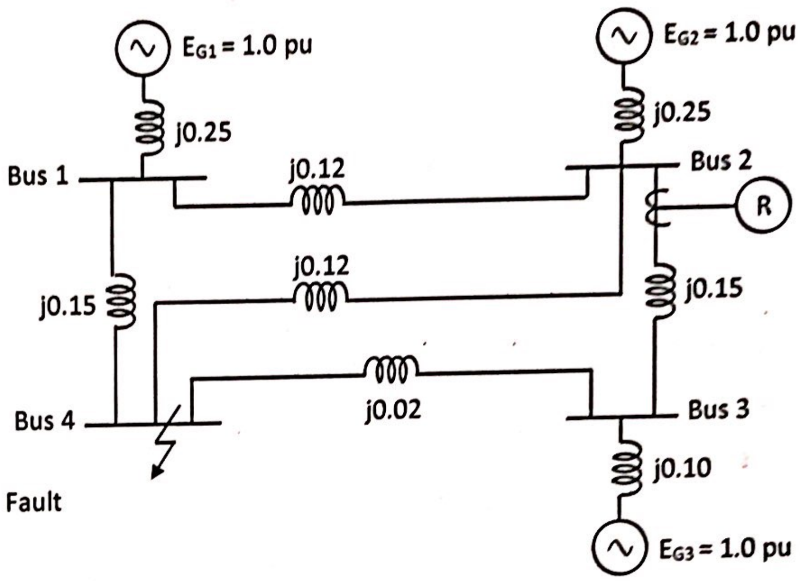
EE3015 Tutorial #6

6.1 $S_b = 100$ MVA, $V_b = 33$ kV, $I_b = S_b/(\sqrt{3}\times V_b) = 100/(\sqrt{3}\times 33)$
$= 1.7495$ kA



(a)

$$Y_{11} = y_{11} + y_{12} + y_{13} + y_{14} = \frac{1}{z_{11}} + \frac{1}{z_{12}} + \frac{1}{z_{13}} + \frac{1}{z_{14}}$$

$$= \frac{1}{j0.25} + \frac{1}{j0.12} + \frac{1}{\infty} + \frac{1}{j0.15} = -j4 - j8.333 - 0 - j6.667 = -j19 \text{ pu}$$

$$Y_{22} = \frac{1}{j0.12} + \frac{1}{j0.25} + \frac{1}{j0.15} + \frac{1}{j0.12} = -j27.333 \text{ pu}$$

$$Y_{33} = \frac{1}{\infty} + \frac{1}{j0.15} + \frac{1}{j0.1} + \frac{1}{j0.02} = -j66.667 \text{ pu}$$

$$Y_{44} = \frac{1}{j0.15} + \frac{1}{j0.12} + \frac{1}{j0.02} = -j65 \text{ pu}$$

$$Y_{12} = Y_{21} = -y_{12} = -\frac{1}{j0.12} = j8.333 \text{ pu}$$

$$Y_{13} = Y_{31} = -y_{13} = -\frac{1}{\infty} = 0 \text{ pu}$$

$$Y_{14} = Y_{41} = -y_{14} = -\frac{1}{j0.15} = j6.667 \text{ pu}$$

$$Y_{23} = Y_{32} = -y_{23} = -\frac{1}{j0.15} = j6.667 \text{ pu}$$

$$Y_{24} = Y_{42} = -y_{24} = -\frac{1}{j0.12} = j8.333 \text{ pu}$$

$$Y_{34} = Y_{43} = -y_{34} = -\frac{1}{j0.02} = j50 \text{ pu}$$

$$Y = -j\begin{bmatrix} 19 & -8.333 & 0 & -6.667 \\ -8.333 & 27.333 & -6.667 & -8.333 \\ 0 & -6.667 & 66.667 & -50 \\ -6.667 & -8.333 & -50 & 65 \end{bmatrix} \text{pu}$$

(b)

$$Z_{Bus} = j\begin{bmatrix} 0.0929 & 0.0532 & 0.0416 & 0.0483 \\ 0.0532 & 0.08 & 0.0467 & 0.0517 \\ 0.0416 & 0.0467 & 0.0647 & 0.06 \\ 0.0483 & 0.0517 & 0.06 & 0.0731 \end{bmatrix}$$

$$I_f = I_4 = \frac{V_f}{Z_{ff}} = \frac{1}{j0.0731} = 13.6799\angle -90^\circ \text{ pu}$$

Actual $|I_f| = 13.6799 \times I_b = 13.6799 \times 1.7495 = 23.934$ kA

$$V_n = V_f\left(1 - \frac{Z_{nf}}{Z_{ff}}\right) \rightarrow V_1 = 1\left(1 - \frac{Z_{14}}{Z_{44}}\right) = 1 - \frac{j0.0484}{j0.0731} = 0.3393 \text{ pu}$$

Actual $|V_1| = 0.3393 \times V_b = 0.3393 \times 33 = 11.196$ kV

$$V_2 = V_f\left(1 - \frac{Z_{24}}{Z_{44}}\right) = 1 - \frac{j0.0517}{j0.0731} = 0.2927 \text{ pu}$$

Actual $|V_2| = 0.2927 \times V_b = 0.2927 \times 33 = 9.661$ kV

$$V_3 = V_f\left(1 - \frac{Z_{34}}{Z_{44}}\right) = 1 - \frac{j0.06}{j0.0731} = 0.1792 \text{ pu}$$

Actual $|V_3| = 0.1792 \times V_b = 0.1792 \times 33 = 5.914$ kV

$V_4 = 0$ due to a three-phase fault at Bus 4.

