

University of Saskatchewan
College of Engineering
EE 342: Power Systems I
Midterm Examination
A one formula sheet is allowed

Instructor: S.O. Faried
Duration: 90 minutes

November 3, 2004

1. Each conductor of the bundled-conductor line shown in Fig.1 is ACSR Bobolink (outside diameter = 1.427 inch, GMR = 0.047 ft). Find the 60-Hz inductive reactance and capacitive susceptance in ohms per km and siemens per km per phase, respectively. The spacing between the conductors of the bundle is 0.3 m.

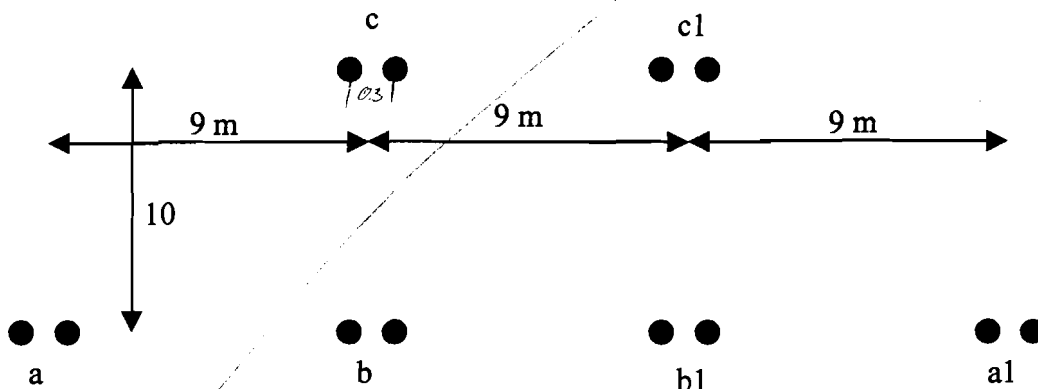


Fig. 1.

2. Draw the one line reactance diagram for the power system shown in Fig. 1. Select 500 MVA base and 20 kV base at Generator 3.

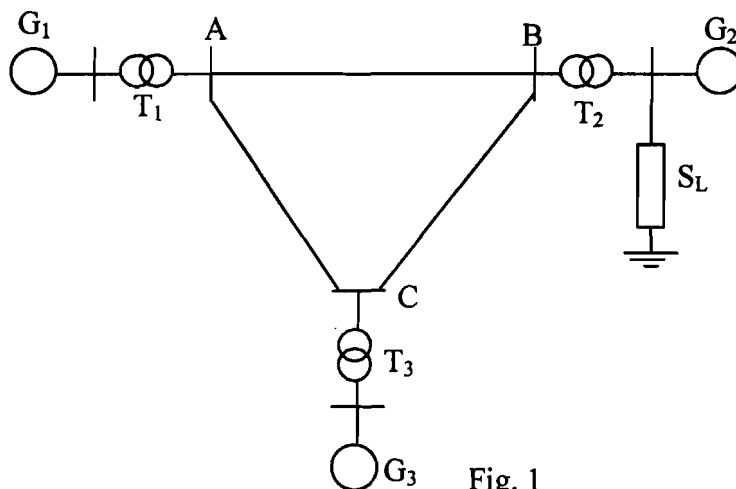


Fig. 1

$G_1, 400 \text{ MVA}, 26 \text{ kV}, x = 0.8 \text{ p.u.}$
 $G_2, 600 \text{ MVA}, 13 \text{ kV}, x = 0.8 \text{ p.u.}$
 $G_3, 500 \text{ MVA}, 18 \text{ kV}, x = 1.0 \text{ p.u.}$
 $T_1, 400 \text{ MVA}, 26/500 \text{ kV}, x = 0.1 \text{ p.u.}$
 $T_2, 700 \text{ MVA}, 13/500 \text{ kV}, x = 0.1 \text{ p.u.}$
 $T_3, 600 \text{ MVA}, 18/500 \text{ kV}, x = 0.1 \text{ p.u.}$
 $T.L_{AB}, x = j50 \Omega$
 $T.L_{BC}, x = j40 \Omega$
 $T.L_{AC}, x = j60 \Omega$
 $S_L, 0.05 + j0.2 \Omega$

