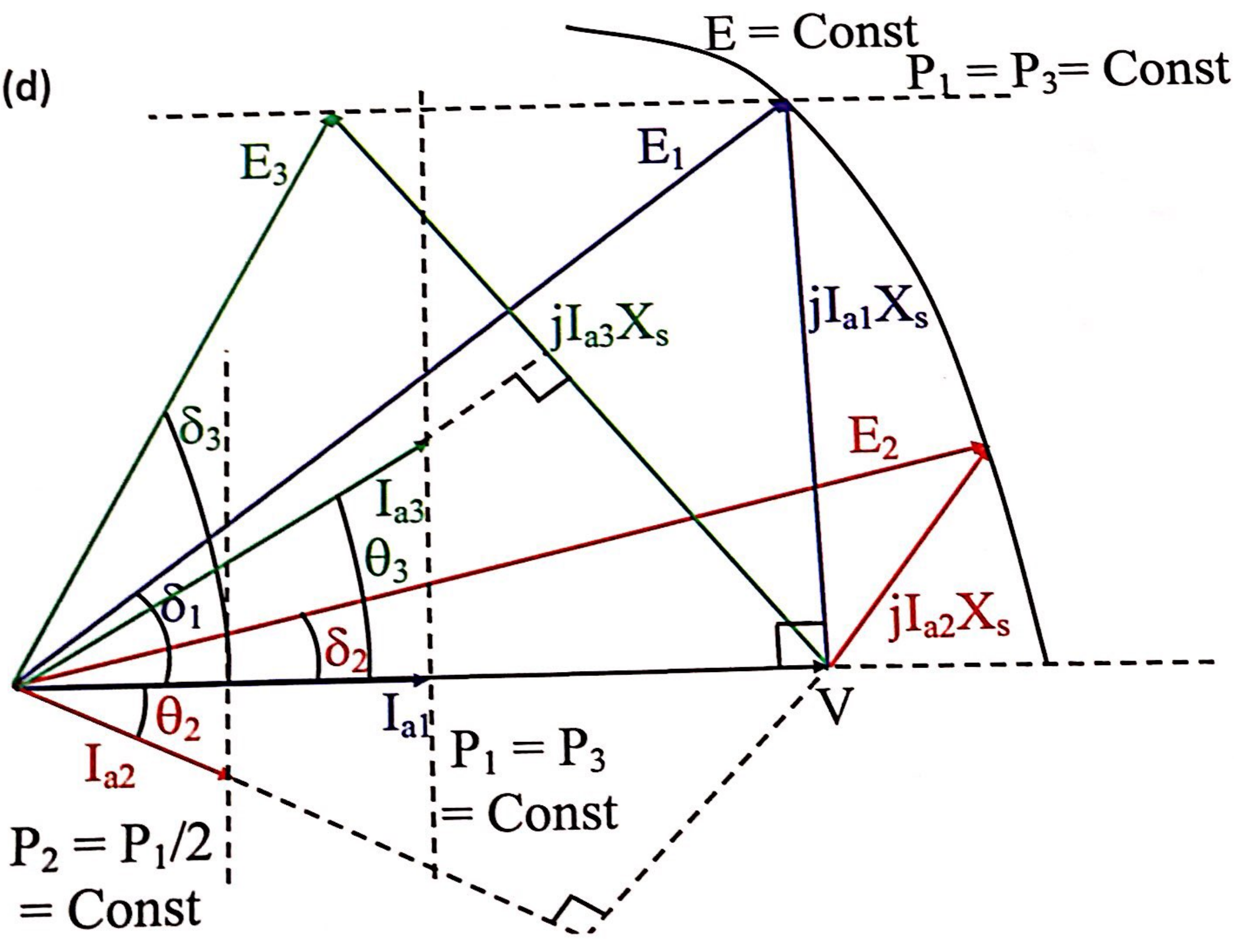
$E_3 = V + jX_s I_{a3} = 1\angle 0^{\circ} + 1.2196\angle 90^{\circ} \times 1\angle 36.87^{\circ} = 1.0119\angle 74.63^{\circ}$ pu

