Indian Institute of Technology Patna
Department of Electrical Engineering
EE3101 - Power Systems-I
Autumn - 2025
End Semester Exam — Solution.
November 27, 2025

There are 5 questions. They carry equal marks.

$(5 \times 10 = 50)$

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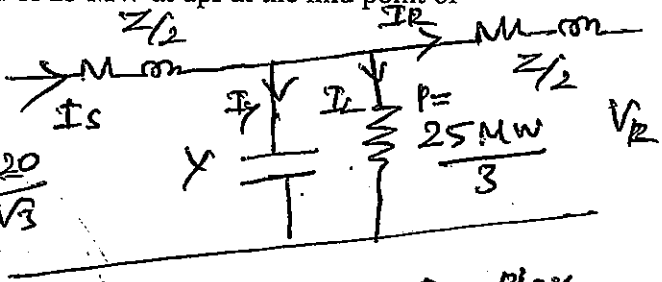
1. A 50 MVA generating station is connected to a three-phase line having impedance $Z = 300\angle 75^\circ\ \Omega$ and admittance $Y = j0.0010\ \mho$. The power at the generating station is 50 MVA at upf at a voltage of 220 kV. There is a load of 25 MW at upf at the mid point of the line. Find the
   (a) line voltage at the receiving end.
   (b) complex power at the receiving end.

   Use nominal-T model for the transmission line.



$I_s = \dfrac{50 \times 10^3}{\sqrt{3} \times 220 \times 1} = 131.26$ A.

Let V_x be the mid point voltage.

$V_x = V_{s\,phase} - I_s \times Z/2$

$V_x = 123.4\angle -8.86^\circ$ kV/phase

$I_y = V_x Y = 19.01 + j121.9$

$I_y = 123.4\angle 81.14^\circ$ A

$I_L = \dfrac{25/3 \times 10^3}{123.4 \times 1} \quad \left(\dfrac{P}{V \times \cos\phi}\right)$

$I_L = 67.53\angle -8.86^\circ$ A (in phase with V_x)

$I_R = I_s - I_L - I_y$

$= 131.26\angle 0^\circ - 67.53\angle -8.86^\circ - 123.4\angle 81.14^\circ$

$\boxed{I_R = 139.92\angle -71.03^\circ \text{ A}}$ 1

a) $V_R = V_x - I_r \times Z/2$

$= 103.04\angle -11.45^\circ$ kV/phase

$\boxed{V_{R\,(Line)} = 178.45 \text{ kV}}$

b) $S_R = V_{R\,phase}\, I_R^*$

$= 7.3 + j12.4$ MVA

$S_{R\,(3\phi)} = (21.9 + j37.3)$ MVA

$S_{R\,3\phi} = 43.25\angle 59.58^\circ$ MVA

2. A three-phase, 50 Hz transmission line is 400 km long. The voltage at the sending end is 220 kV. The line parameters are r = 0.125 Ω/km, x = 0.4 Ω/km and y = 2.8×10^{-6} ℧/km. Use nominal-π model.

   (a) Find the sending-end current and receiving-end voltage when there is no load on the line.

   (b) Find the maximum permissible line length if the receiving-end no-load voltage is not to exceed 235 kV.

   (c) Find the maximum permissible line frequency if the receiving-end no-load voltage is not to exceed 250 kV.

a) $Z = (r + jx) \times 400 = (50 + j160)\,\Omega$

$Y = y \times 400 = j1.12 \times 10^{-3}\,℧$

$V_{S\,phase} = A V_{R\,phase} = \left(1 + \frac{ZY}{2}\right) V_{R\,phase} \quad (I_R = 0)$

$|V_R| = \frac{V_S}{|A|} = 139.45\text{ kV (phase)}$

$\boxed{|V_L| = 241.54\text{ kV (Line)}}$

b) $|A| = \dfrac{220/\sqrt{3}}{235/\sqrt{3}} = 0.9362$

$\left|1 + \frac{ZY}{2}\right| = \left|1 + \frac{(r + jx)l \times jyl}{2}\right| = 0.9362$

on solving then

$\boxed{l = 338\text{ km}}$

c) $|A| = \dfrac{220/\sqrt{3}}{250/\sqrt{3}} = 0.88$

$|A| = \left|1 + \left(50 + j\frac{160}{50} \times f\right) j\frac{1.12\times10^{-3} \times f}{50}\right| = 0.88$

on solving then; $\boxed{f = 57.9\text{ Hz}}$

3. A 50 Hz, three-phase 275 kV line of length 400 km has the following parameters:

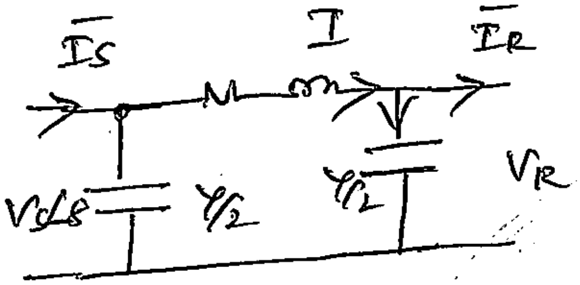
$$r = 0.035\ \Omega/\text{km};\ L = 1\ \text{mH/km};\ C = 0.01\ \mu\text{F/km}$$

The line is represented by the nominal-π model. With the magnitudes of the sending end and the receiving end voltages of the line (denoted by V_S and V_R, respectively) maintained at 275 kV, find the following.

