SOLUTION ELE 746

Mid-Term Exam, October, 2011

Q1: Figure-1 shows an industrial complex which has one set of 3-phase load (**LOAD1**), which is 6MW at 0.7 power factor lagging, and another set of 3-phase load (**LOAD2**), which is 8MW load of0.8 power factor lagging.

The supply is 3-phase, 60 Hz, 3.3kV line-to-line.

(i) Assuming both the loads are connected in Y, calculate the power factor, and the line current due to the combined load. [8]

(ii) If 3-phase Y-connected bank of capacitors are switched in parallel to the loads to improve the combined power factor to unity, calculate the value of the capacitor per phase, and the new line current. [12]

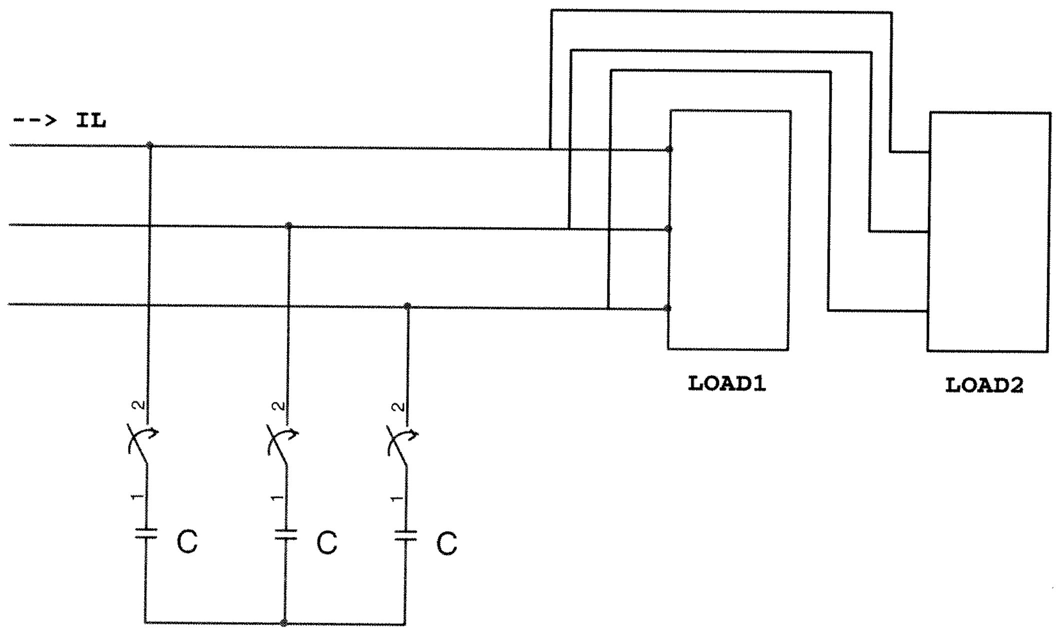

Figure-1

(i) Without C

Load-1: $P_1 = 6MW$, $P_f = 0.7$ lagging, $\cos\theta = 0.7 \rightarrow \theta = 45.57^\circ$

(3) $Q_1 = P_1 \tan\theta = 6 \tan 45.57^\circ = 6.121$ MVAR

$\therefore \bar{S}_1 = 6 + j6.121 = 8.571\angle 45.47^\circ$ MVA

Load-2: $P_2 = 8MW$, $P_f = \cos\theta = 0.8$ lagging $\rightarrow \theta = 36.87^\circ$

(3) $Q_2 = P_2 \tan\theta = 8 \tan 36.87^\circ = 6$ MVAR

$\bar{S}_2 = P_2 + jQ_2 = 8 + j6 = 10\angle 36.87^\circ$ MVA

Total, $\bar{S}_T = \bar{S}_1 + \bar{S}_2 = 8.571\angle 45.47^\circ + 10\angle 36.87^\circ = \underbrace{18.52\angle 40.84^\circ}_{14+j12.121 \text{ MVA}}$