$|E_3| = 1.0119 \times V_b = 1.0119 \times 13.2 = 13.357$ kV; $\delta_3 = 74.63^{\circ}$

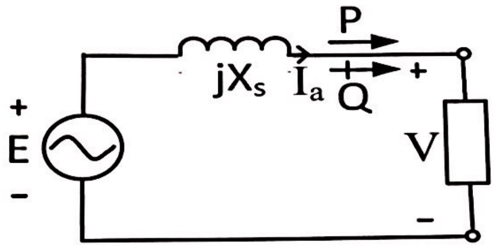
$Q_3 = -V I_{a3} \operatorname{Sin}\theta_3 = -1\text{x}1 \operatorname{Sin} 36.87^{\circ} = -0.6$ pu

Actual $Q_3 = -0.6 \times S_b = -75$ Mvar (or 75 Mvar absorbed by the generator).

(d)



3.2 $I_b = 188$ A, $V_b = 13.2$ kV $\rightarrow S_b = \frac{\sqrt{3}V_b I_b}{1000} = 4.298$ MVA



$Z_b = 13.2^2/4.298 = 40.537\ \Omega$

$X_s = 10/40.537 = 0.2467$ pu

$V = \frac{13.2}{V_b} = 1\angle 0^\circ$ pu, ref angle $= 0^\circ$

$$S_{old} = \frac{\sqrt{3}x13.2x0.188}{S_b} = 1\angle 0^\circ \text{ pu; } 0^\circ \text{ because of unity pf}$$

$$I_{a,\,old} = \left(\frac{S_{old}}{V}\right)^* = \left(\frac{1\angle 0^\circ}{1\angle 0^\circ}\right)^* = 1\angle 0^\circ \text{ pu}$$

$E_{old} = V + jX_s\, I_{a,\,old} = 1\angle 0^\circ + 0.2467\angle 90^\circ \times 1\angle 0^\circ = 1.03\angle 13.857^\circ$ pu

$|E_{new}| = 1.25|E_{old}|$

Without changing the mechanical power input $\rightarrow$ P = Constant

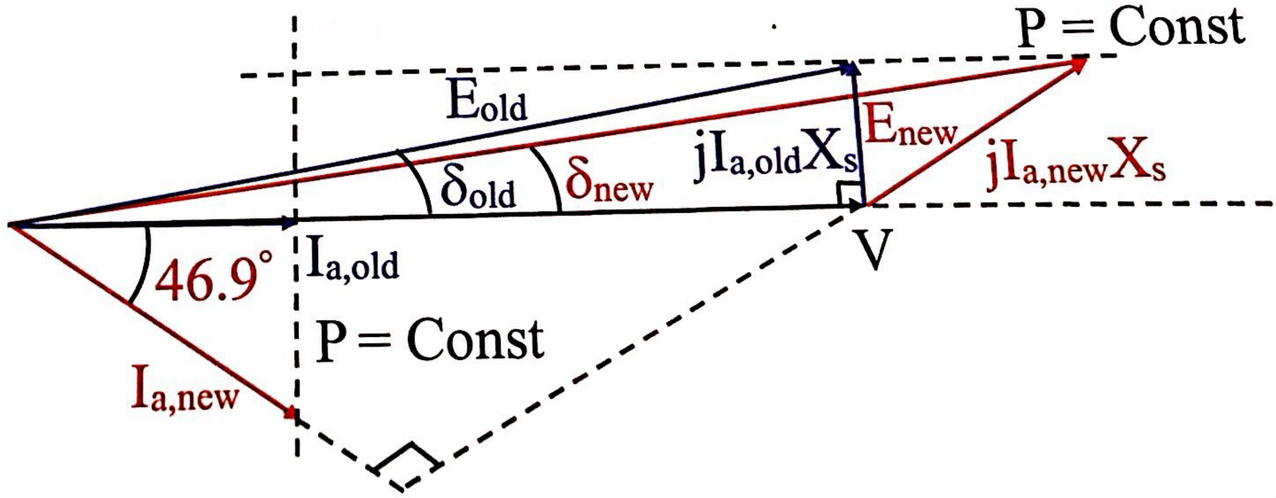
$E_{new} \sin \delta_{new} = E_{old} \sin \delta_{old} \rightarrow 1.25E_{old} \sin \delta_{new} = E_{old} \sin \delta_{old}$

