KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

ELECTRICAL ENGINEERING DEPARTMENT

EE 463 – Term 131

HW # 1: Basic Concepts

Key Solution

From Text: 2.3; 2.5; 2.15; 3.11; 3.13; 3.15

Extra Problems:

Problem # 1)
An industrial plant consisting primarily of induction motor loads absorbs 1000kW at 0.7 power factor lagging.
(a) Compute the required kVA rating of a shunt capacitor to improve the power factor to 0.9 lagging.
(b) Calculate the resulting power factor if a synchronous motor rated 1000 hp with 90% efficiency operating at rated load and at unity power factor is added to the plant instead of the capacitor.

Due Dates:

UTR Classes: Sep. 15th 2013.

MW Classes: Sep. 16th 2013

From Text:

2.3. An inductive load consisting of R and X in series feeding from a 2400-V rms supply absorbs 288 kW at a lagging power factor of 0.8. Determine R and X.

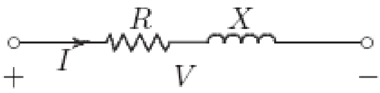


FIGURE 5
An inductive load, with R and X in series.

$$\theta = \cos^{-1} 0.8 = 36.87°$$

The complex power is

$$S = \frac{288}{0.8}\angle 36.87° = 360\angle 36.87° \ \ \text{kVA}$$

The current given from $S = VI^*$, is

$$I = \frac{360 \times 10^3 \angle -36.87°}{2400\angle 0°} = 150\angle -36.87 \ \ \text{A}$$

Therefore, the series impedance is

$$Z = R + jX = \frac{V}{I} = \frac{2400\angle 0°}{150\angle -36.87°} = 12.8 + j9.6 \ \ \Omega$$

Therefore, $R = 12.8\ \Omega$ and $X = 9.6\ \Omega$.

2.5. Two loads connected in parallel are supplied from a single-phase 240-V rms source. The two loads draw a total real power of 400 kW at a power factor of 0.8 lagging. One of the loads draws 120 kW at a power factor of 0.96 leading. Find the complex power of the other load.

$$\theta = \cos^{-1} 0.8 = 36.87^\circ$$

The total complex load is

$$S = \frac{400}{0.8}\angle 36.87^\circ = 500\angle 36.87^\circ \ \ \text{kVA}$$
$$= 400 \text{ kW} + j300 \text{ kvar}$$

The 120 kW load complex power is

$$S = \frac{120}{0.96}\angle -16.26^\circ = 125\angle -16.26^\circ \ \ \text{kVA}$$
$$= 120 \text{ kW} - j35 \text{ kvar}$$

Therefore, the second load complex power is

$$S_2 = 400 + j300 - (120 - j35) = 280 \text{ kW} + j335 \text{ kvar}$$

2.15. Three loads are connected in parallel across a 12.47 kV three-phase supply.

Load 1: Inductive load, 60 kW and 660 kvar.
Load 2: Capacitive load, 240 kW at 0.8 power factor.
Load 3: Resistive load of 60 kW.

(a) Find the total complex power, power factor, and the supply current.
(b) A Y-connected capacitor bank is connected in parallel with the loads. Find the total kvar and the capacitance per phase in μF to improve the overall power factor to 0.8 lagging. What is the new line current?

$$\begin{aligned} S_1 &= 60 \text{ kW} + j660 \text{ kvar} \\ S_2 &= 240 \text{ kW} - j180 \text{ kvar} \\ S_3 &= 60 \text{ kW} + j0 \text{ kvar} \end{aligned}$$

(a) The total complex power is

$$S = 360 \text{ kW} + j480 \text{ kvar} = 600\angle 53.13^\circ \text{ kVA}$$

The phase voltage is

$$V = \frac{12.47}{\sqrt{3}} = 7.2\angle 0^\circ \ \text{ kV}$$

The supply current is

$$I = \frac{600\angle -53.13^\circ}{(3)(7.2)} = 27.77\angle -53.13^\circ \ \text{ A}$$

The power factor is $\cos 53.13^\circ = 0.6$ lagging.

(b) The net reactive power for 0.8 power factor lagging is

$$Q' = 360 \tan 36.87^\circ = 270 \ \text{ kvar}$$

Therefore, the capacitor kvar is $Q_c = 480 - 270 = 210$ kvar, or $S_c = -j210$ kVA.

$$X_c = \frac{|V_L|^2}{S_c^*} = \frac{(12.47 \times 1000)^2}{j210000} = -j740.48\ \Omega$$

$$C = \frac{10^6}{(2\pi)(60)(740.48)} = 3.58\mu\text{F}$$

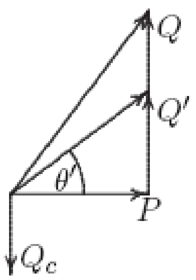


FIGURE 14
The power diagram for Problem 2.15.

$$I = \frac{S^*}{V^*} = \frac{360 - j270}{(3)(7.2)} = 20.835\angle{-36.87^\circ} \ \ \text{A}$$

3.11. A three-phase, Y-connected, 75-MVA, 27-kV synchronous generator has a synchronous reactance of $9.0\ \Omega$ per phase. Using rated MVA and voltage as base values, determine the per unit reactance. Then refer this per unit value to a 100-MVA, 30-kV base.