- ~~2.~~ A three-phase 60-Hz, ^{L-L} 765 kV, 300 km transmission line has the following impedance and admittance:
- $z = 0.0165 + j 0.3306 \Omega/\text{km}$
 $y = j4.674 \mu\text{S}/\text{km}$
- ~~(a)~~ what is the surge impedance loading of this line?
~~(b)~~ If the line delivers 2000 MW at 765 kV and 0.8 p.f. lagging find the sending end voltage, the sending end current and the line efficiency.



problem #1

Inductance

$$L_{\text{phase}} = 2 \times 10^{-7} \ln \frac{D_{\text{eq}}}{D_s}$$

$$D_{\text{eq}} = \sqrt[3]{D_{ab} D_{bc} D_{ca}}$$

$$D_{ab} = \sqrt[4]{D_{ab} D_{ab1} D_{ab2} D_{ab3}} = \sqrt[4]{(9\text{m})(8\text{m})(18\text{m})(9\text{m})} = 12.73\text{m}$$

$$D_{bc} = \sqrt[4]{D_{bc} D_{bc1} D_{bc2} D_{bc3}} = \sqrt[4]{(10\text{m})(13.45\text{m})(13.45\text{m})(10\text{m})} = 11.60\text{m}$$

$$D_{ca} = \sqrt[4]{D_{ca} D_{ca1} D_{ca2} D_{ca3}} = \sqrt[4]{(13.45\text{m})(20.59\text{m})(20.59\text{m})(13.45\text{m})} = 16.64\text{m}$$

$$D_{\text{eq}} = \sqrt[3]{(12.73\text{m})(11.60\text{m})(16.64\text{m})} = 13.49\text{m} \quad \checkmark$$

$$D_s = \sqrt[9]{D_{aa} D_{ab} D_{ac} D_{bb} D_{ba} D_{bc} D_{cc} D_{ca} D_{cb}}$$

$$\text{GMR} = 0.0475\text{ft} \Rightarrow 0.0143256\text{m}$$

$$D_{aa} = \sqrt{(0.0143256\text{m})(0.3\text{m})} = 0.06556\text{m}$$

$$D_{aa} = D_{bb} = D_{cc}$$

$$D_s = \sqrt[9]{(0.06556\text{m})^3 (9\text{m})(13.45\text{m})(9\text{m})(10\text{m})(13.45\text{m})(10\text{m})} = 1.953\text{m} \quad \times$$

$$L_{\text{phase}} = 2 \times 10^{-7} \ln \left(\frac{13.49\text{m}}{1.953\text{m}} \right) = 3.865 \times 10^{-7} \frac{\text{H}}{\text{m}} = 0.3865 \frac{\text{mH}}{\text{km}}$$

$$Z_{\text{ph}} = L_{\text{phase}} 2\pi f = \left(\frac{0.3865\text{mH}}{\text{km}} \right) 2\pi(60)$$

$$Z_{\text{ph}} = 0.1457 \Omega/\text{km}$$

Capacitance

$$C = \frac{2\pi\epsilon_0}{\ln \frac{D_{\text{eq}}}{D_s}} = \frac{2\pi(8.854 \times 10^{-12} \text{F/m})}{\ln(13.49\text{m}/1.953\text{m})} = 28.786 \times 10^{-12} \frac{\text{F}}{\text{m}}$$

$$C = 28.786 \times 10^{-9} \text{F}/\text{km}$$

$$Y_{\text{ph}} = 2\pi f C = 2\pi(60)(28.786 \times 10^{-9} \text{F}/\text{km}) = 10.85 \times 10^{-6} \text{S}/\text{km}$$

