Three-Phase Power Calculations

100 Questions with Answers: Real, Reactive, Complex, Apparent Power & Power Factor

1. What is the formula for real (active) power in a balanced three-phase system?

Answer: $P = \sqrt{3} \times V_L \times I_L \times \cos\varphi$, or equivalently $P = 3 \times V_\varphi \times I_\varphi \times \cos\varphi$, where VL is line voltage, IL is line current, Vφ is phase voltage, Iφ is phase current, and cos φ is the power factor.

2. What is reactive power in a three-phase system and what is its unit?

Answer: Reactive power (Q) is the power stored and released by inductive or capacitive elements, measured in volt-amperes reactive (VAR). Formula: $Q = \sqrt{3} \times V_L \times I_L \times \sin\varphi = 3 \times V_\varphi \times I_\varphi \times \sin\varphi$.

3. Define apparent power in a three-phase system.

Answer: Apparent power (S) is the total power supplied by the source, combining real and reactive power. $S = \sqrt{3} \times V_L \times I_L = 3 \times V_\varphi \times I_\varphi$, measured in volt-amperes (VA).

4. What is the relationship between real, reactive, and apparent power?

Answer: $S^2 = P^2 + Q^2$, or $S = \sqrt{P^2 + Q^2}$. This forms the power triangle where S is the hypotenuse.

5. Define power factor in a three-phase system.

Answer: Power factor (PF) = cos φ = P / S = Real Power / Apparent Power. It ranges from 0 to 1 and indicates how effectively the load converts apparent power into useful real power.

6. What is the power factor of a purely resistive three-phase load?

Answer: PF = 1 (unity power factor), because $\varphi = 0°$, $\cos 0° = 1$, meaning all apparent power is converted to real power and Q = 0.

7. What is the power factor of a purely inductive three-phase load?

Answer: PF = 0 (lagging), because $\varphi = 90°$, $\cos 90° = 0$. All power is reactive (Q = S) and no real power is consumed.

8. What is the phase voltage relationship to line voltage in a balanced three-phase star (Y) system?

Answer: $V_L = \sqrt{3} \times V_\varphi$, or $V_\varphi = V_L / \sqrt{3}$. For a 400 V line voltage, the phase voltage = $400/\sqrt{3} \approx 230.9$ V.

9. What is the current relationship in a balanced three-phase star (Y) connected system?

Answer: In a Y-connected system, the line current equals the phase current: $I_L = I_\varphi$.

10. What is the current relationship in a balanced three-phase delta (Δ) connected system?

Answer: In a Δ-connected system, $I_L = \sqrt{3} \times I_\varphi$, or $I_\varphi = I_L / \sqrt{3}$. Line current is √3 times the phase current.

11. A balanced Y-connected load has a phase impedance of Z = 10 + j6 Ω. If VL = 400 V, find the phase current.

Answer: $|Z| = \sqrt{10^2 + 6^2} = \sqrt{136} \approx 11.66$ Ω. $V_\varphi = 400/\sqrt{3} \approx 230.94$ V. $I_\varphi = I_L = V_\varphi/|Z| = 230.94/11.66 \approx 19.81$ A.

12. For the load in Q11, calculate the real power consumed.

Answer: $\cos\varphi = R/|Z| = 10/11.66 \approx 0.858$ (lagging). $P = 3 \times V_\varphi \times I_\varphi \times \cos\varphi = 3 \times 230.94 \times 19.81 \times 0.858 \approx 11{,}788$ W ≈ 11.79 kW.

13. For the load in Q11, calculate the reactive power.

Answer: $\sin\varphi = X/|Z| = 6/11.66 \approx 0.515$. $Q = 3 \times V_\varphi \times I_\varphi \times \sin\varphi = 3 \times 230.94 \times 19.81 \times 0.515 \approx$ 7,079 VAR ≈ 7.08 kVAR.

14. For the load in Q11, calculate the apparent power.

Answer: $S = 3 \times V_\varphi \times I_\varphi = 3 \times 230.94 \times 19.81 \approx$ 13,735 VA ≈ 13.74 kVA. Verify: $S = \sqrt{P^2 + Q^2} = \sqrt{11788^2 + 7079^2} \approx$ 13,736 VA ✓

15. A balanced Y-connected resistive load of 8 Ω per phase is connected to a 415 V, 50 Hz supply. Find the line current.

Answer: $V_\varphi = 415/\sqrt{3} \approx 239.6$ V. $I_\varphi = I_L = V_\varphi/R = 239.6/8 \approx 29.95$ A.

16. What is the total real power for the load in Q15?

Answer: $P = 3 \times I_\varphi^2 \times R = 3 \times 29.95^2 \times 8 = 3 \times 897 \times 8 \approx$ 21,528 W ≈ 21.53 kW. Or $P = \sqrt{3} \times V_L \times I_L = \sqrt{3} \times 415 \times 29.95 \approx$ 21,530 W ✓

17. A Y-connected load draws 15 A per phase from a 380 V three-phase supply at a power factor of 0.8 lagging. Calculate P, Q, and S.

