S. KARAKI AMERICAN UNIVERSITY OF BEIRUT FALL 2003/2004

**FACULTY OF ENGINEERING AND ARCHITECTURE**

MIDTERM

**FUNDAMENTALS OF POWER SYSTEMS ANALYSIS**
**(EECE 471)**

**CLOSED BOOK (2 HOURS)** **DECEMBER 4, 2003**

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 oil-fired power station schematic shown in Fig.1 below:

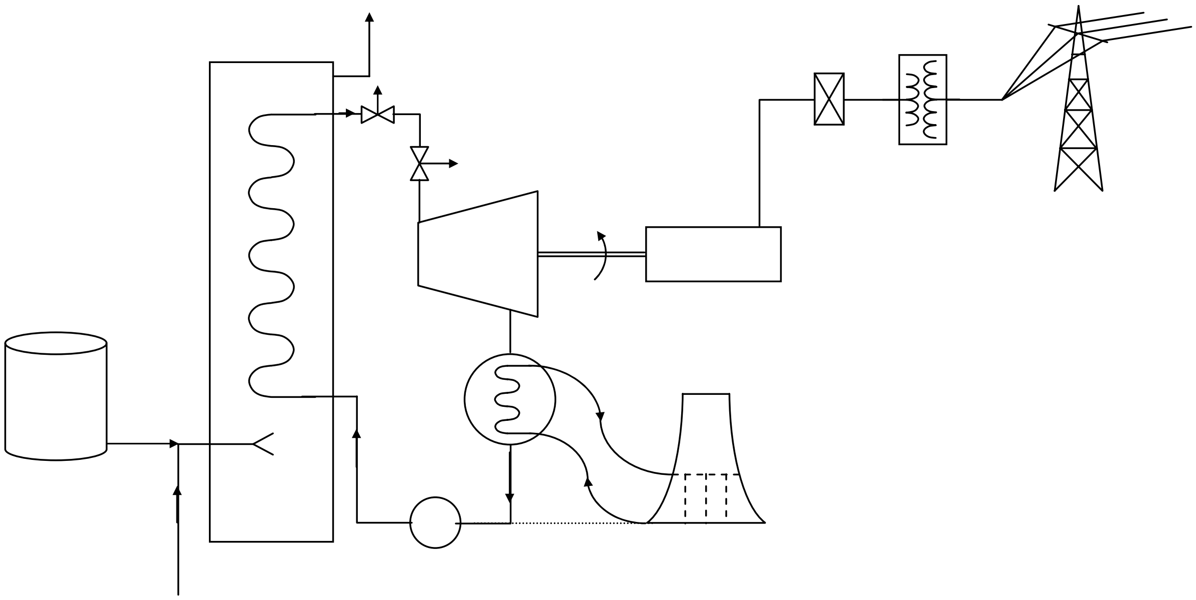


**Fig.1:** Oil-fired power station schematic

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

   ______________________________________________________________

   c) Name two environmental problems associated with fossil-fuel power plants?

   ______________________________________________________________

d) Why would the world with current technologies and resources face an energy crisis in the next 50 to 150 years?

______________________________________________________________

e) Name three types of renewable energy technologies?

______________________________________________________________

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

______________________________________________________________

g) When we design generators with higher rating which dimension is usually increased, the diameter or the length of the generator and why?

______________________________________________________________

h) What is the relationship between ac and dc resistances and why are they different?

______________________________________________________________

i) For a given line, how do the shunt capacitive susceptance and the series inductive reactance in per unit change as we increase its operating voltage?

______________________________________________________________

j) What is the surge impedance loading of a line?

______________________________________________________________

2. A three-phase load draws 500 kW at a PF of 0.707 lagging from a 440 V line. It is required to compensate the load and bring the PF of the compensation equipment and load up to 0.9.

a) Determine the line current and reactive power supplied before compensation.

b) Determine the line current and reactive power supplied after compensation.

c) What is the kind of compensation equipment used and what is its size?

d) Draw a phasor diagram showing voltage and current before and after compensation and comment on the effect of compensation on the system.

