National Exams December 2004

98-Elec-B7, Power Systems Engineering

Open Book examination

3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.
2. Any non-communicating calculator is permitted. This is an Open Book examination. Note to the candidates: you must indicate the type of calculator being used, i.e. write the name and model designation of the calculator on the first inside left hand sheet of the exam work book.
3. Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.
4. All questions are of equal value.

Problem 1

a- Discuss the effects of increasing the ambient temperature on the series impedance Z and the shunt admittance Y of an overhead transmission line. [5 Points]

b- Consider a three-phase loss-less transmission line modeled using the ABCD parameters as follows:

$$V_s = AV_r + BI_r$$
$$I_s = CV_r + AI_r$$
$$A^2 - BC = 1$$

Assume that:

$$A = 0.92 \qquad B = j140\Omega \qquad C = j1.097x10^{-3}\,S$$

To improve the performance of the line, series capacitors are installed at both ends of the line in each phase of the line. As a result, the ABCD parameters of the compensated line become:

$$\tilde{A} = A - 0.5jCX_C \qquad \tilde{B} = B - jAX_c - 0.25CX_C^2$$

Find the ABCD parameters of the compensated line. Assume that $X_C = 100\Omega$ [5 Points]

c- Find the sending end current, power factor, and efficiency of transmission when the compensated line of part (b) delivers 1000 MVA at 0.85 power factor lagging at 490 kV. [10 Points]

Problem 2

a- Sketch the reactive capability curve of a synchronous machine, and explain the underlying principles for its various segments. [5 points]

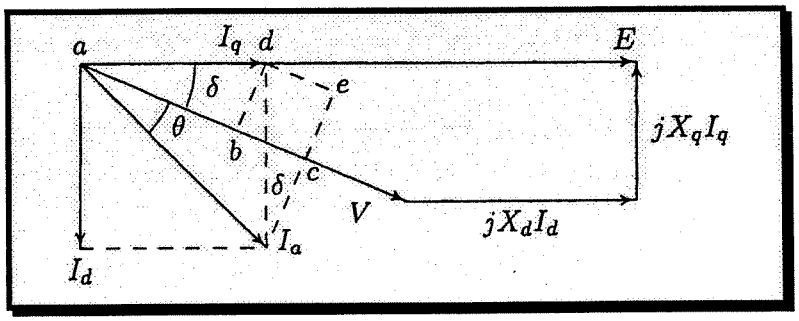
A three phase salient pole synchronous generator is connected to an infinite bus bar whose voltage is 1 per unit. The quadrature axis and direct axis reactance are X_d = 1.6 per unit and X_q= 1.35 per unit.

b- The generator delivers rated MVA at 0.95 power factor lagging. Find the excitation voltage E and the power angle δ . [7.5 points]

c- Assume that the excitation voltage is fixed at E=1.2 per unit and the infinite bus receives rated voltage. Find the active and reactive powers delivered to the infinite bus when the power angle $\delta = 20^o$ [7.5 points]

$$\tan\delta = \frac{X_q \mid I_a \mid \cos\theta}{V + X_q \mid I_a \mid \sin\theta}$$

$$\mid E \mid = \mid V \mid \cos\delta + X_d \mid I_a \mid \sin(\theta + \delta)$$



Phasor diagram for a salient pole generator

Problem 3

a- List the different types of losses in a transformer and explain possible ways of reducing them. [5 points]

A 25-kVA, 2200/220 V, 60-Hz, single-phase transformer has the following equivalent-circuit parameters referred to the high-voltage side.

$R_1 = 3.0\ \Omega$ $R'_2 = 3.0\ \Omega$

$X_{l1} = 12\ \Omega$ $X'_{l2} = 12\ \Omega$

$X_m = 20{,}000\ \Omega$ $R_c = 50{,}000\ \Omega$

Use the equivalent Cantilever model circuit of the transformer shown in Figure (1).

b- A short circuit test is conducted on the transformer with 22 volts applied to the secondary side with the primary short circuited. Determine the readings of the ammeter and wattmeter connected to the secondary side for this test. [5 points]

c- An open circuit test is conducted on the transformer with 2200 volts applied to the primary side with the secondary side left open. Determine the readings of the ammeter and wattmeter connected to the primary for this open circuit test. [5 points]

d- The transformer is supplying 15 kVA at 220-V and a lagging power factor of 0.85. Determine the primary voltage. [5 points]