Problem #1

$$D_{SL} = \sqrt[3]{D_{sa} D_{sb} D_{sc}}$$

$$D_{sbundle} = \sqrt{0.3 * 0.0143296} = 0.06556m$$

$$D_{sa} = \sqrt{D_{sbundle} (2.7)} = 1.3304m$$

$$D_{sb} = D_{sc} = \sqrt{D_{sbundle} (9)} = 0.7684m$$

$$D_{SL} =$$

$$L = 5.3655 \times 10^{-7} H/m$$

$$X_L = 0.2023 \text{ km}$$

$$D_{SO} = \sqrt[3]{D_{sa} D_{sb} D_{sc}}$$

$$D_{sbundle} = \sqrt{(0.3) \frac{1.427}{2} * \frac{2.54}{100}} = 0.0737m$$

$$D_{sa} = \sqrt{(0.0737m) (2.7)} = 1.411m$$

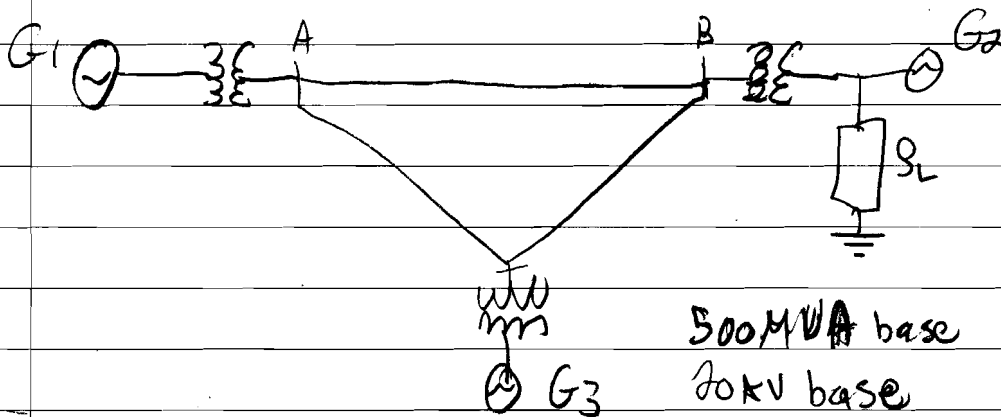
$$D_{sb} = D_{sc} = \sqrt{(0.0737m) (9m)} = 0.8144$$

$$D_{sc} = 0.9781m$$

$$C = 2.1188 \times 10^{-11} F/m$$

$$Y = 7.9879 \times 10^{-6} \text{ s/km}^2$$

Problem #2



At ptc

$$V_{base(A)} \Rightarrow \frac{20 \text{ kV base}}{18 \text{ kV}} = \frac{V_{base(C)}}{500 \text{ kV}}$$

$$V_{base(C)} = 555.6 \text{ kV base}$$

$$Z_{base(C)} = \frac{(kV_{b-l-l})^2}{MVA_b} = \frac{(555.6 \text{ kV})^2}{500 \text{ MVA}} = j617.28 \Omega$$

