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FACULTY OF ENGINEERING AND ARCHITECTURE

FINAL EXAM

FUNDAMENTALS OF POWER SYSTEMS ANALYSIS (EECE 471E)

CLOSED BOOK (2.5 HOURS) January 26, 2008

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

BRIEFLY EXPLAIN CALCULATIONS BY SHOWING FORMULAE USED.

NAME: ________________________ **ID#:** ________________________

1. The transmission system shown in Fig. 1 is to be designed to provide the load with an adequate level of supply at 50 Hz. The transmission system consists of one OHL tower having two circuits. The practice in the utility has been to allow for a maximum current density of 2.5 A/mm^2 for thermal rating of a line, and the tower dimensions are such that we have a typical conductor spacing of 0.04 m/kV. The utility uses several standard voltages, namely 400, 220, and 150 kV, which have surge impedances of 250, 275 and 300Ω, respectively. Transformers have usually leakage reactance of 12% on rating. Furthermore, the following data is known about the system:

   Generator G_1: 250 MVA, PF= 0.85, 13 kV, X_S= 120%.
   Generator G_2: 120 MVA, PF= 0.85, 11 kV, X_S= 110%.
   Transmission line: 450 km.
   Load: 300+j120 MVA

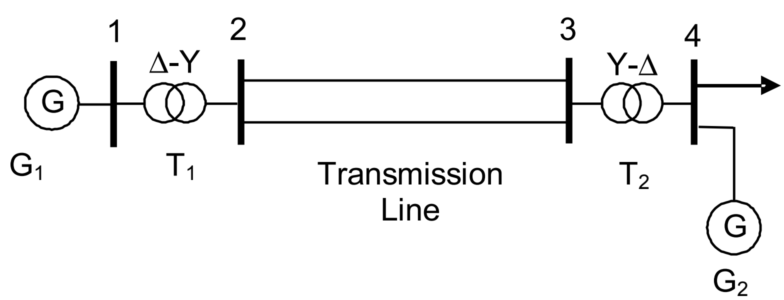

Fig. 1: Transmission system under analysis.

a) Determine the most appropriate voltage that should be used for transmission and the surge impedance loading of the line. For stability reasons the angle deviation from node 1 to node 4 should be less than about 45°.

b) From Table 1 given below select the most appropriate conductor size at the selected voltage. The current density is not to exceed 2.5 A/mm^2 at the prevailing ambient conditions and the line losses for the selected conductor are not to exceed 7%. Consider using bundled conductors in your design with up to 4 conductors per bundle. Use a bundle distance of 1ft. Note that 1 kcmil= $0.507mm^2$ and 1 ft= 0.305 m.

c) Calculate the resistance, inductance and capacitance per km 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?

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
Starling	715.5	0.154	0.0355
Drake	795.0	0.139	0.0375
Redbird	954.0	0.117	0.0404

d) Calculate the series reactance and shunt susceptance of each transmission line in per unit to a 100 MVA base. Estimate the transformer rating in MVA and determine their reactance and the generators synchronous reactance values in per unit to the same base.

2. In this part it is required to examine the solution of the load flow problem of the system of Fig. 1 using the fast-decoupled load flow (FDLF). This is a variant of the Newton-Raphson method 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. The generators can supply up to rated value of reactive power and can absorb up to 15% of the rated value. The voltage under normal operating conditions is in the range 1 ± 0.05 per unit, and under contingent conditions the range is relaxed to 1 ± 0.1 per unit.

a) Write down, with justification, the two iterative equations in matrix form of this method. Calculate the nodal admittance matrix of this system and deduce the two matrix partitions needed in the FDLF method. To simplify the calculation neglect the transmission line resistances.

b) The load flow results of the system, under peak load conditions are shown in Table 2 below. Examine the results given and describe what seems to be the problem and the underlying reasons and discuss ways to remedy it. What would be the cheapest and most effective way to remedy the situation? Can you predict what would happen if you implemented the remedy that you identified?

Table 2. Load Flow Results at Peak Load Conditions: Base Case.

--- Branch Flows ---

From	To	(MW)	(MVAr)	(MW)	(MVAr)
1	2	216.955	-49.179	-216.955	70.725
2	3	108.478	-35.362	-106.145	-44.834
2	3	108.478	-35.362	-106.145	-44.834
3	4	212.290	89.667	-200.001	-66.071

--- Node Results ---

Node	Type	Voltage (pu)	Phase (deg)	----- Load ----- (MW)	(MVAr)	---- Generation ---- (MW)	(MVAr)
1	slk	1.050	0.000	0.00	0.00	216.96	-49.18
2	pq	1.077	-5.283	0.00	0.00	0.00	0.00
3	pq	1.039	-18.563	0.00	0.00	0.00	0.00
4	pv	0.950	-23.180	300.00	120.00	100.00	53.93

c) The load flow results of the system at peak load conditions with one circuit on outage are shown in Table 3 below. Again, examine the results given and describe what seems to be the problem and the underlying reasons and discuss ways to remedy it. Again, what would be the cheapest and most effective way to remedy the situation? Determine approximate numerical result relevant to your assessment.

Table 3. Load Flow Results at Peak Load Conditions: circuit 2 – 3 on Outage.

--- Branch Flows ---

From	To	(MW)	(MVAr)	(MW)	(MVAr)
1	2	222.297	30.572	-222.297	-8.650
2	3	0.000	0.000	0.000	0.000
2	3	222.297	8.650	-211.397	11.900
3	4	211.397	-11.900	-200.001	33.781

--- Node Results ---

Node	Type	Voltage (pu)	Phase (deg)	----- Load ----- (MW)	(MVAr)	---- Generation ---- (MW)	(MVAr)
1	slk	1.050	0.000	0.00	0.00	222.30	30.57
2	pq	1.041	-5.602	0.00	0.00	0.00	0.00
3	pq	0.992	-36.005	0.00	0.00	0.00	0.00
4	pv	0.950	-42.370	300.00	120.00	100.00	153.78

3. In this 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 generator transient, sub-

transient and leakage reactances are given as 30%, 20% and 6% on rating. The generators are Y-connected with the neutral solidly grounded and the Y-sides of the transformers are also solidly grounded. The zero sequence impedance of a transmission line is approximately equal to 3 times its positive sequence one.

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:

$$\mathbf{Z}^{+} = \begin{bmatrix} j0.1084 & j0.1038 & j0.0804 & j0.0674 \\ j0.1038 & j0.1453 & j0.1126 & j0.0944 \\ j0.0804 & j0.1126 & j0.1805 & j0.1515 \\ j0.0674 & j0.0944 & j0.1515 & j0.1673 \end{bmatrix}$$

$$\mathbf{Z}^{-} = \begin{bmatrix} j0.0715 & j0.0665 & j0.0462 & j0.0360 \\ j0.0665 & j0.1063 & j0.0739 & j0.0576 \\ j0.0462 & j0.0739 & j0.1350 & j0.1053 \\ j0.0360 & j0.0576 & j0.1053 & j0.1196 \end{bmatrix}$$

$$\mathbf{Z}^{0} = \begin{bmatrix} j0.024 & 0 & 0 & 0 \\ 0 & j0.0448 & j0.0055 & 0 \\ 0 & j0.0055 & j0.0448 & 0 \\ 0 & 0 & 0 & j0.0500 \end{bmatrix}$$

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}^{+} and Z_{22}^{0}.

c) Using the data provided in Part b, deduce the equivalent sequence networks for a fault at node 2 and connect them for a SLG, and a LLG faults.

d) For the SLG 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.