Solution to Midterm II

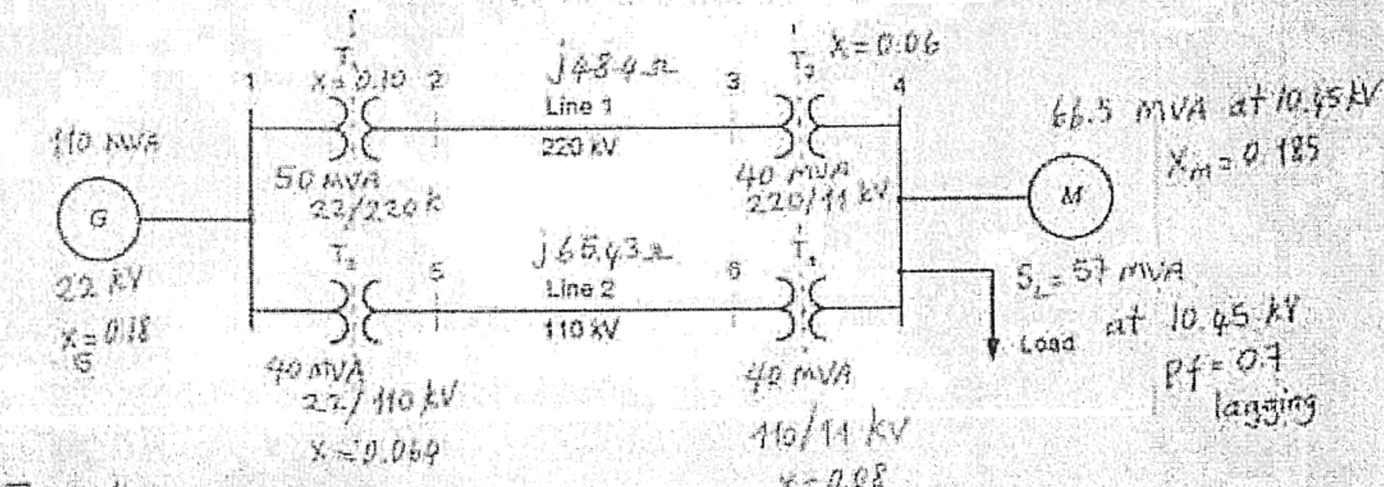
Power system Analysis I   Yrd. Doç. Dr. Bünyamin Tamyürek

Solution to Problem 1:   9   1

**Problem 1 (40 pts):** The figure below shows the one-line diagram of the three-phase power system. By selecting a common base of 90 MVA and 22 kV on the generator side, draw an impedance diagram showing all impedances including the load impedance in per-unit. The data are given as follows:

| | | | | |
|---|---|---|---|---|
| G: | 110 MVA | 22 kV | x=0.18 | per unit |
| T1: | 50 MVA | 22/220 kV | x=0.10 | per unit |
| T2: | 40 MVA | 220/11 kV | x=0.06 | per unit |
| T3: | 40 MVA | 22/110 kV | x=0.064 | per unit |
| T4: | 40 MVA | 110/11 kV | x=0.08 | per unit |
| M: | 66.5 MVA | 10.45 kV | x=0.185 | per unit |

Lines 1 and 2 have series reactance of 48.4 and 65.43Ω, respectively. At bus 4, the three-phase load absorbs 57 MVA at 10.45 kV and 0.7 power factor lagging.




