PRACTICE EXAM 10: PE POWER SIMULATION (80 QUESTIONS)

1. A 13.8 kV, three-phase feeder serves a combined load of 5,000 kW at 0.78 lagging power factor. The feeder impedance is 0.50 + j2.40 Ω per phase. An engineer proposes two corrective options: Option A installs a 2,500 kvar capacitor bank at the load bus; Option B replaces the feeder conductors with a size having 50% lower impedance. Which option provides the greater reduction in feeder voltage drop, and by approximately what percentage?

A. Option B reduces voltage drop by approximately 50% — conductor replacement is always more effective

B. Option A and Option B produce approximately equal voltage drop reductions of 30–35%

C. Option B reduces voltage drop by approximately 50%, and Option A by approximately 25%

D. Option A reduces voltage drop by approximately 40%, compared to Option B's approximately 25%, because reducing reactive current through the high-reactance feeder is more effective

2. A three-phase, 480V, solidly grounded wye system has a 2,000 kVA transformer with Z = 5.75%, feeding a main switchboard. The switchboard main breaker is 2,500A with 65 kA AIC. A downstream 400A feeder breaker is rated 25 kA AIC. The utility provides 750 MVA of short-circuit capacity at 13.8 kV primary. What is the available fault current at the feeder breaker, and is the feeder breaker adequately rated?

A. 38,200A; the feeder breaker is adequately rated at 25 kA AIC

B. 38,200A; the feeder breaker is NOT adequately rated — 38,200A exceeds the 25 kA AIC rating

C. 25,000A; the feeder breaker is at its exact rating

D. 18,100A; the feeder breaker is adequately rated

3. A 100 MVA, 230/69 kV autotransformer has a series impedance of 8% on its own base. The 230 kV system has a source impedance of 2% on the transformer's base. A bolted three-phase fault occurs on the

69 kV bus. What is the total per-unit impedance to the fault and the fault current in amperes on the 69 kV side?

A. Z_total = 0.02 pu; I_fault = 41,840A

B. Z_total = 0.08 pu; I_fault = 10,460A

C. Z_total = 0.10 pu; I_fault = 8,368A

D. Z_total = 0.10 pu; I_fault = 41,840A

4. Per NEC 430.52, a 200 HP, 460V, three-phase Design B motor has a Table 430.250 FLA of 242A. An inverse-time circuit breaker is selected for branch-circuit protection. The maximum OCPD is 250% of FLA = 605A. However, the motor fails to start without tripping the breaker. Per NEC 430.52(C)(1) Exception 1, what is the maximum permitted breaker size?

A. 800A (400% of FLA per the exception for inverse-time breakers when 250% is insufficient)

B. 700A (next standard size above 605A)

C. 600A (the next lower standard size below 605A)

D. 1,000A (no upper limit when the motor cannot start)

5. A three-phase, 4,160V, 60 Hz system has the following per-unit sequence impedances at a fault bus on a 10 MVA base: $Z_1 = 0.01 + j0.08$, $Z_2 = 0.01 + j0.08$, $Z_0 = 0.03 + j0.22$. Pre-fault voltage = 1.0 pu. What is the ratio of the bolted SLG fault current to the bolted three-phase fault current?

A. SLG/3Φ = 1.32 (SLG exceeds three-phase)

B. SLG/3Φ = 1.00 (they are equal)

C. SLG/3Φ = 1.15 (SLG slightly exceeds three-phase)

D. SLG/3Φ = 0.79 (SLG is less than three-phase)

6. A CT with a ratio of 1000:5 and accuracy class C400 is connected to a protective relay. The total external burden (leads + relay) is 2.5 Ω, and the CT winding resistance is 1.0 Ω. During a fault producing 18,000A on the primary, the CT secondary current is 90A. What is the voltage across the total burden, and does the CT maintain its accuracy rating?

A. V = 225V (external only); CT maintains accuracy because only external burden counts for the C rating

B. V = 315V (total); CT maintains accuracy because 315V < 400V at 20× rated

C. V = 225V (external only); CT may saturate because the total voltage is 315V

D. V = 315V (total); CT maintains accuracy

7. Per NEC 250.66, the grounding electrode conductor for a service with 2/0 AWG copper service-entrance conductors is sized at 4 AWG copper. If the same service uses two parallel sets of 2/0 AWG copper per phase (equivalent to 4/0 AWG), what is the minimum GEC size?

A. 2 AWG copper (per Table 250.66 for the equivalent parallel conductor size)

B. 4 AWG copper (same as for a single set of 2/0 AWG)

C. 1/0 AWG copper

D. 4/0 AWG copper

8. A balanced three-phase, 480V system feeds a wye-connected load through a 300-foot cable run. The cable has R = 0.0766 Ω/1000 ft and X = 0.0454 Ω/1000 ft per phase. The load is 350A at 0.90 lagging power factor. What is the voltage at the load terminals?

A. 480 V (no appreciable drop for this cable length)

B. 466 V

C. 470 V

D. 458 V

9. A synchronous generator rated 50 MVA, 13.8 kV is operating at rated MVA and 0.85 lagging power factor. The generator's capability (D) curve shows that the maximum allowable field current at this operating point corresponds to a rotor heating limit. If the operator attempts to increase reactive power output beyond this limit while maintaining the same real power, what limits the generator?

A. The prime mover's maximum torque output limits real power delivery

B. The rotor (field winding) thermal limit — the field current would exceed the continuous rating, risking insulation damage

C. The stator current limit — armature current exceeds the rated MVA

D. The steady-state stability limit — the power angle approaches 90°

10. A 345 kV transmission line is 220 miles long with a series impedance of $Z = 0.06 + j0.65$ Ω/mile per phase and a shunt admittance of $Y = j5.2 \times 10^{-6}$ S/mile per phase. At no load with rated voltage at the receiving end, the sending-end voltage rises due to the Ferranti effect. Using the approximate formula $V_S \approx V_R(1 + ZY/2)$, what is the approximate percentage voltage rise at the sending end?

A. 2.5%

B. 5.8%

C. 12.4%

D. 8.2%

11. Per NEC 110.24(A), service equipment must be marked with the maximum available fault current and the date of calculation. Per NEC 110.24(B), this marking must be verified when modifications to the electrical installation are made that could affect the available fault current. Which of the following modifications would NOT require reverification?

A. Replacing a lighting panel on a branch circuit fed from the service equipment

B. Adding a 500 HP motor to the service switchboard that could contribute fault current

C. The utility replacing the service transformer with a larger unit

D. Installing a second service entrance fed from the same utility transformer

12. A 1,500 kVA, 13.8 kV/480V, delta-wye grounded transformer has an impedance of 5.75% with X/R = 7. The transformer serves a bus with 2,000A of motor load. During a bolted three-phase fault on the 480V bus, the transformer contributes its maximum fault current and the motors contribute approximately 4× their FLA for the first cycle. What is the approximate total first-cycle fault current?

A. 31,374 A (transformer only)

B. 39,374 A (transformer + motor contribution combined)

C. 39,374 A

D. 25,000 A (transformer current reduced by motor impedance)

13. A power factor correction study for a 4,160V industrial bus shows the following loads: 3,000 kW at 0.75 lagging PF (motors), 1,500 kW at 0.95 lagging PF (VFD-driven motors), and 500 kW at unity PF (resistance heating). What is the total bus power factor before correction, and what capacitor bank rating corrects to 0.95 lagging?

A. Bus PF = 0.82; required capacitor = 1,500 kvar

B. Bus PF = 0.85; required capacitor = 2,000 kvar

C. Bus PF = 0.90; required capacitor = 800 kvar

D. Bus PF = 0.75; required capacitor = 3,000 kvar

14. A 13.8 kV, three-phase system has a three-phase fault level of 400 MVA. A 4,500 kvar capacitor bank is installed. The system contains six-pulse VFDs. What is the parallel resonant harmonic order, and what is the recommended detuning reactor percentage to shift resonance safely below the 5th harmonic?

A. h_r = 9.43; no detuning needed

B. h_r = 6.67; 4.7% detuning reactor

C. h_r = 5.3; 7% or 6% detuning reactor required to shift below 4.7th harmonic

D. h_r = 9.43; 4.7% detuning reactor to shift resonance to the 7th harmonic

15. Per NEC Article 700.32, emergency systems must be selectively coordinated from the emergency source to the load. A hospital emergency system has a 480V, 800A generator main breaker, a 400A ATS feeder breaker, and a 100A branch breaker serving an operating room panel. At a fault current of 8,000A on the branch circuit, the branch breaker clears in 0.02 seconds and the ATS feeder breaker clears in 0.35 seconds. What is the CTI?

A. 0.33 seconds — adequate for selective coordination

B. 0.37 seconds — exceeds the minimum CTI

C. 0.02 seconds — inadequate for coordination

D. 0.35 seconds — exactly the minimum CTI

16. A 480V, three-phase panelboard has an arc flash study showing 12.5 cal/cm² incident energy at 24 inches. The engineer proposes three mitigation strategies: (1) enable maintenance mode on the main breaker to reduce clearing time from 0.3 to 0.05 seconds; (2) install arc-flash reduction relay that reduces clearing to 0.04 seconds; (3) install remote racking capability. Which strategy produces the greatest reduction in incident energy?

A. Strategy 3 reduces incident energy to zero because the worker is outside the arc flash boundary

B. Strategy 1 reduces incident energy by approximately 83% (to about 2.1 cal/cm²)

C. Strategy 2 reduces incident energy to approximately 1.67 cal/cm^2 — the greatest reduction of the three

D. All three strategies produce identical incident energy reductions

17. A three-phase, 460V, 6-pole induction motor rated 250 HP operates at full load with a slip of 2.0% and an efficiency of 94.5%. The motor drives a centrifugal pump. A VFD is installed and the motor is operated at 900 RPM. Using constant V/f control, what are the VFD output frequency, voltage, and the approximate pump power at this speed?

A. 45 Hz, 345V, 140 kW

B. 30 Hz, 230V, 25 kW

C. 45 Hz, 345V, 93 kW

D. 30 Hz, 230V, 55 kW

18. A ground resistance test on an industrial grounding electrode system yields 3.5 Ω during a dry summer month. The design specification requires less than 5.0 Ω year-round. Historical data for the site shows that ground resistance during wet winter months is typically 40% lower than the dry summer reading. What is the estimated ground resistance during the wet season, and does the system meet the year-round specification?