3. It is required to design a transmission line of 150 mile length to transmit 400 MW of power considering one of two voltages 220 and 400 kV at a frequency of 50Hz. The tower configurations and dimensions of the proposed line designs are given in Fig. 2 below. Note that 1 kcmil= 0.507mm$^2$ and 1 ft= 0.305 m.

   a) From Table 1 shown below select the most appropriate conductor sizes if the current density at given load conditions is not to exceed 2 A/mm$^2$.

   b) Calculate line resistance, inductance and capacitance for both line designs.

   c) Calculate the characteristic impedance, propagation constant and surge impedance loading for both voltage levels.

   d) Select a voltage to maintain a stability margin such that the phase angle from sending to receiving is smaller than or equal to 45°. Refer to Fig. 3 below.

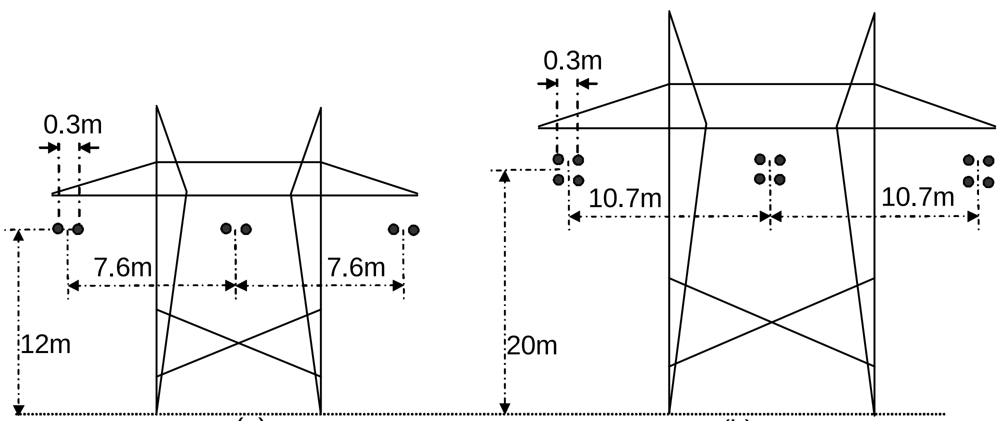



**Fig. 2:** Tower configurations of a 220 kV (a) and 400 kV (b) transmission lines

**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 |

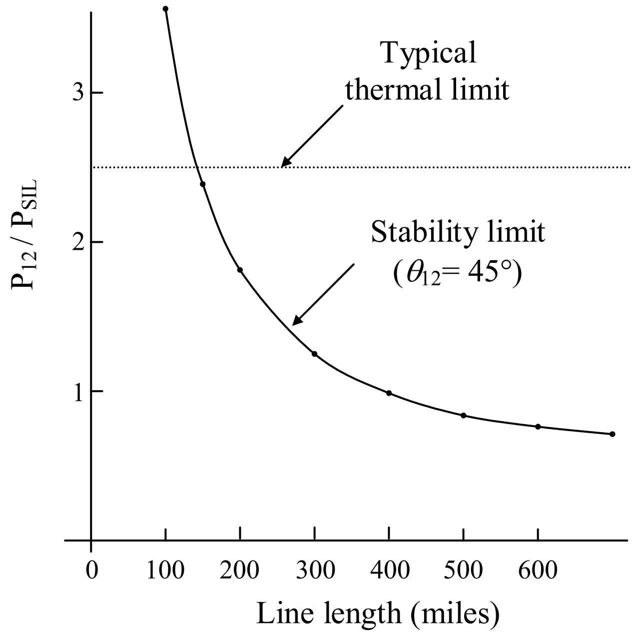



**Fig. 3:** Stability limit of lines

4. Consider the generation system supplying a load through a Δ-Y connected transformer and a transmission line, shown in Fig. 4 below. The nominal line-to-line voltages on the transformer are 12.7-220 kV. The leakage and magnetizing reactance of one set of low-high turns are $x_l$= 0.6Ω and $x_m$= 24Ω, referred to the low voltage side. The load is Y-connected and consumes 150 MW at 0.9 PF when the voltage at the receiving end is nominal. The line length is 100km, its series reactance is $x_l$= 0.375Ω/ km, its resistance is 0.075Ω/ km, and its susceptance is $y_c$= 3.8 µS/ km.

