S. KARAKI AMERICAN UNIVERSITY OF BEIRUT FALL 2005/2006

FACULTY OF ENGINEERING AND ARCHITECTURE

MIDTERM

FUNDAMENTALS OF POWER SYSTEMS ANALYSIS
(EECE 471)

CLOSED BOOK (90 MINUTES) **NOVEMBER 14, 2005**

PROGRAMMABLE CALCULATORS ARE NOT ALLOWED

THIS QUESTION SHEET MUST BE RETURNED WITH THE ANSWER BOOKLET.

NAME: ______________________ **ID#:** ______________________

1. Answer the following questions in the space provided for each on this question sheet:

a) Label the various components of the power station schematic shown in Fig.1 below and give it a specific caption next to the figure number.

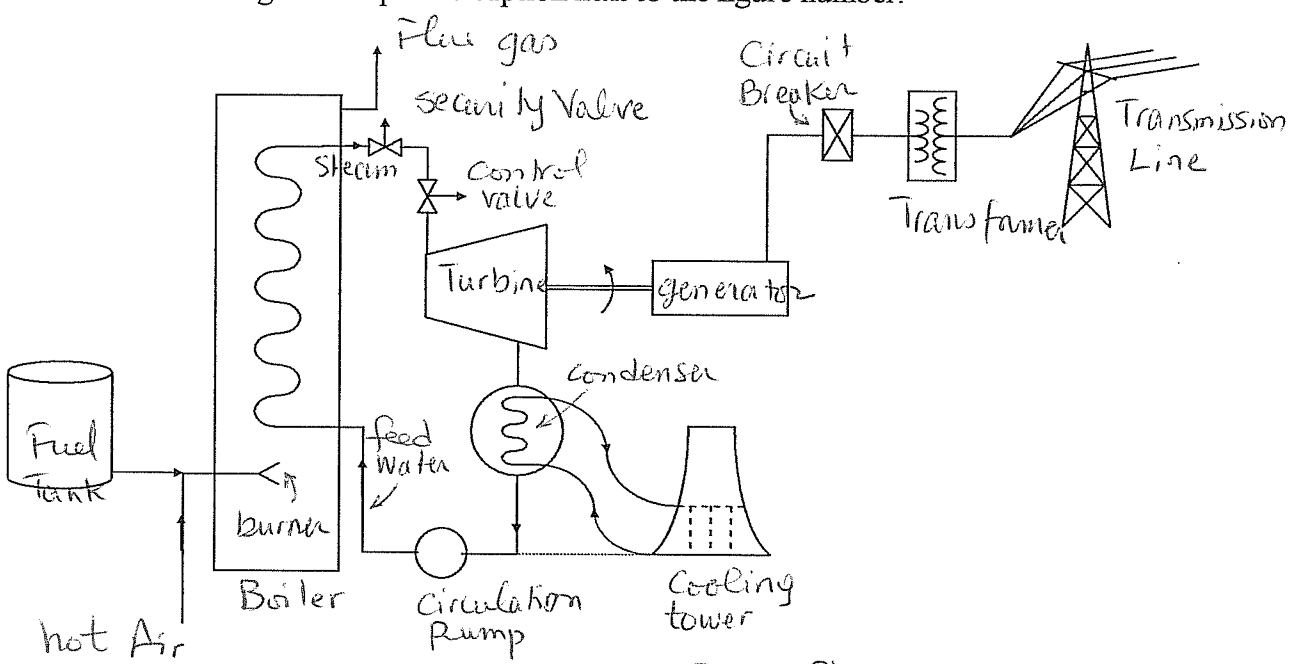


Fig.1: Oil-fired Steam Power Plant

b) What is the most efficient thermal power generation technology used throughout the world nowadays and what is its approximate efficiency?

Combined Cycle power plant; efficiency is about 50%

c) Name two environmental problems associated with fossil-fuel power plants and indicate ways of mitigating them?

Emission of Carbon dioxide and Sulfur Oxides. The first is a green-house gas while the second is associated with acid rain. CO_2 can be neutralized by planting tree and SO, SO_2 effect are reduced by desulfurization of fuel or by transforming them into Sulfur.

d) Name a renewable energy technology that you believe is most likely to be used and explain the reasons?

1000 $/kW

Wind energy: technology is mature and economic and can be used when available. Solar photovoltaic energy could be used ~~wherever available but its cost is still high ($4000/kW)~~.

e) Why do we raise the voltage to transmit a given amount of power over a long distance?

Over a long distance R is high and I^2R (losses) are high if I is high. "I" is reduced by raising V since P=VI (@unity Power factor).

