Instructions:

- Closed book, but you are allowed to have one-page single-sided handwritten notes.
- Read all the problems first.
- Attempt to solve first the problems you can, don’t spend too much time on a problem.
- Read carefully the statement and/or circuits of each problem.
- **Write your solutions neatly and box your answers (and box steps for partial credits)**
**Problem 1 (0.40 pu)** A 3-phase 480 V source supplies two balanced loads in parallel: one in Y-connection and the other in Δ-connection. The Y-connected load draws 10 kW at pf of 0.866 lagging and the Δ-connected load 10 kVA at pf of 0.5 leading.

1. (0.15 pu) Determine the real, reactive, and apparent power delivered by the source and draw the power triangles for the source and two loads.
2. (0.15 pu) Calculate the line (i.e., the source) current and respective impedances of the Y-connected load and Δ-connected load.

**Solution Key**

1. \( P_Y = 10 \text{ kW}, \ \text{pf}_Y = 0.866 \text{ lagging} \), thus
   \( S_Y = \frac{P_Y}{\text{pf}_Y} = \frac{10}{0.866} = 11.55 \text{ kVA} \), and
   \( Q_Y = S_Y \cdot \sin(\cos^{-1}(\text{pf}_Y)) = 11.55 \cdot \sin(30°) = 5.77 \text{ kVar} \).

   \( S_\Delta = 10 \text{ kVA}, \ \text{pf}_\Delta = 0.5 \text{ leading} \), thus
   \( P_\Delta = S_\Delta \cdot \text{pf}_\Delta = 10 \cdot 0.5 = 5 \text{ kW} \), and
   \( Q_\Delta = -S_\Delta \cdot \sin(\cos^{-1}(\text{pf}_\Delta)) = -10 \cdot \sin(60°) = 8.66 \text{ kVar} \).

   \( P_S = P_Y + P_\Delta = 15 \text{ kW} \)
   \( Q_S = Q_Y + Q_\Delta = -2.89 \text{ kVar} \)
   \( S_S = (P_S^2 + Q_S^2)^{1/2} = 15.275 \text{ kVA} \)

2. \( I_{\text{line}} = \frac{S_S}{(1.732 \cdot V_{\text{ll}}) / \tan^{-1}(Q_S/P_S)} = \frac{15.275 \text{ kVA}}{(1.732 \cdot 480) / \tan^{-1}(-2.89/15)} = 18.37/10.9° \text{ A} \)

   \( Z_Y = \frac{(V_{\text{ll}}^2 / S_Y) / \cos^{-1}(\text{pf}_Y)}{11.55 \text{ kVA} / \cos^{-1}0.866} = 19.95/30° = 17.275 + j9.975 \Omega \)

   \( Z_\Delta = \frac{(3 \cdot V_{\text{ll}}^2 / S_Y) / \cos^{-1}(\text{pf}_\Delta)}{3 \cdot 480^2 / 10 \text{ kVA} / \cos^{-1}0.5} = 69.12/-60° = 34.56 - j59.9 \Omega \)
**Problem 2** (0.40 pu) A three-zone 3-phase network is shown below. Using base values of 50 kVA and 480 V in Zone 1, draw the pu circuit (0.03 pu) and determine the pu values for the source voltage (0.03 pu) and all the impedances (0.24 pu). Calculate the load current in pu and in amps (0.10 pu).

**Solution Key**

\[
\begin{align*}
S_{\text{base}} &= 50 \text{ kVA} \\
V_{\text{base,1}} &= 480 \text{ V} \\
V_{\text{base,2}} &= 480 \text{ V} (2400/480) = 2400 \text{ V} \\
V_{\text{base,3}} &= 2400 \text{ V} (460/2300) = 480 \text{ V} \\
\text{No change} &
\end{align*}
\]

\[
\begin{align*}
Z_{\text{base,2}} &= V_{\text{base,2}}^2 / S_{\text{base}} = 115.2 \Omega \\
Z_{\text{base,3}} &= V_{\text{base,3}}^2 / S_{\text{base}} = 4.608 \Omega \\
X_{\text{eq} \text{ no change in pu}} &
\end{align*}
\]

\[
\begin{align*}
Z_{\text{line,pu}} &= Z_{\text{line}} / Z_{\text{base}} = 0.00868 \text{ pu} \\
X_{\text{eq2,pu}} &= X_{\text{eq2,old}} (460^2 / 30k) / Z_{\text{base,3}} = 0.153 \text{ pu} \\
Z_{\text{load,pu}} &= Z_{\text{load}} / Z_{\text{base,3}} = 2.17 + j2.17 \text{ pu} \\
\end{align*}
\]

\[
\begin{align*}
I_{L,pu} &= 1/0^\circ / (j1 + j0.00868 + j0.153 + 2.17 + j2.17) = 1/0^\circ / (2.17 + j2.43) = 0.307 / -48^\circ \text{ pu} \\
I_{L,base} &= S_{\text{base}} / (1.732* V_{\text{base,3}}) = 50 k / (1.732* 480) = 60.14 \text{ A} \\
I_{L,amps} &= I_{L,pu} * I_{L,base} = 18.46 / -48^\circ \text{ A}
\end{align*}
\]
**Problem 3 (0.20 pu)** A single-phase 50 kVA, 2300/230 V, 60 Hz distribution transformer has 2 ohm total equivalent leakage reactance and a 2000 ohm magnetizing reactance referred to the high-voltage side. Neglect the copper and core losses. Assume that the rated voltage is applied to the high-voltage side and equal leakage reactances for the primary and referred secondary. Draw the equivalent circuit and determine its parameters in pu for the transformer (0.10 pu). Calculate the open circuit voltage in pu (0.10 pu).

**Solution Key**

\[ S_{\text{base}} = 50 \text{ kVA} \]
\[ V_{1\text{ base}} = 2300 \text{ V} \]
\[ Z_{1\text{ base}} = \frac{V_{1\text{ base}}}{2} / S_{\text{base}} = 105.8 \Omega \]
\[ X_{\text{eq1 pu}} = \frac{1 \text{ ohm}}{Z_{1\text{ base}}} = 0.00945 \text{ pu} \] (2 ohm equally divided between the primary and referred secondary leakage reactance)
\[ X_{\text{m pu}} = \frac{2000 \text{ ohm}}{Z_{1\text{ base}}} = 18.90 \text{ pu} \]

\[ V_1 = 1 \text{ pu} \]
\[ V_2 = V_1 \times 18.90 / (18.90 + 0.00945) = 0.99950 \text{ pu} \text{ or} \]
\[ V_2 = V_1 \times j18.90 / (j18.90 + j0.00945) = 0.99950 / 0^\circ \text{ pu} , \text{ assuming } V_1 = 1 / 0^\circ \text{ pu}. \]