Answer: $V_\varphi = 380/\sqrt{3} \approx 219.4$ V. $S = 3 \times 219.4 \times 15 \approx$ 9,873 VA. $P = S \times 0.8 \approx$ 7,898 W. $Q = S \times \sin(\cos^{-1}0.8) = 9{,}873 \times 0.6 \approx$ 5,924 VAR.

18. Express the complex power S for a Y-connected load with Z = 5∠30° Ω per phase at VL = 200 V.

Answer: $V_\varphi = 200/\sqrt{3} \approx 115.5$ V. $I_\varphi = 115.5/5 = 23.1$ A. $S = 3 \times V_\varphi \times I_\varphi\angle\varphi = 3 \times 115.5 \times 23.1\angle 30°$ ≈ 8,012∠30° VA. So P ≈ 6,938 W, Q ≈ 4,006 VAR.

19. A balanced Y load has R = 12 Ω and XL = 9 Ω per phase. VL = 440 V. Find the power factor angle.

Answer: $\varphi = \tan^{-1}(X_L/R) = \tan^{-1}(9/12) = \tan^{-1}(0.75) \approx 36.87°$. PF = cos(36.87°) = 0.8 lagging.

20. For the load in Q19, find the three-phase apparent power.

Answer: $|Z| = \sqrt{12^2 + 9^2} = \sqrt{225} = 15$ Ω. $V_\varphi = 440/\sqrt{3} \approx 254.03$ V. $I_L = I_\varphi = 254.03/15 \approx 16.94$ A. $S = \sqrt{3} \times 440 \times 16.94 \approx$ 12,909 VA ≈ 12.91 kVA.

21. A balanced delta-connected load has Z = 30∠45° Ω per phase. VL = 400 V. Find the phase current.

Answer: In delta, $V_\varphi = V_L = 400$ V. $I_\varphi = V_\varphi/|Z| = 400/30 \approx 13.33$ A.

22. For the load in Q21, find the line current.

Answer: $I_L = \sqrt{3} \times I_\varphi = \sqrt{3} \times 13.33 \approx 23.09$ A.

23. For the load in Q21, calculate the total real power.

Answer: PF = cos(45°) ≈ 0.707. $P = \sqrt{3} \times V_L \times I_L \times \cos\varphi = \sqrt{3} \times 400 \times 23.09 \times 0.707 \approx$ 11,313 W ≈ 11.31 kW. Or $P = 3 \times I_\varphi^2 \times R = 3 \times 13.33^2 \times (30 \cos 45°) = 3 \times 177.7 \times 21.21 \approx$ 11,310 W ✓

24. For the load in Q21, calculate the total reactive power.

Answer: $Q = \sqrt{3} \times V_L \times I_L \times \sin\varphi = \sqrt{3} \times 400 \times 23.09 \times \sin(45°) = \sqrt{3} \times 400 \times 23.09 \times 0.707 \approx$ 11,313 VAR ≈ 11.31 kVAR.

25. A delta-connected load of 20 + j15 Ω per phase is supplied at 415 V. Find P and Q.

Answer: $|Z| = \sqrt{400 + 225} = 25$ Ω. $I_\varphi = 415/25 = 16.6$ A. $\cos\varphi = 20/25 = 0.8$, $\sin\varphi = 0.6$. $P = 3 \times 16.6^2 \times 20 = 3 \times 275.6 \times 20 \approx$ 16,536 W ≈ 16.54 kW. $Q = 3 \times 16.6^2 \times 15 \approx$ 12,402 VAR ≈ 12.40 kVAR.

26. How does the power consumed by a delta-connected load compare to an equivalent Y-connected load with the same line voltage?

Answer: $P_{delta} = 3 \times P_Y$. Because in delta, each phase sees the full line voltage ($V_{\varphi\_delta} = V_L$), while in Y each phase sees $V_L/\sqrt{3}$. The delta load consumes 3 times more power for the same impedance value.

27. A balanced delta load draws 10 kW at 0.75 power factor lagging from a 380 V supply. Find the line current.

Answer: $P = \sqrt{3} \times V_L \times I_L \times PF \rightarrow I_L = P / (\sqrt{3} \times V_L \times PF) = 10{,}000 / (\sqrt{3} \times 380 \times 0.75) = 10{,}000 / 494.0 \approx 20.24$ A.

28. For the load in Q27, find the reactive power.

Answer: $\sin \varphi = \sin(\cos^{-1}0.75) \approx 0.661$. $Q = P \times \tan \varphi = 10{,}000 \times (0.661/0.75) = 10{,}000 \times 0.8819 \approx 8{,}819$ VAR ≈ 8.82 kVAR.

29. For the load in Q27, find the apparent power.

Answer: $S = P / PF = 10{,}000 / 0.75 \approx 13{,}333$ VA ≈ 13.33 kVA. Or $S = \sqrt{P^2 + Q^2} = \sqrt{10000^2 + 8819^2} \approx 13{,}333$ VA ✓

30. A delta load has phase impedance of 60 Ω purely resistive. VL = 400 V. Find the total power.

Answer: $I_\varphi = V_L/R = 400/60 \approx 6.667$ A. $P = 3 \times I_\varphi^2 \times R = 3 \times 44.44 \times 60 = 8{,}000$ W = 8 kW. Or $P = 3 \times V_L^2/R = 3 \times 160{,}000/60 = 8{,}000$ W ✓

31. Define complex power S in phasor notation.

Answer: $S = P + jQ$ (VA), where P is real power (W) and Q is reactive power (VAR). For inductive loads $Q > 0$, for capacitive loads $Q < 0$. Also $S = V \times I^*$ where I^* is the complex conjugate of the current phasor.