$$Z_{p.u.}(AB) = \frac{j50 \Omega}{j617.28 \Omega} = j0.081 \text{ p.u.}$$

$$Z_{p.u.}(BC) = \frac{j40 \Omega}{j617.28 \Omega} = j0.0648 \text{ p.u.}$$

$$Z_{p.u.}(CA) = \frac{j60 \Omega}{j617.28 \Omega} = j0.0972 \text{ p.u.}$$

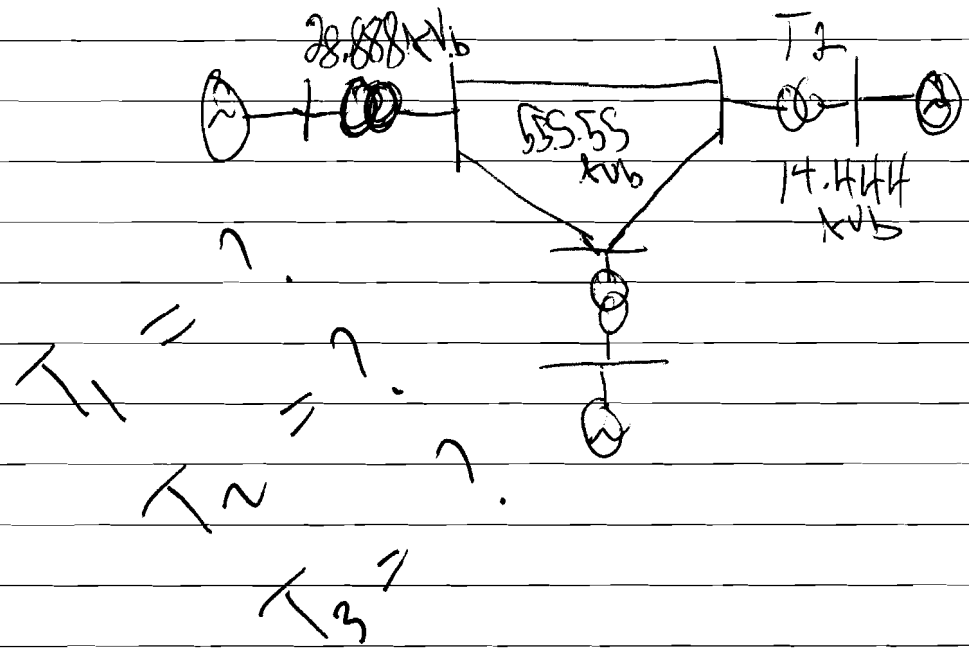
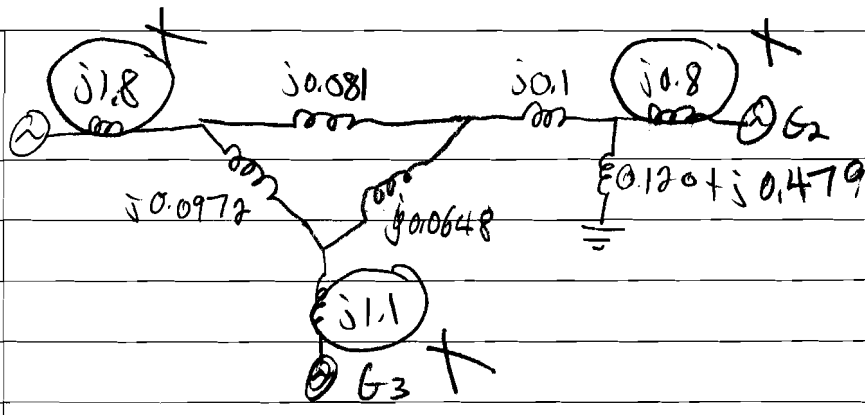
at Load

$$V_{base(Load)} \Rightarrow \frac{555.6 \text{ kV}}{500 \text{ kV}} = \frac{V_{base(Load)}}{13 \text{ kV}}$$

$$V_{base(Load)} = 14.4 \text{ kV}$$

$$Z_{base(Load)} = \frac{(kV_{b-l-l})^2}{MVA_b} = 0.4173 \Omega$$

$$S_{p.u.} = \frac{0.05 + j0.2 \Omega}{0.4173 \Omega} = \underline{0.120 + j0.479 \Omega}$$



$$X_{G1} = 50.8 \left(\frac{500}{400} \right) \left(\frac{26}{28.88} \right)^2 = j0.81 \text{ p.u.}$$

$$X_{G2} = 50.8 \left(\frac{500}{600} \right) \left(\frac{13}{14.44} \right)^2 = j0.34 \text{ p.u.}$$

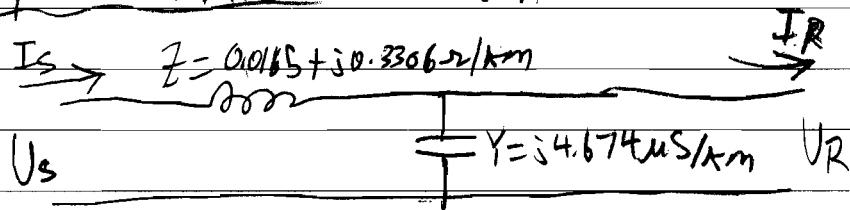
$$X_{G3} = 51 * \frac{500}{500} \left(\frac{18}{20} \right)^2 = j0.81 \text{ p.u.}$$

$$X_{T1} = 50.1 * \left(\frac{500}{400} \right) \left(\frac{26}{28.88} \right)^2 = j0.1425 \text{ p.u.}$$

$$X_{T2} = 50.1 * \left(\frac{500}{700} \right) \left(\frac{13}{14.44} \right)^2 = j0.0578 \text{ p.u.}$$

$$X_{T3} = 50.1 * \left(\frac{500}{600} \right) \left(\frac{18}{20} \right)^2 = j0.0675 \text{ p.u.}$$