   a) Determine the per-phase equivalent load impedance.

   b) Draw the per-phase equivalent circuit of the system and show the values of all impedances.

   c) If power to the load is delivered at nominal voltage determine the phase currents on the transformer primary (low voltage) and secondary sides.

   d) Determine the voltage at the generator terminal and the active and reactive power supplied by the generator.

   e) Draw the phasor diagram of the transmission line showing currents and voltages at the sending and receiving, and the voltage drop across the line.

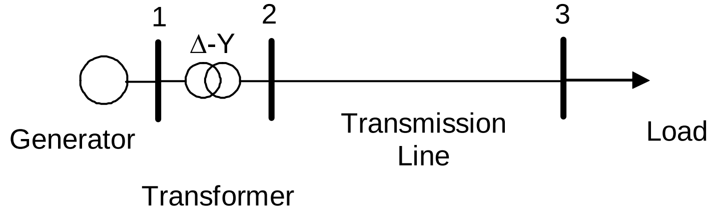



**Fig. 4:** Small power system for Problem 4

# Fundamentals of Power Systems Analysis
## (EECE 471)
## FORMULAE

- Ch.2: **Basic Principles**

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

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

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

$D$: 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**

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

    $I_1 = I_2 \quad \cosh \gamma l + \frac{V_2}{Z_c} \quad \sinh \gamma l = CV_2 + DI_2$

    $T = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$ 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

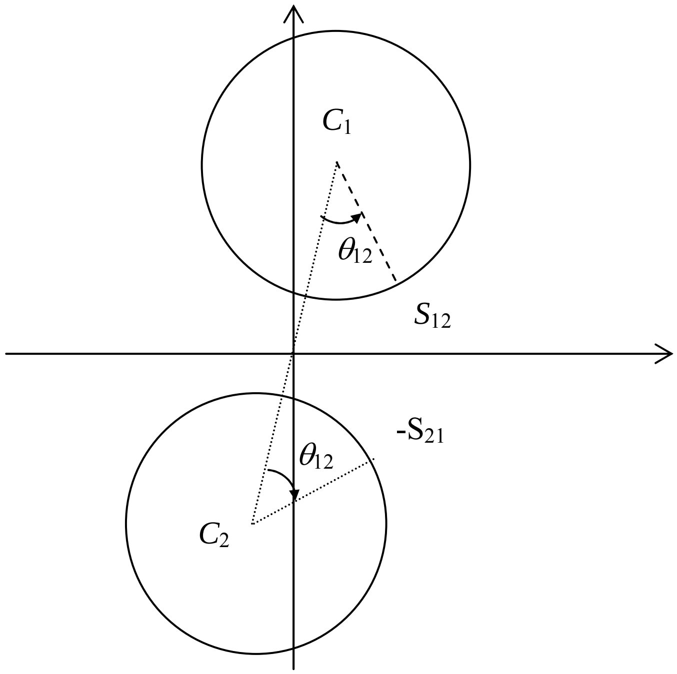
  - Power Flow on a short loss-less line:

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

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

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

- Power Circle Diagram




Both circles have a radius: $B = \dfrac{|V_1||V_2|}{|Z|}$

$$C_1 = \frac{|V_1|^2}{|Z|}\angle Z \qquad C_2 = -\frac{|V_2|^2}{|Z|}\angle Z$$

- Power transmission capability:

$$P_{12} = \frac{|V_1|^2}{Z_c}\frac{\sin\theta_{12}}{\sin\beta l} = P_{SIL}\frac{\sin\theta_{12}}{\sin\beta l}$$

$$\beta = \operatorname{Im}(\gamma)$$

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

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

$$\Delta - Y : K = \sqrt{3} \quad n \quad e^{j\frac{\pi}{6}} \qquad Y - \Delta : K = \frac{n}{\sqrt{3}} \quad e^{j\frac{\pi}{6}} \qquad n = \frac{N2}{N_1}$$

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