$\delta_{new} = \sin^{-1}(\sin 13.857^\circ/1.25) = 11.046^\circ$

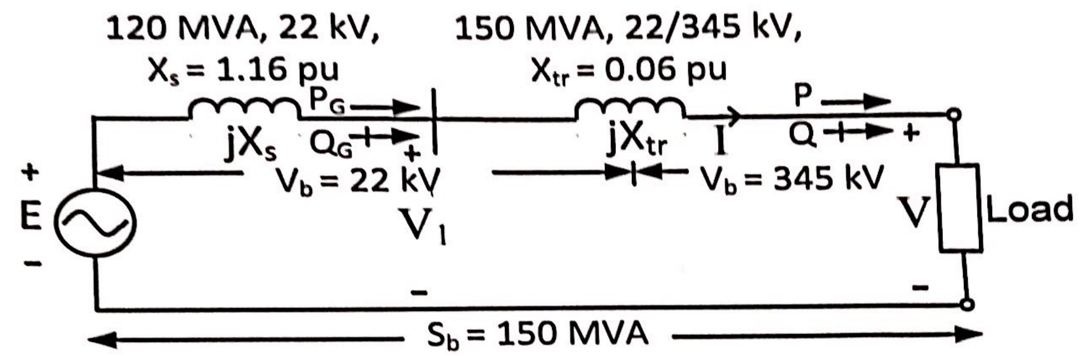
$$I_{a,new} = \frac{E_{new} - V}{jX_s} = \left(\frac{1.25x1.03\angle 11.046^\circ - 1\angle 0^\circ}{0.2467\angle 90^\circ}\right) = 1.4636\angle -46.9^\circ \text{ pu}$$

Actual $|I_{a,new}| = 1.4636 \times I_b = 1.4636 \times 188 = 275.15$ A

pf of generator = $\cos 46.9^\circ = 0.683$ lag ($I_{a,new}$ lags V)



3.3



$X_s = 1.16 x \frac{150}{120} = 1.45$ pu after converting to S_b = 150 MVA

(a) $V = 345/V_b = 345/345 = 1\angle 0^\circ$ pu

$$S_{Load} = \left(\frac{80}{0.8}\angle -36.87^\circ\right)/150 = 0.667\angle -36.87^\circ \text{ pu}$$

$$I = \left(\frac{S_{Load}}{V}\right)^* = \left(\frac{0.667\angle -36.87^\circ}{1\angle 0^\circ}\right)^* = 0.667\angle 36.87^\circ \text{ pu}$$

$V_1 = V + jX_{tr} I = 1\angle 0^\circ + 0.06\angle 90^\circ \times 0.667\angle 36.87^\circ = 0.9765\angle 1.88^\circ$ pu

Actual $|V_1| = 0.9765 \times V_b = 0.9765 \times 22 = 21.4835$ kV

$E = V_1 + jX_s I = 0.9765\angle 1.88^\circ + 1.45\angle 90^\circ \times 0.667\angle 36.87^\circ =$
$0.8974\angle 63.815^\circ$ pu

Actual $|E| = 0.8974 \times V_b = 0.8974 \times 22 = 19.743$ kV

(b) (i) $|E'| = 1.2|E|$ where $E = 0.8974\angle 63.815^\circ$ from (a)

Constant load of 80 MW $\rightarrow$ P = Constant $\rightarrow E' \sin \delta' = E \sin \delta \rightarrow$
$1.2E \sin \delta' = E \sin 63.815^\circ$

$\delta' = \sin^{-1} (\sin 63.815^\circ/1.2) = 48.4^\circ$

$$I' = \frac{E' - V}{j(X_s + X_{tr})} = \left(\frac{1.2x0.8974\angle 48.4^\circ - 1\angle 0^\circ}{1.51\angle 90^\circ}\right) = 0.5657\angle 19.49^\circ \text{ pu}$$