**Zone 1:**

$S_{base3\phi} = 90 \text{ MVA}$

$V_{base1LL} = 22 \text{ kV}$

$X_{G_{newpu}} = 0.18\left(\frac{90}{110}\right) = 0.14727 \text{ pu}$ 3

$E_{Gpu} = 1.0 \text{ pu}$ 3

**Zone 2:**

$X_{T1newpu} = 0.1\left(\frac{90}{50}\right) = 0.18 \text{ pu}$ 3

$X_{T3newpu} = 0.064\left(\frac{90}{40}\right) = 0.144 \text{ pu}$ 3

**Zone 3:**

$V_{base3LL} = \frac{11}{220} \cdot 220 = 11 \text{ kV}_{LL}$

$E_{mpu} = \frac{10.45}{11} = 0.95 \text{ pu}$ 3

$X_{m\,newpu} = 0.185\left(\frac{10.45}{11}\right)^2\left(\frac{90}{66.5}\right) = 0.22596 \text{ pu}$ 3

**Line 1:** $V_{base2LL} = \frac{220}{22} \cdot 22 = 220 \text{ kV}_{LL}$

$Z_{base2} = \frac{220^2}{90} = 537.78\ \Omega \qquad X_{Line1pu} = \frac{48.4}{537.78} = 0.09 \text{ pu}$ 3

**Line 2:**

$V_{base2LL} = \frac{110}{22} \cdot 22 = 110 \text{ kV}_{LL}$

$Z_{base2} = \frac{110^2}{90} = 134.44\ \Omega \qquad X_{Line2pu} = \frac{65.43}{134.44} = 0.48667 \text{ pu}$ 3

$$X_{T_3\,new\,pu} = 0.06\left(\frac{90}{40}\right) = 0.135 \text{ pu} \quad 3$$

$$X_{T_4\,new\,pu} = 0.08\left(\frac{90}{40}\right) = 0.18 \text{ pu} \quad 3$$

(10)

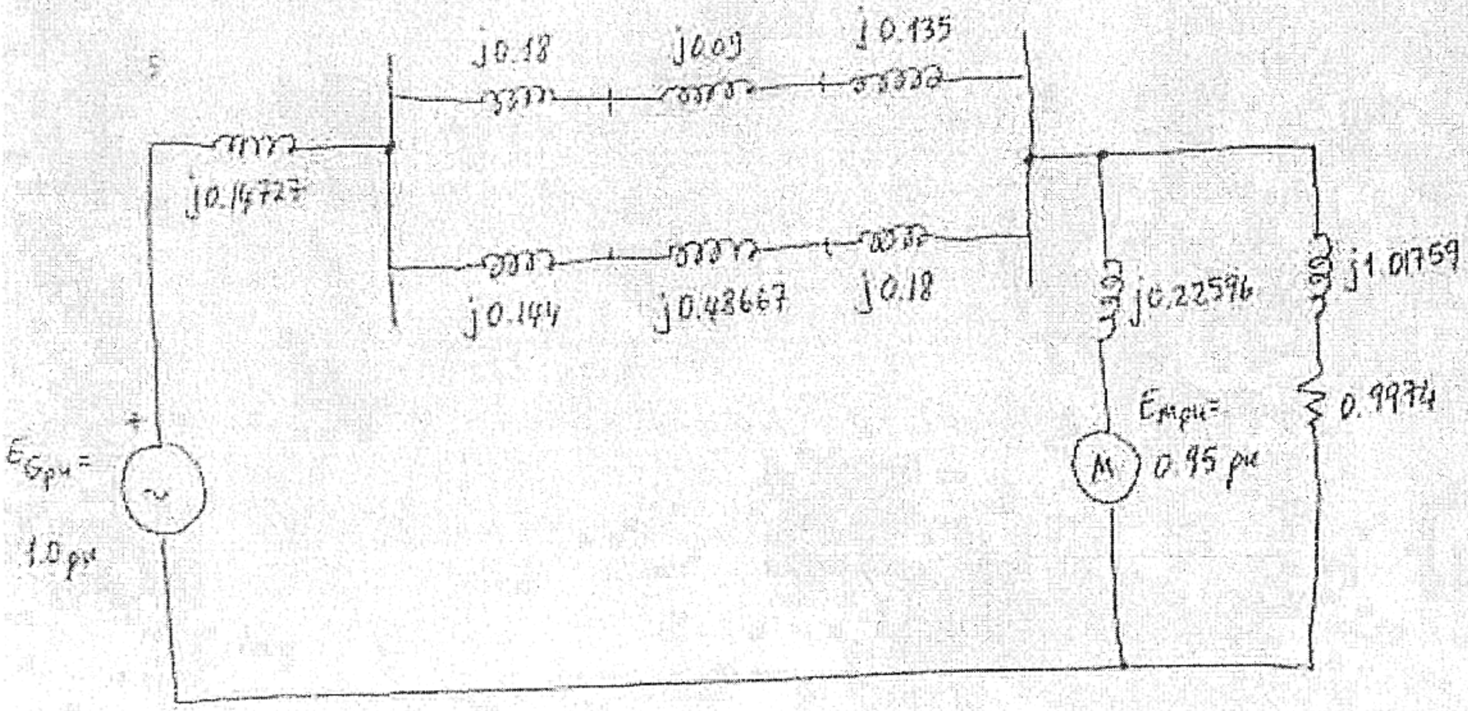
Load:

$$\bar{Z}_{load\,1\phi} = \frac{V_{LL}^2}{S_{3\phi}} \underline{\left|\cos^{-1}(0.7)\right.} = \frac{10.45^2}{57} \underline{\left|\cos^{-1}(0.7)\right.} = 1.91583 \underline{\left|45.57^\circ\right.}$$

$$= 1.341 + j\,1.3681 \;\Omega \quad 2$$

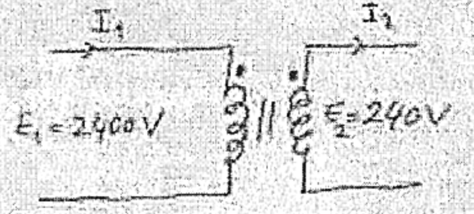
$$\bar{Z}_{base\,load} = \frac{V_{base\,LL}^2}{S_{base\,3\phi}} = \frac{11^2}{90} = 1.3444$$

$$\bar{Z}_{load\,pu} = 0.9974 + j\,1.01759 \text{ pu} \quad 3$$

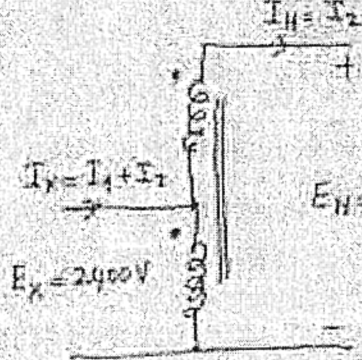


**Problem 2 (20 pts):** A single-phase 15-kVA, 2400/240-volt, 60 Hz two winding distribution transformer is connected as an autotransformer to step up the voltage from 2400 to 2640 volts.
a) Draw a schematic diagram of this arrangement, showing all voltages and currents when delivering full load at rated voltage.
b) Find the permissible kVA rating of the autotransformer if the winding voltages and currents are not to exceed the rated values as a two-winding transformer. How much of this kVA rating is transformed by the magnetic induction?

Solution:




a)




$E_H = E_1 + E_2 = 2400 + 240 = 2640\ V$

$S = 15\ kVA$
$2400/240\ V$
$60\ Hz$

$I_1 = \frac{15000}{2400} = 6.25\ A$ rated primary current

$I_2 = 6.25 \times \frac{2400}{240} = 62.5\ A$ rated secondary current

$E_X = 2400$ Volt

$E_H = 2640$ Volt

$I_X = 68.75\ A$

$I_H = 62.5\ A$

b) $S_{autotransformer} = E_X I_X = E_H I_H = 2400 \cdot (68.75) = 2640 \cdot (62.5)$
$= 165000 = 165000 = 165\ kVA$

15 kVA of 165 kVA is transformed by the magnetic induction

150 kVA is transformed by electrically.