32. A three-phase load has complex power S = 12 + j9 kVA. Find P, Q, S (magnitude), and PF.

Answer: P = 12 kW, Q = 9 kVAR (inductive). $|S| = \sqrt{12^2 + 9^2} = \sqrt{144 + 81} = \sqrt{225} = 15$ kVA. $PF = P/|S| = 12/15 = 0.8$ lagging.

33. Two three-phase loads are connected in parallel: Load 1: S1 = 10 + j6 kVA; Load 2: S2 = 8 – j4 kVA. Find total S.

Answer: $S_{total} = S_1 + S_2 = (10+8) + j(6-4) = 18 + j2$ kVA. $|S| = \sqrt{18^2 + 2^2} = \sqrt{328} \approx 18.11$ kVA. $PF = 18/18.11 \approx 0.994$ lagging.

34. A generator supplies S = 50∠36.87° kVA to a three-phase load. Find P and Q.

Answer: $P = 50 \times \cos(36.87°) = 50 \times 0.8 = 40$ kW. $Q = 50 \times \sin(36.87°) = 50 \times 0.6 = 30$ kVAR (inductive, lagging).

35. How is complex power computed from voltage and current phasors?

Answer: $S = V \times I^*$ per phase (single-phase equivalent). For three-phase: $S_{3\varphi} = 3 \times V_\varphi \times I_\varphi^* = \sqrt{3} \times V_L\angle(\varphi_v) \times I_L\angle(-\varphi_i)$. The conjugate of I ensures the sign of Q is correct (positive for inductive loads).

36. A three-phase Y-load: Vφ = 120∠0° V, Iφ = 10∠-30° A per phase. Find S per phase and total S.

Answer: $S_{phase} = V_\varphi \times I_\varphi^* = 120\angle 0° \times 10\angle +30° = 1200\angle 30°$ VA $= 1039 + j600$ VA. Total $S_{3\varphi} = 3 \times 1200\angle 30° = 3600\angle 30°$ VA $= 3117 + j1800$ VA.

37. What does a negative value of Q (reactive power) indicate?

Answer: $Q < 0$ indicates a capacitive load. The load is supplying reactive power to the system (leading power factor). Capacitive loads generate reactive power rather than absorbing it.

38. Three loads connected to a 480 V three-phase bus: L1 = 20 kW at PF 1.0; L2 = 30 kW at PF 0.9 lag; L3 = 15 kW at PF 0.8 lead. Find total P, Q, and |S|.

Answer: P_{total} = 20+30+15 = 65 kW. Q1 = 0; Q2 = 30×tan($\cos^{-1}$0.9) = 30×0.4843 = 14.53 kVAR; Q3 = -15×tan($\cos^{-1}$0.8) = -15×0.75 = -11.25 kVAR. Q_{total} = 0+14.53-11.25 = 3.28 kVAR. |S| = $\sqrt{65^2+3.28^2}$ ≈ 65.08 kVA.

39. Express the power triangle relationship mathematically.

Answer: The power triangle has sides P (adjacent), Q (opposite), and S (hypotenuse) with angle φ. Relations: $P = S \cos \varphi$; $Q = S \sin \varphi$; $\tan \varphi = Q/P$; $S = P/\cos \varphi = Q/\sin \varphi = \sqrt{P^2+Q^2}$.

40. A three-phase motor draws 45 kVA at 0.85 PF lagging. Find P and Q.

Answer: P = S × PF = 45 × 0.85 = 38.25 kW. sin φ = $\sqrt{1-0.85^2}$ = $\sqrt{1-0.7225}$ = $\sqrt{0.2775}$ ≈ 0.5268. Q = S × sin φ = 45 × 0.5268 ≈ 23.71 kVAR (lagging/inductive).

41. A balanced three-phase load draws 60 kW at a power factor of 0.6 lagging. What is the apparent power?

Answer: S = P / PF = 60,000 / 0.6 = 100,000 VA = 100 kVA.

42. A three-phase load of 80 kVA operates at 0.9 power factor lagging. Determine real and reactive power.

Answer: P = 80 × 0.9 = 72 kW. Q = 80 × sin($\cos^{-1}$0.9) = 80 × 0.4359 ≈ 34.87 kVAR.

43. What is the power factor if a three-phase load has P = 30 kW and Q = 40 kVAR?

Answer: |S| = $\sqrt{30^2 + 40^2}$ = $\sqrt{2500}$ = 50 kVA. PF = P/S = 30/50 = 0.6 lagging (since Q > 0, load is inductive).

44. What distinguishes lagging from leading power factor?

Answer: Lagging PF: current lags voltage (inductive load, Q > 0). Leading PF: current leads voltage (capacitive load, Q < 0). Unity PF: current in phase with voltage (resistive load, Q = 0).

45. A three-phase induction motor has P = 75 kW and operates at PF = 0.85 lag from a 415 V supply. Find the line current.