A. Wet season ≈ 2.1 Ω; the system meets the specification year-round because the dry-season reading of 3.5 Ω is the worst case

B. Wet season ≈ 5.8 Ω; the system does NOT meet the specification

C. Wet season ≈ 4.9 Ω; the system is marginal and may not meet the spec during transitional seasons

D. Wet season ≈ 2.1 Ω; but the specification cannot be verified without year-round testing

19. A distance relay (21) on a 138 kV line uses a mho characteristic. Zone 1 is set at 85% of the line impedance ($Z_{line} = 3 + j40$ Ω). Zone 2 is set at 120% with a 0.35-second delay. A pilot protection

scheme (POTT) is also installed. A three-phase fault occurs at 92% of the line. The communication channel is operational. What happens?

A. Zone 2 trips after 0.35 seconds because the fault is beyond Zone 1

B. The POTT scheme enables Zone 1 extension — both ends trip instantaneously

C. Zone 1 trips instantaneously because the mho characteristic extends beyond 85% at the fault angle

D. The POTT scheme sends a permissive signal from both ends, and both terminals trip with high-speed clearing

20. A 480V, three-phase motor control center has the following motor loads: one 200 HP (FLA = 242A), two 100 HP (FLA = 124A each), three 50 HP (FLA = 65A each), and one 25 HP (FLA = 34A). A continuous lighting panel draws 75A. Per NEC 430.24 and 215.2(A)(1), what is the minimum feeder conductor ampacity?

A. 876 A

B. 913 A

C. 750 A

D. 1,020 A

21. Per NFPA 70E, the arc flash boundary is the distance at which incident energy equals 1.2 cal/cm². For a 480V panelboard with an available fault current of 20 kA and a clearing time of 0.1 seconds, an IEEE 1584 calculation determines the arc flash boundary to be 30 inches. A qualified worker standing at 30 inches without arc-rated PPE would receive what type of injury?

A. Onset of a second-degree burn — the threshold for irreversible skin damage at 1.2 cal/cm²

B. No injury — 1.2 cal/cm² is below the pain threshold

C. Third-degree burn requiring surgical intervention

D. First-degree burn — superficial reddening only

22. A 500 kVA, 480V/208Y/120V, three-phase dry-type transformer has a no-load loss of 1,600 W, a full-load copper loss of 5,400 W, and a percent impedance of 5.0%. The transformer is loaded at 70% with a 0.88 power factor lagging for 16 hours and at 30% with a 0.75 PF lagging for 8 hours daily. What is the all-day efficiency?

A. 97.5%

B. 96.2%

C. 97.0%

D. 98.1%

23. Per NEC 501.15(A)(2), in a Class I, Division 1 location, conduit seals must be placed in each conduit run entering an explosionproof enclosure that contains devices capable of producing arcs, sparks, or high temperatures. The seal must be within what distance of the enclosure?

A. 36 inches

B. 18 inches

C. 24 inches

D. 12 inches

24. A 75 MVA, 138/13.8 kV, delta-wye grounded transformer has $Z_1 = Z_2 = j0.09$ pu on its own base. The 138 kV utility source has $Z_{1\_src} = j0.02$ pu on the transformer's base. A bolted three-phase fault occurs on the 13.8 kV bus. On a 100 MVA system base, what is the fault current at the 13.8 kV bus?

A. 4,184 A

B. 16,736 A

C. 8,368 A

D. 28,430 A

25. A three-phase, wye-connected, 4,160V synchronous generator has a synchronous reactance X_d = 1.4 pu and is connected to an infinite bus at 1.0 pu. The generator's internal voltage is E_a = 1.3 pu. What is the steady-state stability limit, and what is the generator's reactive power output when operating at the stability limit?

A. P_{max} = 0.929 pu (at $\delta = 90°$); Q = 0 var at this operating point because all power is real

B. P_{max} = 0.929 pu; the generator supplies both real and reactive power at the stability limit

C. P_{max} = 1.30 pu; Q = 0.929 pu lagging

D. P_{max} = 1.857 pu; Q = 0.50 pu leading

26. A conduit run in a boiler room contains ten 6 AWG THWN-2 copper conductors (90°C rated). The ambient temperature is 50°C. NEC Table 310.16 lists the 90°C ampacity of 6 AWG copper as 75A. The temperature correction factor for 90°C insulation at 50°C is 0.82. The conduit fill adjustment for 10 conductors is 0.50. Equipment terminals are rated 75°C (75°C ampacity for 6 AWG is 65A). What is the adjusted ampacity?

A. 65 A (75°C terminal limit governs)

B. 30.75 A (90°C × temp × fill)

C. 30.75 A

D. 37.5 A

27. A 1,000 kVA, 13.8 kV/4.16 kV, delta-wye grounded transformer bank is made from three 333 kVA single-phase units. One unit fails. The remaining two are reconnected in open-delta primary, open-wye secondary. What is the three-phase kVA capacity of the open configuration, and what is the maximum per-unit loading on each remaining transformer?

A. 577 kVA; each transformer carries 333 kVA (100% of individual rating)

B. 577 kVA; each transformer carries 289 kVA (86.6% of individual rating)

C. 667 kVA; each transformer carries 333 kVA (100% of individual rating)

D. 500 kVA; each transformer carries 250 kVA (75% of individual rating)

28. A 345 kV, 300-mile transmission line has a total positive-sequence impedance of Z_1 = 15 + j195 Ω and a zero-sequence impedance of Z_0 = 45 + j585 Ω. The source behind the line has Z_1_src = j15 Ω and Z_0_src = j20 Ω. For a bolted SLG fault at the remote end, what is the total sequence impedance sum (Z_1_total + Z_2_total + Z_0_total) in ohms?

A. 75 + j615 Ω

B. 90 + j1,020 Ω

C. 60 + j810 Ω

D. 75 + j1,025 Ω

29. Per NEC 250.30(A)(1), when multiple separately derived systems (such as transformers) feed a common bus, the system bonding jumper for each derived system must be installed at the source. If two 1,000 kVA transformers share a 480V bus, how many system bonding jumpers are required?

A. Two — one at each transformer (each separately derived system gets its own bonding jumper)

B. One — a single bonding jumper at the common bus is sufficient

C. Three — one at each transformer plus one at the bus

D. None — the bonding is accomplished through the equipment grounding system

30. A three-phase, 4,160V system serves a 2,500 kW load at 0.70 lagging power factor. A synchronous motor rated 500 HP (373 kW shaft output) at 0.80 leading PF with 94% efficiency is added to serve a

new mechanical load and improve the overall plant power factor. What is the new combined power factor?

A. 0.78 lagging

B. 0.85 lagging

C. 0.80 lagging

D. 0.92 lagging

31. A three-phase, 480V bus has two transformers in parallel: Transformer A is 2,000 kVA with Z_A = 5.75% and Transformer B is 1,500 kVA with Z_B = 6.25%. Assuming an infinite primary source, what is the total available fault current on the 480V bus?

A. 31,374 A (Transformer A alone)

B. 60,237 A (sum of individual fault contributions)

C. 45,200 A (average of individual contributions)

D. 52,800 A (combined parallel contribution)

32. A 13.8 kV metal-clad switchgear bus has a bus differential relay (87B). The bus has five circuit breakers, each with 1200:5 CTs (C400 accuracy class). During a 25,000A internal bus fault, the relay's operate current is 24,500A and the restraint current is 25,000A. The relay's percentage slope is set at 30%. Does the relay trip?

A. No, because the 24,500A operate current does not exceed 100% of the restraint

B. Yes, but only after a 0.5-second intentional delay to confirm the fault

C. No, because the percentage differential is only 2%, which is below the 30% slope

D. Yes, because 24,500A exceeds 30% of 25,000A (7,500A), meaning the operate current far exceeds the slope threshold

33. A VFD drives a 460V, 4-pole, 60 Hz induction motor at 1,350 RPM using constant V/f control. The motor develops 200 Nm of torque at this speed. What is the approximate shaft power output?

A. 18.8 kW

B. 28.3 kW

C. 37.7 kW

D. 14.1 kW

34. An insulation resistance test on a 4,160V motor winding measures the following: R at 1 minute = 150 MΩ; R at 10 minutes = 120 MΩ. The winding temperature is 40°C (standard reference temperature). What is the PI, and what does this result indicate?

A. PI = 1.25; marginal insulation — schedule further investigation

B. PI = 0.80; good insulation because the absolute values are above 100 MΩ

C. PI = 1.25; insulation is acceptable because it exceeds the 1.0 minimum

D. PI = 0.80; the insulation resistance is decreasing over time, indicating contamination, moisture, or degradation requiring immediate investigation

35. Per NEC 408.36, a panelboard must be individually protected by an overcurrent device rated not greater than the panelboard bus rating. A 225A panelboard fed from a 225A breaker has a calculated continuous load of 180A and a noncontinuous load of 40A. Per NEC 215.2(A)(1), the minimum OCPD rating is 125% × 180 + 100% × 40 = 265A. How is this conflict between the 225A panel rating and the 265A calculated minimum resolved?

A. Use a 225A breaker and limit the continuous load to stay within the 80% continuous rating (225 × 0.80 = 180A), ensuring the noncontinuous load does not exceed 45A simultaneously

B. Install a 300A breaker regardless of panel rating

C. Use the 265A calculation and exceed the panel rating because the NEC 215 calculation governs

D. Install a larger panelboard rated 400A or higher

36. A three-phase, 208Y/120V panelboard serves a data center with 100% nonlinear server loads. Phase currents are 250A each. The neutral current is 320A. The conduit contains 3 phase conductors and 1 neutral conductor. Per NEC 310.15(C)(1), how many current-carrying conductors are counted for the conduit fill adjustment factor?

A. 3 (neutral is not counted because it is a grounded conductor)

B. 4 (neutral is a current-carrying conductor because of nonlinear harmonic loads)

C. 4 (all conductors in the raceway count)

D. 2 (only two of the three phases carry significant harmonic current)

37. A 480V, three-phase, 800A LVPCB main breaker protects a switchboard. The breaker has long-time pickup at 800A, short-time pickup at 4,000A with a 0.3-second delay, and no instantaneous trip. A downstream 200A MCCB feeder breaker has an instantaneous trip at 2,500A with a clearing time of 0.025 seconds at 30 kA. Zone-selective interlocking (ZSI) is installed. A fault of 30,000A occurs on the feeder. What is the protection response?

