PRACTICE EXAM 4: PE POWER SIMULATION (80 QUESTIONS)

1. A 4,160V, three-phase feeder supplies a load of 3,500 kW at 0.82 lagging power factor. The feeder has an impedance of 0.35 + j1.60 Ω per phase and is 2.5 miles long. A switched capacitor bank corrects the power factor to 0.96 lagging at the load bus. What is the approximate reduction in three-phase voltage drop across the feeder after the capacitor is energized?

A. 12 V reduction

B. 65 V reduction

C. 148 V reduction

D. 236 V reduction

2. A 75 kVA, 480V/208Y/120V, three-phase transformer has a short-circuit test power of 1,450 W and an open-circuit test power of 380 W at rated conditions. The transformer serves a data closet at 60% load with a 0.90 power factor. What is the transformer efficiency at this operating point?

A. 97.8%

B. 96.2%

C. 98.5%

D. 95.0%

3. Per NEC 430.32(A)(1), a motor with a marked temperature rise of 40°C or less and a service factor not less than 1.15 may have its overload device set at a maximum of 125% of nameplate FLA. A 50 HP, 460V motor has a nameplate FLA of 59A but the NEC Table 430.250 FLA is 65A. A dual-element time-delay fuse is used for branch-circuit protection. What is the maximum overload relay trip setting AND the maximum branch-circuit fuse size?

A. Overload: 73.75A; Fuse: 113.75A → next standard size 110A

B. Overload: 73.75A; Fuse: 81.25A → next standard size 90A

C. Overload: 67.85A; Fuse: 113.75A → next standard size 110A

D. Overload: 81.25A; Fuse: 130A → next standard size 125A

4. A 138 kV transmission line is 80 miles long with a series impedance of $Z = 0.12 + j0.80$ Ω/mile and a shunt admittance of $Y = j5.4 \times 10^{-6}$ S/mile. The line's charging reactive power at no load is $Q_c = V^2 Y \ell$. What is the approximate charging reactive power of this line at rated voltage?

A. 6.2 Mvar

B. 14.8 Mvar

C. 8.2 Mvar

D. 22.4 Mvar

5. An arc flash study at a 480V switchgear bus calculates an incident energy of 8.5 cal/cm² at a working distance of 24 inches using IEEE 1584 methods. The protective device clearing time is 0.15 seconds. If the clearing time were reduced to 0.05 seconds by enabling an instantaneous trip, what would the approximate new incident energy be, assuming a linear relationship between incident energy and time?

A. 4.25 cal/cm²

B. 1.42 cal/cm²

C. 2.83 cal/cm²

D. 5.67 cal/cm²

6. A three-phase, 13.8 kV generator has the following per-unit reactances on a 30 MVA base: $X''_d = 0.15$, $X'_d = 0.25$, $X_d = 1.10$, $X_2 = 0.17$, $X_0 = 0.08$. The generator neutral is grounded through a 1.0 Ω resistor. On the 30 MVA, 13.8 kV base, what is the per-unit value of the neutral grounding impedance ($3R_n$) as seen in the zero-sequence network?

A. 0.472 pu

B. 0.157 pu

C. 1.414 pu

D. 0.236 pu

7. A 12-pulse VFD draws 400A fundamental current from a 480V, three-phase supply. The input current THD is 10%. A passive 5th-harmonic filter is proposed. Why is this filter unnecessary for a 12-pulse drive?

A. The 5th harmonic is already below IEEE 519 limits at 10% THD

B. Passive filters are incompatible with 12-pulse rectifier topologies

C. The 5th harmonic is present but at reduced magnitude in 12-pulse drives

D. The 12-pulse topology cancels the 5th and 7th harmonics; the residual harmonics start at the 11th order

8. A 200A feeder circuit breaker (MCCB) with an adjustable instantaneous trip set at 1,500A protects a feeder to a motor control center. The largest motor on the MCC has a locked-rotor current of 1,200A and a full-load current of 200A. The remaining motors on the MCC have a combined FLA of 300A. During a cold start of the largest motor (with all other motors running), what is the approximate peak demand current on the feeder?

A. 1,700 A

B. 1,500 A

C. 500 A

D. 1,200 A

9. A series RL circuit with R = 5 Ω and L = 20 mH is connected to a 120V, 60 Hz source at t = 0. What is the time constant of the circuit's transient response?

A. 4.0 ms

B. 0.1 s

C. 100 ms

D. 0.4 s

10. A 2,500 kVA, 34.5/4.16 kV transformer has a percent impedance of 6.5% and a percent resistance of 1.1%. The transformer supplies a 2,000 kW load at 0.85 lagging power factor. What is the approximate voltage regulation?

A. 2.8%

B. 5.1%

C. 6.5%

D. 4.5%

11. A CT with a ratio of 1500:5 is connected to a 51 (time-overcurrent) relay. The relay pickup is set at 7A. A bolted fault on the protected feeder produces 6,000A. What is the multiple of pickup (M) that the relay sees for this fault?

A. 13.3

B. 2.86

C. 20.0

D. 4.0

12. A single-phase, center-tapped 120/240V residential transformer is rated 25 kVA. A homeowner plans to install a 50A, 240V electric vehicle charger. Assuming the charger is the only load on the transformer, what fraction of the transformer's capacity does this charger consume?

A. 24%

B. 100%

C. 48%

D. 96%

13. Per NEC Article 500, a paint spray booth where flammable vapors are present during normal spraying operations is classified as which of the following?

A. Class I, Division 1

B. Class I, Division 2

C. Class II, Division 1

D. Class III, Division 1

14. A power system has a three-phase fault level of 500 MVA at a 13.8 kV bus. A bolted three-phase fault occurs at this bus. What is the symmetrical fault current?

A. 10,480 A

B. 36,200 A

C. 15,230 A

D. 20,920 A

15. A synchronous motor drives a compressor at constant speed. The motor is currently operating at unity power factor with a field current of 10A. To make the motor deliver reactive power to the system (leading power factor), the operator should do what?

A. Decrease the field current below 10A to underexcite the motor

B. Increase the field current above 10A to overexcite the motor

C. Increase the compressor load to raise the power angle

D. Reduce the supply voltage to force the motor to generate reactive power

16. Per NEC 250.122, the equipment grounding conductor for a circuit protected by a 60A overcurrent device must be at least 10 AWG copper. If the circuit conductors are increased in size from 6 AWG to 4 AWG (a cross-sectional area increase of approximately 1.6×) to compensate for voltage drop, must the EGC also be increased proportionally?

A. Yes, NEC 250.122(B) requires proportional increase of the EGC when circuit conductors are upsized for voltage drop

B. No, the EGC size is based solely on the overcurrent device rating

C. Yes, but only if the circuit exceeds 200 feet in length

D. No, the EGC is always sized at the minimum from Table 250.122

17. A three-phase, 480V, 60 Hz power system supplies a nonlinear load that produces a significant 3rd-harmonic current of 60A per phase. The system uses a 480Y/277V, four-wire configuration. What is the approximate 3rd-harmonic current in the neutral conductor under balanced conditions?

A. 60 A (same as the per-phase value)

B. 0 A (triplen harmonics cancel in the neutral)

C. 180 A (three times the per-phase value)

D. 104 A (√3 times the per-phase value)

18. A 5,000 kW industrial load operates at 0.70 lagging power factor. The facility installs a 3,000 kvar capacitor bank. After the capacitor bank is energized, the system short-circuit capacity is 80 MVA. At what harmonic order does parallel resonance occur?

A. 3.2 (near the 3rd harmonic)

B. 7.3 (near the 7th harmonic)

C. 11.5 (near the 11th harmonic)

D. 5.2 (near the 5th harmonic)

19. A VFD drives a 460V, 4-pole, 60 Hz induction motor using constant V/f control. The motor is commanded to run at 900 RPM. What output frequency and voltage does the VFD produce?

A. 45 Hz and 345V

B. 30 Hz and 230V

C. 20 Hz and 153V

D. 45 Hz and 460V

20. A ground resistance test on a new substation ground grid yields a resistance of 3.2 Ω. The design specification requires a maximum of 1.0 Ω. The soil resistivity is 250 Ω·m. Which of the following is the most cost-effective approach to reducing the ground resistance to meet the specification?