Answer: S = P/PF = 75,000/0.85 ≈ 88,235 VA. IL = S/($\sqrt{3}$ × VL) = 88,235/($\sqrt{3}$ × 415) ≈ 88,235/718.7 ≈ 122.8 A.

46. A three-phase load draws IL = 50 A from a 380 V supply. The real power is 25 kW. Find the power factor.

Answer: S = $\sqrt{3}$ × VL × IL = $\sqrt{3}$ × 380 × 50 ≈ 32,909 VA. PF = P/S = 25,000/32,909 ≈ 0.760.

47. If φ = 53.13°, is the power factor leading or lagging, and what is its value?

Answer: PF = cos(53.13°) = 0.6. The sign depends on the load: if inductive (current lags), it is 0.6 lagging; if capacitive (current leads), it is 0.6 leading.

48. A three-phase system has P = 100 kW, Q = 0 kVAR. What is the power factor and what type of load is it?

Answer: PF = P/S = 100/100 = 1.0 (unity). Q = 0 means the load is purely resistive with no reactive component.

49. The power factor of a three-phase load is 0.707 lagging. The apparent power is 20 kVA. Find P and Q.

Answer: P = 20 × 0.707 = 14.14 kW. sin φ = sin(45°) = 0.707. Q = 20 × 0.707 = 14.14 kVAR lagging.

50. A wattmeter reads 15 kW in a three-phase circuit where VL = 400 V, IL = 30 A. Find the power factor.

Answer: $S = \sqrt{3} \times 400 \times 30 \approx 20{,}785$ VA. $PF = P/S = 15{,}000/20{,}785 \approx 0.722$.

51. A balanced three-phase star-connected load consists of Z = 8 + j6 Ω per phase connected to a 415 V, 50 Hz system. Calculate IL, P, Q, S, and PF.

Answer: $|Z| = 10\ \Omega$. $V\varphi = 415/\sqrt{3} \approx 239.6$ V. $IL = I\varphi = 239.6/10 = 23.96$ A. $PF = 8/10 = 0.8$ lag. $P = 3\times239.6\times23.96\times0.8 \approx 13{,}806$ W ≈ 13.81 kW. $Q = 3\times239.6\times23.96\times0.6 \approx 10{,}354$ VAR ≈ 10.35 kVAR. $S = 3\times239.6\times23.96 \approx 17{,}208$ VA ≈ 17.21 kVA.

52. A delta load of Z = 15∠-30° Ω (capacitive) is connected to a 400 V supply. Find P, Q, and S.

Answer: $I\varphi = 400/15 \approx 26.67$ A. $IL = \sqrt{3} \times 26.67 \approx 46.19$ A. $PF = \cos(30°) \approx 0.866$ leading. $P = \sqrt{3} \times 400 \times 46.19 \times 0.866 \approx 27{,}711$ W ≈ 27.71 kW. $Q = \sqrt{3} \times 400 \times 46.19 \times 0.5 \approx 16{,}007$ VAR ≈ -16.0 kVAR (capacitive). $S = \sqrt{3} \times 400 \times 46.19 \approx 32{,}003$ VA ≈ 32.0 kVA.

53. Two balanced three-phase loads in parallel: Load A draws 50 kW at 0.8 PF lag; Load B draws 30 kW at 0.9 PF lag. Find total P, Q, S, and combined PF.

Answer: $QA = 50\times(0.6/0.8) = 37.5$ kVAR. $QB = 30\times(\sqrt{(1-0.81)}/0.9) = 30\times0.4843/0.9 = 14.53$ kVAR. P = 80 kW. Q = 52.03 kVAR. $S = \sqrt{(80^2+52.03^2)} \approx 95.53$ kVA. $PF = 80/95.53 \approx 0.838$ lag.

54. A 415 V three-phase motor develops 20 hp mechanical output with 90% efficiency and 0.85 PF lag. Find the line current. (1 hp = 746 W)

Answer: $P_{out} = 20 \times 746 = 14{,}920$ W. $P_{in} = 14{,}920/0.90 = 16{,}578$ W. $S = P_{in}/PF = 16{,}578/0.85 = 19{,}503$ VA. $IL = S/(\sqrt{3} \times 415) = 19{,}503/718.7 \approx 27.1$ A.

55. In a balanced three-phase system, VL = 11 kV, IL = 100 A, PF = 0.95 lag. Calculate P, Q, and S.

Answer: $S = \sqrt{3} \times 11{,}000 \times 100 \approx 1{,}904{,}941$ VA ≈ 1.905 MVA. $P = 1.905 \times 0.95 \approx 1.810$ MW. $\sin\varphi = \sqrt{(1-0.9025)} \approx 0.3122$. $Q = 1.905 \times 0.3122 \approx 0.595$ MVAR.

56. A three-phase transformer supplies a load of S = 500 kVA at 0.8 PF lagging, 11 kV. Find P, Q, and IL.

Answer: $P = 500 \times 0.8 = 400$ kW. $Q = 500 \times 0.6 = 300$ kVAR. $IL = S/(\sqrt{3} \times VL) = 500{,}000/(\sqrt{3} \times 11{,}000) = 500{,}000/19{,}053 \approx 26.25$ A.

