University of Saskatchewan
College of Engineering

EE 342: Power Systems I
Midterm Examination
A one formula sheet is allowed

Instructor: S.O. Faried **November 3, 2004**
Duration: 90 minutes

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.

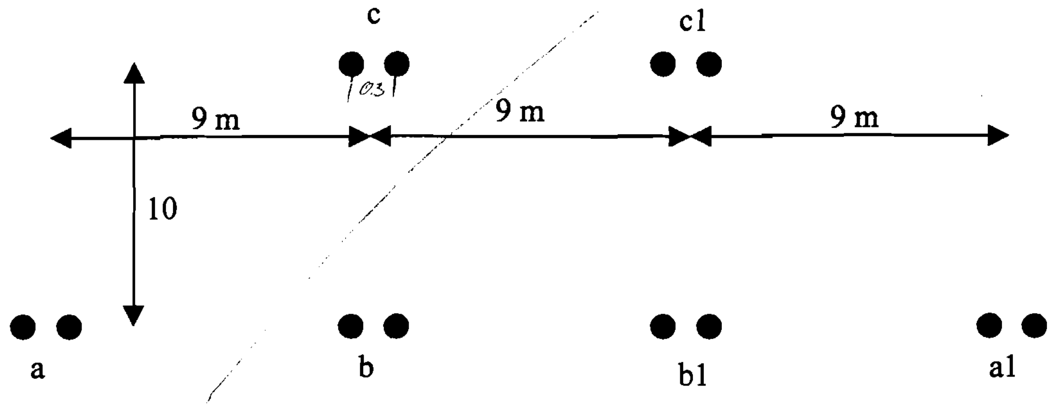


Fig. 1.

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.

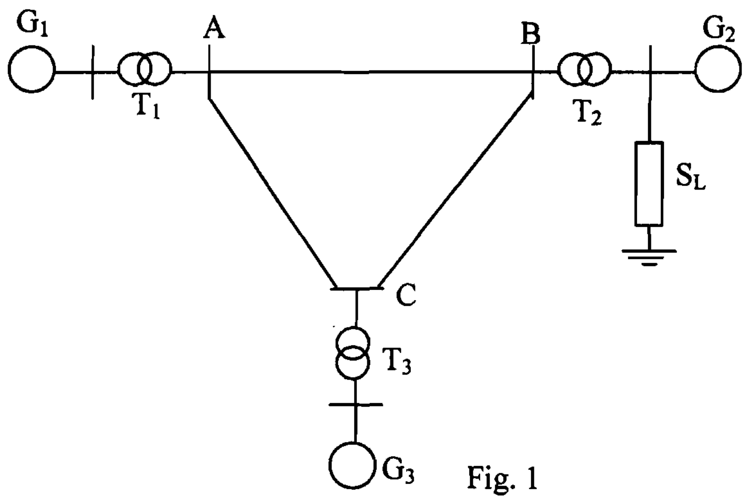


Fig. 1

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

L-L

2. A three-phase 60-Hz , 765 kV, 300 km transmission line has the following impedance and admittance:

$z = 0.0165 + j\ 0.3306\ \Omega/km$

$y = j4.674\ \mu S/km$

(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

$$L_{phase} = 2\times10^{-7} \ln \frac{D_{eq}}{D_s}$$

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

$$D_{ab} = \sqrt[4]{D_{ab} D_{ab_1} D_{a_1b} D_{a_1b_1}} = \sqrt[4]{(9m)(8m)(18m)(9m)} = 12.73m$$

$$D_{bc} = \sqrt[4]{D_{bc} D_{bc_1} D_{b_1c} D_{b_1c_1}} = \sqrt[4]{(10m)(13.45m)(13.45m)(10m)} = 11.60m$$

$$D_{ca} = \sqrt[4]{D_{ca} D_{ca_1} D_{c_1a} D_{c_1a_1}} = \sqrt[4]{(13.45m)(20.59m)(20.59m)(13.45m)} = 16.64m$$

$$D_{eq} = \sqrt[3]{(12.73m)(11.6m)(16.64m)} = 13.49m$$

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

$GMR = 0.047ft \Rightarrow 0.0143256m$

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

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

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

$$\therefore L_{phase} = 2\times10^{-7} \ln\left(\frac{13.49m}{1.953m}\right) = 3.865\times10^{-7}\frac{H}{m} = 0.3865\frac{mH}{km}$$

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

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

Capacitance

$$C = \frac{2\pi\epsilon_0}{\ln\frac{D_{eq}}{D_s}} = \frac{2\pi(8.854\times10^{-12}\ F/m)}{\ln(13.49m/1.953m)} = 28.786\times10^{-12}\frac{F}{m}$$

$$C = 28.786\times10^{-9}\ F/km$$

$$Y_{ph} = 2\pi f C = 2\pi(60)(28.786\times10^{-9}\ F/km) = \boxed{10.85\times10^{-6}\ S/km}$$

