1) [20 pts] A 4-bus system is described by its positive sequence subtransient impedance and admittance matrices as given below.

\[
\begin{bmatrix}
0.1488 & 0.0651 & 0.0864 & 0.0978 \\
0.0651 & 0.1554 & 0.0798 & 0.0967 \\
0.0864 & 0.0798 & 0.1314 & 0.1058 \\
0.0978 & 0.0967 & 0.1058 & 0.1566
\end{bmatrix}
\]

\[
\begin{bmatrix}
-12.33 & 0.0 & 4.0 & 5.0 \\
0.0 & -10.83 & 2.5 & 5.0 \\
4.0 & 2.5 & -17.83 & 8.0 \\
5.0 & 5.0 & 8.0 & -18.0
\end{bmatrix}
\]

\[
z_{bus}^1 = j
\]

\[
y_{bus}^1 = j
\]

a) A balanced 3\(\phi\) fault occurs at bus 2. Calculate the fault current.

b) Calculate the phasor voltages that exist during the fault at buses 1, 3 and 4.

c) Calculate the phasor currents \(I_{12}\), \(I_{23}\) and \(I_{42}\) flowing between the faulted bus and the other system buses.
2) [20 pts] A 400-MVA 23-kV generator has the following parameters, given on the base of the generator:

\[
\begin{align*}
X_d &= 1.85 \\
T_A &= 0.2 \text{s} \\
X_d' &= 0.33 \\
T_d' &= 0.8 \text{s} \\
X_d'' &= 0.25 \\
T_d'' &= 0.04 \text{s}
\end{align*}
\]

Assume that the generator is operating at no load and rated voltage when a 3\phi fault occurs directly on the terminals.

a) Calculate the initial subtransient symmetrical RMS fault current \(I_{ac}(0)\) and the steady state fault current \(I(\infty)\).

b) Write the expression for the maximum dc offset as a function of time.

c) Calculate the asymmetrical worst-case RMS short circuit current (in amps) that a 2-cycle breaker would have to interrupt.
3) [20 pts] The sequence bus impedance matrices (in per unit) for a 3-bus system are given below. Assume that the system has balanced positive sequence sources and that the prefault value of $V_{AN}$ is 1.05 $\text{o}$.0°.

\[
Z_{bus}^0 = j \begin{bmatrix}
0.15 & 0.08 & 0.0 \\
0.08 & 0.20 & 0.0 \\
0.0 & 0.0 & 0.30
\end{bmatrix}
\]

\[
Z_{bus}^1 = Z_{bus}^2 = j \begin{bmatrix}
0.12 & 0.08 & 0.04 \\
0.08 & 0.12 & 0.06 \\
0.04 & 0.06 & 0.08
\end{bmatrix}
\]

a) Calculate the phasor values of $I_{A1}$, $I_{A2}$, $I_{Ad}$, and $I_c$ flowing in the fault for a L-L-G short circuit at bus 1.

b) Calculate the phasor values of $V_{Ad}$, $V_{A1}$, $V_{A2}$ and $V_A$ at bus 2 during the fault.

c) Calculate the phasor value of $V_A$ at bus 1 during the fault.
4) [20 pts] Answer any four of the following short concept/essay questions. Be sure to clearly indicate which one you do not want graded, or the first four will be graded. Explain in your own words - explanations copied word-for-word from your textbook will not be given full credit.

a) [5 pts] Explain how you would correct network fault current flows to account for prefault load current for a L-G fault.

b) [5 pts] How do you incorporate a fault impedance \( Z_f \) into the \( Z_0, Z_1, Z_2 \) network connections for a L-L-G fault?

c) [5 pts] Dry rocky soils have a higher resistivity than wet silty soils. Explain what effect this has (if any) on the a) positive sequence, b) negative sequence and c) zero sequence impedances of a transmission line.

d) [5 pts] Give at least 3 good reasons/uses for performing fault study calculations.

e) [5 pts] The conductor spacing of transmission lines increases with voltage. What effect does an increase in phase spacing have on the characteristic impedance of the line? Explain.
5) [20 pts] A L-L fault occurs between phases B & C at bus 2 of the network shown. Assume that the prefault voltage at bus 2 is 1.05 per unit. Assume that the voltage at the generator leads corresponding voltages on the transmission line by 30°.

\[ X_1 = X_2 = 0.8 \]  
\[ X_0 = 0.5 \]  
\[ X_0 = 0.7 \text{ p.u.} \]  
\[ X_1 = X_2 = 0.5 \text{ p.u.} \]  
\[ T \text{- Line} \]

a) Draw the sequence impedance networks and connect for the fault given.
b) Thevenize the sequence networks about bus 2, connect for fault, and label all sequence voltages and currents.
c) Solve for \( I_{A0}, I_{A1}, I_{A2}, \) and \( I_c \) flowing in the fault.
d) Solve for \( I_{A0}, I_{A1}, I_{A2}, \) and \( I_a, I_b, I_c \) flowing through bus 1 toward the fault.
6) [20 pts] A medium-length transmission line connects Bus 2 to Bus 3 in a power system. The system base used for calculations is 100 MVA. It is modelled as a \( \pi \)-section. \( R = 0.05 \) p.u. and \( X = 0.15 \) p.u. The half-line charging susceptance is given as 3.0 MVAR at rated voltage. \( V_2 \) is known to be \( 1.0/0^\circ \) p.u. The magnitude of \( V_3 \) is unknown. It is known that the complex power leaving Bus 2 (toward Bus 3) is \( 0.5 + j0.25 \) p.u. When calculating \( P \) & \( Q \), give the correct signs based on the reference directions shown on the figure below. (Don’t forget that \( S = VI^* \) or your instructor will not be very happy).

\[ V_{23} = 0.5 + j0.25 \text{ p.u.} \]

\[ V_2 = 1.0/0^\circ \text{ p.u.} \]

a) Calculate the correct value of susceptance to use for each capacitance in the \( \pi \) equivalent. Calculate the actual value of \( Q_{N2} \) in per unit.

b) Find \( P_2 \) and \( Q_2 \) in per unit.

c) Determine the phasor values of \( I \) and \( V_3 \).

d) Find \( P_3 \), \( Q_3 \) and \( Q_{N3} \) in per unit.

e) Find \( P_{32} \) and \( Q_{32} \) in per unit.