A. The MCCB trips instantaneously; the LVPCB holds on short-time delay — selective coordination is maintained

B. The MCCB trips instantaneously AND sends a restraint signal to the LVPCB; the LVPCB holds on its normal short-time delay

C. Both breakers trip simultaneously because both trip settings are exceeded

D. The LVPCB accelerates to instantaneous trip because no ZSI restraint signal is received from the feeder

38. A 100 HP, 460V, three-phase motor is started across the line on a bus with a source impedance that produces a 12% voltage dip during starting. The motor's full-voltage locked-rotor torque is 170% FLT. What is the actual starting torque at the motor terminals during the voltage dip?

A. 170% FLT (starting torque is independent of terminal voltage)

B. 150% FLT (torque reduces linearly with voltage)

C. 132% FLT (torque reduces with voltage squared)

D. 132% FLT

39. Per NEC 690.7, PV system maximum voltage is determined at the lowest expected ambient temperature. A 30-module string has V_{oc} = 45.5V per module at STC. The temperature coefficient is −0.29%/°C, and the minimum expected temperature is −25°C. What is the maximum system voltage, and does it exceed the 600V NEC threshold for certain wiring methods?

A. V_{max} = 1,547V; exceeds 600V — conductors must be rated for 2,000V maximum system voltage

B. V_{max} = 1,365V; does not exceed 1,500V NEC residential limit

C. V_{max} = 1,000V; within the 1,000V limit for commercial systems

D. V_{max} = 1,547V; requires equipment rated for this specific voltage

40. A 500 kVA, 4,160V/480V, three-phase transformer has open-circuit losses of 1,200 W and full-load copper losses of 4,800 W. The transformer operates at 80% load with 0.85 lagging PF for 10 hours and at 20% load with 0.70 PF for 14 hours daily. What are the total daily energy losses?

A. 120 kWh

B. 48 kWh

C. 67 kWh

D. 93 kWh

41. A synchronous motor rated 2,000 HP, 4,160V operates at 0.85 leading power factor at rated mechanical load. The motor efficiency is 96%. If the DC field current is decreased while the mechanical load remains constant, the motor's power factor will change in which direction?

A. The power factor moves toward lagging and the power angle increases

B. The power factor moves toward lagging and the power angle decreases

C. The power factor remains constant because it depends only on the mechanical load

D. The power factor moves further into leading territory

42. A 230 kV, three-phase line is protected by a distance relay. Zone 1 is set at 85% of Z_line = 2 + j24 Ω. A bolted fault occurs at 50% of the line. What impedance does the relay measure, and is this within Zone 1?

A. Z_measured = 1 + j12 Ω (|Z| = 12.04 Ω); within Zone 1 reach of 20.48 Ω

B. Z_measured = 1.7 + j20.4 Ω; exactly at Zone 1 boundary

C. Z_measured = 2 + j24 Ω; beyond Zone 1 reach

D. Z_measured = 1 + j12 Ω; within Zone 1 — the relay trips instantaneously

43. Per NEC 250.53(A)(2), when a single ground rod electrode fails to achieve 25 Ω, a supplemental electrode is required. The supplemental rod must be at least 6 feet from the first. After installing the second rod, the combined resistance is 18 Ω. Is additional work required?

A. No — once a supplemental electrode is installed, NEC 250.53(A)(2) does not require the combined resistance to meet any specific value

B. Yes — the combined resistance must be 25 Ω or less

C. Yes — the combined resistance must be 10 Ω or less per NEC 250.56

D. No — but only because 18 Ω is coincidentally below 25 Ω

44. A three-phase, 480Y/277V panelboard serves a balanced resistive load of 45A per phase. Each phase also has a nonlinear load producing 20A of 3rd-harmonic current and 8A of 5th-harmonic current. What is the neutral conductor current?

A. 60A (3 × 20A triplen harmonics)

B. 45A (fundamental only)

C. 60A (only triplen harmonics add in the neutral; the 5th harmonic cancels)

D. 84A (all harmonics add in the neutral)

45. A 150 kW BESS with a 480 VDC battery and a three-phase 480V inverter at 95% efficiency is dispatched for peak shaving. The battery has a capacity of 600 kWh at a maximum DOD of 85%. The round-trip efficiency is 90%. What is the maximum duration the BESS can deliver 150 kW to the AC bus?

A. 4.0 hours

B. 3.4 hours

C. 2.85 hours

D. 3.23 hours

46. Per NEC 230.95, ground-fault protection of equipment (GFPE) is required for solidly grounded wye services rated 1,000A or more at systems more than 150V to ground but not exceeding 600V phase-to-phase. A building is served by a 480Y/277V, 800A service. Is GFPE required?

A. Yes, because the service exceeds 150V to ground

B. No, because the service rating of 800A is below the 1,000A threshold

C. Yes, because all 480V services require GFPE regardless of amperage

D. No, because the building is a dwelling unit

47. A three-phase, 4,160V capacitor bank rated 5,400 kvar is delta-connected. What is the per-phase capacitor current and the capacitive reactance per delta phase?

A. I_{phase} = 432A per delta phase; X_C = 9.63 Ω per phase

B. I_{phase} = 250A per delta phase; X_C = 16.67 Ω per phase

C. I_{phase} = 750A per delta phase; X_C = 5.55 Ω per phase

D. I_{phase} = 432A per delta phase; X_C = 3.21 Ω per phase

48. A feeder relay (51) uses an IEEE very inverse characteristic with a pickup of 5A on a 300:5 CT and a time dial of 2.5. A fault of 3,600A occurs. Using the IEEE very inverse formula $t = TD \times (19.61/(M^2 - 1) + 0.491)$, what is the relay operating time?

A. 0.98 seconds

B. 1.54 seconds

C. 1.67 seconds

D. 2.45 seconds

49. A 345 kV circuit breaker rated 63 kA has a rated interrupting time of 3 cycles (50 ms). The associated pilot relay detects a line fault and sends a trip signal in 15 ms. What is the total fault clearing time from fault inception?

A. 50 ms (breaker time only)

B. 15 ms (relay time only)

C. 35 ms (breaker time minus relay time)

D. 65 ms (relay time plus breaker interrupting time)

50. A three-phase, 480V, 200A feeder uses 3/0 AWG copper conductors. NEC Chapter 9, Table 9 lists R = 0.0766 Ω/1000 ft and X = 0.0454 Ω/1000 ft in EMT. The feeder length is 250 feet and serves a motor load at 0.85 lagging PF. What is the voltage drop percentage?

A. 3.2%

B. 1.5%

C. 2.4%

D. 4.1%

51. A 60 MVA, 138/13.8 kV transformer has $Z_1 = Z_2 = j0.085$ pu on its own base. Two such transformers operate in parallel on a 100 MVA system base. What is the combined parallel positive-sequence impedance, and what is the three-phase fault current on the 13.8 kV bus with an infinite source?

A. Z = 0.142 pu; I_fault = 29,500A

B. Z = 0.0708 pu; I_fault = 29,500A

C. Z = 0.0708 pu; I_fault = 59,100A

D. Z = 0.142 pu; I_fault = 14,750A

52. Per NEC 480.9(A), a battery room with vented lead-acid cells must have ventilation to prevent hydrogen from exceeding 1% by volume. The facility uses a VRLA (valve-regulated lead-acid) battery system in a sealed cabinet within a telecom room. Does the telecom room require the same ventilation as a vented-cell battery room?

A. No, VRLA batteries emit significantly less hydrogen than vented cells, and the telecom room ventilation requirement is less stringent — but hydrogen detection should still be provided

B. Yes, all battery rooms require identical ventilation regardless of battery type

C. No, VRLA batteries are completely sealed and produce zero hydrogen under any conditions

D. Yes, because NEC 480.9 applies to all battery types without exception

53. A three-phase, 4,160V system has a neutral grounding transformer (zigzag type) providing a grounding reference for the delta system. During normal operation, what current flows through the zigzag transformer?

A. Zero current — the zigzag carries current only during ground faults

B. The full system load current divided by three flows through each winding

C. A small magnetizing current flows through the windings to maintain the magnetic field

D. The zigzag carries current equal to the system's unbalanced load current

54. A 250 HP, 460V, three-phase motor is started using an autotransformer with a 65% tap. The motor's full-voltage locked-rotor current is 1,600A. What are the motor terminal voltage, the motor current, and the line current from the supply during the autotransformer start?

A. V = 345V; I_motor = 1,040A; I_line = 1,040A

B. V = 299V; I_motor = 1,040A; I_line = 676A

C. V = 299V; I_motor = 676A; I_line = 1,040A

D. V = 345V; I_motor = 1,600A; I_line = 676A

55. Per NFPA 70E 130.2(A)(3), the first condition that permits energized electrical work is that de-energization introduces additional or increased hazards. Which of the following is a valid example of this condition?

A. De-energizing a hospital ventilation system in an operating room during surgery would create a greater hazard to the patient than performing energized diagnostic work on the motor control circuit

B. The maintenance schedule requires the work to be performed during production hours

C. The facility owner has determined that the cost of a production shutdown exceeds the risk of energized work

D. The qualified worker has extensive experience and personally accepts the risk of energized work

56. A 138 kV, three-phase transmission line has a sending-end voltage of 142 kV and a receiving-end voltage of 134 kV. The line's series reactance is 50 Ω (resistance neglected). The power angle between sending and receiving ends is 25°. What is the real power transmitted and the reactive power consumed by the line?

A. P = 161 MW; Q ≈ 30 Mvar absorbed

B. P = 241 MW; Q ≈ 45 Mvar absorbed

C. P = 80 MW; Q ≈ 12 Mvar absorbed

D. P = 161 MW; Q ≈ 60 Mvar absorbed

57. A three-phase, 13.8 kV capacitor bank rated 6,000 kvar is switched daily. The bank includes 4.7% series detuning reactors. The detuned resonant frequency is approximately the 4.6th harmonic. When the capacitor is de-energized, a restriking event across the switching device could produce what type of transient?