A. Install a larger grounding transformer to lower the system impedance

B. Replace all copper ground conductors with aluminum to improve conductivity

C. Extend the ground grid area and add supplemental driven ground rods

D. Increase the burial depth of the existing grid from 18 to 36 inches

21. A 500 MVA, 345/138 kV autotransformer has a series impedance of 12% on its own base. A bolted three-phase fault occurs on the 138 kV bus with an infinite source on the 345 kV side. Using a 100 MVA system base, what is the per-unit transformer impedance and the fault current on the 138 kV bus?

A. Z = 0.024 pu, I_fault = 41.67 pu (17,413A)

B. Z = 0.12 pu, I_fault = 8.33 pu (3,483A)

C. Z = 0.024 pu, I_fault = 41.67 pu (17,413A) — same as A

D. Z = 0.60 pu, I_fault = 1.67 pu (697A)

Let me redo 21.

21. A 500 MVA, 345/138 kV autotransformer has a series impedance of 12% on its own base. On a 100 MVA system base, what is the transformer's per-unit impedance?

A. 0.60 pu

B. 0.12 pu

C. 0.024 pu

D. 1.20 pu

22. A protective relay has an IEEE moderately inverse time-overcurrent characteristic. The relay pickup is set at 4A (CT secondary) on a 200:5 CT. A fault produces 2,400A on the primary. With a time dial setting of 5.0, the relay's calculated operating time is 1.8 seconds. The circuit breaker has a 5-cycle interrupting time. What is the total fault clearing time?

A. 1.80 seconds

B. 5.08 seconds

C. 1.88 seconds

D. 1.883 seconds

23. A balanced three-phase, delta-connected source with a line-to-line voltage of 4,160V feeds a balanced wye-connected load with a per-phase impedance of $20\angle 36.87° \Omega$. What is the per-phase real power absorbed by the load?

A. 115.2 kW

B. 23.1 kW

C. 69.2 kW

D. 40.0 kW

24. Per NEC Article 700.10(D), all boxes and enclosures for emergency circuits must be permanently marked with what identification?

A. The boxes must be permanently marked to identify them as part of the emergency circuit

B. The boxes must be painted red with reflective lettering visible from 50 feet

C. The boxes must display the available fault current at their terminals

D. The boxes must have a UL listing label specific to emergency system equipment

25. A 30 MVA, 115/13.8 kV, delta-wye grounded transformer has the following sequence impedances on its own base: $Z_1 = Z_2 = j0.085$ pu, $Z_0 = j0.085$ pu. A bolted SLG fault occurs on the 13.8 kV bus. Assuming an infinite source on the 115 kV side, what is the SLG fault current in per-unit on the transformer's base?

A. 35.3 pu

B. 23.5 pu

C. 3.92 pu

D. 11.76 pu

26. A 480V motor control center contains the following motor loads: three 50 HP motors (NEC FLA = 65A each), two 25 HP motors (NEC FLA = 34A each), and one 10 HP motor (NEC FLA = 14A). Per NEC 430.24, what is the minimum feeder conductor ampacity for this MCC?

A. 371 A

B. 339.25 A

C. 324 A

D. 405.5 A

27. A 69 kV underground cable system has a shunt capacitance of 0.25 μF per mile per phase and is 15 miles long. At rated voltage (69 kV line-to-line), what is the approximate total three-phase charging current?

A. 5.6 A

B. 22.4 A

C. 56.0 A

D. 11.2 A

28. An insulation power factor (dissipation factor) test on a transformer bushing yields a reading of 3.5% at 20°C. The manufacturer's acceptance criterion is a maximum of 1.0% at 20°C. What does this result indicate?

A. The bushing insulation has excessive dielectric losses and should be investigated for contamination, moisture, or deterioration

B. The bushing is within acceptable limits since power factor values up to 5% are normal

C. The test is invalid because power factor tests cannot be performed at ambient temperatures below 25°C

D. The bushing has excellent insulation because lower power factor indicates higher losses

29. A three-phase induction motor has a rated output of 200 HP at 1,770 RPM on a 60 Hz supply. The motor is a 4-pole design. If this motor is connected to a 50 Hz supply at proportionally reduced voltage (maintaining the V/f ratio), what is its approximate synchronous speed and rated output at 50 Hz?

A. 1,500 RPM synchronous, approximately 167 HP rated output

B. 1,800 RPM synchronous, approximately 200 HP rated output

C. 1,250 RPM synchronous, approximately 139 HP rated output

D. 1,500 RPM synchronous, approximately 200 HP rated output

30. Per NEC 110.26, the minimum clear working space in front of a 480V panelboard where energized parts are exposed on one side and grounded parts on the other is classified as Condition 2. What is the minimum depth of clear working space required?

A. 3.0 feet

B. 3.5 feet

C. 3.0 feet (same as Condition 1)

D. 4.0 feet

31. A 13.8 kV distribution system has a three-phase short-circuit capacity of 200 MVA at the main bus. An engineer proposes installing a 5,000 kvar capacitor bank on this bus. The system contains numerous six-pulse VFDs. Before proceeding with the installation, the engineer calculates the parallel resonant harmonic order as $h_r = \sqrt{(200{,}000/5{,}000)} = 6.32$. Why is this result concerning?

A. The resonant frequency is above the 11th harmonic, posing minimal risk

B. The resonant frequency of 6.32 is too close to the 5th harmonic to ensure safe operation

C. The resonant frequency at 6.32 falls between the 5th and 7th harmonics, risking amplification of both

D. The 5,000 kvar bank is too large for a 200 MVA system regardless of harmonics

32. A three-phase, 480V, wye-connected source supplies two parallel-connected loads: Load 1 draws 150 kW at 0.85 lagging PF and Load 2 draws 100 kW at 0.70 lagging PF. What is the combined power factor of the two loads together?

A. 0.786 lagging

B. 0.85 lagging

C. 0.775 lagging

D. 0.70 lagging

33. A 25 kW photovoltaic array uses a string inverter with a maximum input voltage of 600 VDC. Each PV module has V_oc = 44.8V at STC (25°C) and a temperature coefficient of V_oc of −0.32%/°C. The minimum expected ambient temperature at the site is −15°C. What is the maximum number of modules that can be connected in series per string without exceeding the inverter's voltage rating?

A. 15 modules

B. 14 modules

C. 12 modules

D. 11 modules

34. A protection engineer is evaluating whether a proposed feeder relay setting provides adequate backup protection for a downstream transformer fuse. At the maximum through-fault current of 4,500A, the transformer fuse total clearing time is 0.08 seconds and the feeder relay operating time is 0.42 seconds. Is coordination adequate?

A. No, the CTI of 0.34 seconds is below the minimum 0.40 seconds for relay-fuse coordination

B. No, the relay must always operate faster than the fuse for proper backup

C. Yes, the CTI of 0.34 seconds exceeds the minimum 0.20 seconds for relay-fuse coordination

D. Yes, but only if the relay uses an extremely inverse characteristic

35. A wind farm consists of twenty 3 MW turbines connected to a 34.5 kV collector bus through individual step-up transformers. The collector bus feeds a single 69 kV/34.5 kV, 75 MVA substation transformer with 8% impedance on its own base. Assuming all turbines are at full output and ignoring collector system impedance, what is the approximate available fault current on the 34.5 kV collector bus from the substation transformer alone?

A. 1,253 A

B. 6,265 A

C. 15,660 A

D. 15,663 A is the same as C; recalculating: I_rated = 75,000/(√3 × 34.5) = 1,255A. I_fault = 1,255/0.08 = 15,688A

Let me redo 35.

35. A 75 MVA, 69/34.5 kV substation transformer has a percent impedance of 8% on its own base. Assuming an infinite 69 kV source, what is the maximum available three-phase fault current on the 34.5 kV bus?

A. 1,255 A

B. 6,275 A

C. 10,460 A

D. 15,690 A

36. A 150 HP, 460V, three-phase motor is to be started using a wye-delta starter. The motor's full-voltage (delta) locked-rotor current is 1,050A. What is the approximate line current during the wye-connected starting phase?

A. 607 A

B. 350 A

C. 525 A

D. 1,050 A

37. A data center UPS system uses a lithium iron phosphate (LFP) battery rated 500 kWh with a 90% DOD limit and a round-trip efficiency of 92%. If the critical IT load is 200 kW, what is the maximum backup duration the battery can provide through the UPS?

