S. KARAKI AMERICAN UNIVERSITY OF BEIRUT FALL 2003/ 2004

FACULTY OF ENGINEERING AND ARCHITECTURE

FINAL EXAM

POWER SYSTEMS FUNDAMENTALS (EECE 471)

CLOSED BOOK (3 HOURS) January 29, 2004

FIRST READ CAREFULLY THE QUESTION SHEET AND THEN START:

- PROGRAMMABLE CALCULATORS ARE NOT ALLOWED.
- THIS QUESTION SHEET MUST BE RETURNED WITH THE ANSWER BOOKLET.
- BRIEFLY EXPLAIN CALCULATIONS BY SHOWING FORMULAE OR OTHERWISE AS NEEDED.
- ON YOUR ANSWER BOOKLET, USE THE RECTO FOR ANSWER AND THE VERSO FOR SCRATCH

NAME: ________________________ **ID#:** ________________________

1. Consider the following power system shown in Fig. 1 below. The load will be modeled as a constant impedance load taking 32+j16 MVA at nominal voltage. The given percent impedances are with respect to corresponding equipment rating. For this exercise calculations are to be done with S_B= 10 MVA.

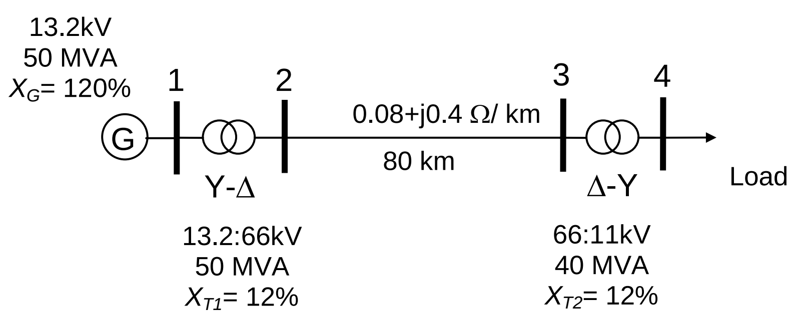


Fig. 1: 4-Node System for Problem 1.

a) Calculate the load impedance in ohms.
b) Select the generator rated voltage as a base voltage on generator side. What should be the base voltages on the transmission and load sides? What are base impedances on the generator, transmission, and load sides?
c) Draw an impedance diagram showing the generator equivalent circuit, the transformers, transmission line and load, and label it properly with per unit impedances. Show the per unit calculation of the generator and transmission line impedances and for the other just show the per unit values on the diagram.
d) If the generator terminal voltage is regulated to 1 pu, calculate the complex power delivered by the generator, the voltage at node 4 (V_4), and the internal generator voltage E_a.
e) If the rated power factor of the generator is 0.85, use its capability curve to determine its reactive power limits when it delivers the active power calculated in Part e) above? Explain whether the generator is operating satisfactorily.

2. Consider the power system shown in Fig. 2 below for which a load flow is to be solved using the Gauss-Seidel iterative approach. The powers are given in MVA and the line reactances are given in per-unit on S_B= 100 MVA base. Node 1 is the reference node with a voltage $V_1 = 1.05\angle 0$.

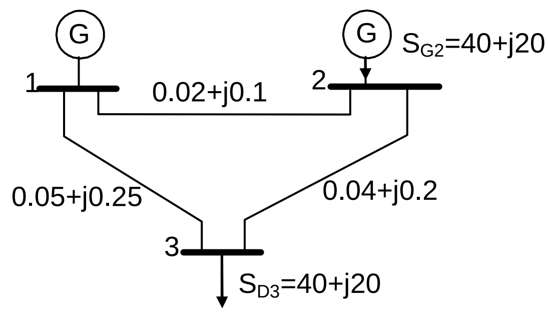


Fig. 2: 3-Node system for Problem 2

   a) Determine the nodal admittance matrix (***Y***) of the above network. Show the calculation for one diagonal and one off-diagonal elements, and for other elements just provide the vales on the matrix.
   b) Write down the Gauss-Seidel iterative expressions for this problem for V_2 and V_3. Write down the expressions in variable form then in numeric for replacing appropriate quantities by their values.
   c) Starting the iterative process at nominal values (1+j0 pu), calculate the values of V_2 and V_3 at the end of the first and second iterations.