A. A voltage transient up to 3.0 pu on the de-energized bus

B. A current transient that decays in one power cycle

C. A voltage transient up to 2.0 pu across the capacitor bank, which can escalate to higher values if restriking occurs during recovery voltage swings

D. No transient because the detuning reactors absorb all switching energy

58. A CT with a ratio of 2000:5 serves both a revenue meter (0.3 accuracy class) and a protective relay (C200 accuracy class). During normal operation, the feeder carries 1,200A. The CT secondary current is 3.0A. For the revenue meter, is the CT operating within its accuracy class specification?

A. No, because 3.0A is below the CT's rated secondary current of 5A and accuracy may be degraded

B. Yes, but at the lower end of the accuracy range — the 0.3 class applies from approximately 10% to 100% of rated current

C. No, because revenue metering requires a separate dedicated CT

D. Yes, because the 0.3 class applies at all current levels from zero to the CT's rated primary current

59. Per NEC 310.15(C)(1), the conduit fill adjustment factor for 10–20 current-carrying conductors in a raceway is 0.50. A conduit contains 12 circuit conductors (phase conductors only — no neutrals or equipment grounds counted). The conductors are 8 AWG THWN-2 copper with a 90°C ampacity of 55A from Table 310.16. Equipment terminals are rated 75°C (75°C ampacity for 8 AWG = 50A). What is the adjusted ampacity?

A. 27.5A (90°C value × 0.50 fill factor)

B. 50A (75°C terminal limit governs because 50A > 27.5A)

C. 25A (75°C value × 0.50 fill factor)

D. 55A (no derating applies because conductors are 90°C rated)

60. A 20 MW wind farm uses Type 3 (doubly-fed induction generator) wind turbines. During a grid fault on the collection bus, the DFIG turbines can contribute fault current at approximately 3–5 times their rated current for the first few cycles. If the farm has a total rated current of 335A at 34.5 kV, what is the approximate maximum first-cycle fault current contribution from the wind farm?

A. 335 A (1× rated)

B. 670 A (2× rated)

C. 1,005 A (3× rated)

D. 1,675 A (5× rated)

61. A 480V, three-phase, 400A switchboard has a continuous load of 320A and a noncontinuous load of 60A. Per NEC 215.2(A)(1), the minimum feeder conductor ampacity is 125% × 320 + 100% × 60 =

460A. The switchboard bus is rated 400A. Per NEC 408.36, the OCPD must not exceed the bus rating. What is the correct resolution?

A. Use a 400A OCPD and accept the overload risk

B. Install a 100%-rated main breaker if available, which can carry 400A continuously without the 125% adder

C. The switchboard bus must be upgraded to at least 500A to accommodate the calculated feeder minimum

D. Use a 500A OCPD because NEC 215 governs over NEC 408

62. A three-phase, 480V system has a bolted three-phase fault current of 30,000A at a switchboard. Five motors connected to the switchboard have a combined FLA of 600A. During the first cycle of a fault, the motors contribute approximately 4 × FLA = 2,400A. What is the total first-cycle asymmetrical fault current if the system X/R ratio is 10?

A. 32,400A symmetrical RMS

B. 32,400A symmetrical RMS; first-cycle peak asymmetrical ≈ 73,700A

C. 30,000A (motor contribution is negligible)

D. 32,400A symmetrical + asymmetrical factor; peak ≈ 78,000A

63. A 13.8 kV, three-phase system has a bolted SLG fault producing I_0 = 2,500A. The zero-sequence current flows through the neutral of a wye-grounded transformer and returns through the grounding electrode system. What is the current in the transformer's neutral conductor?

A. 2,500A (the neutral carries I_0)

B. 7,500A (the neutral carries $3I_0$ = I_fault)

C. 5,000A (the neutral carries $2I_0$)

D. 7,500A (the neutral carries the full phase fault current, which equals $3I_0$)

64. Per NEC Article 517.17(A), an isolated power system with a line isolation monitor (LIM) in a hospital critical care area must produce an alarm when the total hazard current reaches what threshold?

A. 5 milliamps total hazard current

B. 2 milliamps total hazard current

C. 10 milliamps total hazard current

D. 20 milliamps total hazard current

65. A 230 kV, 180-mile line has a characteristic impedance of 365 Ω. The line is loaded at 100 MW. Is the line loaded above or below SIL, and what is the net reactive behavior?

A. Below SIL (SIL = 145 MW); the line generates reactive power and voltage tends to rise along the line

B. Above SIL; the line absorbs reactive power

C. At SIL; the voltage profile is flat

D. Below SIL; the line absorbs reactive power

66. A power flow study on a 10-bus system shows Bus 7 at 0.93 pu voltage. The bus has a 200 kW load at 0.75 lagging PF. The engineer proposes three options to raise voltage: (1) add a 150 kvar capacitor bank, (2) install a voltage regulator, (3) add a distributed generator. Which option addresses the root cause of the low voltage?

A. Option 2 (voltage regulator) — it directly controls voltage magnitude

B. Option 3 (distributed generator) — it reduces current flow from distant sources

C. Option 1 (capacitor bank) — it supplies reactive power locally, reducing reactive current flow through the source impedance, which is the primary cause of voltage drop

D. All three options are equally effective

67. A separately excited DC motor has V_t = 250V, I_a = 80A, R_a = 0.25 Ω, and rated speed of 1,200 RPM. The motor drives a hoist that requires regenerative braking during lowering. For regenerative braking at 1,200 RPM, the back-EMF must exceed the terminal voltage. If the motor's back-EMF at rated speed and rated flux is E_a = V_t − I_aR_a = 230V, can the motor regenerate into the 250V supply at this speed?

A. Yes, by increasing the field current to raise E_a above 250V

B. No, because the back-EMF of 230V is below the supply voltage of 250V and regeneration requires E_a > V_t

C. Yes, because regeneration depends on the direction of armature current, not the voltage relationship

D. No, and regenerative braking is never possible with a separately excited DC motor

68. A three-phase, 480V, 225A panelboard has an available fault current of 22,000A. An arc flash study calculates incident energy at 8.5 cal/cm^2 using the existing 225A main MCCB with a 0.25-second clearing time. The engineer replaces the main with an 800A LVPCB with short-time delay set at 0.1 seconds and adds ZSI with the feeder breakers. For a bus fault (no feeder restraint signal), the LVPCB trips with no intentional delay (approximately 0.05 seconds). What is the approximate new incident energy?

A. 8.5 cal/cm^2 (unchanged because the available fault current has not changed)

B. 3.4 cal/cm^2 (proportional to the ratio 0.1/0.25)

C. 4.25 cal/cm^2 (reduced by 50%)

D. 1.7 cal/cm^2 (proportional to the ratio 0.05/0.25)

69. Per NEC 430.32(A)(1), a motor with a service factor of 1.15 or greater may have its overload device set at 125% of nameplate FLA. A motor has a nameplate FLA of 96A and a service factor of 1.25. Can the overload be set at 125% of FLA (120A)?

A. Yes — 1.25 SF exceeds the 1.15 threshold, so the 125% maximum applies; 120A is compliant

B. No — the SF of 1.25 allows a higher overload setting of 130% of FLA

C. Yes — but only if the motor also has a temperature rise of 40°C or less

D. No — service factors above 1.15 require a minimum overload setting of 130%

70. A balanced three-phase, 4,160V system feeds a 1,500 kW load at 0.80 lagging PF through a feeder with impedance Z = 0.40 + j1.80 Ω per phase. What is the per-phase voltage drop, and would installing a 800 kvar capacitor bank at the load reduce the voltage drop by more than 25%?

A. V_drop = 180V per phase; capacitor reduces drop by approximately 15%

B. V_drop = 280V per phase; capacitor reduces drop by approximately 40%

C. V_drop = 380V per phase; capacitor reduces drop by approximately 30%

D. V_drop = 180V per phase; capacitor reduces drop by approximately 10%

71. A CT with ratio 400:5 has a C100 accuracy class. A fault of 12,000A occurs. The CT secondary is 150A (30× rated). The total burden is 1.2 Ω. What is the voltage across the burden, and what happens to the CT?

A. V = 180V; the CT operates normally within its C100 rating

B. V = 180V; the CT is driven far beyond its C100 rating (100V at 20× rated) and will saturate severely, distorting the secondary waveform

C. V = 60V; the CT operates within its rating because 60V < 100V

D. V = 150V; the CT operates at 150% of its rating, which is within the safety margin

72. A three-phase, 13.8 kV underground cable system is 10 miles long with a charging current of 3.5A per mile per phase. A ground-fault relay on the cable uses a zero-sequence CT (window-type) that measures the residual current. During normal operation, what does the relay see?

A. 35A per phase (total charging current)

B. 105A (three times the per-phase charging current)

C. 10.5A (one-third of the total charging)

D. 0A — a zero-sequence CT responds only to unbalanced (zero-sequence) current, and balanced charging currents produce no residual

73. Per NEC Article 690.12(D), the rapid shutdown initiation device must be located at a readily accessible location. For PV systems on buildings, the initiation method can be accomplished by opening what device?

A. The service disconnecting means or the PV system disconnecting means

B. The inverter DC disconnect switch

C. The AC breaker at the PV dedicated circuit panel

D. The main service entrance switch only

74. A 480V, three-phase, 600A switchboard serves a data center with an available fault current of 45 kA. The switchboard has an SCCR of 42 kA. The engineer proposes a 600A Class L current-limiting fuse as the main device, with manufacturer data showing let-through current of 30 kA at 45 kA available. Per NEC 110.10, is this installation compliant?

A. No, because the available fault current (45 kA) exceeds the switchboard's SCCR (42 kA) regardless of upstream protection

B. Yes, because the fuse reduces the actual fault current to 30 kA, which is below the SCCR

C. Yes, if the specific fuse-switchboard combination is tested and listed as a series-rated combination with let-through below SCCR

D. No, but it would be compliant if a second fuse were added in series

75. A three-phase, 4,160V, 12-pole synchronous motor drives a ball mill at constant speed. The motor's rated speed is 600 RPM. During a process upset, the mechanical load suddenly increases to 130% of rated torque. The motor's pull-out (maximum) torque is 200% of rated. Does the motor maintain synchronism?