(1) Power factor, $\cos 40.84^\circ = \boxed{0.757 \text{ Lagging}}$

(1) Line current, $|I_L| = \frac{|S_T|}{\sqrt{3}V_L} = \frac{18.52\times10^6}{\sqrt{3}(3.3\times10^3)} = \boxed{3240.25A}$

Q1 (ii) with C

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$$\text{Total } \bar{S}_{T\,(new)} = \bar{S}_{T\,(old)} - jQ_C = \underbrace{P_T + jQ_T}_{old} - jQ_C$$

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$$S_{T\,(new)} = \underbrace{14}_{P_T} + j\underbrace{12.121}_{Q_T} - jQ_C$$

For Unity power factor, $Q_C = Q_T = 12.121 \times 10^6$ VAR

Per phase $Q_C = \frac{Q_T}{3} = \frac{12.121 \times 10^6}{3} = 4.0403 \times 10^6$ VAR

$$Q_{c\,(ph)} = \frac{V_{ph}^2}{X_c} \longrightarrow X_c = \frac{V_{ph}^2}{Q_{c\,(ph)}} = \frac{(3.3 \times 10^3/\sqrt{3})^2}{4.0403 \times 10^6} = 0.8985 \text{ VAR}$$

$$\therefore X_c = \frac{1}{2\pi f C} = \frac{1}{2\pi(60)C} = 0.8985$$

4

$$\therefore C = \frac{1}{2\pi(60)(0.8985)} = 0.002952 \text{ F}$$

$$\boxed{C = 2.95 \text{ mF}/ph}$$

New Line current, $|I_L| = \frac{P_T}{\sqrt{3}(3.3 \times 10^3)\underbrace{\cos\theta}_{1}}$

4

$$I_L = \frac{14 \times 10^6}{\sqrt{3}(3.3 \times 10^3)(1)} = \boxed{2449.44 \text{ A}}$$

Q2: **<u>Part-A</u>**

Write the $\mathbf{Y}_{\mathbf{BUS}}$ matrix of the network shown in Figure-2a. [10]