3. Consider a generation system consisting of three units for which it is required to perform an economic load dispatch study. The units have the following fuel-cost curves and limits.

$$C_1(P_{G1}) = 250 + 25\,P_{G1} + 0.010\,P_{G1}^2 \ \ \$/h$$
$$C_2(P_{G2}) = 350 + 20\,P_{G2} + 0.020\,P_{G2}^2 \ \ \$/h$$
$$C_3(P_{G3}) = 240 + 20\,P_{G3} + 0.025\,P_{G3}^2 \ \ \$/h$$

$$50 \le P_{G1} \le 150 \text{ MW}$$
$$80 \le P_{G2} \le 250 \text{ MW}$$
$$50 \le P_{G3} \le 150 \text{ MW}$$

   a) Write down the equations needed to determine the optimum point of system operation when the demand is 400 MW.
   b) Solve the equations set up in Part a) and determine the power delivered by each generator and the incremental cost of the system.
   c) What is the optimum operating point of the system, its incremental cost and the power delivered by each unit when the demand is raised to 500 MW and then to 520 MW?

4. Consider the system shown in Fig. 3 below, which has the following data in per unit on a 10 MVA base:

   $V_1 = 1 \angle 0$ $\quad Z_L = j\,0.2$
   $S_{D1} = 0.4 + j\,0.2$ $\quad S_{D2} = 0.8 + j\,0.4$

   The generator rating is 15 MVA at 0.9 PF.

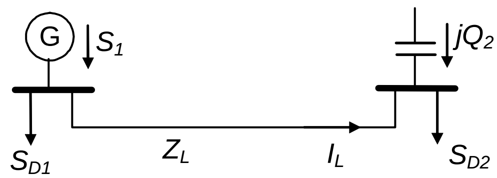


Fig. 3: System of two nodes for Problem 4

   a) Use a Gauss-Seidel iterative method to determine V_2 when Q_2 is 0. Set up the iterative equation of V_2 and carry out 4 iterations only.
   b) What are the line current I_L and the complex power S_1 supplied by the generator? Is the complex power supplied within the capability limit of the generator? Explain.
   c) What would be the reactive power Q_2 if $|V_2|$ is to be regulated to 1? Under these conditions what is the line current I_L and the complex power S_1 supplied by the generator?
   d) If you were a system designer in a power company, would you recommend installing a capacitor bank to supply Q_2? Can Q_2 be made smaller? If so how small can Q_2 be made approximately? Explain.

5. Write a 100 to 150 words abstract explaining what was your project about, the scope of work that you have done, the methodology followed or main topics discussed, the main results, conclusions, or recommendations that you achieved. Then explain with just enough details to specifically clarify your personal contribution to the project.

Fundamentals of Power Systems Analysis (EECE 471)
FORMULAE

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

  - Complex Power Flow on Medium Line:

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

    For S_{21} exchange indices 1 and 2 in above equation

  - Power Flow on a short loss-less line:

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

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

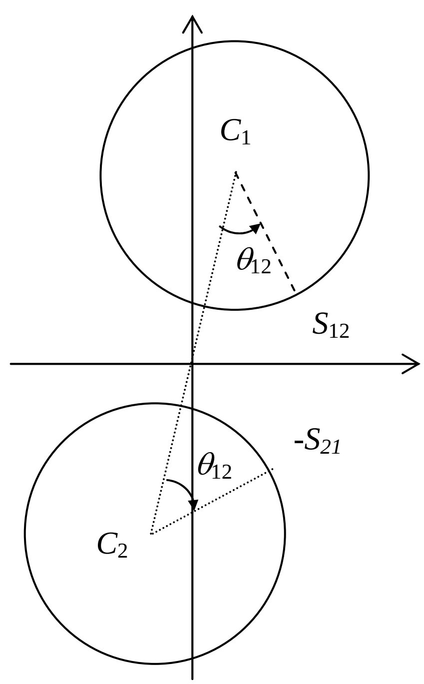
    $$Q_{21} = \frac{|V_2|^2}{X} - \frac{|V_1||V_2|}{X}\cos\theta_{12} \qquad l\text{: length of line}$$

  - Power Circle Diagram

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

    $$C_1 = \frac{|V_1|^2}{|Z|}\angle Z$$

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



  - Power transmission capability:

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

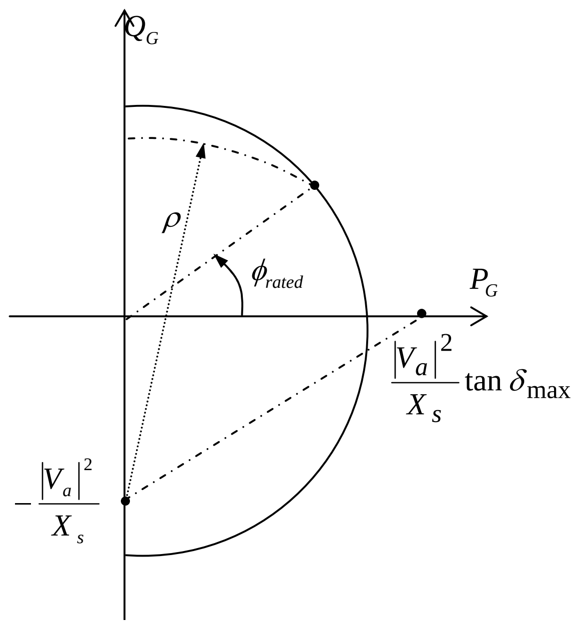
    $$\beta = \mathrm{Im}(\gamma)$$

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

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

- *Ch.6: **Generator Capability Limit**

$$P_G = \frac{E_a V_a}{X_s} \sin\delta_m$$
$$Q_G = \frac{V_a}{X_s}\left(E_a \cos\delta_m - V_a\right)$$
$$\rho = \frac{|V_a||E_{a\max}|}{X_s}$$
$$E_a = k\ i_f$$

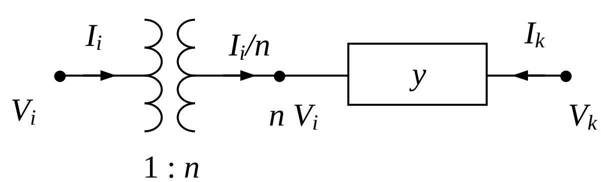


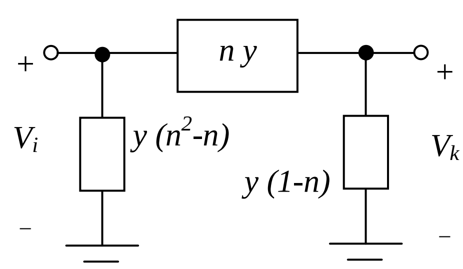
- ∗Ch.9: **Nodal Admittance Matrix**

$$I = Y\ V$$

- Y_{ii} is the sum of all admittances connected to node i;
- Y_{ik} is the negative of the series admittance between nodes i and k.

A transformer between nodes i and k can be modeled using a Π-equivalent as shown below:





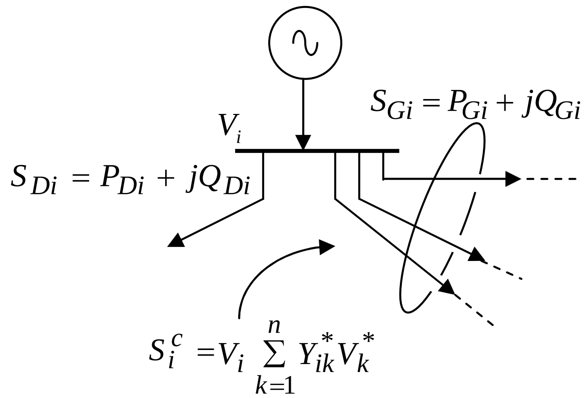
- Ch.10: **Power Flow Analysis**

$$S_i = V_i I_i^* = V_i \sum_{k=1}^{n} Y_{ik}^* V_k^* \qquad i = 2, 3 \ldots n$$

$$S_i \overset{\Delta}{=} S_{Gi} - S_{Di}$$

$$Y_{ik} = G_{ik} + jB_{ik}$$

$$\theta_{ik} = \theta_i - \theta_k$$



$$P_i^c = \sum_{k=1}^{n} V_i V_k \left(G_{ik} \cos\theta_{ik} + B_{ik} \sin\theta_{ik}\right)$$

$$Q_i^c = \sum_{k=1}^{n} V_i V_k \left(G_{ik} \sin\theta_{ik} - B_{ik} \cos\theta_{ik}\right)$$

  - Gauss-Seidel Load Flow:

$$V_i = \frac{1}{Y_{ii}} \left[\frac{S_i^*}{V_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k \right] \qquad i = 2, 3 \ldots n$$

- Ch.11: **Economic Operation of Power Systems**

Minimize $C_T = \sum_{i=1}^{m} C_i\left(P_{Gi}\right)$

Subject to $\sum_{i=1}^{m} P_{Gi} = P_D$ and $P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}$ $\quad i = 1 \ldots m$

$$C_i\left(P_{Gi}\right) = \alpha + \beta P_{Gi} + \gamma P_{Gi}^2$$