The base impedance is

$$Z_B = \frac{(KV_B)^2}{MVA_B} = \frac{(27)^2}{75} = 9.72\ \Omega$$

$$X_{pu} = \frac{9}{9.72} = 0.926 \text{ pu}$$

The generator reactance on a 100-MVA, 30-kV base is

$$X_{pu_{new}} = 0.926 \left(\frac{100}{75}\right)\left(\frac{27}{30}\right)^2 = 1.0 \text{ pu}$$

3.13. Draw an impedance diagram for the electric power system shown in Figure 26 showing all impedances in per unit on a 100-MVA base. Choose 20 kV as the voltage base for generator. The three-phase power and line-line ratings are given below.

G_1 :	90 MVA	20 kV	$X = 9\%$
T_1 :	80 MVA	20/200 kV	$X = 16\%$
T_2 :	80 MVA	200/20 kV	$X = 20\%$
G_2 :	90 MVA	18 kV	$X = 9\%$
Line:		200 kV	$X = 120\ \Omega$
Load:		200 kV	$S = 48$ MW $+j64$ Mvar

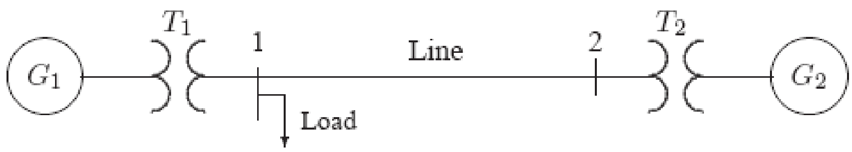


FIGURE 26
One-line diagram for Problem 3.13

The base voltage V_{BG1} on the LV side of T_1 is 20 kV. Hence the base on its HV side is

$$V_{B1} = 20\left(\frac{200}{20}\right) = 200 \quad \text{kV}$$

This fixes the base on the HV side of T_2 at $V_{B2} = 200$ kV, and on its LV side at

$$V_{BG2} = 200\left(\frac{20}{200}\right) = 20 \quad \text{kV}$$

The generator and transformer reactances in per unit on a 100 MVA base, from (3.69)and (3.70) are

$$G: \quad X = 0.09\left(\frac{100}{90}\right) = 0.10 \text{ pu}$$

$$T_1: \quad X = 0.16\left(\frac{100}{80}\right) = 0.20 \text{ pu}$$

$$T_2: \quad X = 0.20\left(\frac{100}{80}\right) = 0.25 \text{ pu}$$

$$G_2: \quad X = 0.09\left(\frac{100}{90}\right)\left(\frac{18}{20}\right)^2 = 0.081 \text{ pu}$$

The base impedance for the transmission line is

$$Z_{BL} = \frac{(200)^2}{100} = 400 \ \Omega$$

The per unit line reactance is

$$Line: \quad X = \left(\frac{120}{400}\right) = 0.30 \text{ pu}$$

The load impedance in ohms is

$$Z_L = \frac{(V_{L-L})^2}{S^*_{L(3\phi)}} = \frac{(200)^2}{48 - j64} = 300 + j400 \ \Omega$$

The load impedance in per unit is

$$Z_{L(pu)} = \frac{300 + j400}{400} = 0.75 + j1.0 \text{ pu}$$

The per unit equivalent circuit is shown in Figure 27.

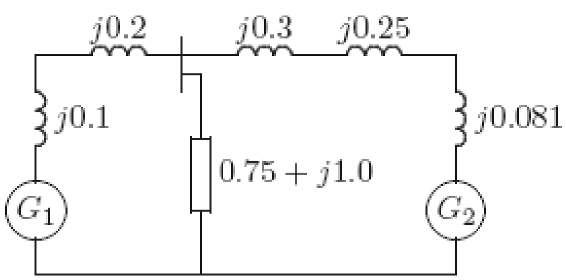


FIGURE 27
Per unit impedance diagram for Problem 3.11.

3.15. The three-phase power and line-line ratings of the electric power system shown in Figure 30 are given below.

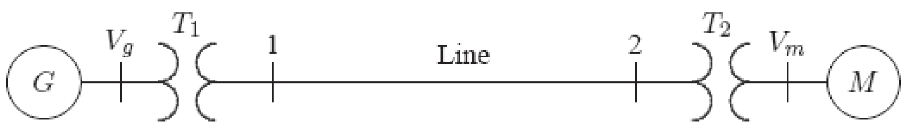


FIGURE 30
One-line diagram for Problem 3.15

G_1 :	60 MVA	20 kV	$X = 9\%$
T_1 :	50 MVA	20/200 kV	$X = 10\%$
T_2 :	50 MVA	200/20 kV	$X = 10\%$
M :	43.2 MVA	18 kV	$X = 8\%$
Line:		200 kV	$Z = 120 + j200\ \Omega$

(a) Draw an impedance diagram showing all impedances in per unit on a 100-MVA base. Choose 20 kV as the voltage base for generator.

