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

Consider the network shown in Figure (1) with a round rotor synchronous machine feeding a load through two parallel lines. Assume for the first line linking buses 1 and 2 that the parameters A and B in per unit are given by:

\[ A_1 = 0.996 \quad B_1 = j0.02 \]

In addition, the per unit series impedance and shunt admittance parameters of the second line (represented by an equivalent pi) are \( Z_2 = j0.05 \) and \( Y_2 / 2 = j0.02 \)

a- Convert the \( A_1 \) and \( B_1 \) parameters to equivalent pi network \( Z_1 \) and \( Y_1 \). [5 points]

b- Reduce the two parallel lines to one equivalent line represented by \( Z_{eq} \) and \( Y_{eq}/2 \) [5 points]

c- Suppose now that the magnitude of the voltage at bus 2 is 1.00 p.u. and that the active power load at bus 2 in per unit is 1.2 at 0.75 p.f. lagging. Determine the values of voltage, phase angle, active and reactive power at bus 1 (the synchronous machine terminals). [5 points]

d- Find the required synchronous machine excitation voltage and power (torque) angle assuming that the machine's synchronous reactance is \( X_s = 0.03 \) p.u. Note that all power formulae in the text are given with bus 1 being the reference with phase angle =0.00 [5 points]

![Figure (1) Electric network for Problem 1](image-url)
Problem 2

A salient pole synchronous machine is connected to an infinite bus whose voltage is kept constant at 1.00 pu. The direct axis reactance is 0.95 pu.

a- To produce an active power of \( P = 1.1 \), the excitation voltage is \( E = 1.1 \) and the torque angle is given by \( \delta = 30^\circ \). Determine the value of the quadrature axis reactance of the machine. [4 points]

b- Assume that \( X_d = 0.6 \). Complete table (1) relating to four operating conditions of the machine \((Q_2\) is the reactive power at machine terminals.) Neglect armature reaction.

<table>
<thead>
<tr>
<th>Condition</th>
<th>( P )</th>
<th>( Q_2 )</th>
<th>( E )</th>
<th>( \delta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A [4points]</td>
<td>?</td>
<td>0.0</td>
<td>1.18</td>
<td>?</td>
</tr>
<tr>
<td>C [4points]</td>
<td>?</td>
<td>?</td>
<td>1.15</td>
<td>37.5°</td>
</tr>
<tr>
<td>D [4points]</td>
<td>1.25</td>
<td>?</td>
<td>1.18</td>
<td>?</td>
</tr>
</tbody>
</table>

Problem 3

Consider the 1100-kV, 400 km, bundle-conductor line shown in Figure (2). Assume phase spacing \( D_1 = 17.5 \) m, bundle separation \( S = 48.0 \) cm, and conductor diameter is 3.65 cm.

a- Calculate the inductance in henries per m per phase. [4points]

b- Calculate the capacitance in farads per meter per phase neglecting earth effects. [4points]

c- Calculate the capacitance in farads per m per phase including earth effects with \( h_1 = 25.00 \) m. [4points]

d- Use the long line formula to calculate the \( A \) and \( B \) parameters of the line neglecting resistance and earth effects. [4points]

e- Calculate the receiving-end voltage magnitude (line-to-line,) when the sending end of the line delivers 450 MVA at 0.8 PF lagging at rated voltage. [4points]

![Figure (2) Line configuration for Problem (3)](image-url)
Problem 4
Consider the system of Figure (3). Treat the motor load at bus 4 as a generator. The reactances of all components in pu are indicated in Table (2).

a- Sketch and label carefully the positive, and negative, equivalent networks for this system. [5 points]

b- Sketch and label carefully the zero sequence equivalent network. [5 points]

c- Assume that a single line to ground fault takes place at bus 2. Find the fault current through phase A. [5 points]

d- Assume that a three phase ground fault takes place at bus 2. Find the fault current. [5 points]

Table (2) Component reactance's in per unit

<table>
<thead>
<tr>
<th></th>
<th>Generators $G_1$, $G_2$ &amp; $M_1$</th>
<th>Transformers $T_1$, $T_2$ and $T_3$</th>
<th>Lines $L_1$, $L_2$ &amp; $L_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive sequence reactance $X_+$</td>
<td>0.15</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>Negative sequence reactance $X_-$</td>
<td>0.15</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>Zero sequence reactance $X_o$</td>
<td>0.05</td>
<td>0.05</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Figure (3) One-line diagram for Problem (4)
Problem 5
Consider the three-bus electric power network shown in Figure (4). It is required to find the following:

a- The active and reactive power generated at bus 1. [7 points]
b- The active and reactive power load at bus 2. [7 points]
c- The active and reactive power load at bus 3. [6 points]

\[ P_1 = ?, \quad Q_1 = ? \]
\[ |V_1| = 1.0, \quad \theta_1 = 0.0 \]
\[ jX_L = j0.1 \text{ p.u.} \]

\[ P_2 = ?, \quad Q_2 = ? \]
\[ |V_2| = 1.0, \quad \theta_2 = -5^\circ \]
\[ jX_L = j0.2 \text{ p.u.} \]

\[ P_3 = ?, \quad Q_3 = ? \]
\[ |V_3| = 1.0, \quad \theta_3 = -10^\circ \]

Figure (4) Circuit for Problem 5

Problem 6
Consider the system shown in the single-line diagram of Figure (5). All reactances are shown in per unit to the same base. Assume that the voltage at both sources is 1 p.u.

a- Find the fault current due to a bolted- three-phase short circuit at bus 4. [5 Points]
b- Find the voltage at bus 5 under the fault conditions of part a [5 Points]
c- Find the fault current due to a bolted- three-phase short circuit at bus 3. [5 Points]
d- Find the voltage at bus 2 under the fault conditions of part c [5 Points]

Figure (5) Single-line diagrams for Problem 6
Problem 7
Consider the circuit shown in Figure (6) Assume that $E = 1.1$ p.u., and $V = 1.05$ p.u. A three phase short circuit takes place in the middle of transmission line 3.

![Circuit Diagram]

Figure (6) Circuit for Problem 7

a) Assume that the active component of the load on the circuit is 2 p.u., when the fault takes place. Verify that the system will be stable under sustained fault conditions. [6 points]

b) Assume now that the active component of the load on the circuit is 3 p.u., when the fault takes place. Will the system be stable under sustained fault conditions? [7 points]

c) Assume that for the conditions of part (b,) the fault is cleared at $\delta_c = 90^\circ$ by opening the circuit breakers at both ends of line 3. Carry out the necessary calculations to show that the system will remain stable under these conditions. [7 points]