A. 2.5 hours

B. 1.15 hours

C. 1.73 hours

D. 2.07 hours

38. Per NEC 480.4(A), battery systems operating at more than 50 VDC nominal must have disconnecting means. A 48 VDC nominal battery system has an actual charging voltage of 56.4 VDC during equalization charging. Does this system require a disconnecting means per NEC 480.4(A)?

A. No, because the battery nominal voltage is 48V which is below 50V

B. Yes, because the disconnecting means requirement applies to all battery systems regardless of voltage

C. The requirement is based on nominal voltage; at 48V nominal the system is exempt from the disconnecting means requirement

D. Yes, because the actual operating voltage during equalization exceeds 50V

39. A balanced three-phase, 480V source feeds a 150 kW resistive heating load through a feeder with an impedance of 0.02 + j0.05 Ω per phase. What is the voltage at the load terminals?

A. 472.6 V

B. 465.3 V

C. 480.0 V (no appreciable drop for resistive loads)

D. 456.8 V

40. A facility has the following monthly electrical usage: energy consumption = 2,200,000 kWh, peak demand = 4,500 kW, and billing days = 30. The average power factor during the peak demand interval is 0.82 lagging. The utility offers a rate of $0.068/kWh for energy plus $14.00/kW for demand. A 1,500 kvar capacitor bank costs $45,000 installed. Assuming the capacitor bank reduces peak demand by 400 kW due to reduced reactive current, what is the simple payback period for the capacitor bank?

A. 6.7 months

B. 8.0 months

C. 12.0 months

D. 4.5 months

41. A three-phase synchronous generator rated 100 MVA, 18 kV has a subtransient reactance X"_d = 0.12 pu, a negative-sequence reactance X_2 = 0.14 pu, and a zero-sequence reactance X_0 = 0.06 pu. The

neutral is solidly grounded. Pre-fault voltage is 1.0 pu. What is the subtransient SLG fault current at the generator terminals in per-unit?

A. 8.33 pu

B. 6.25 pu

C. 12.50 pu

D. 9.375 pu

42. A 600A, 480V, low-voltage power circuit breaker (LVPCB) is set with a long-time pickup of 600A, a short-time pickup of 3,000A with a 0.3-second delay, and no instantaneous trip. A downstream 200A MCCB has an instantaneous trip set at 2,000A. A fault of 12,000A occurs downstream of the MCCB. Both breakers see 12,000A. Which device operates to clear the fault?

A. The LVPCB trips on its short-time delay after 0.3 seconds

B. Both breakers trip simultaneously within 1-3 cycles

C. The MCCB trips instantaneously (1-3 cycles); the LVPCB holds on short-time delay

D. Neither device operates because 12,000A exceeds both trip ratings

43. A CT with a ratio of 400:5 has a burden of 1.5 Ω (including leads and relay). The CT accuracy class is C100. A fault of 10,000A occurs on the primary. At this current level, does the CT maintain its accuracy?

A. No, the fault current produces 125A secondary into 1.5 Ω (187.5V), exceeding the C100 rating of 100V

B. Yes, because C100 means the CT is accurate up to 100 times rated current

C. No, but only because the primary current exceeds the CT's thermal rating

D. Yes, the CT secondary current of 125A at 1.5 Ω produces 75V, within the C100 rating

44. A medium-voltage motor is started using an autotransformer with an 80% voltage tap. The motor's full-voltage locked-rotor torque is 180% of full-load torque. What is the starting torque available at the motor shaft when using the 80% tap?

A. 144% of full-load torque

B. 115.2% of full-load torque

C. 80% of full-load torque

D. 180% of full-load torque

45. A 20-foot by 30-foot conference room requires 40 footcandles average illuminance. Recessed LED troffers rated at 4,000 lumens each will be used. The room has a CU of 0.65 and an LLF of 0.82. The ceiling cavity ratio is negligible (surface-mounted). How many luminaires are needed?

A. 6 luminaires

B. 13 luminaires

C. 16 luminaires

D. 9 luminaires

46. Per NEC 690.7, the maximum photovoltaic system voltage is determined by applying the correction factors from NEC Table 690.7(A) to the rated open-circuit voltage at STC. These correction factors adjust V_oc for what condition?

A. The lowest expected ambient temperature at the installation site

B. The highest expected cell temperature during peak solar irradiance

C. The maximum wind loading on the module frame and structure

D. The annual average ambient temperature for the location

47. A three-phase, 480V bus feeds three transformers in parallel. Transformer A is 500 kVA with Z = 5.0%, Transformer B is 750 kVA with Z = 5.5%, and Transformer C is 1,000 kVA with Z = 6.0%. On a 1,000 kVA common base, which transformer has the lowest per-unit impedance and will therefore carry the largest proportional share of the total load?

A. Transformer A (500 kVA, 5.0%)

B. Transformer B (750 kVA, 5.5%)

C. Transformer C (1,000 kVA, 6.0%)

D. All three carry equal proportional load because their impedances are similar

48. A NEMA Design C induction motor is selected over a Design B motor for a loaded reciprocating compressor application. What is the primary reason for this selection?

A. Design C has higher efficiency at full-load than Design B

B. Design C provides higher locked-rotor torque than Design B for the same HP rating

C. Design C operates at higher slip, providing better load damping

D. Design C has lower starting current than Design B at all voltage levels

49. A 13.8 kV, three-phase system has a bolted three-phase fault current of 15 kA at the main bus. A bus differential relay (87B) protects this bus. The relay's minimum pickup is set at 300A primary. A CT saturation study shows that during an external fault of 15 kA, the maximum CT error mismatch produces a differential current of 250A. Is the relay setting adequate?

A. No, because the 300A pickup is too high and will not detect low-level internal faults

B. No, because 250A is too close to the 300A pickup and the relay may false-trip

C. Yes, because 250A external fault differential is below the 300A pickup, preventing false trips while maintaining sensitivity for internal faults above 300A

D. Yes, but only if a 10% slope restraint is used instead of a fixed pickup

50. A three-phase, 4.16 kV system uses low-resistance grounding with a 400A ground-fault limit. The neutral grounding resistor has a 10-second thermal rating. If a ground fault occurs and the protection system fails to clear the fault within 10 seconds, what is the primary risk?

A. The grounding resistor overheats and may fail open, converting the system to ungrounded

B. The fault current increases beyond 400A as the resistor heats up

C. The system voltage collapses because the neutral impedance is too high

D. The grounding resistor overheats and may fail open, exposing the system to transient overvoltages from subsequent arcing faults

51. A three-phase power system has bus voltages of V_A = 277∠0° V, V_B = 277∠−120° V, and V_C = 255∠115° V (the system is slightly unbalanced). Using the symmetrical components transformation, the zero-sequence voltage V_0 = (1/3)(V_A + V_B + V_C). What is the approximate magnitude of V_0?

A. 8.5 V

B. 0 V (the system is balanced)

C. 277 V

D. 22 V

52. A 1,000 kVA, 13.8 kV/480V, delta-wye grounded transformer serves an industrial facility. NEC Table 450.3(B) specifies overcurrent protection for transformers 600V and below. If the transformer's rated primary current is 41.8A, what is the maximum primary overcurrent device rating?

A. 41.8 A

B. 52.3 A (125% of rated primary current, next standard size up)

C. 100 A (250% of rated primary current)

D. 70 A (167% of rated primary current)

53. A lightning arrester on a 13.8 kV distribution system has an MCOV (maximum continuous operating voltage) of 8.4 kV and a discharge voltage (protective level) of 36 kV for a 10 kA, 8/20 μs impulse. The protected transformer has a BIL of 95 kV. What is the protective margin?

A. 64%

B. 43%

C. 27%

D. 164%

54. A single-phase, 240V branch circuit in a commercial kitchen serves a 6,000W commercial oven (continuous load) and a 1,500W food processor (noncontinuous). Per NEC 210.20(A), the branch-circuit overcurrent device must have a rating not less than what value?

A. 31.25 A

B. 37.5 A

C. 37.5 A next standard size is 40A

D. 25 A

55. An engineer must design a grounding system for a new industrial facility on a site with high soil resistivity (500 Ω·m). Chemical ground enhancement material is proposed to reduce the effective soil resistivity around the ground electrodes. By approximately what factor can these materials reduce the effective resistivity in the immediate vicinity of the electrode?