57. Find the complex power per phase for a Y-connected load: Z = 10∠60° Ω, VL = 200 V.

Answer: $V\varphi = 200/\sqrt{3} \approx 115.47$ V. $I\varphi = 115.47/10 = 11.547$ A. $S_{phase} = V\varphi \times I\varphi\angle60°$ (since V leads I by φ = 60°) = $115.47 \times 11.547\angle60° = 1333\angle60°$ VA = 666.5 + j1154.7 VA.

58. A balanced three-phase system supplies a load where each phase absorbs 2 kW at 0.7 PF lagging. Find total P, Q, and S.

Answer: $P = 3 \times 2 = 6$ kW. Per phase: $Q_{phase} = P_{phase} \times \tan(\cos^{-1}0.7) = 2000 \times 1.0202 \approx 2040$ VAR. $Q_{total} = 3 \times 2040 = 6{,}122$ VAR ≈ 6.12 kVAR. $S_{total} = 6000/0.7 \approx 8{,}571$ VA ≈ 8.57 kVA.

59. A Y-connected capacitive load: each phase has R = 10 Ω, XC = 10 Ω. VL = 346 V. Find P, Q, and PF.

Answer: $|Z| = \sqrt{(10^2 + 10^2)} = \sqrt{200} \approx 14.14\ \Omega$. $V\varphi = 346/\sqrt{3} = 200$ V. $I\varphi = 200/14.14 \approx 14.14$ A. $P = 3 \times 14.14^2 \times 10 = 6{,}000$ W = 6 kW. $Q = 3 \times 14.14^2 \times (-10) = -6{,}000$ VAR = -6 kVAR (capacitive). $PF = \cos(45°) = 0.707$ leading.

60. What is the per-phase equivalent circuit approach for analyzing balanced three-phase loads?

Answer: In a balanced three-phase system, we can analyze one phase (usually phase A) and multiply by 3 for total 3-phase power. For Y loads, use $V_\varphi = V_L/\sqrt{3}$ and $I_\varphi = I_L$. For delta loads, convert to equivalent Y ($Z_Y = Z_\Delta/3$), solve, then convert back if needed.

61. A 3-phase generator rated 10 MVA, 11 kV, 0.8 PF lag delivers full load power. Find P, Q, and S.

Answer: S = 10 MVA. P = 10 × 0.8 = 8 MW. Q = 10 × sin($\cos^{-1}$0.8) = 10 × 0.6 = 6 MVAR. These represent the maximum rated outputs at rated power factor.

62. What is the three-phase power formula in terms of line quantities only?

Answer: $P = \sqrt{3} \times V_L \times I_L \times \cos\varphi$. $Q = \sqrt{3} \times V_L \times I_L \times \sin\varphi$. $S = \sqrt{3} \times V_L \times I_L$. These formulas apply to both Y and delta connections when using line voltage and line current.

63. A three-phase system has VL = 6.6 kV and feeds a load of 3 MW at 0.85 PF. Find Q and S.

Answer: S = 3/0.85 ≈ 3.529 MVA. $\sin\varphi = \sqrt{1-0.7225} \approx 0.5268$. Q = 3.529 × 0.5268 ≈ 1.858 MVAR.

64. Define the power angle φ and its significance in three-phase power calculations.

Answer: φ is the phase angle between the voltage and current phasors. cos φ = PF determines how much of apparent power is useful real power. tan φ = Q/P gives the ratio of reactive to real power. The sign of φ determines leading (capacitive) or lagging (inductive) behavior.

65. A factory's three-phase supply is 440 V, 50 Hz. It has three loads: L1 = 10 kW (PF 1.0); L2 = 15 kW (PF 0.8 lag); L3 = 8 kW (PF 0.6 lag). Find total line current.

Answer: Q1 = 0; Q2 = 15×0.75 = 11.25 kVAR; Q3 = 8×(0.8/0.6) = 10.67 kVAR. P = 33 kW, Q = 21.92 kVAR. $S = \sqrt{33^2 + 21.92^2} \approx 39.55$ kVA. $I_L = 39{,}550/(\sqrt{3} \times 440) \approx 51.91$ A.

66. Two three-phase loads: Load 1 is 100 kVA, 0.7 PF lag; Load 2 is 50 kW, 0.8 PF lead. Find combined PF.

Answer: P1 = 70 kW, Q1 = 100×sin($\cos^{-1}$0.7) = 71.41 kVAR. P2 = 50 kW, Q2 = -50×(0.6/0.8) = -37.5 kVAR. P = 120 kW, Q = 33.91 kVAR. $S = \sqrt{120^2 + 33.91^2} \approx 124.69$ kVA. PF = 120/124.69 ≈ 0.962 lag.

67. How is power measured using the two-wattmeter method in a three-phase system?

Answer: Total P = W1 + W2 (sum of both wattmeter readings). Reactive power: $Q = \sqrt{3} \times (W1 - W2)$. Power factor: $PF = \cos[\tan^{-1}(\sqrt{3} \times (W1-W2)/(W1+W2))]$. If one wattmeter reads negative, it must be reversed and subtracted.