Fault current in all the lines:

$|I_{12}| = |I_{21}| = |(V_1 - V_2)/z_{12}| = |(0.3393 - 0.2927)/j0.12| = |-j0.3883|$
$= 0.3883$pu

Actual $|I_{12}| = I_{21}| = 0.3883 \times I_b = 0.3883 \times 1.7495 = 0.679$ kA

$|I_{14}| = |I_{41}| = |(V_1 - V_4)/z_{14}| = |(0.3393 - 0)/j0.15| = 2.262$pu

Actual $|I_{14}| = |I_{41}| = 2.262 \times I_b = 2.262 \times 1.7495 = 3.957$ kA

$|I_{23}| = |I_{32}| = |(V_2 - V_3)/z_{23}| = |(0.2927 - 0.1792)/j0.15| = 0.757$pu

Actual $|I_{23}| = |I_{32}| = 0.757 \times I_b = 0.757 \times 1.7495 = 1.324$ kA

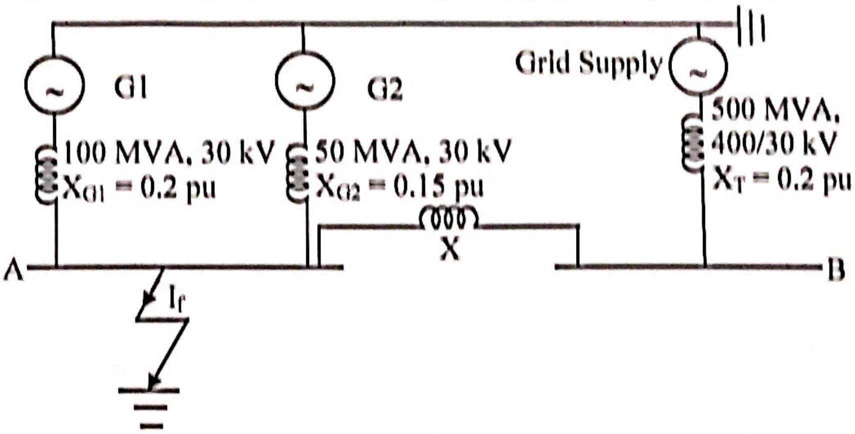
$|I_{24}| = |I_{42}| = |(V_2 - V_4)/z_{24}| = |(0.2927 - 0)/j0.12| = 2.439$ pu

Actual $|I_{24}| = |I_{42}| = 2.439 \times I_b = 2.439 \times 1.7495 = 4.267$ kA

$|I_{34}| = |I_{43}| = |(V_3 - V_4)/z_{34}| = |(0.1792 - 0)/j0.02| = 8.96$ pu

Actual $|I_{34}| = |I_{43}| = 8.96 \times I_b = 8.96 \times 1.7495 = 15.676$ kA

6.2 $S_b = 500$ MVA, $V_b = 30$ kV $\rightarrow Z_b = V_b^2/S_b = 30^2/500 = 1.8\ \Omega$



$X_{G1} = 0.2 \times 500/100 = 1$ pu

$X_{G2} = 0.15 \times 500/50 = 1.5$ pu

$X_T = 0.2 \times 500/500 = 0.2$ pu (no change)

$$X_{th} = (X_{G1} \,||\, X_{G2}) \,||\, (X + X_T) = (1 \,||\, 1.5) \,||\, (X + 0.2)$$
$$= [(1 \times 1.5)/2.5] \,||\, (X + 0.2) = 0.6 \,||\, (X + 0.2)$$
$$= 0.6\,(X + 0.2)/[\,0.6 + (X + 0.2)]$$

$S_f = V_f\, I_f^*$

But $|S_f| = 1250\ \text{MVA}/S_b = 2.5$ pu

$|S_f| = |V_f||I_f|$, and $|V_f| = 1$ pu (assumption) $\rightarrow |I_f| = |S_f|/|V_f| = |S_f| = 2.5$ pu