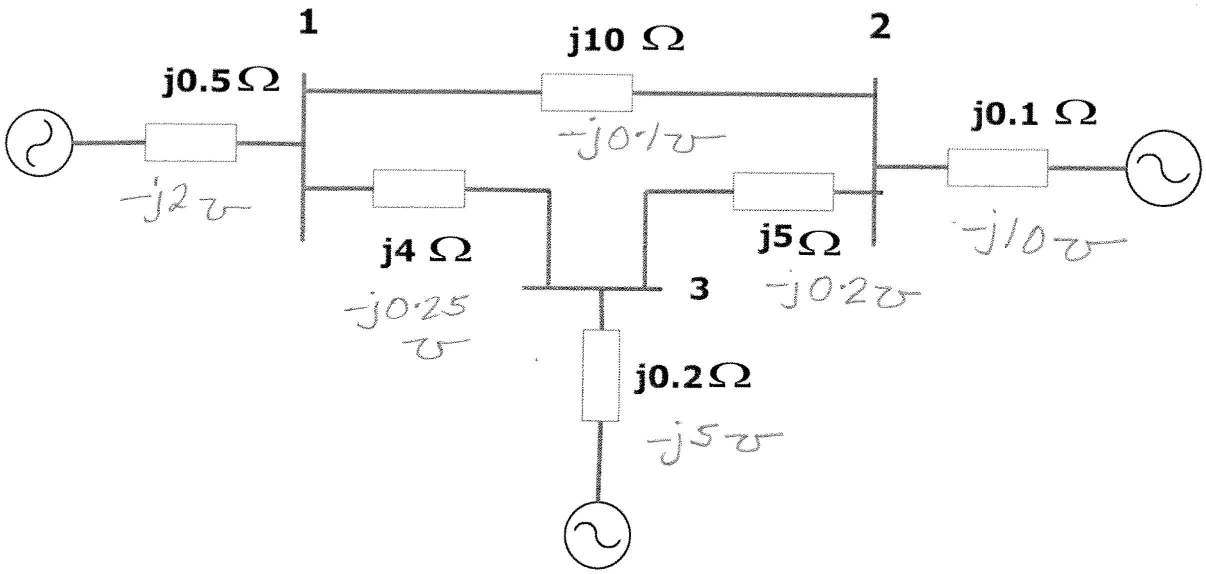

Figure-2a

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$j0.5\,\Omega \rightarrow -j2\,℧$, $j4\,\Omega \rightarrow -j0.25\,℧$, $j10\,\Omega \rightarrow -j0.1\,℧$

$j5\,\Omega \rightarrow -j0.2\,℧$, $j0.2\,\Omega \rightarrow -j5\,℧$, $j0.1\,\Omega \rightarrow -j10\,℧$

$$[Y_{BUS}] = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} = \begin{bmatrix} -j(2+0.25+0.1) & -(-j0.1) & -(-j0.25) \\ -(-j0.1) & -j(0.1+10+0.2) & -(-j0.2) \\ -(-j0.25) & -(-j0.2) & -j(0.25+5+0.2) \end{bmatrix}$$

$$[Y_{BUS}] = \begin{bmatrix} -j2.35 & +j0.1 & +j0.25 \\ +j0.1 & -j10.3 & +j0.2 \\ +j0.25 & +j0.2 & -j5.45 \end{bmatrix} = j\begin{bmatrix} -2.35 & 0.1 & 0.25 \\ 0.1 & -10.3 & 0.2 \\ 0.25 & 0.2 & -5.45 \end{bmatrix}$$

6

Q2: **Part-B**

Figure-2b shows three 1-phase transformers each of which has primary 11kV and secondary 3.3kV. The DOT terminals shown as 0 are shown in the diagram.

(i) Connect the primary in Δ and secondary in **Y**, and draw the phasor diagrams of the phase and line voltages of the primary and secondary voltages for positive phase sequence. In the phasor diagram, take the primary side phase voltage, V_{A1A2} as reference. [6]

(ii) If the load in the secondary of the three-phase transformer is 25kW at 0.8 power factor lagging, calculate the primary and secondary line currents, assuming zero losses inside the transformer. [4]

(i)

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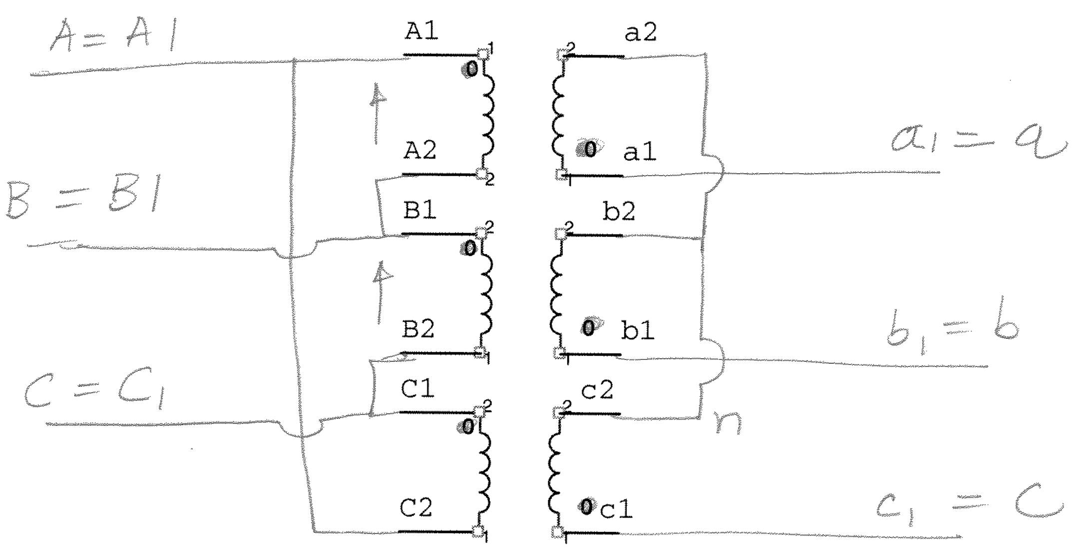