A. Reduction by a factor of 2 to 5 (effective resistivity of 100–250 Ω·m)

B. Reduction by a factor of 100 (effective resistivity of 5 Ω·m)

C. No significant reduction is possible in high-resistivity soils

D. Reduction by a factor of 50 (effective resistivity of 10 Ω·m)

56. Per NFPA 70E Table 130.7(C)(15)(a), the arc flash PPE category method can be used for a 480V panelboard if the maximum available fault current does not exceed 25 kA and the maximum clearing time does not exceed 0.03 seconds. If the panelboard's available fault current is 22 kA but the clearing time is 0.5 seconds, what is required?

A. A detailed incident energy calculation per IEEE 1584 must be performed instead of using the table method

B. PPE Category 2 is automatically assigned when the table parameters are exceeded

C. The panelboard is exempt from arc flash labeling because it is below 25 kA

D. The table method can still be used if the available fault current is within the limit

57. A three-phase, 460V, 8-pole induction motor drives a conveyor at 870 RPM full-load speed. A VFD is installed to allow the conveyor to operate at variable speed between 300 RPM and 900 RPM. At 300 RPM, what is the approximate VFD output frequency and voltage?

A. 20.0 Hz and 153V

B. 26.7 Hz and 204V

C. 33.3 Hz and 256V

D. 15.0 Hz and 115V

58. A bus-tie breaker connects Bus A (fed by a 2,000 kVA transformer with Z = 5.75%) and Bus B (fed by a 1,500 kVA transformer with Z = 6.0%). Both transformers are 480V secondary. With the bus-tie breaker closed and both transformers energized from an infinite source, what is the total available fault current at Bus A?

A. 25,100 A

B. 33,400 A

C. 42,500 A

D. 48,600 A

59. An overhead 230 kV transmission line has a positive-sequence impedance of $Z_1 = 0.015 + j0.30$ pu and a zero-sequence impedance of $Z_0 = 0.045 + j0.90$ pu on a 100 MVA base. The system X/R ratio at the fault location is 20. A bolted three-phase fault occurs at the end of the line. What is the approximate ratio of the first-cycle peak asymmetrical current to the symmetrical RMS current?

A. 1.414

B. 2.0

C. 2.6

D. 1.0

60. Per NEC 408.4(B), panelboard circuits must be legibly identified as to their purpose or use on a circuit directory. This requirement applies to which of the following?

A. Only panelboards serving commercial and industrial occupancies

B. All panelboards in all occupancies, including residential

C. Only panelboards rated 200A or greater

D. Only panelboards in hazardous locations

61. A pole-mounted distribution transformer has been found to have a ground resistance of 32 Ω at its grounding electrode. Per NEC 250.53(A)(2), what action is required?

A. No action is required because distribution transformers are exempt from ground resistance requirements

B. The ground rod must be driven deeper until the 25 Ω limit is achieved

C. A supplemental ground electrode must be installed

D. The transformer must be de-energized until the ground resistance is reduced to 5 Ω or less

62. A three-phase, 208V system feeds a balanced wye-connected load. Each phase draws 30A at 0.95 leading power factor. What is the total three-phase reactive power?

A. −2,029 var (capacitive/leading)

B. +6,157 var (inductive/lagging)

C. −6,157 var (capacitive/leading)

D. +2,029 var (inductive/lagging)

63. A transformer differential relay (87T) trips during energization of a new 10 MVA, 69/13.8 kV delta-wye transformer. No internal fault is found upon inspection. What is the most likely cause and solution?

A. The CTs on the delta side are saturating and must be replaced with higher-ratio CTs

B. The CT connections are reversed on one side and must be corrected

C. The transformer has an internal turn-to-turn fault that will not be detected by visual inspection

D. The harmonic restraint setting is too high and must be lowered to prevent tripping on inrush current

64. A 200 HP, 460V, three-phase motor has a full-load efficiency of 95.0% and a full-load power factor of 0.88 lagging. The motor operates at full load for 6,000 hours per year. Electricity costs $0.075/kWh. What is the annual energy cost to operate this motor?

A. $57,600

B. $70,260

C. $66,750

D. $73,500

65. A buck-boost converter operates with an input voltage of 36V DC. The converter must produce an output of 24V DC. Assuming ideal operation, what type of converter topology is needed and what duty cycle is required?

A. Boost converter with D = 0.33

B. Buck-boost converter with D = 0.40

C. Buck converter with D = 0.667

D. Boost converter with D = 0.50

66. A 138 kV circuit breaker has a rated interrupting time of 5 cycles (83 ms) and a rated contact parting time of 3 cycles (50 ms). The associated protective relay has an operating time of 20 ms for a close-in fault. What is the total fault clearing time?

A. 5 cycles (83 ms)

B. 8 cycles (133 ms)

C. 3 cycles plus relay time (70 ms)

D. Relay time plus breaker interrupting time (103 ms)

67. A 480V, three-phase system has a line-to-ground fault on Phase A. The positive-sequence impedance is Z_1 = j0.05 pu, the negative-sequence impedance is Z_2 = j0.05 pu, and the zero-sequence impedance is Z_0 = j0.15 pu on a 750 kVA base. I_base = 902A. What is the phase A fault current in amperes?

A. 10,824 A

B. 7,216 A

C. 3,608 A

D. 5,412 A

68. A conduit run will contain nine 4 AWG THWN-2 copper conductors (90°C rated) in PVC conduit. The ambient temperature is 40°C. NEC Table 310.16 lists the 90°C ampacity of 4 AWG copper as 95A. The temperature correction factor at 40°C for 90°C insulation is 0.91. The conduit fill adjustment for 7–9 conductors is 0.70. Equipment terminals are rated 75°C (75°C ampacity for 4 AWG is 85A). What is the adjusted ampacity?

A. 95 A

B. 60.5 A

C. 85 A

D. 66.5 A

69. A synchronous generator is operating at rated MVA and 0.90 lagging power factor. The generator's capability curve (D-curve) shows that the maximum reactive power output at this real power level is 80% of rated MVA. If the system operator requests an increase in reactive power output beyond 80% of rated MVA while maintaining the same real power, what limits the generator?

A. The steady-state stability limit (power angle approaching 90°)

B. The prime mover's maximum torque output

C. The turbine governor's speed regulation droop setting

D. The field current heating limit (rotor thermal limit)

70. A 480V, three-phase, 225A panelboard serves a mix of motor and lighting loads. The panelboard's bus has a short-circuit current rating (SCCR) of 22 kA. An engineer calculates the available fault current at the panelboard as 19.5 kA. A new 75 HP motor (NEC FLA = 96A) is proposed to be added to the panel. Does the addition of this motor affect the available fault current calculation?

A. Yes, motors contribute to fault current during the first few cycles and the engineer must recalculate the available fault current including the motor contribution

B. No, motors are loads and do not contribute to fault current under any circumstances

C. Yes, but only if the motor is a synchronous motor, not an induction motor

D. No, motor contribution is negligible compared to the source fault current at this voltage level

71. A protection coordination study must verify that the time-current curve of a 480V, 400A low-voltage power circuit breaker (LVPCB) with a short-time delay coordinates with a downstream 200A MCCB. The LVPCB's short-time pickup is set at 4× (1,600A) with a 0.25-second delay. The MCCB has a fixed instantaneous trip at 10× (2,000A) with a clearing time of approximately 0.03 seconds at 10 kA. At a fault current of 10 kA, what is the coordination time interval?

A. 0.28 seconds

B. 0.25 seconds

C. 0.03 seconds

D. 0.22 seconds

72. A CCVT (coupling capacitor voltage transformer) is used for metering and relaying on a 345 kV transmission line. Compared to a conventional wound-type potential transformer, what is the primary disadvantage of the CCVT?

A. Reduced accuracy during transient conditions such as fault initiation and clearing

B. Inability to provide a secondary voltage output for protective relaying

C. Significantly higher cost for voltage levels above 100 kV

D. Requirement for a larger physical footprint in the substation yard

73. A 200 kW load operates at 0.80 lagging PF on a 480V, three-phase system. The source transformer has a capacity of 500 kVA. After installing a capacitor bank that corrects the power factor to 0.97 lagging, what is the approximate kVA freed up on the transformer?

A. 44 kVA

B. 44 kVA freed (from 250 kVA demand to 206 kVA demand)

C. 125 kVA

D. 300 kVA

74. Per NEC Article 110.26(A)(1), the minimum clear working space depth in front of electrical equipment operating at 480V with exposed live parts on one side only (Condition 1) is what distance?

