3.2. A 60-MVA, 69.3-kV, three-phase synchronous generator has a synchronous reactance of 15 Ω/phase and negligible armature resistance.

(a) The generator is delivering rated power at 0.8 power factor lagging at the rated terminal voltage to an infinite bus bar. Determine the magnitude of the generated emf per phase and the power angle δ.

(b) If the generated emf is 36 kV per phase, what is the maximum three-phase power that the generator can deliver before losing its synchronism?

(c) The generator is delivering 48 MW to the bus bar at the rated voltage with its field current adjusted for a generated emf of 46 kV per phase. Determine the armature current and the power factor. State whether power factor is lagging or leading?

3.3. A 24,000-kVA, 17.32-kV, 60-Hz, three-phase synchronous generator has a synchronous reactance of 5 Ω/phase and negligible armature resistance.

(a) At a certain excitation, the generator delivers rated load, 0.8 power factor lagging to an infinite bus bar at a line-to-line voltage of 17.32 kV. Determine the excitation voltage per phase.

(b) The excitation voltage is maintained at 13.4 kV/phase and the terminal voltage at 10 kV/phase. What is the maximum three-phase real power that the generator can develop before pulling out of synchronism?

(c) Determine the armature current for the condition of part (b).

3.4. A 34.64-kV, 60-MVA, three-phase salient-pole synchronous generator has a direct axis reactance of 13.5 Ω and a quadrature-axis reactance of 9.333 Ω. The armature resistance is negligible.

(a) Referring to the phasor diagram of a salient-pole generator shown in Figure 3.8, show that the power angle δ is given by

\[ \delta = \tan^{-1}\left(\frac{X_q |I_a| \cos \theta}{|V| + X_q |I_a| \sin \theta}\right) \]

(b) Compute the load angle δ and the per phase excitation voltage E when the generator delivers rated MVA, 0.8 power factor lagging to an infinite bus bar of 34.64-kV line-to-line voltage.

(c) The generator excitation voltage is kept constant at the value found in part (b). Use MATLAB to obtain a plot of the power angle curve, i.e., equation (3.32) over a range of δ = 0:0.05:180°. Use the command \([P_{\text{max}}, k] = \text{max}(P); \ d_{\text{max}} = d(k),\) to obtain the steady-state maximum power \(P_{\text{max}}\) and the corresponding power angle \(d_{\text{max}}\).
3.5. A 150-kVA, 2400/240-V single-phase transformer has the parameters as shown in Figure 3.31.

(a) Determine the equivalent circuit referred to the high-voltage side.

(b) Find the primary voltage and voltage regulation when transformer is operating at full load 0.8 power factor lagging and 240 V.

(c) Find the primary voltage and voltage regulation when the transformer is operating at full-load 0.8 power factor leading.

(d) Verify your answers by running the trans program in MATLAB and obtain the transformer efficiency curve.

3.6. A 60-kVA, 4800/2400-V single-phase transformer gave the following test results:

1. Rated voltage is applied to the low voltage winding and the high voltage winding is open-circuited. Under this condition, the current into the low voltage winding is 2.4 A and the power taken from the 2400 V source is 3456 W.

2. A reduced voltage of 1250 V is applied to the high voltage winding and the low voltage winding is short-circuited. Under this condition, the current flowing into the high voltage winding is 12.5 A and the power taken from the 1250 V source is 4375 W.

(a) Determine parameters of the equivalent circuit referred to the high voltage side.

(b) Determine voltage regulation and efficiency when transformer is operating at full-load, 0.8 power factor lagging, and a terminal voltage of 2400 V.

(c) What is the load kVA for maximum efficiency and the maximum efficiency at 0.8 power factor?

