S. KARAKI AMERICAN UNIVERSITY OF BEIRUT FALL 2005/ 2006

FACULTY OF ENGINEERING AND ARCHITECTURE

FINAL EXAM

FUNDAMENTALS OF POWER SYSTEMS ANALYSIS (EECE 471E)

CLOSED BOOK (3 HOURS) January 28, 2006

PROGRAMMABLE CALCULATORS ARE NOT ALLOWED.
THIS QUESTION SHEET MUST BE RETURNED WITH THE ANSWER BOOKLET.

BRIEFLY EXPLAIN CALCULATIONS BY SHOWING FORMULAE USED OR OTHERWISE AS NEEDED.

NAME: ________________________ **ID#:** ________________________

1. In this exam the operational analysis of the transmission system shown in Fig. 1 is considered. In this first problem the power flow problem of the transmission system is solved, however, partially due to time limitation. In the second problem the economic load dispatch (ELD) of this system is formulated and solved with and without losses. And in the third part the fault level analysis of the transmission system is carried out for a line-to-line and a line-to-ground fault. Except for the simple calculation of the line and other system parameters in per unit in Part a) and the generation limits in this problem, the three problems are essentially independent. The practice in the utility has been to allow for a maximum current density of 2 A/mm^2 for thermal rating and the conductors are 2×200 mm^2 per phase. The transmission voltage is 220 kV and the line length is 320 km. The transmission lines specific series impedance is given as $r_l + jx_l$= 0.08 + j0.35 Ω/km. Its shunt admittance is given by y_s= j3.2 μS/km. The transformers have a rating of 300 MVA each and a leakage reactance of 10% on rating. Furthermore, the following additional data is known about the system:

   Generator G_1: 300 MVA, PF= 0.85,13 kV, X_S= 125%.
   Generator G_2: 80 MVA, PF= 0.85,11 kV, X_S= 100%.
   Load at node 1: 20 + j10 MVA
   Load at node 4: 180 + j80 MVA

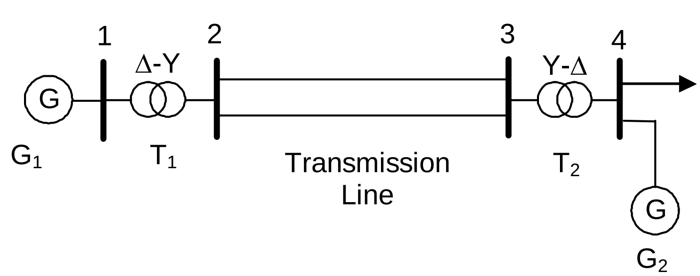

Fig. 1: Transmission system under analysis.

a) Calculate the transmission line, series resistance and reactance, and its shunt susceptance in ohms and in per unit to a 100 MVA base. Determine the transformer and generator reactance values in per unit to the same base.

b) What are the upper and lower reactive power limits of the two generators when working at rated power factor load? These values will be used for any active power schedule.

c) Given the line loading capability curve shown in Fig. 2 that gives P_L/P_{SIL} in terms of line length, is the proposed transmission line appropriately designed to carry the maximum load when one circuit is on outage. Explain your answer.

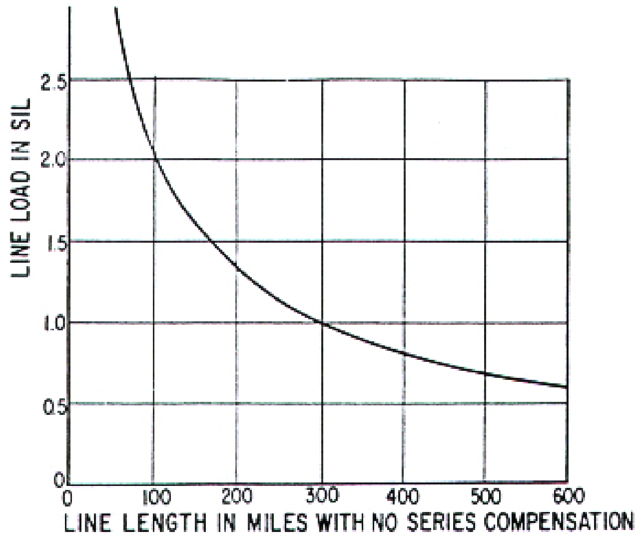

Fig. 2: Line loading capability curve.

d) In this part it is required to solve the load flow problem of the system of Fig. 1. The method to be used is the fast-decoupled load flow (FDLF), which is a variant of the Newton-Raphson procedure with a constant approximate Jacobian matrix evaluated at the flat start voltages, i.e., all voltage magnitudes are equal to 1 per unit, and all phase angles are zero. Write down, with justification, the two iterative equations of this method. Calculate the nodal admittance matrix of this system and deduce the two matrix partitions needed in the FDLF method. Select node 1 to be the slack and node 4 to be a PV node.

e) If the inverse of the Jacobian matrix partitions are as given below, then carry out an iteration of the FDLF method to determine the updated voltage magnitudes and phase angles at the end of the first iteration. Start with $\boldsymbol{V}$= [1.07 1.0 1.0 0.95] and $\boldsymbol{\theta}$= [0 0 0 0]. The inverse of the Jacobian matrix partitions are:

$$[\boldsymbol{J}^{11}]^{-1} = \begin{bmatrix} 1.0 & 0 & 0 & 0 \\ 0 & 0.0345 & 0.0367 & 0.0367 \\ 0 & 0.0367 & 0.1684 & 0.1684 \\ 0 & 0.0367 & 0.1684 & 0.2017 \end{bmatrix}$$

$$[\boldsymbol{J}^{22}]^{-1} = \begin{bmatrix} 1.0 & 0 & 0 & 0 \\ 0 & 0.0278 & 0.0061 & 0 \\ 0 & 0.0061 & 0.0278 & 0 \\ 0 & 0 & 0 & 1.0 \end{bmatrix}$$

f) The load flow results of the system when operated with one circuit (2 – 3) on outage are shown in Table 1 below. Examine the results given and describe what seems to be the problem and the underlying reasons and discuss ways with approximate numerical values based on some justification to remedy it.