(b) The motor is drawing 45 MVA, 0.80 power factor lagging at a line-to-line terminal voltage of 18 kV. Determine the terminal voltage and the internal emf of the generator in per unit and in kV.

The base voltage V_{BG1} on the LV side of T_1 is 20 kV. Hence the base on its HV side is

$$V_{B1} = 20\left(\frac{200}{20}\right) = 200 \quad \text{kV}$$

This fixes the base on the HV side of T_2 at $V_{B2} = 200$ kV, and on its LV side at

$$V_{Bm} = 200\left(\frac{20}{200}\right) = 20 \quad \text{kV}$$

The generator and transformer reactances in per unit on a 100 MVA base, from (3.69)and (3.70) are

$$G: \qquad X = 0.09\left(\frac{100}{60}\right) = 0.15 \ \text{pu}$$

$$T_1: \qquad X = 0.10\left(\frac{100}{50}\right) = 0.20 \ \text{pu}$$

$$T_2: \qquad X = 0.10\left(\frac{100}{50}\right) = 0.20 \ \text{pu}$$

$$M: \qquad X = 0.08\left(\frac{100}{43.2}\right)\left(\frac{18}{20}\right)^2 = 0.15 \ \text{pu}$$

The base impedance for the transmission line is

$$Z_{BL} = \frac{(200)^2}{100} = 400 \;\; \Omega$$

The per unit line impedance is

$$Line: \qquad Z_{line} = (\frac{120 + j200}{400}) = 0.30 + j0.5 \;\; \text{pu}$$

The per unit equivalent circuit is shown in Figure 31.

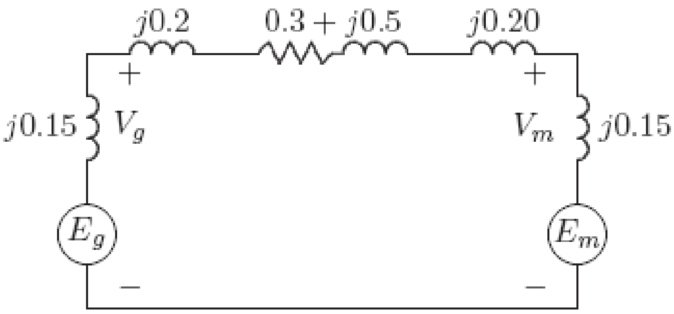


FIGURE 31
Per unit impedance diagram for Problem 3.15.

(b) The motor complex power in per unit is

$$S_m = \frac{45\angle 36.87^\circ}{100} = 0.45\angle 36.87^\circ \;\; \text{pu}$$

and the motor terminal voltage is

$$V_m = \frac{18\angle 0^\circ}{20} = 0.90\angle 0^\circ \;\; \text{pu}$$

$$I = \frac{0.45\angle{-36.87^\circ}}{0.90\angle 0^\circ} = 0.5\angle{-36.87^\circ} \text{ pu}$$

$$V_g = 0.90\angle 0^\circ + (0.3 + j0.9)(0.5\angle{-36.87^\circ} = 1.31795\angle 11.82^\circ \text{ pu}$$

Thus, the generator line-to-line terminal voltage is

$$V_g = (1.31795)(20) = 26.359 \text{ kV}$$

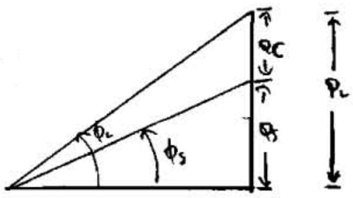
$$E_g = 0.90\angle 0^\circ + (0.3 + j1.05)(0.5\angle{-36.87^\circ} = 1.375\angle 13.88^\circ \text{ pu}$$

Thus, the generator line-to-line internal emf is

$$E_g = (1.375)(20) = 27.5 \text{ kV}$$

Extra Problems:

Problem # 1)



$\phi_L = \cos^{-1} 0.7 = 45.57^\circ$

$Q_L = P \tan\phi_L = 1000 \tan(45.57^\circ)$

$Q_L = 1020.2$ KVAR

$\phi_s = \cos^{-1} 0.9 = 25.84^\circ$

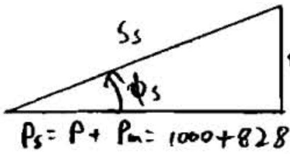
$Q_s = P \tan\phi_s = 1000 \tan(25.84^\circ) = 484.3$ KVAR

$Q_C = Q_L - Q_s = 1020.2 - 484.3 = 535.9$ KVAR

$\underline{S_c = Q_c = 535.9 \text{ KVA}}$

b) Synchronous Motor Absorbs $P_m = \dfrac{1000\text{hp}\ (0.746)\text{kw}}{(0.9)\ (1\text{hp})} = \underline{828.9 \text{ KW}}$

and $Q_m = 0$ KVAR (because of unity pf)



$Q_s = Q_L = 1020.2$ KVAR

$P_s = P + P_m = 1000 + 828.9$
$= 1828.9$ kw

$pf = \cos\left[\tan^{-1}\left(\frac{1020.2}{1828.9}\right)\right]$

$\underline{pf = 0.873 \text{ lagging}}$