(12)

**Problem 3 (25 pts):** It is desired to construct a 480Δ/208Y three-phase transformer from three single-phase 480/120 volt two-winding transformers. Positive sequence line-to-neutral voltages at the 480V side must lead the corresponding line-to-neutral voltages on the secondary side by 90°. Labeling the 480V side terminals as A, B and C and the 208V side as *a*, *b* and c,

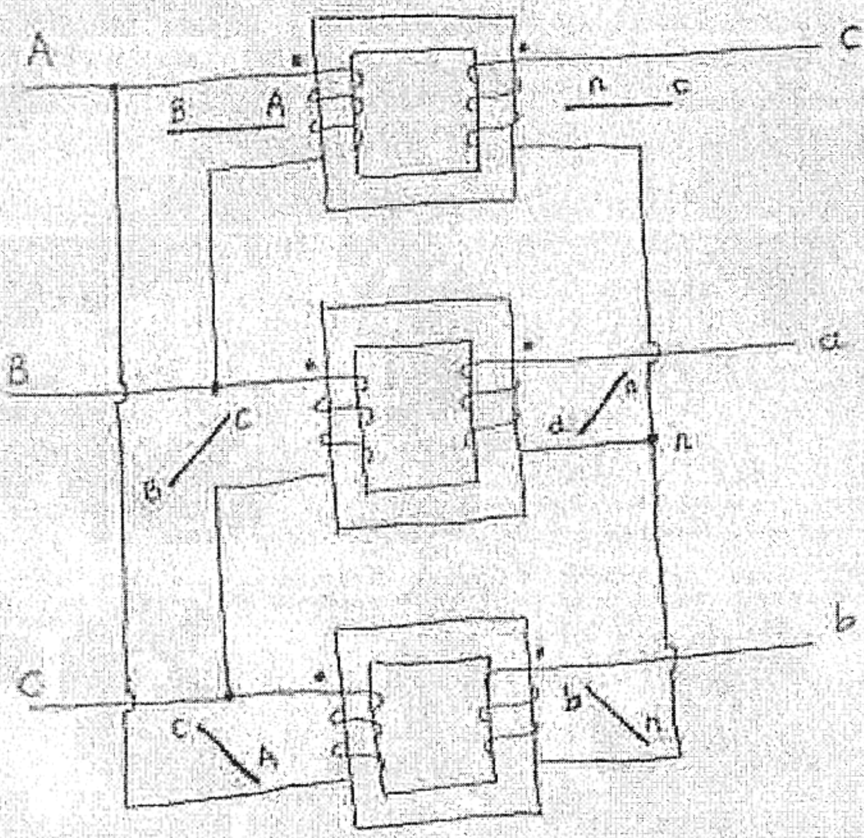
a) Draw the core and coil arrangements for the desired system by correctly connecting and labeling the terminals.

b) Draw the positive-sequence phasor diagram to indicate the phase shift.

Solution:

a)