(d) Determine the efficiency when transformer is operating at 3/4 full-load, 0.8 power factor lagging, and a terminal voltage of 2400 V.
3.9. A 400-MVA, 240-kV/24-kV, three-phase Y-Ω transformer has an equivalent series impedance of $1.2 + j6 \, \Omega$ per phase referred to the high-voltage side. The transformer is supplying a three-phase load of 400-MVA, 0.8 power factor lagging at a terminal voltage of 24 kV (line to line) on its low-voltage side. The primary is supplied from a feeder with an impedance of $0.6 + j1.2 \, \Omega$ per phase. Determine the line-to-line voltage at the high-voltage terminals of the transformer and the sending-end of the feeder.

3.10. In Problem 3.9, with transformer rated values as base quantities, express all impedances in per-unit. Working with per-unit values, determine the line-to-line voltage at the high-voltage terminals of the transformer and the sending-end of the feeder.

3.14. The one-line diagram of a power system is shown in Figure 3.33.

![Figure 3.33](image)

*FIGURE 3.33*
One-line diagram for Problem 3.14

The three-phase power and line-line ratings are given below.
$G$: 80 MVA 22 kV  $X = 24\%$
$T_1$: 50 MVA 22/220 kV  $X = 10\%$
$T_2$: 40 MVA 220/22 kV  $X = 6.0\%$
$T_3$: 40 MVA 22/110 kV  $X = 6.4\%$
Line 1: 220 kV  $X = 121 \, \Omega$
Line 2: 110 kV  $X = 42.35 \, \Omega$
$M$: 68.85 MVA 20 kV  $X = 22.5\%$
Load: 10 Mvar 4 kV  $\Delta$-connected capacitors

The three-phase ratings of the three-winding transformer are

Primary:  $Y$-connected 40 MVA, 110 kV
Secondary: $Y$-connected 40 MVA, 22 kV
Tertiary: $\Delta$-connected 15 MVA, 4 kV

The per phase measured reactances at the terminal of a winding with the second one short-circuited and the third open-circuited are

$Z_{ps} = 9.6\%$ 40 MVA, 110 kV/22 kV
$Z_{pt} = 7.2\%$ 40 MVA, 110 kV/4 kV
$Z_{st} = 12\%$ 40 MVA, 22 kV/4 kV

Obtain the T-circuit equivalent impedances of the three-winding transformer to the common 100-MVA base. Draw an impedance diagram showing all impedances in per-unit on a 100-MVA base. Choose 22 kV as the voltage base for generator.

3.15. The three-phase power and line-line ratings of the electric power system shown in Figure 3.34 are given below.

![Diagram](image)

**FIGURE 3.34**
One-line diagram for Problem 3.15

$G_1$: 60 MVA 20 kV  $X = 9\%$
$T_1$: 50 MVA 20/200 kV  $X = 10\%$
$T_2$: 50 MVA 200/20 kV  $X = 10\%$
$M$: 43.2 MVA 18 kV  $X = 8\%$
Line: 200 kV  $Z = 120 + j200 \, \Omega$

(a) Draw an impedance diagram showing all impedances in per-unit on a 100-MVA base. Choose 20 kV as the voltage base for generator.

(b) The motor is drawing 45 MVA, 0.80 power factor lagging at a line-to-line terminal voltage of 18 kV. Determine the terminal voltage and the internal emf of the generator in per-unit and in kV.
3.17. The one-line diagram of a three-phase power system is as shown in Figure 3.36. The transformer reactance is 20 percent on a base of 100 MVA, 23/115 kV and the line impedance is \( Z = j66.125 \Omega \). The load at bus 2 is \( S_2 = 184.8 \text{ MW} + j6.6 \text{ Mvar} \), and at bus 3 is \( S_3 = 0 \text{ MW} + j20 \text{ Mvar} \). It is required to hold the voltage at bus 3 at 115\( \pm 0^\circ \) kV. Working in per-unit, determine the voltage at buses 2 and 1.

\[ V_2 \quad j66.125 \Omega \quad V_3 \]

\( S_2 \)

\( S_3 \)

**FIGURE 3.36**
One-line diagram for Problem 3.17