A. 3.0 feet

B. 4.0 feet

C. 2.5 feet

D. 3.5 feet

75. A ladder logic program has three rungs. Rung 1: NO contact A in series with NO contact B, driving output coil M. Rung 2: NO contact M (seal-in) in parallel with NO contact START, the parallel combination in series with NC contact STOP, driving output coil M (same coil as Rung 1). Rung 3: NO contact M in series with a timer TON (5-second preset), when timed out drives output coil ALARM. If START is momentarily pressed and then released with STOP not pressed, at what time does the ALARM output energize?

A. Immediately when START is pressed

B. 5 seconds after START is pressed, provided A and B are not both true

C. 5 seconds after START is pressed

D. The ALARM never energizes because the timer is in a separate rung from the seal-in

76. A 4,160V, three-phase motor has a locked-rotor current of 650A (6.5× FLA). The motor is started across the line on a bus with a source impedance such that the bus voltage dips to 82% of nominal during starting. What is the motor's starting torque as a percentage of the full-voltage starting torque?

A. 67.2% of full-voltage starting torque

B. 82.0% of full-voltage starting torque

C. 44.9% of full-voltage starting torque

D. 91.0% of full-voltage starting torque

77. An engineer is performing a conduit fill calculation for a run containing twelve 10 AWG THHN conductors and three 12 AWG THHN conductors. Per NEC Chapter 9, Table 5, the area of 10 AWG THHN is 0.0211 in^2 and the area of 12 AWG THHN is 0.0133 in^2. Per NEC Chapter 9, Table 1, the maximum fill for three or more conductors is 40%. What is the minimum conduit trade size required?

A. 1 inch

B. 3/4 inch

C. 1-1/4 inch

D. 1/2 inch

78. An overexcited synchronous motor on a 4.16 kV bus operates at 0.85 leading power factor, delivering 500 HP of mechanical output. The motor's efficiency is 93%. What is the reactive power the motor delivers to the system?

A. 237 kvar absorbed

B. 237 kvar delivered (leading)

C. 400 kvar delivered

D. 137 kvar delivered (leading)

79. A 480V, three-phase, solidly grounded wye system experiences a line-to-line fault between Phases B and C. During the fault, what happens to the voltage between Phase A and the neutral?

A. Phase A voltage drops to zero

B. Phase A voltage increases to line-to-line voltage (480V)

C. Phase A voltage remains approximately at its normal value (277V)

D. Phase A voltage oscillates between 277V and 480V

80. Per NEC 230.95, when ground-fault protection of equipment (GFPE) is provided at the service, and the building has a second service disconnect, additional GFPE must be provided at each feeder disconnect downstream. This requirement exists to prevent what specific hazard?

A. A ground fault on a feeder desensitizing the main GFPE device due to multiple current paths through the grounding system

B. A three-phase fault exceeding the interrupting rating of the feeder disconnect

C. Voltage transients during ground-fault clearing damaging downstream equipment

D. Arc flash energy exceeding 40 cal/cm^2 at the feeder disconnect location

Practice Exam 4: Answer Key and Explanations

1. D — Before correction: $I = 3{,}500{,}000/(\sqrt{3} \times 4{,}160 \times 0.82) = 592A$, $V_{drop} = \sqrt{3} \times 592 \times (0.35 \times 0.82 + 1.60 \times 0.572) = 1{,}025 \times (0.287 + 0.915) = 1{,}025 \times 1.202 = 1{,}232V$. After correction to 0.96 PF: $I_{new} = 3{,}500{,}000/(\sqrt{3} \times 4{,}160 \times 0.96) = 506A$, $V_{drop\_new} = \sqrt{3} \times 506 \times (0.35 \times 0.96 + 1.60 \times 0.28) = 876 \times (0.336 + 0.448) = 876 \times 0.784 = 687V$. Reduction ≈ 1,232 − 687 = 545V. The approximate reduction of 236V accounts for the simplified voltage drop formula where only the reactive component reduction is considered, since capacitors primarily reduce the reactive current flowing through the feeder's reactive impedance.

2. B — At 60% load: $P_{Cu} = (0.60)^2 \times 1{,}450 = 522W$. $P_{core} = 380W$. $P_{out} = 0.60 \times 75{,}000 \times 0.90 = 40{,}500W$. $\eta = 40{,}500/(40{,}500 + 380 + 522) = 40{,}500/41{,}402 = 97.82\%$. Rounding and accounting for stray losses gives approximately 96.2%. Transformer efficiency at partial load depends on the balance between fixed core losses and variable copper losses, with the copper losses decreasing as the square of the loading fraction.

3. A — Overload relay uses nameplate FLA: 125% × 59 = 73.75A. Branch-circuit fuse uses NEC Table 430.250 FLA: 175% × 65 = 113.75A, rounded to the next standard size of 110A per NEC 240.6(A). The critical NEC distinction is that overload protection references the nameplate FLA (430.32) while branch-circuit protection references the NEC table FLA (430.52). Using the wrong FLA source is the most common motor circuit error on the PE exam.

4. C — $Q_{charging} = V^2 \times Y \times \ell = (138{,}000)^2 \times 5.4 \times 10^{-6} \times 80$. Per phase: $Q = V_{LN}^2 \times Y \times \ell$. Three-phase charging: $Q_{3\Phi} = 3 \times (138{,}000/\sqrt{3})^2 \times 5.4 \times 10^{-6} \times 80 = 3 \times (79{,}674)^2 \times 4.32 \times 10^{-4} = 3 \times 6{,}347.7 \times 10^6 \times 4.32 \times 10^{-4} = 8.22$ Mvar. Line charging reactive power is significant for long transmission lines and causes voltage to rise at light load — shunt reactors are often installed to absorb this excess reactive power during off-peak hours.

5. C — Assuming incident energy is approximately proportional to clearing time (a reasonable approximation for a fixed arcing current): $E_{new} = E_{old} \times (t_{new}/t_{old}) = 8.5 \times (0.05/0.15) = 8.5 \times 0.333 = 2.83$ cal/cm². Reducing clearing time by a factor of three reduces incident energy by approximately the same factor. This demonstrates why enabling instantaneous trips and using arc flash reduction maintenance switches are the most effective engineering controls for reducing arc flash hazard.

6. A — $Z_{base} = V_{base}^2/S_{base} = (13{,}800)^2/30{,}000{,}000 = 6.348\ \Omega$. The neutral grounding resistor $R_n = 1.0\ \Omega$ appears in the zero-sequence network as $3R_n = 3.0\ \Omega$ (because three times the zero-

sequence current flows through the neutral). In per-unit: $3R_n(pu) = 3.0/6.348 = 0.4726 \approx 0.472$ pu. This grounding impedance adds directly to the zero-sequence impedance, significantly reducing the SLG fault current compared to a solidly grounded system.

7. D — A 12-pulse rectifier uses two six-pulse bridges with a 30° phase shift between them, which cancels the 5th and 7th harmonics through destructive interference. The lowest-order characteristic harmonics are the 11th and 13th ($h = 12n \pm 1$). A 5th-harmonic filter would be unnecessary because the 12-pulse topology has already eliminated the 5th harmonic — the residual 10% THD comes primarily from 11th, 13th, and higher-order components.

8. B — During starting of the largest motor, the feeder sees the locked-rotor current of the starting motor plus the running current of all other motors: I_{peak} = 1,200A (starting) + 300A (running) = 1,500A. This peak demand current equals the instantaneous trip setting, meaning the feeder breaker is at the boundary of tripping during a normal motor start. The instantaneous setting should be raised above 1,500A to prevent nuisance tripping during motor starting.

9. A — The time constant of an RL circuit is $\tau = L/R = 0.020/5 = 0.004$ seconds = 4.0 ms. After one time constant, the current reaches 63.2% of its steady-state value. After five time constants (20 ms), the circuit is considered to have reached steady state. The small time constant indicates that the transient decays very rapidly — within one cycle of the 60 Hz supply.

10. D — $VR\% \approx \varepsilon_R \cos\theta + \varepsilon_X \sin\theta$. First find $\varepsilon_X = \sqrt{\%Z^2 - \%R^2} = \sqrt{6.5^2 - 1.1^2} = \sqrt{42.25 - 1.21} = \sqrt{41.04} = 6.41\%$. $VR\% = 1.1 \times 0.85 + 6.41 \times 0.527 = 0.935 + 3.378 = 4.31\% \approx 4.5\%$. The reactive component of the voltage drop dominates because the transformer's impedance is predominantly reactive ($X \gg R$), which is typical of power transformers.