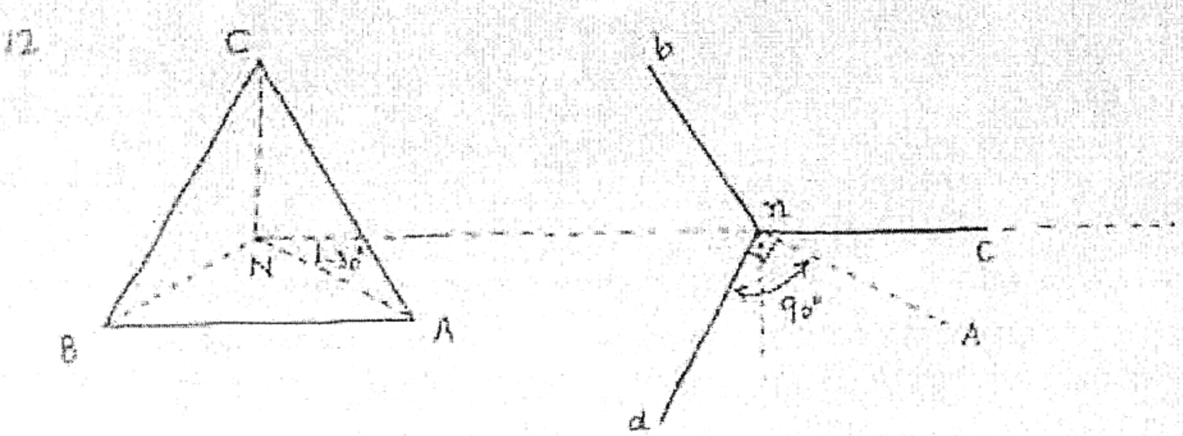
13




$\bar{V}_{AN}$ leads $\bar{V}_{an}$ by 90°

b)

12

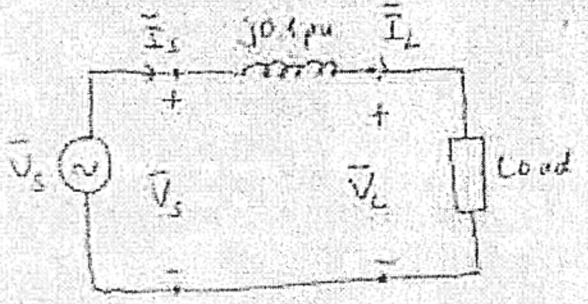


**Problem 4 (15 pts):** A three-phase transformer has a series impedance of j0.1pu. A balanced three-phase source is connected to the primary and a balanced three-phase load of $\bar{S} = 1.0\angle -36.87°$ pu connected to the secondary. The terminal voltage at the load is $1.0\angle 0°$. Using the per phase equivalent and leaving all quantities in per-unit,

a) Calculate the phasor value of the load current in per unit

b) Calculate the phasor value of the source voltage in per unit

Solution:




8

a) $\bar{I}_L = \left(\dfrac{\bar{S}_L}{\bar{V}_L}\right)^* = \left(\dfrac{1.0\angle -36.87°}{1.0\angle 0°}\right)^* = 1.0\angle 36.87°$ pu

7

b) $\bar{V}_s = 0.1\angle 90° \times 1.0\angle 36.87° + 1.0\angle 0°$

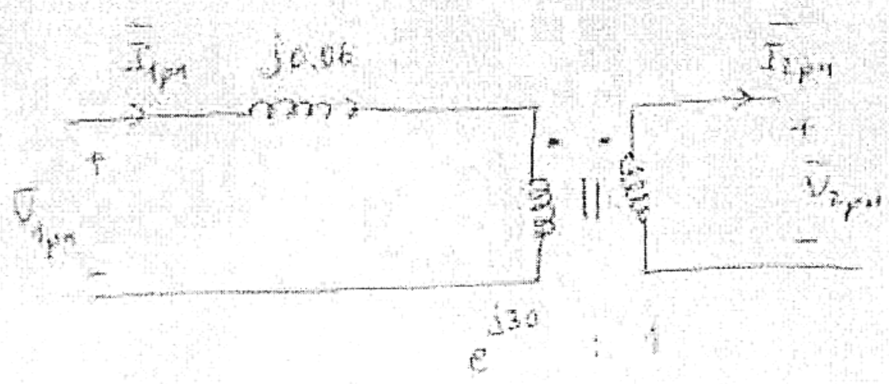
$= 0.1\angle 126.87° + 1.0\angle 0°$

$= -0.06 + j0.08 + 1.0 = 0.94 + j0.08$

$= 0.9434\angle 4.86°$ pu

**Problem 5 (5 pts):** The leakage reactance of a three-phase, 300MVA, 230 Y/ 23 Δ kV transformer is 0.06 per unit based on its own ratings. The Y winding has a solidly grounded neutral. Draw the positive-sequence per-unit equivalent circuit. Neglect the exciting admittance and assume American standard phase shift.