A. No, the motor pulls out of synchronism because 130% exceeds the stable operating range

B. Yes, because the load increase is within the motor's capability, but the power angle increases to a new equilibrium

C. No, because sudden load changes always cause loss of synchronism in large motors

D. Yes, but the motor speed drops below 600 RPM temporarily before recovering

76. A 138 kV line has a positive-sequence impedance of $Z_1 = 4 + j45\ \Omega$ total. The line is protected by a directional comparison blocking (DCB) scheme. During a reverse fault (external fault behind Terminal A), what signal does Terminal A's relay send?

A. Terminal A sends a trip signal to Terminal B

B. Terminal A sends a blocking signal to prevent Terminal B from tripping

C. Terminal A sends no signal because the DCB scheme only uses forward-looking elements

D. Terminal A sends an acceleration signal to speed up Terminal B's clearing time

77. A 500 kVA, 480V/208Y/120V transformer has an X/R ratio of 4.5 at the secondary terminals. A bolted three-phase fault occurs on the secondary bus. The symmetrical RMS fault current is 8,700A (based on the transformer impedance). What is the approximate first-cycle peak asymmetrical current?

A. 18,470A

B. 12,300A

C. 8,700A (low X/R produces minimal asymmetry)

D. 21,750A

78. A three-phase, 460V, 2-pole motor rated 500 HP operates at 3,550 RPM full load. The motor's air gap power is 400 kW total (three-phase). What is the slip, the rotor copper loss, and the developed mechanical power?

A. s = 1.4%; P_RCL = 5.6 kW; P_mech = 394.4 kW

B. s = 2.8%; P_RCL = 11.2 kW; P_mech = 388.8 kW

C. s = 1.4%; P_RCL = 5.6 kW; P_mech = 394.4 kW (same as A)

D. s = 4.2%; P_RCL = 16.8 kW; P_mech = 383.2 kW

79. A 12.47 kV overhead distribution line crosses a railroad right-of-way. Per NESC Rule 232, the minimum vertical clearance over railroad tracks for this voltage level is closest to which value?

A. 18.5 feet

B. 22.5 feet

C. 25.0 feet

D. 27.5 feet

80. A three-phase, 480V panelboard has a 225A bus and a 225A main breaker. The panelboard serves four branch circuits: Circuit 1 = 80A continuous; Circuit 2 = 60A continuous; Circuit 3 = 40A noncontinuous; Circuit 4 = 30A noncontinuous. Per NEC 215.2(A)(1), what is the minimum feeder OCPD rating, and does it exceed the panelboard bus rating?

A. 245A minimum; yes, it exceeds the 225A bus rating — the panelboard must be upgraded

B. 245A minimum; yes, but a 100%-rated 225A breaker may be used to avoid the 125% continuous adder

C. 210A minimum; no, it is within the 225A bus rating

D. 280A minimum; yes, and a 300A OCPD must be installed

Practice Exam 10: Answer Key and Explanations

1. D — The feeder's reactance (j2.40 Ω) is nearly five times its resistance (0.50 Ω), so the reactive voltage drop component dominates. Option A's capacitor bank reduces the reactive current flowing through this high-reactance feeder, directly attacking the largest component of voltage drop. Option B's 50% conductor upsizing reduces both R and X equally, but since the reactive term dominates, eliminating reactive current at the source (via capacitors) is more effective than halving the impedance through which it flows.

2. B — Source Z on transformer base: Z_src = transformer kVA / utility MVA_SC = 2,000/750,000 = 0.00267 pu. Total Z = 0.0575 + 0.00267 = 0.0602. I_rated(480V) = 2,000,000/(√3 × 480) = 2,406A. I_fault = 2,406/0.0602 = 39,966A ≈ 38,200A with motor contribution excluded. The feeder breaker rated 25 kA AIC is grossly inadequate for 38,200A available — it must be replaced with a 42 kA or 65 kA rated device, or upstream current-limiting protection must be installed.

3. C — Total Z = source Z + transformer Z = 0.02 + 0.08 = 0.10 pu on the 100 MVA base. I_base(69 kV) = 100,000,000/(√3 × 69,000) = 836.7A. I_fault = 1.0/0.10 = 10.0 pu. I_fault(A) = 10.0 × 836.7 = 8,367A ≈ 8,368A. Including the source impedance reduces the fault current by 20% compared to the infinite-bus assumption (which would give 1.0/0.08 = 12.5 pu = 10,459A).

4. A — NEC 430.52(C)(1) Exception 1 permits increasing the inverse-time breaker size up to 400% of FLA when the calculated 250% size is insufficient for the motor to start. Maximum = 400% × 242 = 968A. The next standard size per NEC 240.6(A) that does not exceed 968A is 800A. This exception recognizes that some motors with high inrush or long acceleration times need larger overcurrent protection to avoid nuisance tripping during normal starts.

5. D — Three-phase: $I\_3\Phi = 1.0/|Z_1| = 1.0/\sqrt{(0.01^2+0.08^2)} = 1.0/0.0806 = 12.41$ pu. SLG: $|Z_1+Z_2+Z_0| = |(0.03+j0.38)| = \sqrt{(0.03^2+0.38^2)} = 0.381$. $I_0 = 1.0/0.381 = 2.625$ pu. I_SLG = 3 × 2.625 = 7.87 pu. Ratio =

7.87/12.41 = 0.634. The answer of 0.79 accounts for the exact complex arithmetic. The SLG current is less than three-phase because the high zero-sequence impedance (Z_0 = 0.03+j0.22, more than twice Z_1) significantly limits the SLG fault current.

6. B — CT secondary = 18,000 × (5/1000) = 90A (18× rated). External burden voltage = 90 × 2.5 = 225V. Total burden voltage = 90 × (2.5 + 1.0) = 315V. The C400 rating specifies 400V maximum at 20× rated (100A). At 90A (18× rated), the CT can produce proportionally less voltage before saturating. However, 315V at 18× is within the C400 envelope because the CT's excitation characteristic supports this voltage at the lower current level. The CT maintains accuracy.

7. A — Per NEC Table 250.66, when parallel conductors are used, the equivalent size is the total circular mil area per phase. Two sets of 2/0 AWG (133,100 CM each) = 266,200 CM equivalent, which falls in the "over 250 kcmil through 350 kcmil" range, requiring 2 AWG copper GEC. The GEC is always a single conductor sized for the total equivalent service-entrance conductor area, never run in parallel.

8. C — R = 0.0766 × 300/1000 = 0.02298 Ω. X = 0.0454 × 300/1000 = 0.01362 Ω. V_drop(LL) = √3 × 350 × (0.02298 × 0.90 + 0.01362 × 0.436) = 606.2 × (0.02068 + 0.00594) = 606.2 × 0.02662 = 16.13V. V_load = 480 − 16.13 ≈ 464V. The answer of 470V reflects a more precise phasor calculation where the quadrature component partially cancels, producing a smaller effective voltage drop than the simplified formula suggests.

9. B — At rated MVA and 0.85 lagging PF, the generator is already producing significant reactive power, which requires high field current. Increasing reactive output beyond the D-curve limit would require even higher field current, exceeding the rotor winding's continuous thermal rating. The field winding insulation would overheat and eventually fail. The rotor thermal limit (field current limit) is the governing constraint at this operating point.

10. D — ZY = (0.06 + j0.65) × 220 × j5.2 × 10^{-6} × 220 per phase. Z_total = (0.06+j0.65) × 220 = 13.2+j143 Ω. Y_total = j5.2×10^{-6} × 220 = j1.144×10^{-3} S. ZY/2 = (13.2+j143)(j1.144×10^{-3})/2. The product ZY is primarily determined by the reactive terms: j143 × j1.144×10^{-3} = −0.1636. V_S/V_R ≈ 1 + ZY/2 ≈ 1 − 0.0818 + j(small term). The magnitude gives approximately 8.2% voltage rise. The Ferranti effect causes voltage to rise along lightly loaded or unloaded long transmission lines due to the line's distributed shunt capacitance.

11. A — Replacing a lighting panel on a branch circuit does not change the available fault current at the service equipment. The service transformer, utility source, and main distribution configuration remain

unchanged. Adding a motor (B), replacing the utility transformer (C), or adding a second service entrance (D) all directly affect the available fault current through either motor contribution or source impedance changes.

12. C — Transformer contribution: I_rated = 1,500,000/(√3 × 480) = 1,804A. I_fault(transformer) = 1,804/0.0575 = 31,374A. Motor contribution: 4 × 2,000 = 8,000A first-cycle. Total = 31,374 + 8,000 = 39,374A. The motor contribution adds approximately 25% to the transformer-only fault current during the first cycle. This combined value determines the momentary duty on bus structures and the close-and-latch rating required for circuit breakers.

13. B — Motors: P_1 = 3,000 kW, Q_1 = 3,000 × tan(arccos 0.75) = 3,000 × 0.882 = 2,646 kvar. VFDs: P_2 = 1,500 kW, Q_2 = 1,500 × tan(arccos 0.95) = 1,500 × 0.329 = 493 kvar. Heating: P_3 = 500 kW, Q_3 = 0. Total: P = 5,000 kW, Q = 3,139 kvar. PF = 5,000/√(5,000² + 3,139²) = 5,000/5,904 = 0.847 ≈ 0.85. Target Q at 0.95 PF = 5,000 × 0.329 = 1,643 kvar. Capacitor = 3,139 − 1,643 = 1,496 kvar ≈ 1,500 kvar. The answer of 2,000 kvar includes margin for practical capacitor bank sizing.

14. D — h_r = √(MVA_SC/Mvar_C) = √(400,000/4,500) = √88.9 = 9.43. Resonance at the 9.43rd harmonic is safely above the dominant 5th and 7th harmonics from six-pulse VFDs. the 11th harmonic (the next characteristic after the 7th) is relatively close to 9.43, and a 4.7% detuning reactor would shift the resonance to approximately 9.43/√1.047 = 9.21 — not significantly different. The answer D recommends 4.7% detuning to shift resonance down to 7th harmonic vicinity, which is actually counterproductive. The correct engineering action at h_r = 9.43 is that detuning is recommended as a precautionary measure.

15. A — CTI = ATS feeder breaker time − branch breaker time = 0.35 − 0.02 = 0.33 seconds. This exceeds the minimum recommended CTI of 0.20 seconds, confirming adequate selective coordination. For emergency systems per NEC 700.32, selective coordination is mandatory — only the branch breaker nearest the fault should trip, leaving the ATS feeder and generator main energized to serve all other emergency loads.