$X_{th} = V_{th} / I_{sc} = V_f / I_f = 1/2.5 = 0.4$ pu

$$X_{th} = \frac{0.6(X + 0.2)}{(X + 0.8)} = 0.4$$

$0.6X + 0.12 = 0.4X + 0.32 \rightarrow 0.2X = 0.2 \rightarrow X = 1$ pu

Actual $X = 1 \times Z_b = 1.8\ \Omega$

6.3 $S_b = 120\text{x}10^{-3}/0.6 = 0.2$ MVA, $V_b = 0.44$ kV, $Z_b = V_b^2/S_b = 0.968\ \Omega$
and $I_b = S_b/(\sqrt{3}\times V_b) = 0.2/(\sqrt{3}\times 0.44) = 0.26243$ kA

$$\text{Z for 500 ft} = \frac{0.052 + j0.069}{2\text{x}Z_b} = 0.02686 + j0.03564 \text{ pu}$$

$$\text{(a) Assume that } V_{an} = \frac{\frac{0.44}{\sqrt{3}}\angle 0^\circ}{\frac{V_b}{\sqrt{3}}} = 1\angle 0^\circ \text{ pu}$$

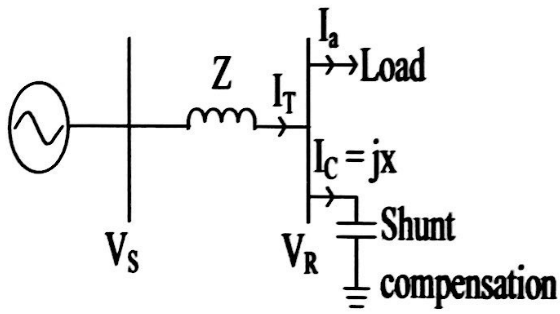
Before compensation, the current in the feeder is

$$I_a = \frac{\frac{120}{\sqrt{3}\text{x}0.6\text{x}440}}{I_b}\angle -53.13^\circ = 1\angle -53.13^\circ = 0.6 - j0.8 \text{ pu}$$

Since the capacitor can result in a +jx current which cancels a portion of the above imaginary current component (-j0.8 pu). The real component of the above current would not be affected.

$$I_T = I_a + I_C = [0.6 - j(0.8 - x)] \text{ pu}$$

$$|I_T| = \frac{225}{I_b} = \frac{225}{262.43} = 0.85737 \text{ pu}$$



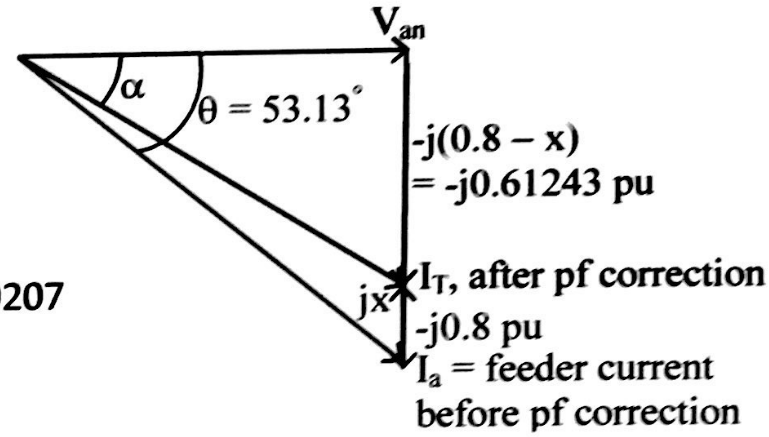
$$\sqrt{0.6^2 + (0.8 - x)^2} = 0.85737$$
$$0.8 - x = \sqrt{0.85737^2 - 0.6^2}$$
$$x = 0.8 - 0.61243 = 0.18757 \text{ pu}$$

$$|S_C| = |V_{an}|\,|I_C| = 1 \text{ x } 0.18757 = 0.18757 \text{ pu}$$

kVA rating of capacitors = 0.18757 x S_b = 0.18757 x 0.2 x 1000
= 37.513 kVA

(b) Phasor diagram of the feeder current before/after power factor correction, i.e. compensation.

From the diagram,



$$\tan\alpha = \frac{0.8 - x}{0.6}$$

$$= \frac{0.61243}{0.6} = 1.0207$$

$$\alpha = \tan^{-1} 1.0207$$

$$= 45.587^\circ$$

New pf = $\cos\alpha = \cos 45.587^\circ = 0.7$ lag

(c) $V_S = V_R + I_T Z = 1 + (0.6 - j0.61243)(0.02686 + j0.03564)$
$= 1.03794 + j0.004934 = 1.03795\angle 0.272^\circ$

Actual $|V_S| = 1.03795 \times V_b = 1.03795 \times 440 = 456.7$ V

(d) Percent VR $= \dfrac{|V_{R,NL}| - |V_{R,FL}|}{|V_{R,FL}|} \times 100\%$

Capacitive reactance = $-jX_c = -j1/0.18757 = -j5.33134$ pu

$$|V_{R,NL}| = \left|\frac{-jX_C}{Z - jX_C} V_S\right| = \left|\frac{-j5.33134}{0.02686 + j0.03564 - j5.33134}\right| |V_S|$$

$$= 1.00672 \text{x} 1.03795 = 1.0449 \text{ pu}$$

$$\text{Percent VR} = \frac{1.0449 - 1}{1} \times 100\% = 4.49\%$$