S. KARAKI AMERICAN UNIVERSITY OF BEIRUT FALL 2007/2008

FACULTY OF ENGINEERING AND ARCHITECTURE

MIDTERM EXAM

FUNDAMENTALS OF POWER SYSTEMS ANALYSIS
(EECE 471)

CLOSED BOOK (1.5 HOURS) **NOVEMBER 27, 2007**

NAME: ________________________ **ID#:** ________________________

1. It is required to design a transmission line of 250 km length to supply a demand of 350 MW at 0.95 PF lagging considering one of three voltages 132, 275 and 400 kV at a frequency of 50Hz with typical phase-to-phase spacing of 7, 10 m and 12 m, respectively. Note that 1 kcmil= 0.507mm^2 and 1 ft= 0.305 m. From previous experience we know that the characteristic impedances of lines at 132, 275, and 400 kV are approximately equal to 325, 300, and 275 Ω, respectively. The land survey indicated that we can build up to two towers side by side in the transmission corridor each capable of carrying two circuits. The generator is rated at 13 kV 400MVA with a rated power factor of 0.9 and the load has a rated voltage of 66kV.

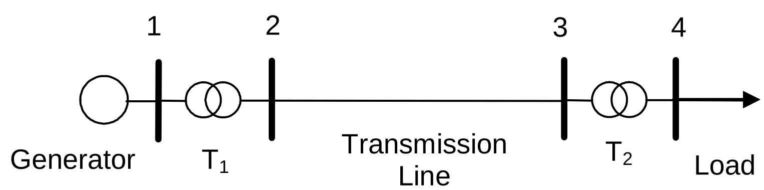

Fig. 1: Small power system for Problem 1

a) Calculate the surge impedance loading (P/P_{SIL}) at the given voltage levels and deduce a suitable voltage that would maintain a stability margin such that the phase angle from sending to receiving is smaller than or equal to 45° from the generator to the load. Deduce the number circuits that need to be built at the selected voltage so as to allow the transmission of the specified power after the first circuit is out. If more than one design is possible then select one and discuss what additional information you need to have confidence in your decision.

b) From the list of conductors appended to this document select the most appropriate conductor size at the selected voltage so that line losses for the selected conductor are not to exceed 2.5%. Consider using bundled conductors in your design and select the appropriate number of bundles in your conductor. Use a bundle distance of 1ft.

c) Calculate the resistance, inductance and capacitance for the line design and determine its total series impedance and shunt admittance. Also calculate the actual (based on the design) characteristic impedance and surge impedance loading. Having reached so far in your design, are you still confident that you have made the correct voltage choice?

d) Specify the transformers that you need to have in your design in terms of their MVA rating, connection, and impedance.

e) Select a system base of 100MVA and the rated generator voltage as a base voltage on the generator side. Model the load as an impedance and draw the per unit equivalent circuit showing all impedance values. Show the calculation details of some of your equivalent circuit parameters.

f) Calculate the ABCD constants of the overall transmission system and calculate the voltage regulation of the transmission line including the transformers.

g) Calculate the sending end voltage and the active and reactive power supplied by the generator. Comment on the results in as far as the voltage magnitude and phase, and the active and reactive powers delivered by the generator.

2. Answer the following questions with the maximum number of 50 words without using diagrams or equations. Just English sentences.

a) Discuss the issues that a planning engineer has to consider in selecting a conductor size when designing a transmission line.

b) Explain the main reasons for dividing the conductor into bundles.

c) Explain a practical situation in transmission operation in which you need to compensate using series capacitors. Where would you put the capacitors?

d) Explain a practical situation in transmission operation in which you need to compensate using shunt capacitors. Where would you put the capacitor?

Fundamentals of Power Systems Analysis
(EECE 471)
FORMULAE

- Ch.2: **Basic Principles**

$$Z_Y = \frac{Z_\Delta}{3}$$

- Ch.3: **Transmission-Line Parameters**

$$l = 2*10^{-7} \ln \frac{D}{R_b} \qquad H/m$$

D: geometric mean distance between phases
R_b: geometric mean radius of bundle

$$D = \sqrt[3]{D_{ab} D_{ac} D_{bc}} \qquad R_b = \sqrt[4]{r' d_{12} d_{13} d_{14}}$$

$$c = \frac{2\pi\varepsilon}{\ln \frac{D}{R_b^c}} \qquad \varepsilon = 8.854*10^{-12} \qquad F/m$$

$$R_b^c = \sqrt[4]{r \quad d_{12} d_{13} d_{14}}$$

- Ch.4: **Transmission Line Modeling**

  - $z = r + j\omega l \qquad \Omega / m \qquad\qquad y = j\omega c \qquad S/m$
  - $\gamma = \sqrt{yz} \qquad\qquad Z_c = \sqrt{\frac{z}{y}}$
  - $V_1 = V_2 \quad \cosh \gamma l + Z_c I_2 \quad \sinh \gamma l = AV_2 + BI_2$

    $I_1 = I_2 \quad \cosh \gamma l + \frac{V_2}{Z_c} \quad \sinh \gamma l = CV_2 + DI_2$
  - $A = D = 1 + \frac{ZY}{2} \qquad B = Z \qquad C = Y\left(1 + \frac{ZY}{4}\right)$

    $T = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$ and $T^{-1} = \begin{bmatrix} D & -B \\ -C & A \end{bmatrix}$
  - Complex Power Flow on Medium Line:

    $$S_{12} = \frac{Y^*}{2} \quad |V_1|^2 + \frac{|V_1|^2}{Z^*} - \frac{|V_1||V_2|}{Z^*} e^{j\theta_{12}}$$

    For S_{21} exchange indices 1 and 2 in above equation
  - Power Flow on a short loss-less line:

    $$P_{12} = -P_{21} = \frac{|V_1||V_2|}{X} \sin \theta_{12} \qquad Z = z \times l = R + jX$$

$$Q_{12} = \frac{|V_1|^2}{X} - \frac{|V_1||V_2|}{X}\cos\theta_{12} \qquad Y = y \times l$$

$$Q_{21} = \frac{|V_2|^2}{X} - \frac{|V_1||V_2|}{X}\cos\theta_{12} \qquad l\text{: length of line}$$

- Power transmission capability:

$$P_{12} = V_{1pu}V_{2pu}\frac{|V_R|^2}{Z_c}\frac{\sin\theta_{12}}{\sin\beta l} = V_{1pu}V_{2pu}P_{SIL}\frac{\sin\theta_{12}}{\sin\beta l}$$

$$\beta = \text{Im}(\gamma) \cong \frac{2\pi}{\lambda}$$

- ∗Ch.5: **Transformers and the Per-Unit System**

$$V_{a'n'} = K \quad V_{an} \qquad \text{and} \qquad I_{a'n'} = \frac{1}{K^*} \quad I_{an}$$

$$\Delta - Y : K = \frac{\sqrt{3}}{a} e^{j\frac{\pi}{6}} \quad Y - \Delta : K = \frac{1}{a\sqrt{3}} \quad e^{j\frac{\pi}{6}} \qquad a = \frac{N_1}{N_2}$$

$$Z_B = \frac{{V_B^{ll}}^2}{S_B^{3\Phi}} = \frac{{V_B}^2}{S_B} \qquad Z_{actual} = Z_{pu} Z_B \qquad Z_{pu}^n = \frac{Z_{actual}}{Z_B^n} = Z_{pu}^o \frac{Z_B^o}{Z_B^n}$$