68. In the two-wattmeter method, W1 = 8 kW and W2 = 4 kW. Find P, Q, and PF.

Answer: P = W1 + W2 = 12 kW. $Q = \sqrt{3} \times (W1 - W2) = \sqrt{3} \times 4 = 6.928$ kVAR. $\varphi = \tan^{-1}(6.928/12) = \tan^{-1}(0.577) = 30°$. PF = cos(30°) ≈ 0.866 lagging.

69. In the two-wattmeter method, W1 = 5 kW and W2 = -2 kW. Find P and Q.

Answer: P = 5 + (-2) = 3 kW (the negative reading means reverse the wattmeter connections). $Q = \sqrt{3} \times (5-(-2)) = \sqrt{3} \times 7 \approx 12.12$ kVAR. This indicates a highly inductive load.

70. What is the condition in the two-wattmeter method when PF = 0.5?

Answer: When PF = 0.5 (φ = 60°), one wattmeter reads zero (W2 = 0). When PF < 0.5, one wattmeter reads negative. When PF = 1.0, both wattmeters read equal positive values (W1 = W2).

71. A balanced three-phase Y load: R = 6 Ω, L = 25.5 mH per phase, f = 50 Hz, VL = 415 V. Find P, Q, S.

Answer: $X_L = 2\pi \times 50 \times 0.0255 \approx 8\ \Omega$. $|Z| = \sqrt{36 + 64} = 10\ \Omega$. $V_\varphi = 415/\sqrt{3} \approx 239.6$ V. $I_\varphi = 23.96$ A. $P = 3 \times 23.96^2 \times 6 \approx 10{,}375$ W. $Q = 3 \times 23.96^2 \times 8 \approx 13{,}833$ VAR. $S = 3 \times 239.6 \times 23.96 \approx 17{,}225$ VA.

72. A three-phase delta load: Z = 24 – j18 Ω per phase (capacitive). VL = 400 V. Find P, Q, PF.

Answer: $|Z| = \sqrt{576 + 324} = 30\ \Omega$. $\cos\varphi = 24/30 = 0.8$, $\sin\varphi = 0.6$. $I_\varphi = 400/30 \approx 13.33$ A. $P = 3 \times 13.33^2 \times 24 \approx 12{,}800$ W = 12.8 kW. $Q = -3 \times 13.33^2 \times 18 \approx -9{,}600$ VAR = -9.6 kVAR (capacitive). PF = 0.8 leading.

73. Calculate the line current for a 3φ load: S = 200 kVA, VL = 11 kV.

Answer: $I_L = S / (\sqrt{3} \times V_L) = 200{,}000 / (\sqrt{3} \times 11{,}000) = 200{,}000 / 19{,}053 \approx 10.5$ A.

74. A balanced 3φ Y load dissipates 36 kW total. Each phase has R = 16 Ω. Find Vφ and VL.

Answer: $P_{phase} = 36/3 = 12$ kW. $I_\varphi^2 \times R = 12{,}000 \rightarrow I_\varphi = \sqrt{12000/16} = \sqrt{750} \approx 27.39$ A. $V_\varphi = I_\varphi \times R = 27.39 \times 16 \approx 438.2$ V. $V_L = \sqrt{3} \times V_\varphi \approx 759$ V.

75. A three-phase motor load: P = 22 kW, Q = 16.5 kVAR. Find S, PF, and φ.

Answer: $S = \sqrt{22^2 + 16.5^2} = \sqrt{484 + 272.25} = \sqrt{756.25} = 27.5$ kVA. PF = 22/27.5 = 0.8 lagging. $\varphi = \cos^{-1}(0.8) = 36.87°$.

76. Three single-phase loads, each 5 kVA at PF = 0.9 lag, are connected in a balanced three-phase system. Find total 3φ P and Q.

Answer: Total S = 3 × 5 = 15 kVA. P = 15 × 0.9 = 13.5 kW. $\sin\varphi = \sqrt{1-0.81} \approx 0.4359$. Q = 15 × 0.4359 ≈ 6.54 kVAR.

77. A 3φ system: VL = 230 V (low voltage), load takes 10 A per line at 0.75 PF. Find P and Q.

Answer: $P = \sqrt{3} \times 230 \times 10 \times 0.75 \approx 2{,}990$ W ≈ 2.99 kW. $\sin\varphi = \sqrt{1-0.5625} \approx 0.6614$. $Q = \sqrt{3} \times 230 \times 10 \times 0.6614 \approx 2{,}638$ VAR ≈ 2.64 kVAR.

78. If the line voltage is 400 V and the load is purely capacitive (Z = -j20 Ω per phase, delta), find P, Q, and S.

Answer: $I_\varphi = 400/20 = 20$ A. $I_L = \sqrt{3} \times 20 \approx 34.64$ A. P = 0 W (purely reactive). $S = \sqrt{3} \times 400 \times 34.64 = 24{,}000$ VA = 24 kVA. Q = -24 kVAR (capacitive, leading).

79. A power system bus has P = 500 MW, Q = 200 MVAR. What is PF and |S|?

Answer: $|S| = \sqrt{500^2 + 200^2} = \sqrt{250{,}000 + 40{,}000} = \sqrt{290{,}000} \approx 538.5$ MVA. PF = 500/538.5 ≈ 0.929 lagging.