(a) the phase angle difference (δ) between V_S and V_R required for maximum possible active power to be delivered to the receiving end, in degree.

(b) the active and reactive power that can be delivered to the receiving end under this condition.

$Z = (r + jx) \times l = 14 + j125.66\ \Omega$



$Y = j\omega C \times l = j0.0013\ \mho$ (jB)

$$\bar{I}_R = \bar{I} - \frac{\bar{V}_R \bar{Y}}{2}$$

$$\bar{I}_R = \left(\frac{V_S\angle\delta - V_R\angle 0^\circ}{Z}\right) - \frac{V_R\, jB}{2}$$

$$\bar{S}_R = \bar{V}_R \bar{I}_R^*$$

$$S_R = V_R\angle 0^\circ \left(\frac{V_S\angle\delta - V_R}{|Z|\angle\theta} - \frac{jV_R B}{2}\right)^*$$

$$P_R = \frac{V_R V_S}{Z}\cos(\theta - \delta) - \frac{V_R^2}{|Z|}\cos\theta \quad \text{①}$$

$$Q_R = \frac{V_R V_S}{Z}\sin(\theta - \delta) - \frac{V_R^2}{2}\sin\theta + \frac{V_R^2 B}{2} \quad \text{②}$$

① $\Rightarrow$ $\dfrac{dP_R}{d\delta} = 0$ $\quad \boxed{\theta = \delta}$ $\quad \boxed{\therefore\ \delta = 83.64^\circ}$

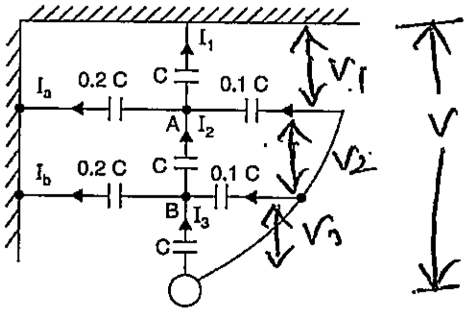
From ① and ②

$P_{R\,(phase)} = 177.29$ MW

$Q_{R\,(phase)} = -182.30$ MVAr

③ $\boxed{\begin{aligned} P_{R\,3\phi} &= 531.88\ \text{MW} \\ Q_{R\,3\phi} &= -546.91\ \text{MVAr} \end{aligned}}$

4. Consider the following suspension insulator with guard ring.



(a) Determine the voltage across each disc of suspension insulators as a percentage of line voltage to earth.

(b) Determine the string efficiency.

By KCL at (A).

$V_1 j\omega C + V_1 j0.2\omega C = V_2 j\omega C + (V - V_1) j0.1\omega C$

$1.3 V_1 - V_2 = 0.1V$ — (1)

By KCL at (B)

$V_3 j\omega C + (V - V_1 - V_2) j0.1\omega C = V_2 j\omega C + (V_1 + V_2) j0.2\omega C$

$1.3 V_1 + 2.3 V_2 = 1.1 V$ — (2)

On solving (1) and (2),

$V_1 = 0.31 V$

$V_2 = 0.303 V$

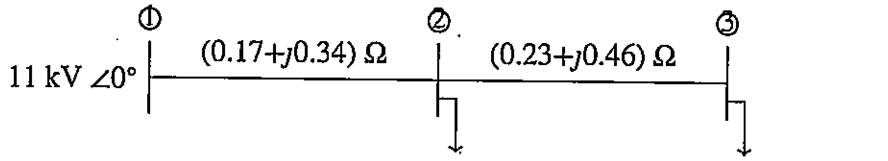
$V_3 = V - V_1 - V_2 = 0.387 V$

$\boxed{V_1 = 31 \% \text{ of } V \quad V_2 = 30.3 \% \text{ of } V \quad V_3 = 38.7 \% \text{ of } V}$

% String efficiency $= \dfrac{1}{3 \times 0.387} \times 100$

$= \boxed{86.13 \%}$

5. Determine the real power loss of the following three phase radial distribution system. Perform two iterations of the backward and forward sweep algorithm to find the voltages and currents.



S_2=(1500 +j750) kVA S_3 = (900 +j450) kVA

$S_{2\,\text{Phase}} = (500 + j250)$ kVA

$S_{3\,\text{Phase}} = (300 + j150)$ kVA

$V_s/\text{phase} = \dfrac{11 \times 10^3}{\sqrt{3}}$

I iteration

$V_2 = \dfrac{11}{\sqrt{3}} \angle 0^\circ$; $V_3 = \dfrac{11}{\sqrt{3}} \angle 0^\circ$

Back word:

$I_{L2} = 78.73 - j39.36$ A

$I_{L3} = 47.23 - j23.62$ A

$I_{12} = I_{L2} + I_{L3} = (125.97 - j63.98)$

Forward:

$V_2 = V_s - I_{12} \times (0.17 + j0.34)$

$V_2 = 6308 - j32$ V

$V_3 = 6286.3 - j48$ V

II iteration

Back word

$I_{L3} = 47.56 - j24.23$ A

$I_{L2} = 79.06 - j40.03$

$I_{12} = I_{L3} + I_{L2} = (126.6 - j64.26)$ A

Forward voltage calculation is not needed to find the losses.

$P_{Loss} = I_{12}^2 \times 0.17 + I_{L3}^2 \times 0.23$

$= 4.08$ KW (phase)

$\boxed{P_{Loss\,(3\phi)} = 12.24 \text{ KW}}$