Figure-2b

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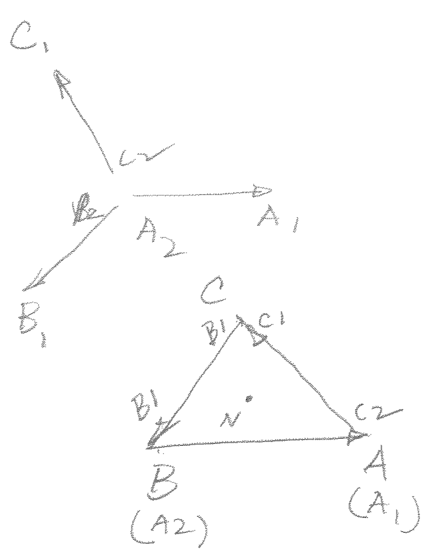
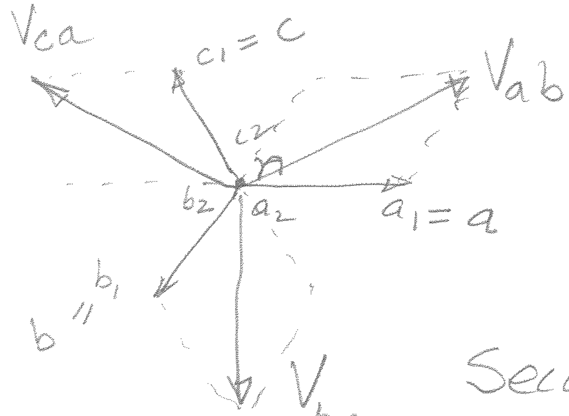


Primary (Δ)



Secondary (Y)

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(ii) Primary (Δ), $V_{LL} = 11kV$

Secondary (Y), $V_{LL} = \sqrt{3}(3.3) = 5.716\ kV$

$$P_T = \sqrt{3}\, V_{LL} I_L \cos\theta$$

2

$$I_L = \frac{P_T}{\sqrt{3}\, V_{LL} \cos\theta}$$

In primary (Δ), $I_L = \dfrac{25\times10^3}{\sqrt{3}\,(11\times10^3)(0.8)} = \boxed{1.640A}$

In Secondary (Y), $I_L = \dfrac{25\times10^3}{\sqrt{3}\,(5.716\times10^3)(0.8)} = \boxed{3.157A}$

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Q3: Figure-3 shows a single line diagram of a power system. The generator, G is supplying two motor loads M1 and M2 over a transmission system.