80. A Y-connected source with Vφ = 120∠0° V feeds a Y-load Z = 5 + j5 Ω. Find S_3φ.

Answer: $I_\varphi = 120/(5+j5) = 120/(7.071\angle 45°) = 16.97\angle -45°$ A. $S_{3\varphi} = 3 \times V_\varphi \times I_\varphi^* = 3 \times 120\angle 0° \times 16.97\angle +45° = 3 \times 2036\angle 45° = 6108\angle 45°$ VA = 4320 + j4320 VA. P = 4.32 kW, Q = 4.32 kVAR.

81. A three-phase system feeds parallel loads: L1: 20 kVA, PF 0.8 lag; L2: 10 kVA, PF 0.6 lag; L3: 15 kVA, PF = 1.0. Find the total complex power.

Answer: $S_1 = 20\angle 36.87° = 16 + j12$ kVA. $S_2 = 10\angle 53.13° = 6 + j8$ kVA. $S_3 = 15 + j0$ kVA. $S_{total} = (16+6+15) + j(12+8+0) = 37 + j20$ kVA. $|S| = \sqrt{37^2 + 20^2} \approx 42.10$ kVA. PF = 37/42.10 ≈ 0.879 lag.

82. For a balanced three-phase system, if P increases while S remains constant, what happens to PF and Q?

Answer: PF = P/S increases (improves). Since $S^2 = P^2 + Q^2$, and S is constant, $Q = \sqrt{S^2 - P^2}$ decreases. A higher P for the same S means less reactive power and better utilization of the supply.

83. What is the significance of unity power factor in three-phase systems?

Answer: At unity PF: P = S (all apparent power is real), Q = 0, minimum line current for given real power, minimum conductor losses (I^2R), and maximum efficiency. Generators and lines are utilized to their maximum capacity for useful work.

84. A Y-connected load: Z1 = 10∠0°, Z2 = 10∠30°, Z3 = 10∠-30° Ω in each of phases A, B, C respectively connected to a 400 V balanced source. Is this a balanced load?

Answer: No, this is an unbalanced load because the three phase impedances are different. The phase angles and magnitudes may differ, creating unequal currents and requiring full three-phase analysis (cannot use single-phase equivalent and multiply by 3).

85. A three-phase induction motor: rated 15 kW, η = 85%, PF = 0.8 lag, VL = 415 V. Find the apparent power input and line current.

Answer: P_input = 15,000/0.85 ≈ 17,647 W. S = P_input/PF = 17,647/0.8 ≈ 22,059 VA. IL = S/(√3 × 415) = 22,059/718.7 ≈ 30.7 A.

86. What is the formula for three-phase power in terms of per-phase impedance for a Y-connected load?

Answer: $P_{3\varphi} = 3 \times V_\varphi^2/R$ (where R is per-phase resistance). Or more generally: $P = 3 \times |I_\varphi|^2 \times R = 3 \times (V_\varphi/|Z|)^2 \times R$. For delta: $P = 3 \times V_L^2/R_\Delta$ where R_Δ is the delta phase resistance.

87. A 33 kV, three-phase feeder carries 50 A at 0.9 PF. Calculate the power transmitted.

Answer: P = √3 × 33,000 × 50 × 0.9 = √3 × 33,000 × 45 ≈ 2,572,274 W ≈ 2.57 MW.

88. How is total reactive power of a three-phase system calculated from per-phase data?

Answer: Q_total = 3 × Q_phase = 3 × Vφ × Iφ × sin φ = √3 × VL × IL × sin φ. For Y: $Q = 3 \times |I_\varphi|^2 \times X_{phase}$. For delta: $Q = 3 \times V_L^2/X_\Delta$, where X_Δ is per-phase reactance.

89. Calculate the per-phase real and reactive power: Vφ = 240 V, Iφ = 15 A, φ = 40°.

Answer: P_phase = Vφ × Iφ × cos φ = 240 × 15 × cos(40°) = 3,600 × 0.766 ≈ 2,758 W. Q_phase = 240 × 15 × sin(40°) = 3,600 × 0.643 ≈ 2,314 VAR. Total 3φ: P = 8,274 W, Q = 6,942 VAR.

90. A 400 V, 3φ system: Z_Y = 4 + j3 Ω. Find the equivalent delta impedance and verify power is the same.

Answer: Z_Δ = 3 × Z_Y = 3×(4+j3) = 12 + j9 Ω. Y: Vφ = 231 V, Iφ = 231/5 = 46.2 A, $P = 3 \times 46.2^2 \times 4 \approx 25,663$ W. Delta: Iφ = 400/15 = 26.67 A, $P = 3 \times 26.67^2 \times 12 \approx 25,603$ W ≈ same ✓ (small difference due to rounding).

91. An industrial plant has the following 3φ loads on a 415 V bus: Motor A: 30 kW, 0.85 PF lag; Lighting: 10 kW, PF 1.0; Heaters: 20 kW, PF 1.0; Motor B: 25 kVA, 0.9 PF lag. Find total P, Q, S, and IL.

Answer: PA = 30 kW, QA = 30×tan(31.79°) ≈ 18.6 kVAR. P_light = 10 kW, Q_light = 0. P_heat = 20 kW, Q_heat = 0. PB = 22.5 kW, QB = 25×0.4359 ≈ 10.9 kVAR. P = 82.5 kW, Q = 29.5 kVAR. $S = \sqrt{82.5^2 + 29.5^2} \approx 87.65$ kVA. IL = 87,650/(√3 × 415) ≈ 121.9 A.