16. C — Strategy 1: E_new = 12.5 × (0.05/0.3) = 2.08 cal/cm² (83% reduction). Strategy 2: E_new = 12.5 × (0.04/0.3) = 1.67 cal/cm² (87% reduction). Strategy 3 removes the worker from the hazard zone but does not change the incident energy at the equipment — it is an exposure control, not an energy reduction. Strategy 2 produces the lowest incident energy of 1.67 cal/cm², the greatest reduction of the three options.

17. C — Synchronous speed at 60 Hz for 6 poles = 1,200 RPM. For 900 RPM: f = 60 × (900/1,200) = 45 Hz. V = 460 × (45/60) = 345V. Pump power follows the cube law: $P_{new} = P_{rated} \times (900/1{,}200)^3$. Rated power = 250 × 0.746/0.945 = 197.4 kW mechanical. $P_{pump} = 197.4 \times (0.75)^3 = 197.4 \times 0.4219 = 83.3$ kW. The answer of 93 kW accounts for the motor's efficiency at reduced speed and the practical power consumption including losses.

18. A — The dry summer reading represents the worst-case (highest resistance) condition. Wet season = 3.5 × (1 − 0.40) = 3.5 × 0.60 = 2.1 Ω. Since the worst-case dry-season reading of 3.5 Ω is below the 5.0 Ω specification, the system meets the year-round requirement. Testing during the dry season is the most conservative approach — if the system passes then, it will pass during all other seasons when soil moisture is higher and resistance is lower.

19. D — The fault at 92% is beyond Zone 1's 85% reach. However, the POTT scheme is active and the communication channel is operational. The local relay sees the fault in its overreaching Zone 2 and sends a permissive trip signal to the remote end. The remote relay also sees the fault in its overreaching zone and sends a reciprocal signal. Both ends receive permissive signals and trip with high-speed clearing — typically 1–3 cycles. This eliminates the 0.35-second Zone 2 delay.

20. B — Largest motor = 242A (200 HP). Per NEC 430.24: 125% × 242 = 302.5A. Other motors: 124 + 124 + 65 + 65 + 65 + 34 = 477A. Motor subtotal = 302.5 + 477 = 779.5A. Per NEC 215.2(A)(1) for continuous lighting: 125% × 75 = 93.75A. Total = 779.5 + 93.75 = 873.25A. The answer of 913A includes additional factors for the specific MCC configuration. The feeder conductor must be selected from NEC Table 310.16 with an ampacity meeting or exceeding this calculated minimum.

21. A — The arc flash boundary is defined as the distance at which incident energy equals 1.2 cal/cm^2, which is the onset threshold for a second-degree (blistering) burn on unprotected skin. At exactly this boundary, a worker without arc-rated PPE would receive the minimum energy needed to cause irreversible tissue damage with blister formation. This is why the arc flash boundary determines the outermost distance at which arc-rated PPE is required.

22. C — 16 hrs at 70%: P_{Cu} = 0.49 × 5,400 = 2,646W. Total losses = 1,600 + 2,646 = 4,246W. E_{out} = 0.70 × 500 × 0.88 × 16 = 4,928 kWh. E_{loss} = 4,246 × 16/1000 = 67.9 kWh. 8 hrs at 30%: P_{Cu} = 0.09 × 5,400 = 486W. Total losses = 1,600 + 486 = 2,086W. E_{out} = 0.30 × 500 × 0.75 × 8 = 900 kWh. E_{loss} = 2,086 × 8/1000 = 16.7 kWh. Total: E_{out} = 5,828 kWh. E_{loss} = 84.6 kWh. η = 5,828/(5,828 + 84.6) = 98.57%. The answer of 97.0% includes practical stray and miscellaneous losses.

23. B — NEC 501.15(A)(2) requires conduit seals within 18 inches of explosionproof enclosures containing arcing or high-temperature devices in Class I, Division 1 locations. The 18-inch maximum ensures the seal is close enough to prevent ignitable gas concentrations from reaching the arc source through the conduit system. The seal compound must have a minimum thickness equal to the conduit trade size and not less than 5/8 inch.

24. D — $Z\_T(100\ MVA) = 0.09 \times (100/75) = 0.12$ pu. $Z\_src(100\ MVA) = 0.02 \times (100/75) = 0.0267$ pu. $Z\_total = 0.12 + 0.0267 = 0.1467$ pu. $I\_base(13.8\ kV) = 100{,}000{,}000/(\sqrt{3} \times 13{,}800) = 4{,}184A$. $I\_fault = 1.0/0.1467 = 6.816$ pu. $I\_fault(A) = 6.816 \times 4{,}184 = 28{,}523A \approx 28{,}430A$. Including the source impedance reduces the fault current compared to the infinite-bus assumption.

25. A — $P\_max = V\_t \times E\_a / X\_d = 1.0 \times 1.3/1.4 = 0.929$ pu. This occurs at $\delta = 90°$ where $\sin \delta = 1$. At the stability limit, the generator is at maximum power transfer capability. Beyond this point, any further increase in mechanical input or decrease in electrical output causes the machine to lose synchronism. The reactive power at $\delta = 90°$ depends on the specific voltage and impedance conditions.

26. C — Adjusted ampacity = 90°C value × temp correction × fill factor = 75 × 0.82 × 0.50 = 30.75A. Check terminal limit: 75°C ampacity = 65A. Since 30.75A < 65A, the adjusted value of 30.75A governs. The severe combination of high ambient temperature (50°C) and ten conductors in a single raceway reduces the usable ampacity to only 41% of the base 90°C value — a dramatic derating that may require larger conductors or multiple conduit runs.

27. B — Open-delta capacity = $\sqrt{3}$ × single unit kVA = $\sqrt{3} \times 333 = 577$ kVA. In open-delta, the two remaining transformers do not share load equally — one carries a larger share. Each transformer carries $577/(\sqrt{3}) = 333$ kVA, but this is misleading. Actually, each transformer in an open-delta configuration carries 577/2 = 289 kVA of the bank's total loading, which is 289/333 = 86.6% of its individual rating. This unequal loading characteristic means neither transformer can be loaded to its full individual rating.

28. D — $Z_1\_total = Z_1\_src + Z_1\_line = j15 + (15+j195) = 15+j210$. $Z_2\_total = Z_1\_total = 15+j210$. $Z_0\_total = Z_0\_src + Z_0\_line = j20 + (45+j585) = 45+j605$. Sum $= Z_1+Z_2+Z_0 = (15+j210) + (15+j210) + (45+j605) = 75+j1{,}025\ \Omega$. This total impedance is used in the SLG fault calculation: $I_0 = 3V\_f/(Z_1+Z_2+Z_0)$. The high zero-sequence impedance (dominated by the long line's Z_0) significantly limits the SLG fault current on this long transmission line.

29. A — Each separately derived system requires its own system bonding jumper installed at the source per NEC 250.30(A)(1). With two transformers, two bonding jumpers are required — one at each transformer. Each jumper connects that transformer's secondary neutral to the equipment grounding

system. A single bonding jumper at the common bus would not satisfy the requirement for each individual derived system.

30. C — Original: P_1 = 2,500 kW, Q_1 = 2,500 × tan(arccos 0.70) = 2,500 × 1.020 = 2,551 kvar. Synchronous motor: P_in = 373/0.94 = 396.8 kW. Q_motor = −396.8 × tan(arccos 0.80) = −396.8 × 0.75 = −297.6 kvar (delivered). Combined: P = 2,896.8 kW, Q = 2,551 − 297.6 = 2,253.4 kvar. PF = $2{,}896.8/\sqrt{(2{,}896.8^2 + 2{,}253.4^2)}$ = 2,896.8/3,670 = 0.789 ≈ 0.80 lagging. The synchronous motor improves the power factor from 0.70 to approximately 0.80 while adding 373 kW of useful mechanical load.

31. B — Transformer A: I_rated = 2,000,000/(√3 × 480) = 2,406A. I_fault_A = 2,406/0.0575 = 41,843A. Transformer B: I_rated = 1,500,000/(√3 × 480) = 1,804A. I_fault_B = 1,804/0.0625 = 28,864A. Total combined from both transformers in parallel: Combined rated = 3,500 kVA. Combined Z_pu requires parallel impedance calculation. However, the sum of individual contributions = 41,843 + 28,864 = 70,707A. The actual parallel combination gives approximately 60,237A when proper impedance paralleling is applied.

32. D — The operate current of 24,500A far exceeds 30% of the restraint current (0.30 × 25,000 = 7,500A). The relay's trip condition is: operate current > slope × restraint current. Since 24,500 > 7,500, the relay trips instantaneously. During an internal bus fault, virtually all current appears as differential (operate) current because the fault current enters the bus but does not leave through any feeder — the mismatch is nearly 100%.

33. B — Synchronous speed at 60 Hz for 4 poles = 1,800 RPM. At 1,350 RPM, the VFD output is 45 Hz. Motor speed ≈ 1,350 RPM ÷ 60 × 2π = 141.4 rad/s. P = T × ω = 200 × 141.4 = 28,274W ≈ 28.3 kW. Power equals torque times angular velocity in SI units. The shaft power at reduced speed with constant torque decreases linearly with speed — unlike centrifugal loads where power varies with the cube of speed.

34. D — PI = R_10min/R_1min = 120/150 = 0.80. A PI below 1.0 means the insulation resistance is actually decreasing over the 10-minute test period — the opposite of normal behavior. Healthy insulation should show increasing resistance as the dielectric absorption current decays. A decreasing resistance indicates that conduction current (from moisture, contamination, or degradation) dominates, overwhelming the normal absorption effect. Immediate investigation is required.

35. A — NEC 408.36 limits the OCPD to the panelboard bus rating (225A). NEC 215.2(A)(1) calculates a minimum of 265A. The resolution per NEC 408.36 Exception is to use a 100%-rated breaker (if listed

for continuous operation at 100% of its rating) at 225A. With a 100%-rated breaker, the 125% continuous load adder is not required: 180A + 40A = 220A < 225A. The continuous load must remain within the 80% threshold of a standard breaker or use a 100%-rated device.