Solution:



Problem 1:

(14)

A three-phase, 60 Hz, completely transposed 230-kV, 200 km line has a positive-sequence series impedance

$z = 0.08 + j\,0.48\ \Omega/km$ and a positive-sequence

shunt admittance

$y = j\,3.33 \times 10^{-6}\ S/km$

At full load, the line delivers 250 MW at 0.99 p.f. lagging and at 220 kV. Assuming a medium-length line, determine the following:

a) ABCD parameters of the nominal $\pi$ circuit
b) Sending-end voltage $V_s$, current $I_s$, and real power $P_s$
c) Find the percent voltage regulation, and comment about the result.
d) Transmission line efficiency at full load.

Problem 2:

15

A 300 km, 500 kV, 60 Hz three-phase uncompensated lossless line has a positive-sequence series reactance

$$x = 0.34 \ \Omega/km$$

and positive-sequence shunt admittance

$$y = j4.5 \times 10^{-6} \ S/km$$

Based on the lossless line assumption, the following ABCD parameters are obtained for the line:

$$\bar{A} = \bar{D} = 0.9319 \angle 0^{\circ} \text{ per unit}$$

$$\bar{B} = j\,99.68 \ \Omega$$

$$\bar{C} = j\,1.319 \times 10^{-3} \ S$$

Rated line voltage (500 kV) is applied to the sending end of the above transmission line. Calculate the receiving-end voltage when receiving end is terminated by

a) an open circuit,

b) the surge impedance of the line, and

c) One-half of the surge impedance.

d) Also find the surge impedance loading of the line.

e) Finally, calculate the theoretical maximum real power that line can deliver when rated voltage is applied to both ends of the line.

Problem 3:



A 400 km, 500 kV, 60 Hz uncompensated three-phase line has the following positive-sequence parameters:

series impedance : $\bar{z} = 0.03 + j\,0.35$ Ω/km

shunt admittance : $\bar{y} = j\,4.4 \times 10^{-6}$ S/km

$\bar{A} = \bar{D} = 0.8794 \angle 0.66^\circ$ per unit

$\bar{B} = 134.8 \angle 85.3^\circ$ Ω

$\bar{C} = 1.688 \times 10^{-3} \angle 90.2^\circ$ S

a) Determine the theoretical maximum power in MW that line given above can deliver. Assume $V_S = V_R = 500$ kV

b) Determine the practical maximum power in MW that the same line can deliver based on the practical line loadability criteria. Use the commonly accepted voltage-drop limit and the steady-state stability limit criteria.

| | $A = D$ | $B$ | $C$ |
|---|---|---|---|
| Units | per unit | $\Omega$ | S |
| short line | $1$ | $\bar{Z}$ | $0$ |
| nominal $\pi$ | $1 + \frac{\bar{Y}\bar{Z}}{2}$ | $\bar{Z}$ | $\bar{Y}\left(1 + \frac{\bar{Y}\bar{Z}}{4}\right)$ |
| Equivalent $\pi$ | $\cos(\gamma l) = 1 + \frac{\bar{Y}'\bar{Z}'}{2}$ | $Z_c \sinh(\gamma l) = \bar{Z}'$ | $\frac{1}{Z_c}\sinh(\gamma l) = \bar{Y}'\left(1 + \frac{\bar{Y}'\bar{Z}'}{4}\right)$ |
| For lossless line | $\cos(\beta l)$ | $j Z_c \sin(\beta l) = \bar{Z}'$ | $j\frac{\sin(\beta l)}{Z_c}$ |

$$Z_c = \sqrt{\frac{z}{y}} = \sqrt{\frac{L}{C}} \ \Omega \qquad \gamma = \sqrt{\bar{z}\bar{y}} = j\beta \ m^{-1}$$

$$\gamma l = \sqrt{\bar{z}.\bar{y}}\ .\ l = j\beta l$$

$$P_R = \frac{V_R V_s}{Z'}\cos(\theta_Z - \delta) - \frac{A V_R^2}{Z'}\cos(\theta_Z - \theta_A)$$

$$SIL = \frac{V_{rated}^2}{Z_c}$$