Problem #1

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

$D_{s\,bundle} = \sqrt{0.3 * 0.0143256} = 0.06556\,m$

$D_{sa} = \sqrt{D_{s\,bundle}(27)} = 1.3304\,m$

$D_{sb} = D_{sc} = \sqrt{D_{s\,bundle}(9)} = 0.7684\,m$

$D_{SL} =$

$L = 8.3655 \times 10^{-7}\,H/m$

$X_L = 0.2073\,\Omega/km$

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

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

$D_{sa} = \sqrt{(0.0737\,m)(27)} = 1.411\,m$

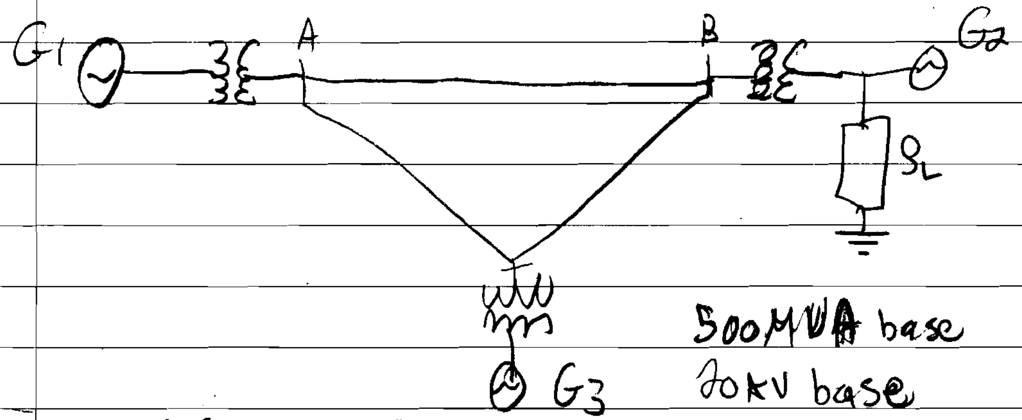
$D_{sb} = D_{sc} = \sqrt{(0.0737\,m)(9\,m)} = 0.8144$

$D_{sc} = 0.9781\,m$

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

$Y = 7.9879 \times 10^{-6}\,\mho/km$

Problem #2



500 MVA base
20 kV base

At pt C

$V_{base(C)} \Rightarrow \dfrac{20 kV_{base}}{18 kV} = \dfrac{V_{base}(C)}{500 kV}$

$V_{base(C)} = 555.6 kV_{base}$

$\therefore Z_{base}(C) = \dfrac{(kV_{bL-L})^2}{MVA_b} = \dfrac{(555.6 kV)^2}{500 MVA} = j617.28\ \Omega$

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

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

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

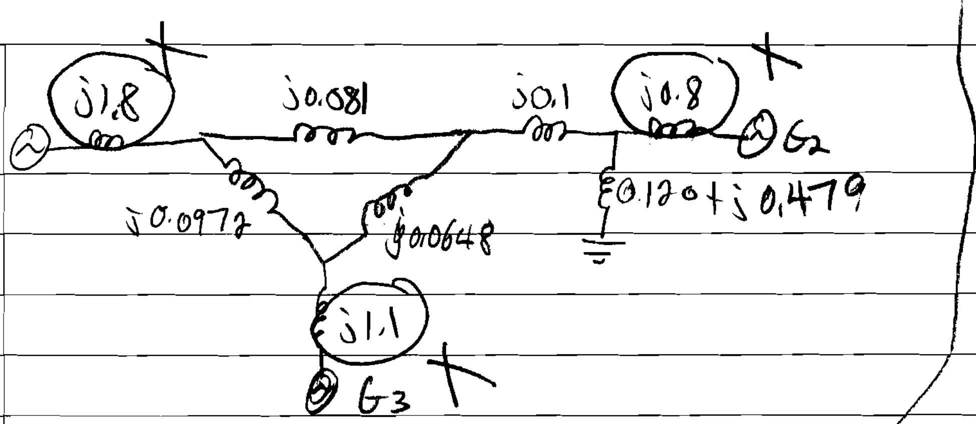
at Load

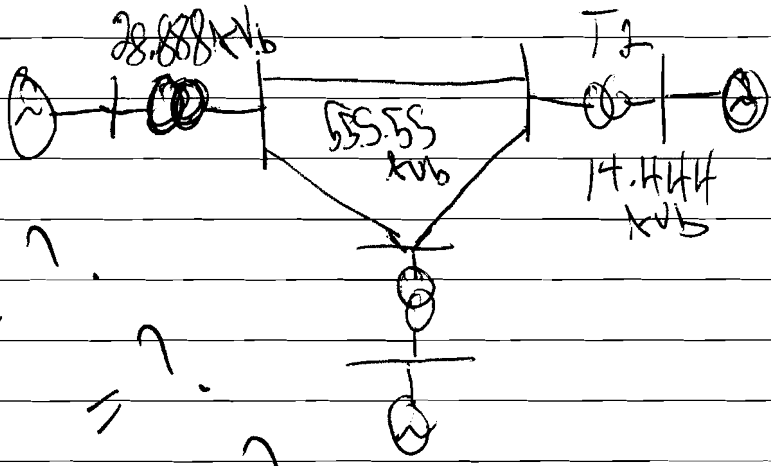
$V_{base}(Load) \Rightarrow \dfrac{555.6 kV}{500 kV} = \dfrac{V_{base}(load)}{13 kV}$