2. It is required to design a transmission line of 200 mile length to supply a demand of 300 MW at 0.9 PF lagging considering one of two voltages 220 and 400 kV at a frequency of 50Hz with typical phase-to-phase spacing of 8 m and 12 m, respectively. Note that 1 kcmil= 0.507mm^2 and 1 ft= 0.305 m.

a) Considering that characteristic impedances of lines vary within a narrow range around 300Ω, calculate the surge impedance loading (P/P_{SIL}) at both voltage levels. Refer to Fig. 2 below and deduce the more economic voltage that would maintain a stability margin such that the phase angle from sending to receiving is smaller than or equal to 45°.

b) From Table 1 shown below select the most appropriate conductor size at the selected voltage if the current density is not to exceed 2.5 A/mm^2 at the given load conditions and the prevailing 35°C ambient temperature. Consider using bundled conductors in your design and select the appropriate number of bundles in your conductor.

c) Calculate the resistance, inductance and capacitance for the line design and determine its actual characteristic impedance and its surge impedance loading at the selected voltage level.

d) If at minimum load conditions, the demand drops to about 40% of its peak value, estimate the voltage at the sending end under such conditions. Having reached so far in your design, are you still confident that you have made the correct voltage choice? Explain.

Table 1: Main Properties of Selected ACSR Bare Wires

Name	Size (kcmil)	Resistance at 60Hz (Ω/mile)	GMR (ft)
Partridge	266.8	0.411	0.0217
Linnet	336.4	0.327	0.0244
Ibis	397.5	0.277	0.0265
Hawk	477.0	0.231	0.0290
Dove	556.5	0.198	0.0313
Grosbeak	636.0	0.173	0.0335
Drake	795.0	0.139	0.0375

2.

(a)

	220 kV	400 kV	
$P_{SIL} = \frac{V^2}{Z_c}$	161.3	533	MW
$\frac{P}{P_{SIL}} = \frac{300}{P_{SIL}}$	1.86	0.56	

At 200 miles $\frac{P}{P_{SIL}} \leq 1.75$ as obtained from curve,

from stability point of view we should select the

However, the 220 kV is fairly close and should not be rejected outright.

b)

The current required is given by:

$$|I| = \frac{300}{\sqrt{3}\, 400 \times 0.9} = 0.48 \text{ kA / phase}$$

at 400 kV 4-bundles are normally used (to minimi corona losses) so

$$A = \frac{0.48 \times 10^3}{4 \times 2.5 \times 0.507} \simeq 95 \text{ kcmil.}$$

This is smaller than Partridge (266.8 kcmil), So 4 partridge conductors will be used per phase.

At 220 kV $|I| = 0.875$ kA

with 4 bundles: $A = 173$ kcmil $\Rightarrow$ Also use Partridge

2 bundles: $A = 346$ kcmil $\Rightarrow$ Use Ibis

c) At 400 kV

$$R = 0.411 \times 200 \times \frac{1}{4} = \frac{82.2}{4} = 20.6\,\Omega$$

$$X_L = \underbrace{2\pi \times 50}_{\omega} \times \underbrace{\ln\left(\frac{12 \times (0.305)^{-1}}{\sqrt[4]{0.0217\sqrt{2}}}\right) \times 2\times10^{-7}}_{H/m} \times \overset{L}{\underbrace{200 \times 1.604 \times 10}_{l \text{ in } m}}$$

0.4185

$$\therefore X_L = 2\pi.50 \times 4.543 \times \underbrace{200 \times 1.604}_{Km} \times 10^{+3} \times 2\times10^{-7}$$

$$= \underset{\Omega/km}{0.2855} \times \underset{Km}{321} = 91.65\,\Omega$$

μH
0.91 mH
$l = 9.1 \times 10^{-7}$
$L = 0.292$

$$Y_C = \left(\frac{1}{\omega C}\right)^{-1} = \left(\frac{\ln(D/R_b^c)}{\omega\, 2\pi\varepsilon}\right)^{-1} \times L$$

$$R_b^c = \sqrt[4]{\frac{0.0217}{0.78} \times \sqrt{2} \times 1 \times 1} = 0.445\text{ ft} = 0.136\text{ m}$$

$\boxed{r \simeq 0.028\text{ ft} = 0.0085\text{ m}}$

$$\ln(D/R_b^c) = \ln\left(\frac{12/0.305}{0.445}\right) = 4.482$$

$$\therefore Y_c = \frac{100\pi \times 2\pi \times 8.854\times10^{-12}}{4.482} \times 200 \times 1.604 \times 10^{3}$$

$$= 100\pi \times \underbrace{12.4\times10^{-9}}_{\substack{C \\ nF/km}} \times 321 = 1250\,\mu S = 1.250\times10^{-3}$$