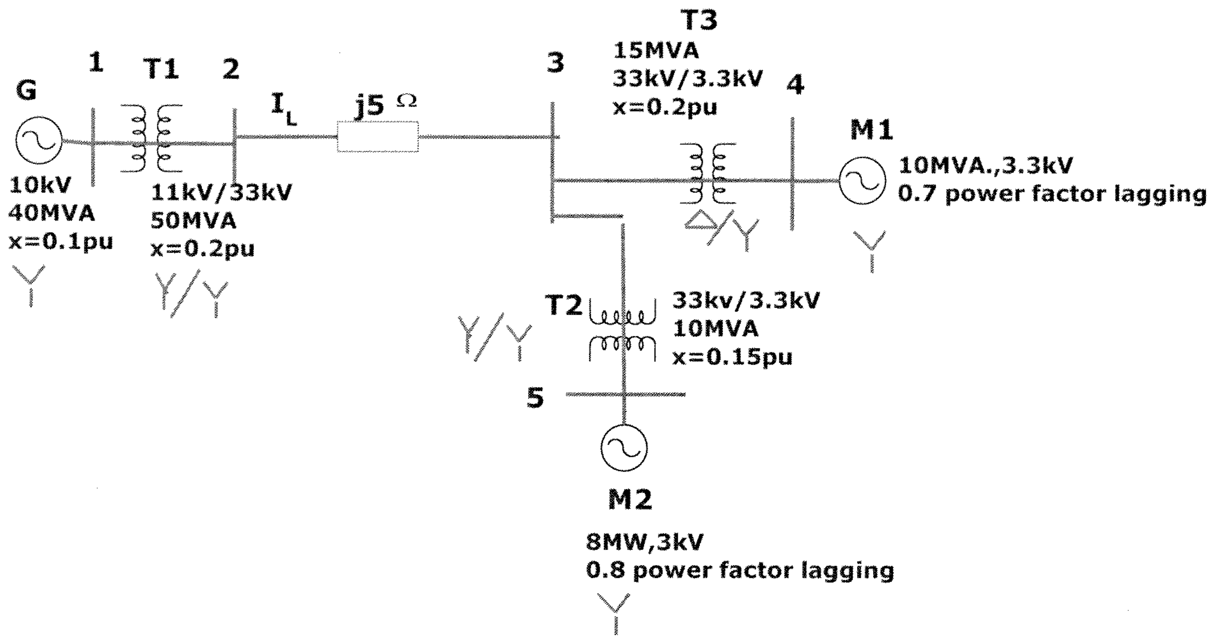

Figure-3

(a) Calculate the line current, I_L in amperes at Bus-2, and [10]

(b) calculate the Bus-2 voltage in kV. [10]

In your calculation, use **<u>S_{Base} = 50 MVA</u>** and **<u>11kV as the Base voltage in the primary side of Transformer, T1.</u>**

(a) $S_B = 50\,MVA$

G: $V_{B_{new}} = 11kV$ $\therefore$ $X = 0.1\times\left(\frac{50}{40}\right)\left(\frac{10}{11}\right)^2 = 0.1033$ p.u

$V_{B_{old}} = 10kV$

T1: $X = 0.2$ p.u. (no change)

Line: $Z_B = \frac{V_B^2}{S_B} = \frac{(33\times10^3)^2}{50\times10^6} = 21.78\,\Omega$ $\therefore 5\,\Omega \to \frac{5}{21.78} = 0.2296$ p.u.

T2: $X = 0.15\times\left(\frac{50}{10}\right) = 0.75$ p.u

T3: $X = 0.2\times\left(\frac{50}{15}\right) = 0.667$ p.u

M1: $I_B = \frac{S_B}{\sqrt{3}\,V_B} = \frac{50\times10^6}{\sqrt{3}\,(3.3\times10^3)} = 8747.99\,A$

Motor current $|I_{M1}| = \frac{10\times10^6}{\sqrt{3}\,(3.3\times10^3)} = 1749.6A$, $\cos\theta = 0.7$ lag, $\theta = 45.57^\circ$

$\therefore I_{m1\,(pu)} = \frac{1749.6}{I_B}\angle -45.57^\circ = 0.2\angle -45.57^\circ$ p.u.