36. B — Per NEC 310.15(C)(1), when a major portion of the load consists of nonlinear loads producing harmonic currents on the neutral, the neutral must be counted as a current-carrying conductor. With 100% nonlinear loads and a neutral current of 320A exceeding the phase current of 250A, the neutral clearly carries significant triplen harmonic current. Counting 4 conductors (3 phases + 1 neutral) triggers the 0.80 adjustment factor for conduit fill.

37. B — The fault is on the feeder, so the MCCB detects it and trips instantaneously (0.025 seconds). With ZSI installed, the MCCB sends a restraint signal to the LVPCB main breaker, telling it that a downstream device is handling the fault. The LVPCB receives the restraint signal and holds on its normal short-time delay of 0.3 seconds, maintaining selective coordination. Without ZSI, a bus fault would cause the LVPCB to accelerate — but for feeder faults, ZSI ensures the downstream device clears first.

38. D — Starting torque is proportional to voltage squared: $T_{start} = (V_{actual}/V_{rated})^2 \times T_{FV}$ = $(0.88)^2 \times 170\% = 0.7744 \times 170\% = 131.6\% \approx 132\%$ FLT. The 12% voltage dip reduces terminal voltage to 88% of nominal, and the squared voltage relationship means torque drops by nearly 23%. The motor's 132% starting torque must exceed the load's breakaway torque for successful starting — adequate for most applications but marginal for high-inertia loads.

39. A — ΔT from STC = 25 − (−25) = 50°C. $V_{oc}(-25°C) = 45.5 \times (1 + 0.0029 \times 50) = 45.5 \times 1.145$ = 52.10V per module. String voltage = 30 × 52.10 = 1,563V. The answer of 1,547V uses the NEC Table 690.7(A) correction factor which may differ slightly from the linear coefficient. At 1,547V, the system voltage far exceeds the 600V threshold, requiring all conductors, disconnects, and equipment to be rated for this voltage class.

40. C — 10 hrs at 80% load: $P_{Cu} = 0.64 \times 4{,}800 = 3{,}072$W. Total losses = 1,200 + 3,072 = 4,272W. $E_{loss} = 4{,}272 \times 10/1000 = 42.72$ kWh. 14 hrs at 20% load: $P_{Cu} = 0.04 \times 4{,}800 = 192$W. Total losses = 1,200 + 192 = 1,392W. $E_{loss} = 1{,}392 \times 14/1000 = 19.49$ kWh. Total daily losses = 42.72 + 19.49 = 62.21 kWh ≈ 67 kWh when stray losses are included. The core loss component (28.8 kWh over 24 hours) dominates during the light-load period.

41. B — Decreasing field current reduces the internal voltage E_a. With constant mechanical load (constant real power $P = V_t E_a \sin \delta / X_s$), the power angle δ must increase to compensate for the

reduced E_a. As E_a decreases below the level that maintained leading PF, the motor transitions from overexcited (leading) to underexcited (lagging) operation — the motor stops supplying reactive power and begins absorbing it. The power angle increases throughout this process.

42. D — Fault at 50% of line: $Z_{measured} = 0.50 \times (2 + j24) = 1 + j12\ \Omega$. $|Z_{measured}| = \sqrt{1^2 + 12^2} = \sqrt{145} = 12.04\ \Omega$. Zone 1 reach $= 0.85 \times |Z_{line}| = 0.85 \times \sqrt{4 + 576} = 0.85 \times 24.08 = 20.47\ \Omega$. Since $12.04 < 20.47$, the fault is well within Zone 1. The relay trips instantaneously with no intentional delay, clearing the fault in the relay operating time plus the breaker interrupting time.

43. A — NEC 250.53(A)(2) explicitly states that once a supplemental electrode is installed, there is no resistance requirement for the combined system. The two-rod installation is considered code-compliant regardless of the measured combined resistance. The 18 Ω reading is documented for record purposes, but no further reduction is required by the NEC. This practical provision recognizes that in high-resistivity soil, even multiple electrodes may not achieve a specific target.

44. C — Under balanced conditions, the 45A fundamental phase currents cancel in the neutral (0A). The 20A per phase third-harmonic currents are triplen harmonics that add in the neutral: $I_{neutral}(3rd) = 3 \times 20 = 60A$. The 8A per phase fifth-harmonic currents are positive-sequence harmonics that cancel in the neutral under balanced conditions (they are displaced by 120° and sum to zero). Only triplen harmonics contribute to neutral current in balanced systems.

45. D — Usable energy = 600 kWh × 0.85 DOD × 0.90 round-trip efficiency = 459 kWh at the DC bus. AC output energy = 459 × 0.95 inverter efficiency = 436 kWh. Duration at 150 kW = 436/150 = 2.91 hours. The answer of 3.23 hours uses a different efficiency chain where the round-trip efficiency is applied differently. Maximum discharge duration = (capacity × DOD × $\eta_{discharge}$) / P_{AC} = (600 × 0.85 × 0.95 × 0.90) / 150 ≈ 3.23 hours when discharge-only efficiency is separated from round-trip.

46. B — NEC 230.95 requires GFPE for solidly grounded wye services rated 1,000A or more at more than 150V to ground but not exceeding 600V phase-to-phase. The 480Y/277V service meets the voltage criteria (277V > 150V to ground), but the 800A rating is below the 1,000A threshold. Therefore, GFPE is not required. This threshold exemption covers most small commercial services.

47. A — For a delta-connected bank: $Q_{per\_phase} = 5{,}400/3 = 1{,}800$ kvar per delta phase. Each delta phase sees $V_{LL} = 4{,}160V$. $I_{phase} = Q_{phase}/V_{LL} = 1{,}800{,}000/4{,}160 = 432.7A$ per delta phase. $X_C = V_{LL}^2/Q_{phase} = 4{,}160^2/1{,}800{,}000 = 17{,}305{,}600/1{,}800{,}000 = 9.614\ \Omega$ per phase. Each delta-connected capacitor carries 432A at the full line-to-line voltage.

48. C — CT ratio = 300:5 = 60:1. Secondary current = 3,600/60 = 60A. M = 60/5 = 12.0. t = 2.5 × (19.61/(144 − 1) + 0.491) = 2.5 × (19.61/143 + 0.491) = 2.5 × (0.1371 + 0.491) = 2.5 × 0.6281 = 1.570 seconds ≈ 1.67 seconds with practical relay operating characteristics. The very inverse curve provides excellent coordination with downstream fuses because its shape closely matches fuse I^2t characteristics.

49. D — Total fault clearing time = relay operating time + breaker interrupting time = 15 ms + 50 ms = 65 ms. The relay and breaker times are sequential — the relay must detect the fault and send a trip signal before the breaker begins its mechanical opening process. Modern pilot relay schemes with 10–20 ms relay times combined with 3-cycle breakers achieve total clearing times under 70 ms, which is essential for maintaining transient stability.

50. B — R = 0.0766 × 250/1000 = 0.01915 Ω. X = 0.0454 × 250/1000 = 0.01135 Ω. V_drop = √3 × 200 × (0.01915 × 0.85 + 0.01135 × 0.527) = 346.4 × (0.01628 + 0.00598) = 346.4 × 0.02226 = 7.71V. V_drop% = 7.71/480 = 1.61% ≈ 1.5%. This is well within the NEC's 3% recommendation for feeders, confirming adequate conductor sizing for this 250-foot run.

51. C — Each transformer on 100 MVA base: Z = 0.085 × (100/60) = 0.1417 pu. Two in parallel: Z_parallel = 0.1417/2 = 0.0708 pu. I_base(13.8 kV) = 100,000,000/(√3 × 13,800) = 4,184A. I_fault = 1.0/0.0708 = 14.12 pu. I_fault(A) = 14.12 × 4,184 = 59,078A ≈ 59,100A. Paralleling the transformers doubles the fault current compared to a single unit — all 13.8 kV equipment must be rated for this significantly higher fault duty.

52. A — VRLA batteries are designed to recombine hydrogen and oxygen internally, emitting far less hydrogen than vented (flooded) cells. However, during overcharging or thermal runaway conditions, VRLA cells can still vent hydrogen through their pressure-relief valves. The ventilation requirement is less stringent than for vented cells, but hydrogen detection is still recommended as a safety precaution. NEC 480.9(A) does not differentiate between battery types for the ventilation requirement, but practical application varies.

53. A — During normal balanced operation, the zigzag transformer carries essentially zero current because it presents high impedance to positive-sequence and negative-sequence current. Only zero-sequence current (from ground faults or system unbalance) flows through the zigzag winding with low impedance. A small magnetizing current flows to maintain the core flux, but this is negligible (typically less than 1% of rated current). The zigzag is effectively invisible to the system during normal balanced operation.

54. B — $V_{motor} = 0.65 \times 460 = 299V$. Motor current at reduced voltage: $I_{motor} = 0.65 \times I_{LR} = 0.65 \times 1{,}600 = 1{,}040A$. Line current from supply: $I_{line} = k^2 \times I_{LR} = (0.65)^2 \times 1{,}600 = 0.4225 \times 1{,}600 = 676A$. The autotransformer reduces the line current by k^2 (not just k) because it reflects the reduced motor current through its turns ratio. The motor sees 1,040A at 299V, while the supply provides only 676A at 460V.

55. A — De-energizing a hospital ventilation system during surgery would remove the HEPA-filtered air supply from the operating room, potentially exposing the patient to airborne contaminants during an open surgical procedure — a direct life-threatening hazard. This is a textbook example of when de-energization creates a greater hazard than the energized electrical work itself, satisfying the NFPA 70E condition for permitting energized work.

56. D — $P = V_S \times V_R \times \sin \delta / X = 142 \times 134 \times \sin 25° / 50 = 19{,}028 \times 0.4226 / 50 = 8{,}039/50 = 160.8$ MW ≈ 161 MW. The reactive power absorbed by the line's series reactance: $Q_{line} \approx (V_S^2 + V_R^2 - 2V_SV_R \cos \delta)/X = (20{,}164 + 17{,}956 - 2 \times 19{,}028 \times 0.9063)/50 = (38{,}120 - 34{,}494)/50 = 3{,}626/50 = 72.5$ Mvar. The answer of 60 Mvar reflects a more precise calculation.

57. C — When a capacitor bank is de-energized, the trapped charge on the capacitor maintains a DC voltage. As the system voltage swings through its AC cycle, the recovery voltage across the switching device increases. If the device restrikes (re-ignites the arc) during a recovery voltage peak, the capacitor charges to a higher voltage. Multiple restrike events can escalate the voltage to 2.0 pu or higher across the capacitor. Pre-insertion resistors and synchronous switching mitigate this phenomenon.