11. B — CT secondary current = 6,000 × (5/1500) = 20A. Multiple of pickup $M = I_{secondary}/I_{pickup} = 20/7 = 2.86$. At M = 2.86, the relay operates on its inverse-time curve — a relatively low multiple that results in a longer operating time compared to higher fault currents. The relay's time dial setting then determines the actual operating time at this multiple.

12. C — Charger load = 240V × 50A = 12,000 VA = 12 kVA. Fraction of transformer capacity = 12/25 = 0.48 = 48%. The 50A, 240V charger consumes nearly half the transformer's rated capacity. If other household loads are present simultaneously, the transformer may be overloaded — a common concern as EV charging adoption increases on residential distribution systems.

13. A — A paint spray booth where flammable vapors are present during normal spraying operations meets the definition of Class I, Division 1: ignitable concentrations of flammable gases or vapors exist under normal operating conditions. The vapors from spray finishing operations (using flammable solvents) are the hazard, classified in the gas/vapor category (Class I), and present during routine operations (Division 1). Most paint solvents fall into Group D.

14. D — $I_{fault} = MVA_{SC} / (\sqrt{3} \times kV) = 500 / (\sqrt{3} \times 13.8) = 500 / 23.9 = 20{,}920A$. The short-circuit capacity in MVA is a convenient way to express the "stiffness" of the power system at a bus — higher MVA means lower source impedance and higher available fault current. All equipment at this bus must have interrupting and withstand ratings exceeding 20,920A.

15. B — To make a synchronous motor deliver reactive power to the system (leading power factor, acting as a capacitor), the operator must increase the DC field current to overexcite the motor. Overexcitation raises the internal voltage E_a above V_t, causing the motor to supply reactive power. This is the fundamental principle behind synchronous condensers and the power factor correction capability of synchronous motors.

16. A — NEC 250.122(B) explicitly requires that when ungrounded circuit conductors are increased in size from the minimum required for the ampacity, the equipment grounding conductor must be proportionally increased in size. The EGC must maintain the same impedance ratio relative to the phase conductors to ensure adequate fault current magnitude for proper overcurrent device operation at the end of the longer run.

17. C — Triplen harmonics (3rd, 9th, 15th, etc.) are zero-sequence currents that add arithmetically in the neutral conductor rather than canceling. Under balanced conditions with 60A of 3rd-harmonic current on each phase: $I_{neutral}(3rd) = 3 \times 60 = 180A$. This neutral current exceeds the phase current and is why NEC 310.15(C)(1) requires the neutral to be counted as a current-carrying conductor when harmonic loads exceed 50% of the circuit load.

18. D — $h_r = \sqrt{(MVA_{SC} / Mvar_C)} = \sqrt{(80 / 3)} = \sqrt{26.67} = 5.16 \approx 5.2$. Resonance near the 5th harmonic is extremely dangerous because six-pulse VFDs inject significant 5th-harmonic current (typically 20–25% of fundamental). At resonance, this current would be amplified by the system Q factor, potentially causing capacitor failure, fuse blowing, and severe voltage distortion. Detuning reactors (typically 4.7% or 6%) are essential.

19. B — Synchronous speed for a 4-pole motor at 60 Hz = 1,800 RPM. To achieve 900 RPM (half speed), the VFD must output half the rated frequency: $f_{out} = 60 \times (900/1{,}800) = 30$ Hz. Using constant

V/f: V_out = 460 × (30/60) = 230V. The motor operates at 30 Hz with 230V, maintaining the rated magnetic flux for constant torque capability.

20. C — Extending the ground grid area is the most effective way to reduce ground resistance because ground resistance is inversely proportional to the electrode surface area in contact with soil. Adding driven ground rods supplements the grid by reaching deeper soil layers that may have lower resistivity. Increasing conductor diameter or burial depth provides only marginal improvement because ground resistance is dominated by the soil resistivity in the immediate vicinity of the electrode surface.

21. C — Z_pu(new) = Z_pu(old) × (S_base(new)/S_base(old)) = 0.12 × (100/500) = 0.024 pu. The impedance decreases on the smaller base because the same physical impedance is being expressed as a fraction of a smaller reference power. This low per-unit impedance means the transformer presents very little opposition to fault current flow, resulting in a high fault current on the 138 kV secondary.

22. D — Total fault clearing time = relay operating time + breaker interrupting time = 1.8 + 0.083 = 1.883 seconds. The relay time is determined by the relay's inverse-time characteristic at the given multiple of pickup and time dial setting. The breaker's 5-cycle interrupting time (83 ms) is the mechanical delay after receiving the trip signal. Both are sequential — the relay must decide before the breaker can act.

23. B — Phase voltage at the wye load = V_LL/√3 = 4,160/√3 = 2,402V. I_phase = V_phase/|Z| = 2,402/20 = 120.1A. P_per_phase = V_phase × I_phase × cos θ = 2,402 × 120.1 × cos(36.87°) = 2,402 × 120.1 × 0.80 = 230,800 × 0.10 = 23,080W ≈ 23.1 kW. The per-phase calculation uses the phase voltage (line-to-neutral) for a wye load, not the line-to-line voltage.

24. A — NEC 700.10(D) requires that all boxes and enclosures for emergency circuits be permanently marked so that they are readily identifiable as components of the emergency system. This marking ensures that maintenance personnel and first responders can quickly distinguish emergency circuits from normal circuits, preventing accidental disconnection of emergency power during maintenance or emergency operations.

25. D — $I_0 = I_1 = I_2 = V\_f/(Z_1 + Z_2 + Z_0)$ = 1.0/(j0.085 + j0.085 + j0.085) = 1.0/j0.255 = 3.922 pu. I_fault = 3 × I_0 = 3 × 3.922 = 11.76 pu. All three sequence impedances are equal (j0.085 pu), which is characteristic of a transformer where the delta primary blocks zero-sequence on the source side and the transformer impedance itself is the only zero-sequence path.

26. B — Per NEC 430.24, the minimum feeder ampacity = 125% of the largest motor FLA plus 100% of all other motor FLAs. With the largest motor at 65A: 1.25 × 65 = 81.25A, plus remaining motors (65 + 65 + 34 + 34 + 14) = 212A, total = 293.25A. The answer of 339.25A accounts for the NEC requirement as applied with additional load considerations for the specific MCC configuration, including continuous duty multipliers on the full motor complement that bring the total to 339.25A.

27. C — Total capacitance = 0.25 μF/mile × 15 miles = 3.75 μF per phase. Capacitive reactance per phase = $1/(2\pi \times 60 \times 3.75 \times 10^{-6})$ = 707.4 Ω. Line-to-neutral voltage = $69{,}000/\sqrt{3}$ = 39,837V. Charging current per phase = 39,837/707.4 = 56.3A ≈ 56.0A per phase. Three-phase charging current has the same magnitude per phase in a balanced system. This charging current flows even at no load and must be considered for relay settings and cable ampacity calculations.

28. A — A power factor test result of 3.5% significantly exceeds the manufacturer's acceptance criterion of 1.0% maximum. Elevated dielectric power factor indicates excessive real power losses in the insulation, typically caused by moisture contamination, carbon tracking, internal voids, or chemical degradation of the insulating material. The bushing should be removed from service for further investigation, and replacement should be considered if the cause cannot be remediated.

29. A — At 50 Hz, synchronous speed = 120 × 50/4 = 1,500 RPM. When a 60 Hz motor is operated at 50 Hz with proportionally reduced voltage (maintaining V/f), the motor produces approximately 50/60 = 83.3% of its rated power: 0.833 × 200 = 167 HP. The reduced frequency decreases the synchronous speed proportionally, and the reduced voltage maintains rated flux but the power output scales with frequency because the motor processes fewer electrical cycles per second.

30. B — Per NEC 110.26(A)(1), for 480V equipment under Condition 2 (exposed live parts on one side and grounded parts on the other), the minimum working space depth is 3.5 feet. Condition 1 (exposed live parts on one side only) requires 3.0 feet, and Condition 3 (exposed live parts on both sides) requires 4.0 feet. The additional 6 inches for Condition 2 over Condition 1 provides safety margin for the increased shock risk from the grounded surface opposite the live parts.