$C = 12.4 \times 10^{-12}$
$y_c = 3.9 \times 10^{-9}$ S/m
3900 pS/m
$c = 3.98\,\mu F$

At 220 kV:

$$R = 20.6\,\Omega$$

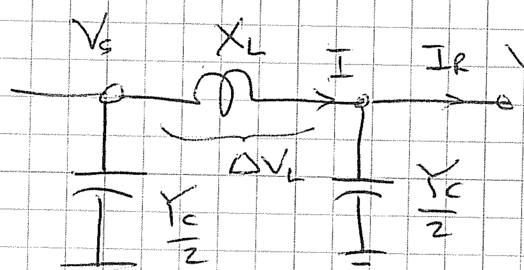
$$X_L = 0.260 \times 321 = 83.5\,\Omega$$

$$Y_c = 100\pi \times 13.6 \times 10^{-9} \times 321 = 1371\,\mu S$$

	at 400k	220kV
$Z_c\ (\Omega)$ $\sqrt{\frac{X_L}{Y_c}}$	271	247
P_{SIL}	590	196
P/P_{SIL}	0.51	1.53

which is smaller than 1.75 at 220kV. Therefo
the correct voltage choice should be __220kV__

d) The voltage at the sending end can be estimated using the following equivalent Circuit



$V_S = V_R + \Delta V_L = V_R + j X_L \big(\underbrace{I_R + j}_{I}$

At 400 kV

$$0.48 + j\,0.144$$

At full load $V_S = \frac{400}{\sqrt{3}} + j\ 91.65 \times \left(0.48 \pm j\ \frac{1250 \times 10^{-6}}{2} \times \frac{400}{\sqrt{3}}\right)$

$$= 218 + j\,44 = 222\ \angle 11.4^\circ$$

$$|V_s^{ll}| = 222 \times \sqrt{3} = 385\ \text{kV} = 0.961\ \text{p.u.}$$

At 40% load $V_s = 218 + j\,17.6 = 219\ \angle 4.62 \quad |V_s^{ll}| = 379\ \text{kV} = 0.95$

At 220 kV

at full load

$$V_s = \frac{220}{\sqrt{3}} + j83.5 \times \left(\overset{0.875 + j0.0871}{0.875 + j \frac{1371}{2} \times 10^{-6} \times \frac{220}{\sqrt{3}}} \right)$$

$$= 119.7 + j73.1 \text{ kV} = 140 \angle 31.4^\circ =$$

$$|V_s^{ll}| = 242.5 \text{ kV} = 1.102 \text{ p.u.}$$

At 40% load

$$V_s = \frac{220}{\sqrt{3}} + j83.5 \left(\overset{0.875 \times 0.4 + j0.0871}{0.875 \times 0.4 + j \frac{1371}{2} \times 10^{-6} \times \frac{220}{\sqrt{3}}} \right)$$

$$= 119.7 + j29.2 = 123 \angle 13.7^\circ \text{ kV}$$

$$|V_s^{ll}| = 213 \text{ kV} = 0.97 \text{ p.u.}$$

Discussion:

For a given voltage at the receiving end (1. pu) at 400 kV the sending end voltage is 0.96 p.u. causing a reactive power flow from the receiving to the sending end. At 40% the reactive flow (in the reverse direction $S \leftarrow R$) is even higher since $V_R = 0.95$ p.u.

At 220 kV and full load the voltage is 1.1 p.u. at the sending end indicating that the generator is likely to supply a large amount of reactive power. At 40% of full load the generator is likely to absorb reactive power but less than that at 400 kV.

3)

a) $S_B = 100\,\text{MVA}$

* $V_{B1} = 13.8\,\text{kV}$ on transformer primary. (generator side

$$Z_{B1} = \frac{V_{B1}^2}{S_B} = \frac{(13.8)^2}{100} = 1.904\,\Omega$$

$2.38\,\Omega$ at $S_B = 80\,\text{MVA}$

* $V_{B2} = 66\,\text{kV}$ on transformer secondary (transmission line side

$$Z_{B2} = \frac{V_B^2}{S_B} = \frac{(66)^2}{100} = 43.56\,\Omega$$

$54.45\,\Omega$ at $S_B = 80\,\text{MVA}$.

b) * Transformer:

$$X_\ell = \frac{0.8}{3} \times \frac{1}{1.904} = 0.14\ \text{p.u.}$$

$$X_m = \frac{25}{3} \times \frac{1}{1.904} = 4.38\ \text{p.u.}$$

* Line

$$Z_{line} = (j0.4 + 0.08) \times 100 \times \frac{1}{43.56} = \frac{8 + j40}{43.56} = 0.184 + j0.$$

at $S_B = 80\,\text{MVA}$: $= 0.147 + j0.7$

$$y_{line} = 4 \times 10^{-6} \times 100 \times 43.56 = 0.0174\ \text{p.u.}\ \left(\frac{0.0218}{2}\right.\ \text{a}$$