Q3 (contd)

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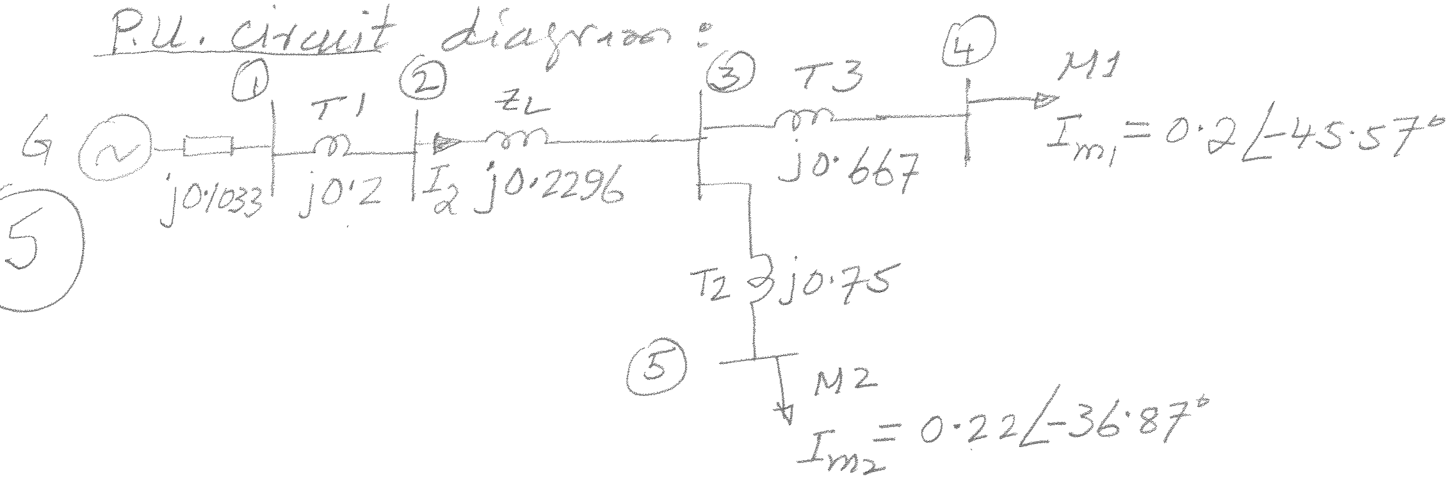
M2: $I_B = 8747.99$, same as in M1.

Motor current, $|I_{M2}| = \dfrac{8\times10^6}{\sqrt{3}\underbrace{(3\times10^3)}_{V_{LL}}(0.8)} = 1924.56A$

$p_f = 0.8$ lagging $\rightarrow \theta = \cos^{-1}(0.8) = 36.87°$

In p.u. $I_{M2} = \dfrac{1924.56\angle-36.87}{8747.99} = 0.22\angle-36.87$

P.U. circuit diagram:



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In Bus-2, $I_2 = I_{m_1} + I_{m_2} = 0.2\angle-45.57° + 0.22\angle-36.87°$ p.u.

$I_2 = 0.4188\angle-41.01°$ p.u.

5 $\underset{(Amp)}{|I_2|} = |0.4188| \times I_B$, $I_B = \dfrac{S_B}{\sqrt{3}V_B} = \dfrac{50\times10^6}{\sqrt{3}(33\times10^3)} = 8747.99$

$\therefore |I_2| = 0.4188 \times 8747.99 = \boxed{3663.66\,A}$

(b) Bus-2, voltage $V_2 = V_4 + V_{drop\ in\ T3} + V_{drop\ in\ Line,\ Z_L}$

5

$= 1\angle0° + j0.667\times0.2\angle-45.57° + j0.2296\times0.4188\angle-41.01°$

$V_2 = 1.1702\angle8.15°$ p.u.

5 $\underset{(kV)}{|V_2|} = 1.1702\times V_B = 1.1702(33) = \boxed{38.62\ kV}$

Q4: Figure-4 shows a cross-section of a 3-phase 110kV,60Hz transmission line, which is fully transposed.

Each phase has a bundle conductor of two. Each of these conductors is solid copper of radious, r =2cm. The separation between the conductors in the bundle is d =20cm. And the separation between the phase conductors is D = 1m.