92. Show that for a Y-connected load: $S_{3\varphi} = 3 \times |V_\varphi|^2 / Z^*$

Answer: Per phase: $S_{phase} = V_\varphi \times I_\varphi^* = V_\varphi \times (V_\varphi/Z)^* = V_\varphi \times V_\varphi^*/Z^* = |V_\varphi|^2/Z^*$. Total $S_{3\varphi} = 3 \times S_{phase} = 3|V_\varphi|^2/Z^*$. Example: Vφ = 120 V, Z = 4+j3 → S = 3×14400/(4-j3) = 43200/(4-j3) = 6912 + j5184 VA.

93. A 3φ load consumes 100 kVA. At PF 0.6 lag, how much real and reactive power is consumed?

Answer: P = 100 × 0.6 = 60 kW. $\sin(\cos^{-1}0.6) = 0.8$. Q = 100 × 0.8 = 80 kVAR lagging. This shows that at low PF, a large portion of the apparent power is reactive and 'wasted'.

94. Compare the line currents for Y and delta connections of the same load impedance at the same line voltage.

Answer: Y connection: $I_L = V_L / (\sqrt{3} \times |Z|)$. Delta connection: $I_L = \sqrt{3} \times V_L / |Z|$. Ratio: $I_{L\_delta} / I_{L\_Y} = 3$. The delta connection draws 3 times more line current than the Y connection for the same impedance at the same line voltage.

95. A three-phase 480 V system powers a 60 kW resistive load. Find the per-phase resistance for both Y and delta connections.

Answer: For Y: $V_\varphi = 480/\sqrt{3} = 277.1$ V, $I_\varphi = P/(3V_\varphi) = 60{,}000/(3\times277.1) = 72.17$ A, $R_Y = 277.1/72.17 \approx 3.84\ \Omega$. For delta: $V_\varphi = 480$ V, $I_\varphi = P/(3\times480) = 41.67$ A, $R_\Delta = 480/41.67 \approx 11.52\ \Omega$. Note $R_\Delta = 3 \times R_Y = 11.52 \approx 3 \times 3.84$ ✓

96. What happens to P, Q, and S if the line voltage in a balanced three-phase system is doubled?

Answer: Since $P = 3|V_\varphi|^2R/|Z|^2$ and $V_\varphi \propto V_L$, doubling V_L doubles V_φ, quadrupling (×4) all power quantities: P, Q, and S all become 4 times their original values. Line current also doubles: $I_L = V_\varphi/|Z|$ doubles.

97. Express reactive power Q in terms of real power P and power factor angle φ.

Answer: $Q = P \times \tan \varphi$. Since $\tan \varphi = \sin \varphi / \cos \varphi = (Q/S)/(P/S) = Q/P$. Therefore $Q = P \tan \varphi = P \times \sqrt{1 - PF^2} / PF$. Example: P = 100 kW, PF = 0.8 ($\varphi = 36.87°$) → $Q = 100 \times \tan(36.87°) = 100 \times 0.75 = 75$ kVAR.

98. A balanced Y-connected source has $V_\varphi = 200\angle0°$ V. It feeds a Y-load of 8 + j6 Ω per phase. Write the complex power in rectangular form.

Answer: Z = 8 + j6, |Z| = 10. $I_\varphi = 200/10\angle36.87° = 20\angle-36.87°$ A. $S_{phase} = V_\varphi \times I_\varphi^* = 200\angle0° \times 20\angle+36.87° = 4000\angle36.87° = 3200 + j2400$ VA. $S_{3\varphi} = 9600 + j7200$ VA. So P = 9.6 kW, Q = 7.2 kVAR lag.

99. A substation bus has P = 2 MW, Q = 1.5 MVAR on a 6.6 kV three-phase system. Find |S|, PF, and IL.

Answer: $|S| = \sqrt{2^2 + 1.5^2} = \sqrt{4 + 2.25} = \sqrt{6.25} = 2.5$ MVA. PF = 2/2.5 = 0.8 lagging. $I_L = S/(\sqrt{3} \times V_L) = 2{,}500{,}000/(\sqrt{3} \times 6{,}600) \approx 218.7$ A.

100. Summarize the key power relationships for a balanced three-phase system.

Answer: Real power: $P = \sqrt{3}\, V_L I_L \cos \varphi = 3V_\varphi I_\varphi \cos \varphi$ (W). Reactive power: $Q = \sqrt{3}\, V_L I_L \sin \varphi = 3V_\varphi I_\varphi \sin \varphi$ (VAR, +inductive/-capacitive). Apparent power: $S = \sqrt{3}\, V_L I_L = 3V_\varphi I_\varphi$ (VA). Complex power: S = P + jQ. Power factor: PF = P/S = cos φ. Power triangle: $S^2 = P^2 + Q^2$. Y: $V_\varphi = V_L/\sqrt{3}$, $I_\varphi = I_L$. Δ: $V_\varphi = V_L$, $I_L = \sqrt{3}\, I_\varphi$.