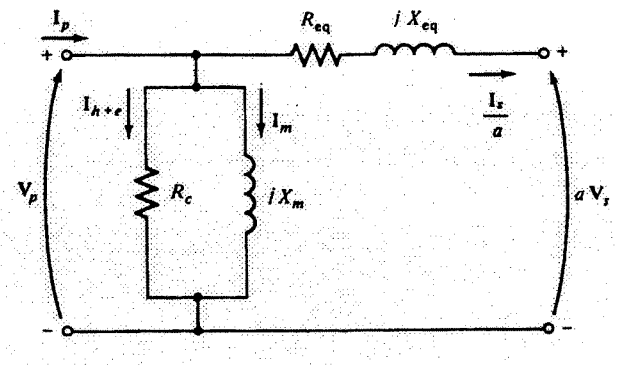


Figure 1 Equivalent Circuit of Transformer for Problem 3

Problem 4

a- What are the advantages and disadvantages of applying series capacitors in electric power systems. [5 points]

Consider the system shown in the single-line diagram of Figure 2, where all line admittances are identical and have the same value of $Y_L = -j5$.

b- Write the bus admittance matrix of the system Y. What are the primary unknowns for the power flow problem for the system? [5 points]

c- Write the power flow equations assuming that bus 1 is the slack bus whose voltage is unity and whose angle is zero. Bus 2 is maintained at a voltage of 1.025 [5 points]

d- Evaluate the Jacobian Matrix required for Newton Raphson iterations at a flat start initial guess (all voltages are unity at zero angle.) [5 points]

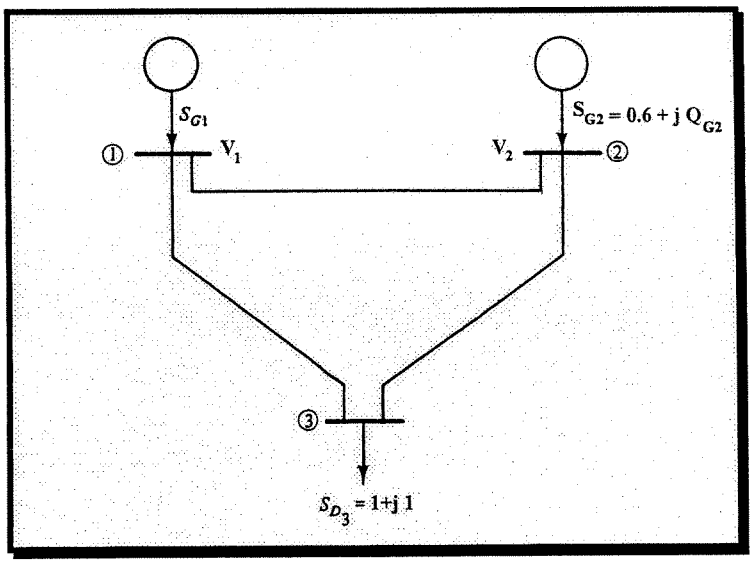


Figure 2 Single-line diagram for Problem 4

Problem 5

a- Discuss the main causes for short circuit faults on Canadian electric power systems. [5 points]

Consider the three bus system represented by the bus impedance matrix:

$$Z_{bus} = j\begin{bmatrix} 0.45 & 0.1 & 0.3 \\ 0.1 & 0.85 & 0.5 \\ 0.3 & 0.5 & 1.25 \end{bmatrix}$$

Pre-fault voltage is 1 per unit and pre-fault current is negligible.

b- A three phase fault occurs at bus 2. Determine the fault current and the voltages at buses 1, 2, and 3 during the fault. [5 points]

c- Assume that new impedance $Z_b = j0.7$ per unit is added between old bus 2 and a new bus 4. Determine the new bus impedance matrix. [5 points]

d- Repeat part (c) if Z_b is added from old bus 2 to the reference bus. [5 points]

Problem 6

A three-bus system has the following sequence bus impedance matrices:

$$Z^1_{bus} = Z^2_{bus} = j\begin{bmatrix} 0.16 & Z^{(1)}_{12} & 0.15 \\ 0.1 & Z^{(1)}_{22} & 0.12 \\ 0.15 & 0.12 & 0.25 \end{bmatrix} \qquad Z^0_{bus} = j\begin{bmatrix} 0.2 & Z^{(0)}_{12} & 0.12 \\ 0.05 & Z^{(0)}_{22} & 0.08 \\ 0.12 & 0.08 & 0.3 \end{bmatrix}$$

Where superscript 1 denotes a positive sequence quantity, superscript 2 denotes a negative sequence quantity, and superscript 0 denotes a zero sequence quantity.

a- For a single-line-to-ground fault at bus 2, the symmetrical components of fault current are found to be:

$$I^0_2(F) = I^1_2(F) = I^2_2(F) = \frac{1}{Z^1_{22} + Z^2_{22} + Z^0_{22}} = -j2$$

The positive sequence component of bus 2 voltage is found to be:

$$V^1_2(F) = 1 - Z^1_{22} I^1_2(F) = 0.6$$

Find the values of Z^1_{22}, Z^2_{22}, and Z^0_{22} and find the corresponding negative sequence and zero sequence components of bus 2 voltage

$V^2_2(F) = 0 - Z^2_{22} I^2_2(F)$.