Problem #3 300km 60Hz



$$a) SIL = \sqrt{3} |V_{L-L}| |I_L|$$

From part b we have $|V_{L-L}| = 947 kV$
 $I_L = 1477 A$

$$SIL = \sqrt{3} |977 \times 10^3| |1477|$$
$$SIL = 2499 MVA$$

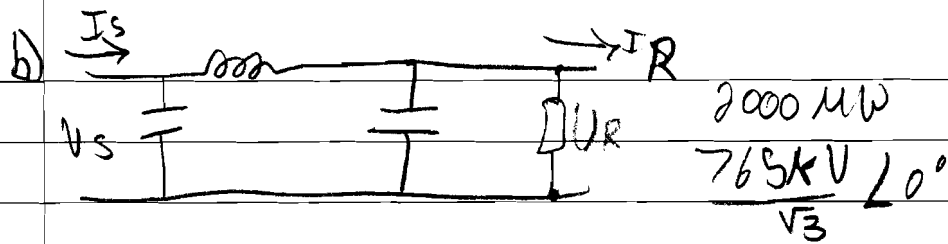
$$\sim SIL \sim 2500 MVA \quad \times$$
$$SIL \sim 2.5 GVA \quad \times$$

$$R_{load} = \sqrt{\frac{99.88 \Omega}{0.0014027}} = 265.9543 \Omega$$

$$I_{load} = \frac{765 kV}{\sqrt{3}} = 1660.71 A$$

$$SIL = 3 I_{load}^2 R_{load} = 2200.472 MW$$

300km, 3 long TX line



$$P_R = \sqrt{3} |V_R| |I_R| \cos \theta$$

$$I_R = \frac{2000 \text{ MW}}{\sqrt{3} (765 \times 10^3) (0.8)} = 1886.77 \angle -36.87^\circ$$

Find V_s , I_s and η .

$$Z_T = \frac{Z}{Y} = \frac{(0.0165 + j0.3306 \Omega/\text{km}) 300 \text{ km}}{(j4.574 \mu\text{S}/\text{km}) 300 \text{ km}} = 266.12 \angle -1.43^\circ$$

$$\gamma = \sqrt{ZY'} = \sqrt{(0.0165 + j0.3306 \Omega/\text{km}) 300 \text{ km} (j4.574 \mu\text{S}/\text{km}) 300 \text{ km}} = 0.3732 \angle 88.57^\circ$$

$$V_{sph} = \cosh \gamma V_{Rph} + Z_C \sinh \gamma I_R$$

$$= \cosh (0.3732 \angle 88.57^\circ) \left(\frac{765 \times 10^3}{\sqrt{3}} \angle 0^\circ \right) + (266.12 \angle -1.43^\circ) \sinh (0.3732 \angle 88.57^\circ) (1886.77 \angle -36.87^\circ)$$

$$V_{sph} = 547 \angle 15.09^\circ \text{ kV}$$

$$V_{sL-L} = V_{sph} (\sqrt{3}) = 947 \angle 15.09^\circ \text{ kV}$$

$$I_s = \sinh \gamma / Z_C V_{Rph} + \cosh \gamma I_R$$

$$= \frac{\sinh (0.3732 \angle 88.57^\circ)}{266.12 \angle -1.43^\circ} \left(\frac{765 \times 10^3}{\sqrt{3}} \angle 0^\circ \right) + \cosh (0.3732 \angle 88.57^\circ) (1886.77 \angle -36.87^\circ)$$

$$I_s = 1477 \angle -17.5^\circ$$

$$P_s = \sqrt{3} |V_s| |I_s| \cos \theta = \sqrt{3} |947 \times 10^3| |1477| \cos (15.09^\circ - (-17.5^\circ))$$

$$P_s = 2041.2 \text{ MW}$$

$$\eta = \frac{P_R}{P_s} \times 100 = \frac{2000 \text{ MW}}{2041.2 \text{ MW}} = 97.98\%$$