(a) Calculate the capacitance per phase per meter of the line. [10]

(b) If the line is 50km long, calculate the line charging current. [10]

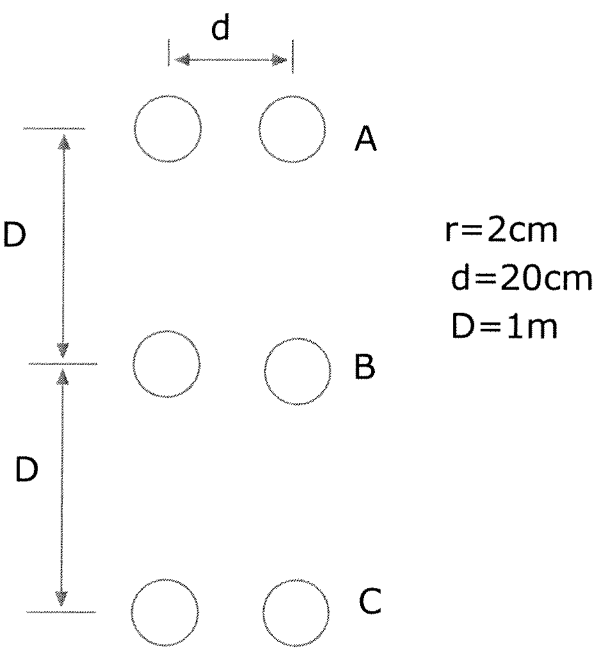

Figure-4

(a) $C_{an} = \dfrac{2\pi \epsilon}{Ln\left(\frac{GMD}{GMR}\right)}$ F/m , $\epsilon = 8.854 \times 10^{-12}$

3 $GMD \approx \sqrt[3]{D \times D \times 2D} = \sqrt[3]{(1)(1)(2)} = 1.2599\ m$

3 $GMR = \sqrt{r \times d} = \sqrt{0.02 \times 0.2} = \sqrt{0.004} = 0.063\ m$

4 $\therefore C_{an} = \dfrac{2\pi(8.854 \times 10^{-12})}{Ln\left(\frac{1.2599}{0.063}\right)} = \dfrac{55.6313 \times 10^{-12}}{2.996} = \boxed{18.569 \times 10^{-12}\ F/m}$

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(b) 3 $X_C = \frac{1}{2\pi f C_T} = \frac{1}{2\pi (60)(18.569 \times 10^{-12} \times 50 \times 10^{3})}$

$= 0.0000002857 \times 10^{9}$

$X_C = 2857\,\Omega$

2 $I_C = \frac{V_{ph}}{X_C}$

5 $I_C = \frac{110 \times 10^{3}/\sqrt{3}}{2857} = \frac{63.51 \times 10^{3}}{2857} = \boxed{22.23\text{ A}}$

Useful formulas and constants

$$Z_{base} = \frac{V^2_{baseLL}}{S_{base3\Phi}} \qquad Z_{p.u.new} = Zp.u.old\left(\frac{V_{baseOld}}{V_{baseNew}}\right)^2\left(\frac{S_{baseNew}}{S_{baseOld}}\right)$$

$$P_T = \sqrt{3}V_{LL}\,I_L\cos\theta \qquad Q_T = \sqrt{3}\,V_{LL}\,I_L\sin\theta \qquad \overline{S_p} = \overline{V_p}.\overline{I_p}^{\,*}$$

$$\mu_o = 4\pi\ x10^{-7} \qquad \varepsilon = 8.854x10^{-12}$$

$$L_a = 2x10^{-7}\ln\left(\frac{GMD}{GMR^1}\right) \qquad H/m$$

$$r^1 = 0.7788\,r$$

$$C_{an} = \frac{2\pi\varepsilon}{\ln\left(\frac{GMD}{GMR}\right)} \qquad F/m$$

$$\begin{bmatrix} V_s \\ I \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}.\begin{bmatrix} V_R \\ I_R \end{bmatrix}$$