* Load

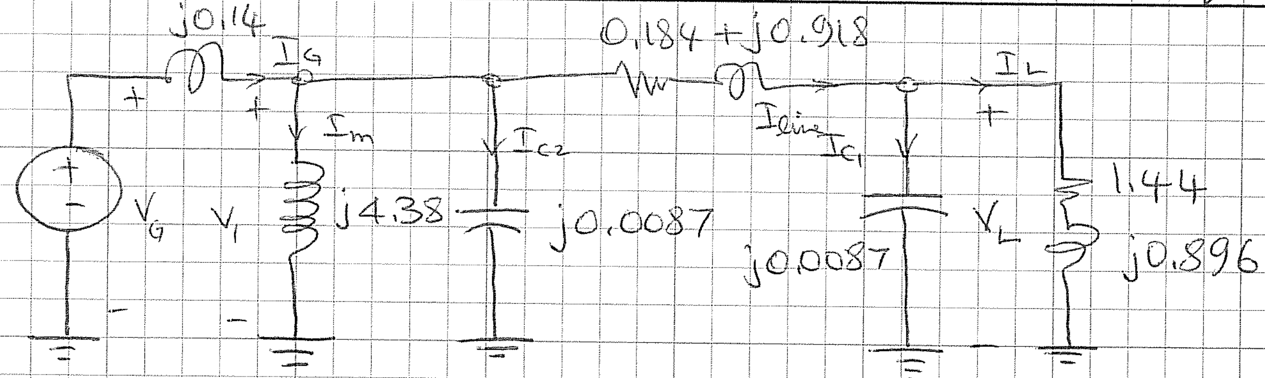
$$Z_{Load} = \frac{V^2}{S^*} = \frac{66^2}{50 - 31j} = 62.9 + j39\,\Omega$$

$$S = 50 + j\tan(\cos^{-1} 0.85)\, 50$$

$$= 50 + j31 \qquad (74\angle 31.8)$$

in per unit, $Z_{load} = \dfrac{62.9 + j39}{43.56} = 1.44 + j0.896$ p

at $S_B = 80\,\text{MVA}$: $1.16 + j0.716$ p.u.



c) $I_L = \dfrac{V_L}{Z_L} = \dfrac{1}{1.44 + j896} = 0.5 - j0.31$

$I_{line} = I_L + I_{c1} = I_L + jV_L \dfrac{Y_c}{2} = 0.5 - j0.31 + j0.0087$

$= 0.5 - j0.301$ p.u. ($S_B = 80$ MVA: $0.624 - j0.3$

$V_1 = V_L + Z_{line} I_{line} = 1 + (0.5 - j0.301)(0.184 + j0.9$

$= 1.368 + j0.404$

$I_G = I_{line} + I_m + I_{c2} = I_{line} + \dfrac{V_1}{jX_m} + jV_1 \dfrac{Y_c}{2}$

$= 0.5 - j0.301 + (1.368 + j0.404)\left(\dfrac{1}{j4.38} + j0.0087\right)$

$= (0.5 - j0.301) + (0.0887 - j0.3) = 0.59 - j0.$

$V_G = V_1 + I_G \times jX_l = 1.368 + j0.404 + (0.59 - j0.6)(j0.14$

$0.084 + j0.082$

$= 1.452 + j0.487$

$= 1.53 \angle 18.5°$

$P_G + jQ_G = V_G I_G^* = (1.452 + j0.487)(0.59 + j0.6) = 0.56 +$

d)

The active power sent by the generator is 0.56 whereas the power received by the load is 0.5, so the percent of transmission loss is: $\frac{0.56-0.5}{0.5} \times 100$

which is relatively high for transmission. A typical figure for transmission loss is 2-3%. The reactive power of load is j0.3, while the reactive power supplied by generator is j1.15 most of which lost in the transformer and transmission line reactance.

Thus the power factor of the generator is

$$\cos\left(\tan^{-1}\left(\frac{Q}{P}\right)\right) = \cos(64.2) = 0.435$$

which is too low. A typical PF of a generator is $0.85 \rightarrow 0.9$.

Furthermore, the voltage at the generator side 1.53 p.u. which 50% higher than the nominal value!

This is definitely a bad design, and the best means to rectify it is to raise the transmission voltage to a higher level, e.g. 220kV.