Table 1. Load Flow Results with one circuit on outage.

--- Branch Flows ---

From	To	(MW)	(MVAr)	(MW)	(MVAr)
1	2	151.471	19.171	-151.471	-12.391
2	3	151.464	12.391	-140.001	-12.963
3	4	140.000	12.962	-140.000	-5.718

--- Node Results ---

Node	Type	Voltage (pu)	Phase (deg)	----- Load ----- (MW)	(MVAr)	---- Generation ---- (MW)	(MVAr)
1	slack	1.070	0.000	20.00	10.00	171.47	29.17
2	PQ	1.065	-2.537	0.00	0.00	0.00	0.00
3	PQ	0.953	-21.412	0.00	0.00	0.00	0.00
4	PV	0.950	-24.363	180.00	80.00	40.00	74.28

2. It is required to perform an economic load dispatch study of the two generators system of Fig. 1. The maximum power limits of the units can be calculated from data given in Problem 1. The units have the following fuel-cost curves:

$$C_1(P_{G1}) = 300 + 25\,P_{G1} + 0.02\,P_{G1}^{\,2} \;\; \$/\text{h}$$
$$C_2(P_{G2}) = 100 + 30\,P_{G2} + 0.02\,P_{G2}^{\,2} \;\; \$/\text{h}$$

a) Formulate the loss-less economic dispatch of the system and find the active powers provided by each units (P_{G1}, P_{G2}), the incremental cost (λ) and the total cost of operation at the given system demand. The solution should be within the determined active generation limit for a total load equal to 180+20= 200 MW. Work out the solution in this and the remaining parts of the problem in per unit using S_B= 100 MVA. In this part both circuits are assumed available and hence lines should not pose any limitation on the operation of the system.

b) Under some extreme heat conditions each circuit in the transmission line is assumed to have a capability of 140 MW and the loads are 25 and 200 MW. When one circuit is on outage, what is the maximum power that can be generated by Generator 1? Under this condition and neglecting line losses, what are the values of P_{G1} and P_{G2} for a minimum-cost operation of the system? What are the incremental costs at nodes at nodes 1 and 4 in this case? Explain why should they be different?

c) In this part we go back to the two lines being available and the given peak loads in Problem 1. Nodes 2 and 3 are removed from the system, using Kron's method, so that there is a direct connection between nodes 1 and 4. It can be shown that the system losses are approximated by: $P_L = (P_{D4} - P_{G2})^2\, G/\, B^2$, where $G + jB$ is the equivalent series admittance between nodes 1 and 4 equal to: 0.781 – j5.38. Formulate the economic dispatch with losses using penalty factors and describe an iterative procedure to solve it. Carry out an iteration of this procedure starting at the lossless ELD solution and determine the incremental cost at nodes 1 and 4 and the power supplied by each generator.

3. In this third problem it is required to carry out a fault level analysis of the system presented in Fig. 1. In addition to the given data the transient, sub-transient and leakage reactances are given as 30%, 20% and 6% on generator rating. Neglect the transmission line resistance in this problem. The generators are Y-connected with the neutral solidly grounded and the Y-sides of the transformers are also solidly grounded.

a) Draw the positive, negative and zero sequence networks of the system with all reactance values given in per unit on 100 MVA base.

b) If the positive, negative and zero sequence impedance matrices are given as follows:

$$\boldsymbol{Z}^{+} = \begin{bmatrix} j\,0.0904 & j\,0.0872 & j\,0.0712 & j\,0.0654 \\ j\,0.0872 & j\,0.1163 & j\,0.0949 & j\,0.0871 \\ j\,0.0712 & j\,0.0949 & j\,0.1716 & j\,0.1576 \\ j\,0.0654 & j\,0.0871 & j\,0.1576 & j\,0.1754 \end{bmatrix}$$

$$\boldsymbol{Z}^{-} = \begin{bmatrix} j\,0.0603 & j\,0.0570 & j\,0.0422 & j\,0.0372 \\ j\,0.0570 & j\,0.0853 & j\,0.0632 & j\,0.0557 \\ j\,0.0422 & j\,0.0632 & j\,0.1323 & j\,0.1168 \\ j\,0.0372 & j\,0.0557 & j\,0.1168 & j\,0.1324 \end{bmatrix}$$

$$\boldsymbol{Z}^{0} = \begin{bmatrix} j\,0.0200 & 0 & 0 & 0 \\ 0 & j\,0.0311 & j\,0.0028 & 0 \\ 0 & j\,0.0028 & j\,0.0311 & 0 \\ 0 & 0 & 0 & j\,0.075 \end{bmatrix}$$

Explain what is the significance of Z_{22}^{+}, Z_{22}^{-} and Z_{22}^{0} in relation to the networks drawn in Part a? Verify your answer for Z_{22}^{+}.

c) Using the data provided in Part b, deduce the sequence networks for a fault at node 2 and connect them for a SLG or a LL fault. Determine the sequence currents (I_2^{+}, I_2^{-} and I_2^{0}) and voltages (V_2^{+}, V_2^{-} and V_2^{0}) at node 2 during the fault and deduce the phase voltages and currents.