$V_{base}(load) = 14.4 kV$

$Z_{base}(load) = \dfrac{(kV_{bL-L})^2}{MVA_b} = 0.4173\ \Omega$

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





$T_1 = ?$

$T_2 = ?$

$T_3 = ?$

$$X_{g_1} = j0.8\left(\frac{500}{400}\right)\left(\frac{26}{28.88}\right)^2 = j\,0.81\,p.u.$$

$$X_{g_2} = j0.8\left(\frac{500}{600}\right)\left(\frac{13}{14.44}\right)^2 = j0.54\,p.u.$$

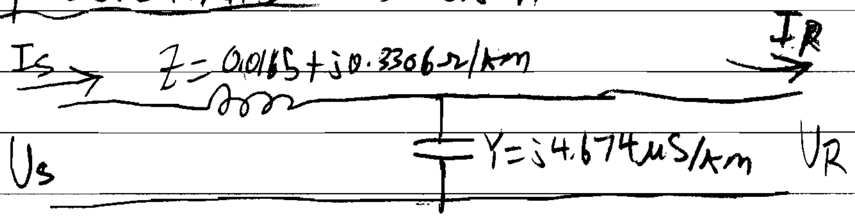
$$X_{g_3} = j1 * \frac{500}{500}\left(\frac{18}{20}\right)^2 = j\,0.81\,p.u.$$

$$X_{T_1} = j0.1 * \left(\frac{500}{400}\right)\left(\frac{26}{28.88}\right)^2 = j\,0.1025\,p.u.$$

$$X_{T_2} = j0.1 * \left(\frac{500}{700}\right)\left(\frac{13}{14.44}\right)^2 = j0.0578\,p.u.$$

$$X_{T_3} = j0.1 * \left(\frac{500}{600}\right)\left(\frac{18}{20}\right)^2 = j0.0675\,p.u.$$

Problem #3 300km 60Hz



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

From part b we have $|V_{L-L}| = 947\,kV$

$I_L = 1477\,A$

$\therefore SIL = \sqrt{3}\,|977\times10^3|\,|1477|$

$SIL = 2499\,MVA$

$\sim \boxed{SIL \sim 2500\,MVA}$ ✗

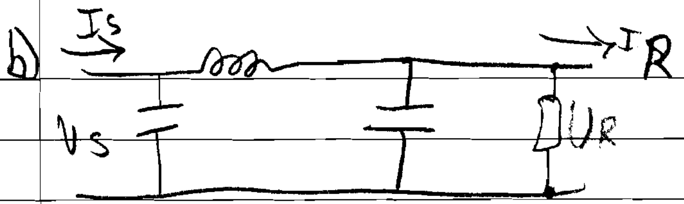
$\boxed{SIL \sim 2.5\,GVA}$ ✗

$R_{load} = \sqrt{\dfrac{99.18\,\Omega}{0.0014027}} = 265.9543\,\Omega$

$I_{load} = \dfrac{765\times10^3}{\sqrt{3}} = 1660.71\,A$

$SIL = 3\,I_{load}^2\,R_{load} = \boxed{2200.472\,MW}$ (with 265.9543 written above R_{load})

300km, 3 long Tx line

b) 

2000 MW

$\frac{765kV}{\sqrt{3}} \angle 0°$

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

$I_R = \frac{2000MW}{\sqrt{3}(765\times10^3)(0.8)} = 1886.77 \angle -36.87°$

Find V_S I_S and line η.

$Z_C = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{(0.0165 + j0.3306\Omega/km)\,300km}{(j4.674\,\mu S/km)\,300km}} = 266.12 \angle -1.43°$

$\gamma = \sqrt{ZY} = \sqrt{(0.0165 + j0.3306\Omega/km)(300km)(j4.674\,\mu S/km)300km}$

$= 0.3732 \angle 88.57$

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

$= \cosh(0.3732\angle 88.57)\left(\frac{765\times10^3}{\sqrt{3}}\angle 0°\right) + (266.12\angle -1.43°)\sinh(0.3732\angle 88.57)(1886.77\angle -36.87°)$

$V_{sph} = 547 \angle 15.09°\ kV$

$V_{SL-L} = V_{sph}(\sqrt{3}) = \boxed{947 \angle 15.09\ kV}$

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

$= \frac{\sinh(0.3732\angle 88.57°)}{(266.12\angle -1.43°)}\left(\frac{765\times10^3\angle 0°}{\sqrt{3}}\right) + \cosh(0.3732\angle 88.57)(1886.77\angle -36.87°)$

$\boxed{I_S = 1477 \angle -17.5°}$

$P_S = \sqrt{3}|V_L||I_L|\cos\theta = \sqrt{3}\,|947\times10^3|\,|1477|\cos(15.09° - (-17.5°))$

$P_S = 2041.2\ MW$

$\eta = \frac{P_R}{P_S}\times100 = \frac{2000MW}{2041.2MW} = \boxed{97.98\%}$