$V_1' = V + jX_{tr}\, I' = 1\angle 0^\circ + 0.06 \times 0.5657\angle 109.49^\circ = 0.9892\angle 1.854^\circ$ pu

Actual generator terminal voltage = 0.9892 x 22 = 21.762 kV

(b) (ii) $S_G = P_G + jQ_G = V_1'(I')^*$

$$Q_G = \mathrm{Imag}\left[V_1'(I')^*\right] = \mathrm{Imag}\left[0.9892\angle 1.854^\circ \text{ x } 0.5657\angle -19.49^\circ\right]$$
$$= \mathrm{Imag}\left[0.5596\angle -17.64^\circ\right] = 0.5596\text{xSin}\left(-17.64^\circ\right) = -0.1697 \text{ pu}$$

Actual reactive power output of the generator = -0.1697 x 150
$= -25.43$ Mvar or 25.43 Mvar absorebed by the generator

Alternative approach: Use $Q_G = \dfrac{V_1'}{X_s}(E'\text{Cos}\delta' - V_1')$

Note that you cannot substitute $\delta' = 48.4^\circ$ in the above equation since the ref angle of V_1' is NOT at zero degree. Instead you need to substitute $\delta' = 48.4^\circ - 1.854^\circ = 46.546^\circ$ since this is the angle difference between E' and V_1'

(b) (iii) $S = P + jQ = V(I')^*$

$$Q = \mathrm{Imag}\left[V(I')^*\right] = \mathrm{Imag}\left[1\angle 0^\circ \text{ x } 0.5657\angle -19.49^\circ\right]$$
$$= \mathrm{Imag}\left[0.5657\angle -19.49^\circ\right] = 0.5657\text{xSin}\left(-19.49^\circ\right) = -0.1887 \text{ pu}$$

Actual reactive power output of the generator = -0.1887 x 150
$= -28.31$ Mvar or 28.31 Mvar flowing towards the transformer

Alternative approach: Use $Q = \dfrac{V}{X_{tr}}(V_1'\text{Cos}\theta_1' - V)$

where θ_1' is the phasor angle of V_1':

Note that no further angle adjustment is required since the ref angle of V is at zero degree.

(c) (i) $\delta = 90^\circ$, $E = 0.8974$ pu and $X_s + X_{tr} = 1.51$ pu

$$P_{max} = \frac{EV}{X_s + X_{tr}} \mathrm{Sin}\delta \Big|_{\delta=90^\circ}$$

$$P_{max} = \frac{0.8974}{1.51} = 0.5943 \text{ pu}$$

Actual $P_{max} = 0.5943 \times 150 = 89.145$ MW

$$I\Big|_{\delta=90^\circ} = \frac{E - V}{j(X_s + X_{tr})} = \left(\frac{0.8974\angle 90^\circ - 1\angle 0^\circ}{1.51\angle 90^\circ}\right) = 0.8898\angle 48.09^\circ \text{ pu}$$

Power factor = Cos 48.09° = 0.6678 lead

(c) (ii) $\delta = 90^\circ$, $E' = 1.2 \times 0.8974$ pu and $X_s + X_{tr} = 1.51$ pu

$$P_{max} = \frac{E'V}{X_s + X_{tr}} \mathrm{Sin}\delta \Big|_{\delta=90^\circ}$$

$$P_{max} = \frac{1.2 \text{x} 0.8974}{1.51} = 0.7132 \text{ pu}$$

Actual $P_{max} = 0.7132 \times 150 = 106.96$ MW

$$I\Big|_{\delta=90^\circ} = \frac{E' - V}{j(X_s + X_{tr})} = \left(\frac{1.2\text{x}0.8974\angle 90^\circ - 1\angle 0^\circ}{1.51\angle 90^\circ}\right) = 0.9733\angle 42.88^\circ \text{ pu}$$

Power factor = Cos 42.88° = 0.7328 lead