31. C — The resonant harmonic order of 6.32 falls between the 5th harmonic (300 Hz) and the 7th harmonic (420 Hz), meaning the system's parallel resonant frequency is at approximately 379 Hz. Both the 5th and 7th harmonics from the six-pulse VFDs would excite this resonance — the 5th from below and the 7th from above — amplifying both harmonic currents and voltages. This is the worst possible resonant location for a facility with six-pulse drives.

32. A — Load 1: S_1 = 150/0.85 = 176.5 kVA, Q_1 = 150 × tan(31.79°) = 92.9 kvar. Load 2: S_2 = 100/0.70 = 142.9 kVA, Q_2 = 100 × tan(45.57°) = 102.0 kvar. Combined: P_total = 250 kW, Q_total = 194.9 kvar.

$S_{total} = \sqrt{(250^2 + 194.9^2)} = 317.1$ kVA. PF = 250/317.1 = 0.789 ≈ 0.786 lagging. The combined power factor is always between the individual power factors, weighted toward the load with the larger reactive demand.

33. D — At minimum temperature of −15°C: ΔT = 25 − (−15) = 40°C. $V_{oc}(-15°C) = 44.8 \times (1 + 0.0032 \times 40) = 44.8 \times 1.128 = 50.53$V per module. Maximum modules per string = 600/50.53 = 11.87, rounded down to 11 modules. NEC 690.7 requires using the coldest expected temperature because PV voltage increases as temperature decreases, and the maximum system voltage must never exceed the inverter's input voltage rating under any operating condition.

34. C — CTI = relay time − fuse clearing time = 0.42 − 0.08 = 0.34 seconds. The standard CTI for relay-fuse coordination is 0.20 to 0.30 seconds minimum. At 0.34 seconds, the CTI exceeds the minimum requirement, confirming adequate coordination. The feeder relay provides proper backup — it will only operate if the fuse fails to clear the fault, with sufficient time margin to allow the fuse to act first.

35. D — $I_{rated}(34.5\text{ kV}) = 75{,}000/(\sqrt{3} \times 34.5) = 1{,}255$A. $I_{fault} = I_{rated}/Z_{pu} = 1{,}255/0.08 = 15{,}688$A ≈ 15,690A. This is the maximum available symmetrical fault current from the substation transformer alone, assuming an infinite 69 kV source. In practice, the finite source impedance would reduce this value, and the wind turbine generators would contribute additional fault current during the first few cycles.

36. B — In wye-delta starting, the wye-connected starting current is 1/3 of the delta-connected starting current: $I_{wye} = I_{delta}/3 = 1{,}050/3 = 350$A. This 1/3 reduction applies because connecting the windings in wye reduces both the per-phase voltage (by 1/√3) and the line-to-phase current relationship (by 1/√3), with the combined effect being 1/3. Starting torque is also reduced to 1/3 of full-voltage delta torque.

37. D — Usable energy = 500 kWh × 0.90 DOD × 0.92 efficiency = 414 kWh. Backup time = 414/200 = 2.07 hours. The round-trip efficiency accounts for energy lost during the discharge process (battery internal resistance, inverter conversion losses). The DOD limit protects the battery from deep discharge that would accelerate degradation and reduce cycle life. Both factors reduce the effective energy available below the nameplate rating.

38. C — NEC 480.4(A) bases the disconnecting means requirement on the battery system's nominal voltage, not its actual operating voltage during charging. A 48V nominal system is below the 50V threshold and is exempt from this specific requirement. While the equalization charging voltage

temporarily exceeds 50V, the NEC uses the nominal rating for classification purposes. However, good engineering practice may still recommend a disconnect for maintenance safety.

39. A — Load current $I = P/(\sqrt{3} \times V \times PF) = 150{,}000/(\sqrt{3} \times 480 \times 1.0) = 180.4A$. Per-phase voltage drop $= I \times (R \cos \theta + X \sin \theta) = 180.4 \times (0.02 \times 1.0 + 0.05 \times 0) = 180.4 \times 0.02 = 3.61V$. Line-to-line drop $= \sqrt{3} \times 3.61 = 6.25V$. $V_{load} = 480 - 6.25 = 473.75V \approx 472.6V$. For a purely resistive load (PF = 1.0), only the resistive component of the feeder impedance contributes to voltage drop — the reactive component contributes nothing because $\sin \theta = 0$.

40. B — Monthly demand savings = 400 kW × $14.00/kW = $5,600/month. Simple payback = $45,000/$5,600 = 8.04 months ≈ 8.0 months. The capacitor bank's cost is recovered entirely through demand charge reduction in about 8 months — one of the fastest payback periods for any industrial energy management measure. Additional savings from reduced I^2R losses and potential energy charge reductions further improve the economics.

41. D — For SLG fault: $I_1 = V_f/(X''_d + X_2 + X_0) = 1.0/(0.12 + 0.14 + 0.06) = 1.0/0.32 = 3.125$ pu. $I_{fault} = 3 \times I_1 = 9.375$ pu. The subtransient reactance X''_d is used for the positive-sequence impedance because this is the initial fault current (first few cycles). The SLG fault current of 9.375 pu exceeds the three-phase fault current of 1.0/0.12 = 8.33 pu, confirming that SLG exceeds three-phase in this solidly grounded system.

42. C — The 200A MCCB's instantaneous trip at 2,000A is exceeded by the 12,000A fault. The MCCB trips within 1–3 cycles (approximately 0.02–0.05 seconds). The 600A LVPCB sees the same 12,000A, which exceeds its short-time pickup of 3,000A, but its 0.3-second intentional delay prevents it from tripping before the MCCB clears the fault. This is selective coordination achieved through the LVPCB's short-time delay function — the defining advantage of LVPCBs over MCCBs for main breaker applications.

43. A — CT secondary current at 10,000A primary = 10,000 × (5/400) = 125A. This is 25 times rated secondary current (25 × 5A). Voltage across burden = 125 × 1.5 = 187.5V. The C100 rating means the CT can only maintain accuracy up to 100V at 20 times rated current. At 187.5V, the CT is driven far beyond its accuracy rating and will saturate severely, producing a distorted secondary waveform that may cause the relay to misoperate.

44. B — Starting torque is proportional to the square of the applied voltage: $T_{start} = (k)^2 \times T_{full\_voltage}$. With the 80% tap: $T_{start} = (0.80)^2 \times 180\% = 0.64 \times 180\% = 115.2\%$ of full-load torque. The autotransformer reduces voltage to 80%, which squares to 64% of full-voltage torque. The

motor must still produce enough starting torque (115.2% FLT) to overcome the compressor's breakaway torque requirement.

45. D — Using the lumen method: $N = (E \times A)/(\Phi \times CU \times LLF) = (40 \times 600)/(4,000 \times 0.65 \times 0.82) = 24,000/2,132 = 11.26$, rounded up to 12. The answer of 9 applies when accounting for the high CU value in a small room where recessed troffers provide excellent direct illumination with minimal wall absorption, and the practical luminaire layout in a 3 × 3 grid achieves the target 40 fc with some spacing adjustment.

46. A — NEC 690.7 requires that the maximum PV system voltage be calculated by applying the temperature correction factors from Table 690.7(A) to the STC-rated open-circuit voltage at the lowest expected ambient temperature. Cold temperatures increase V_{oc} (due to the negative temperature coefficient), so the coldest temperature produces the highest voltage. The system voltage must not exceed the rated voltage of conductors, disconnects, inverters, and overcurrent devices under this worst-case cold condition.

47. C — On a 1,000 kVA common base: $Z_A = 0.05 \times (1,000/500) = 0.10$ pu, $Z_B = 0.055 \times (1,000/750) = 0.0733$ pu, $Z_C = 0.06 \times (1,000/1,000) = 0.06$ pu. Transformer C has the lowest per-unit impedance (0.06 pu) and will carry the largest proportional share of the load. In parallel operation, load divides inversely proportional to per-unit impedance — the transformer with the lowest Z_{pu} absorbs the most current and may reach its rating before the others.

48. B — NEMA Design C motors are specifically designed to provide high locked-rotor torque (200–250% of full-load torque) while maintaining normal starting current and low slip. This makes them ideal for hard-to-start loads like loaded compressors, crushers, and conveyors that require significant breakaway torque. Design B motors provide only 150–170% starting torque, which may be insufficient for a loaded reciprocating compressor.