$V^0_2(F) = 0 - Z^0_{22} I^0_2(F)$

[7.5 points]

b- The positive and zero sequence components of bus 1 voltage are found to be:

$$V^1_1(F) = 1 - Z^1_{12} I^1_2(F) = 0.8$$

$$V^0_1(F) = 0 - Z^0_{12} I^0_2(F) = -0.1$$

Find the values of Z^1_{12}, Z^2_{22}, and Z^0_{12} and find the corresponding negative sequence component of bus 1 voltage.

$V^2_1(F) = 0 - Z^2_{12} I^2_2(F)$

[7.5 points]

c- Find the positive, negative and zero sequence components of bus 3 voltage.

$V^1_3(F) = 1 - Z^1_{32} I^1_2(F)$

$V^0_3(F) = 0 - Z^0_{32} I^0_2(F)$

[5 points]

Problem 7

Consider the system shown in the single-line diagram of Figure 3. Here, a 60-Hz synchronous generator having a transient reactance of 0.3 pu. is connected to an infinite bus through a transformer whose reactance is 0.2 p. u. and a double circuit transmission line with circuits having a reactance of 0.3 p.u. each as indicated in the figure. The generator delivers a real power of 0.8 pu. and reactive power of 0.074 p.u. to the infinite bus. The magnitude of the voltage at the infinite bus is 1.00 p.u. with an angle zero.

a- Determine the excitation voltage of the generator under these conditions. [5 points]

b- A three phase fault occurs at the sending end of one transmission circuit as shown. When the fault is cleared both lines are intact. Determine the critical clearing angle. [7.5 points]

c- A three phase fault occurs in the middle of one transmission circuit. When the fault is cleared, the faulted line is isolated. Determine the critical clearing angle. [7.5 points]

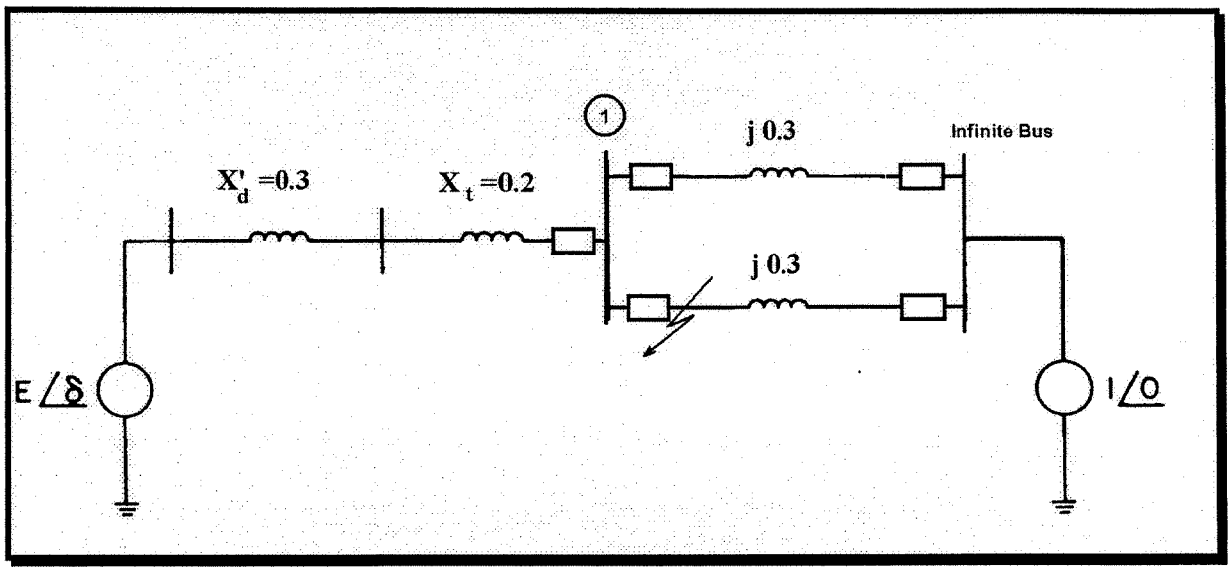


Figure 3 Circuit for Problem 7

Marking Scheme

PROBLEM 1

(a) 5 marks (b) 5 marks (c) 10 marks

PROBLEM 2

(a) 5 marks (b) 7.5 marks (c) 7.5 marks

PROBLEM 3

(a) 5 marks (b) 5 marks (c) 5 marks (d) 5 marks

PROBLEM 4

(a) 5 marks (b) 10 marks (c) 5 marks (d) 5 marks

PROBLEM 5

(a) 5 marks (b) 5 marks (c) 5 marks (b) 5 marks

PROBLEM 6

(a) 7.5 marks (b) 7.5 marks (c) 5 marks

PROBLEM 7

(a) 5 marks (b) 7.5 marks (c) 7.5 marks