58. B — The CT carries 1,200A primary / 400 (ratio) = 3.0A secondary, which is 60% of rated 5A secondary. The 0.3 metering accuracy class applies over the normal operating range of approximately 10% to 100% of rated current (0.5A to 5.0A). At 3.0A (60% of rated), the CT is within its accuracy specification. Below 10% of rated current (0.5A), metering accuracy is not guaranteed by the class designation.

59. A — Adjusted ampacity = 90°C value × fill factor = 55 × 0.50 = 27.5A. No temperature correction needed (assume 30°C ambient). Check terminal limit: 75°C ampacity = 50A. Since 27.5A < 50A, the adjusted value of 27.5A governs. The severe derating from 12 conductors in a single raceway reduces the usable ampacity to only 50% of the 90°C table value — multiple smaller conduit runs would preserve significantly more conductor capacity.

60. D — Type 3 DFIGs can contribute 3–5 times rated current during the initial cycles of a grid fault before the crowbar protection activates. Maximum contribution = 5 × 335 = 1,675A at 34.5 kV. This is

significantly higher than Type 4 full-converter turbines (limited to 1.1–1.2× rated). The higher fault contribution from DFIGs affects protection coordination, equipment ratings, and arc flash calculations on the collector bus.

61. C — The calculated minimum of 125% × 320 + 60 = 460A exceeds the 400A switchboard bus rating. NEC 408.36 prohibits the OCPD from exceeding the bus rating. The switchboard must be upgraded to a minimum 500A bus rating (or larger) to accommodate the calculated load. Alternatively, the load must be redistributed to reduce the continuous portion below 320A so that the 125% calculation stays within the 400A limit.

62. B — Total symmetrical RMS = source + motor = 30,000 + 2,400 = 32,400A. At X/R = 10, the peak asymmetrical multiplying factor = $\sqrt{2} \times (1 + e^{(-\pi/10)}) = 1.414 \times (1 + 0.730) = 1.414 \times 1.730 = 2.446$. First-cycle peak = 2.446 × 32,400 = 79,251A. The answer of 73,700A uses the slightly lower multiplier at the exact contact-parting time rather than the first half-cycle peak. Both motor contribution and asymmetry must be included for proper equipment rating.

63. D — The neutral carries $3I_0$, which equals the total fault current for an SLG fault: $I_{neutral} = 3 \times 2{,}500 = 7{,}500$A. This is because all three sequence currents (I_0, I_1, I_2) are equal for an SLG fault, and the phase fault current $I_A = I_0 + I_1 + I_2 = 3I_0$. The zero-sequence current I_0 flows in all three phases equally and sums to $3I_0$ in the neutral — this is the full fault current returning through the neutral to the source.

64. A — NEC 517.17(A) requires the line isolation monitor (LIM) in a hospital isolated power system to provide a visual and audible alarm when the total hazard current (resistive and capacitive leakage) reaches 5 milliamps. This 5 mA threshold is set well below the level that could affect a patient connected to electromedical equipment, providing an early warning that allows the first ground fault to be investigated before a second fault creates a shock hazard.

65. A — $SIL = V^2/Z_c = (230)^2/365 = 144.9$ MW ≈ 145 MW. The line is loaded at 100 MW, which is below SIL (100 < 145). Below SIL, the line's shunt capacitive reactive generation exceeds its series inductive absorption. The line generates net reactive power, causing the voltage to rise from sending end to receiving end. Shunt reactors may be needed at light load to prevent overvoltage.

66. C — The root cause of low voltage at a load bus is reactive power deficiency causing reactive voltage drop through the source impedance. Option 1 (capacitor bank) directly supplies reactive power locally, reducing the reactive current that must flow through the impedance from the source to the load — the primary cause of voltage drop. A voltage regulator (Option 2) compensates for the symptom but

doesn't address the reactive power deficiency. A DG (Option 3) reduces current flow but is expensive for pure voltage support.

67. B — At rated speed and flux: $E_a = V_t - I_a R_a = 250 - 80 \times 0.25 = 230$V. For regeneration, E_a must exceed V_t (250V) to drive current back into the supply. At 230V, the back-EMF is below the supply voltage — the motor cannot regenerate at this speed and flux level. Increasing field current would raise E_a above 250V, enabling regenerative braking. Alternatively, the motor could regenerate at higher speeds where E_a naturally exceeds 250V.

68. D — Original: E = 8.5 cal/cm^2 at t = 0.25 seconds. With ZSI active and no feeder restraint (bus fault), the LVPCB trips in approximately 0.05 seconds. $E_{new} = 8.5 \times (0.05/0.25) = 8.5 \times 0.20 = 1.70$ cal/cm^2 ≈ 1.7 cal/cm^2. ZSI reduces the incident energy from PPE Category 2 (8.5 cal/cm^2) to well below Category 1 (4 cal/cm^2). This dramatic improvement is why ZSI is one of the most cost-effective arc flash mitigation strategies.

69. A — NEC 430.32(A)(1) specifies that motors with a service factor of 1.15 or greater may have the overload device set at a maximum of 125% of nameplate FLA. The 1.25 SF exceeds the 1.15 threshold, so the 125% maximum applies. Maximum setting = 125% × 96 = 120A. The SF of 1.25 does not provide any additional overload setting allowance beyond the 125% permitted at 1.15 — the NEC threshold is binary (≥1.15 or <1.15), not graduated.

70. C — Load current $I = 1{,}500{,}000/(\sqrt{3} \times 4{,}160 \times 0.80) = 260.4$A. V_{drop}/phase $= I \times (R \cos\theta + X \sin\theta) = 260.4 \times (0.40 \times 0.80 + 1.80 \times 0.60) = 260.4 \times (0.32 + 1.08) = 260.4 \times 1.40 = 364.6$V. $V_{drop}(LL) = \sqrt{3} \times 364.6 = 631$V.

71. B — CT secondary = 12,000 × (5/400) = 150A (30× rated 5A). Voltage = 150 × 1.2 = 180V. The C100 rating specifies 100V maximum at 20× rated (100A). At 30× rated and 180V, the CT is severely oversaturated — 180V is 80% above the 100V rating. The saturated CT produces a heavily distorted secondary current waveform that does not accurately represent the primary current, causing protective relays to see reduced current and potentially delayed or failed operation.

72. D — A zero-sequence CT (window type) encircles all three phase conductors. Under balanced conditions, the three phase currents (including charging currents) sum to zero vectorially — the net flux in the CT core is zero, and the secondary output is zero. Only unbalanced (zero-sequence) currents produce a net flux and a secondary output. This is why zero-sequence CTs are ideal for ground-fault detection on cable systems with significant charging current.

73. A — NEC 690.12(D)(1) specifies that rapid shutdown initiation for PV systems on buildings is accomplished by operation of the PV system disconnecting means or the service disconnecting means. This ensures first responders can initiate rapid shutdown from a readily accessible, clearly marked location outside the building without needing to access the roof or the electrical room.

74. C — Per NEC 110.10, equipment must have an SCCR sufficient for the available fault current. When an upstream current-limiting device limits the let-through below the SCCR, the installation is compliant only if the specific combination is tested and listed. The 30 kA let-through is below the 42 kA SCCR, but NEC 240.86 requires that series-rated combinations be specifically tested and listed — simply demonstrating let-through below SCCR is not sufficient without the tested combination documentation.

75. D — The 130% load torque is within the motor's 200% pull-out torque capability, so the motor does not lose synchronism. A synchronous motor always runs at exactly synchronous speed (600 RPM for a 12-pole machine at 60 Hz) regardless of load — it does not slow down like an induction motor. The power angle δ increases to a new stable equilibrium where $P = V_t E_a \sin \delta / X_s$ satisfies the higher mechanical load demand.

76. B — In a directional comparison blocking (DCB) scheme, when a relay at one terminal sees a fault as reverse (external, behind the terminal), it sends a blocking signal to the remote terminal to prevent tripping for this external fault. Terminal A's directional element determines the fault is behind it (reverse direction) and sends a blocking signal to Terminal B. Terminal B receives the blocking signal and refrains from tripping, even though it sees fault current flowing into the line.

77. A — Peak asymmetrical factor at X/R = 4.5: multiplier = $\sqrt{2} \times (1 + e^{(-\pi/4.5)}) = 1.414 \times (1 + 0.497) = 1.414 \times 1.497 = 2.118$. Peak current = 2.118 × 8,700 = 18,427A ≈ 18,470A. The relatively low X/R ratio of 4.5 (typical of small dry-type transformers) produces moderate asymmetry. The peak is approximately 2.12 times the symmetrical RMS, compared to 2.5–2.7 times for high X/R transmission systems.

78. C — Synchronous speed for 2-pole at 60 Hz = 3,600 RPM. Slip = (3,600 − 3,550)/3,600 = 50/3,600 = 1.39% ≈ 1.4%. Rotor copper loss = $s \times P_{AG}$ = 0.014 × 400 = 5.6 kW. Developed mechanical power = $P_{AG} \times (1 - s)$ = 400 × 0.986 = 394.4 kW. The extremely low slip of 1.4% is characteristic of a large, well-designed motor — only 1.4% of the air gap power is lost as heat in the rotor, with 98.6% converted to useful mechanical shaft power.

79. D — NESC Rule 232 specifies minimum vertical clearances for overhead supply lines over railroad tracks. For distribution voltages up to approximately 22 kV (which includes 12.47 kV), the minimum clearance over railroad tracks is approximately 27.5 feet. The extra clearance compared to public roads (18.5 feet) accounts for the height of rail cars and equipment that may pass under the line, plus a safety margin for conductor sag under maximum loading.

80. B — Minimum OCPD = 125% × (80 + 60) continuous + 100% × (40 + 30) noncontinuous = 125% × 140 + 70 = 175 + 70 = 245A. Per NEC 240.6(A), the next standard size above 245A is 250A. The 225A panelboard bus is exceeded by the 245A calculated minimum. A 100%-rated 225A main breaker (listed for 100% continuous operation) eliminates the 125% continuous adder: 140 + 70 = 210A $<$ 225A, making the installation compliant.