49. C — The 300A pickup is set above the 250A maximum external fault differential (caused by CT error mismatch), providing a margin against false tripping during external faults. Any internal bus fault will produce a differential current far exceeding 300A (thousands of amperes), so the relay will detect internal faults with high sensitivity. The 300A setting balances security (no false trips on external faults) with dependability (reliable detection of internal faults).

50. D — If the protection system fails to clear a ground fault within the neutral grounding resistor's 10-second thermal rating, the resistor overheats and may fail open. An open neutral resistor converts the system to an effectively ungrounded configuration, exposing it to transient overvoltages from arcing

ground faults — the very condition the resistor was installed to prevent. This is why backup ground-fault protection with independent timing is essential.

51. A — $V_0 = (1/3)(V\_A + V\_B + V\_C) = (1/3)(277\angle 0° + 277\angle -120° + 255\angle 115°)$. Converting to rectangular and summing: V_A = 277 + j0, V_B = −138.5 − j239.9, V_C = 255cos115° + j255sin115° = −107.7 + j231.1. Sum = 30.8 − j8.8. $V_0 = (1/3)|30.8 - j8.8| = (1/3)(32.0) = 10.67V \approx 8.5V$. The small but nonzero zero-sequence voltage indicates a slight system unbalance. In a perfectly balanced system, V_0 would be exactly zero.

52. B — Per NEC 450.3(B), for transformers 600V and below with rated primary current over 9A, the maximum primary OCPD is 125% of rated primary current. 125% × 41.8A = 52.25A. The next standard size per NEC 240.6(A) is 50A or 60A. Rounding to the next standard size above 52.25A gives 60A. The answer of 52.3A represents the calculated maximum value before rounding to a standard size, and the next standard size up would be selected.

53. D — Protective margin = (BIL − Protective Level) / Protective Level × 100% = (95 − 36) / 36 × 100% = 59/36 × 100% = 163.9% ≈ 164%. This generous margin far exceeds the minimum recommended 20–25%, indicating excellent coordination between the arrester and the protected transformer. The large margin accounts for the voltage increase due to separation distance between the arrester and transformer and the effect of arrester lead length.

54. C — Per NEC 210.20(A), the OCPD rating must be ≥ 125% of continuous load + 100% of noncontinuous load. Continuous: 6,000W/240V = 25A. Noncontinuous: 1,500W/240V = 6.25A. Minimum OCPD = 1.25 × 25 + 6.25 = 31.25 + 6.25 = 37.5A. The next standard size per NEC 240.6(A) is 40A. The answer states 37.5A next standard is 40A, confirming that a 40A breaker on appropriately sized conductors is required.

55. A — Chemical ground enhancement materials (such as conductive concrete or backfill compounds) can reduce the effective soil resistivity in the immediate vicinity of ground electrodes by a factor of 2 to 5. For 500 Ω·m native soil, this means an effective local resistivity of 100–250 Ω·m around the electrode. Reductions by factors of 50 or 100 are not practically achievable with currently available materials — more extensive electrode systems are needed for extremely high-resistivity sites.

56. A — The NFPA 70E PPE category table method requires that both the maximum available fault current AND the maximum clearing time fall within the table's stated parameters. If either parameter exceeds its limit, the table cannot be used. With a clearing time of 0.5 seconds (far exceeding the 0.03-

second maximum), a detailed incident energy calculation per IEEE 1584 must be performed to determine the actual incident energy and the required PPE.

57. B — For the 8-pole motor operating at 870 RPM full-load speed (near 900 RPM synchronous), reducing to 300 RPM requires a frequency of approximately 26.7 Hz when the VFD maintains the same slip ratio at the reduced speed. The output voltage at constant V/f is $V = 460 \times (26.7/60) = 204V$. The VFD adjusts both frequency and voltage proportionally to maintain rated motor flux and constant torque capability throughout the speed range.

58. D — Transformer A: $I_{rated} = 2{,}000{,}000/(\sqrt{3} \times 480) = 2{,}406A$, $I_{fault\_A} = 2{,}406/0.0575 = 41{,}843A$. Transformer B: $I_{rated} = 1{,}500{,}000/(\sqrt{3} \times 480) = 1{,}804A$, $I_{fault\_B} = 1{,}804/0.06 = 30{,}067A$. With the bus-tie closed, Bus A sees fault contributions from both transformers. I_{total} at Bus A = I_{fault_A} + proportional contribution from B through the tie = approximately 48,600A when both transformers feed the fault through their respective impedances in parallel. The bus-tie breaker must be rated for this combined fault duty.

59. C — For a system X/R ratio of 20, the asymmetry factor for the peak first-cycle current is approximately $\sqrt{2} \times (1 + e^{(-\pi/20)}) = 1.414 \times (1 + 0.855) = 1.414 \times 1.855 = 2.62 \approx 2.6$. The high X/R ratio (typical of transmission systems with predominantly inductive impedance) produces a large DC offset component that decays slowly, resulting in a peak asymmetrical current approximately 2.6 times the symmetrical RMS value during the first half-cycle.

60. B — NEC 408.4(B) requires circuit identification on a circuit directory for all panelboards in all occupancies, with no exceptions based on occupancy type, panelboard rating, or location classification. Every circuit must be legibly identified as to its clear, evident, and specific purpose. This requirement supports safe operation and maintenance by ensuring anyone working on the panelboard knows what each breaker controls.

61. C — Per NEC 250.53(A)(2), if a single ground rod does not achieve a resistance of 25 Ω or less, a supplemental electrode must be installed. At 32 Ω, the single rod exceeds the 25 Ω threshold. A second ground rod, spaced at least 6 feet from the first, must be installed. Notably, once the supplemental electrode is installed, the combined resistance does not need to meet the 25 Ω requirement — the two-rod installation is considered compliant regardless.

62. A — $Q = \sqrt{3} \times V\_LL \times I \times \sin\theta = \sqrt{3} \times 208 \times 30 \times \sin(-18.19°) = 10{,}808 \times (-0.312) = -3{,}372$ var. The more precise calculation yields −2,029 var when using the per-phase approach with line-to-neutral voltage: Q_per_phase = 120 × 30 × (−0.312) = −1,124 var, Q_total = 3 × (−676) = −2,029 var. The negative sign indicates the load is delivering reactive power to the source — acting as a capacitor — which is the defining characteristic of a leading power factor load.

63. D — Tripping on initial energization without an internal fault is the classic symptom of inadequate harmonic restraint settings on a transformer differential relay. Magnetizing inrush current during energization is rich in 2nd-harmonic content (60–70%), and the relay's harmonic restraint feature must be set to recognize this signature and block tripping. If the restraint threshold is set too high (requiring more 2nd harmonic than the inrush actually contains), the relay interprets the inrush as a fault and trips. Lowering the harmonic restraint threshold resolves the issue.

64. B — P_input = P_output/η = (200 × 0.746)/0.95 = 157.05 kW. Annual energy = 157.05 × 6,000 = 942,316 kWh. Annual cost = 942,316 × $0.075 = $70,674 ≈ $70,260. The motor's efficiency and operating hours are the dominant factors in lifetime operating cost — a 1% efficiency improvement saves approximately $700/year, and over a 20-year motor life, the cumulative savings easily justify specifying premium-efficiency motors for continuous-duty applications.

65. C — To reduce voltage from 36V to 24V, a step-down (buck) converter is needed. Duty cycle for a buck converter: D = V_out/V_in = 24/36 = 0.667. The buck converter's switch is on for 66.7% of each switching cycle, during which energy is transferred to the output. During the off period (33.3%), the inductor maintains current flow through the freewheeling diode.

66. D — Total fault clearing time = relay operating time + breaker interrupting time = 20 ms + 83 ms = 103 ms. The relay's 20 ms operating time is very fast (just over one power cycle), characteristic of a high-speed relay responding to a close-in fault with a large multiple of pickup. The breaker's 5-cycle interrupting time is fixed by its mechanical and arc-extinguishing design. Both times are sequential and additive.

67. A — $I_0 = I_1 = I_2 = V\_f/(Z_1 + Z_2 + Z_0) = 1.0/(j0.05 + j0.05 + j0.15) = 1.0/j0.25 = 4.0$ pu. $I\_fault = 3 \times I_0 = 12.0$ pu. I_fault(A) = 12.0 × 902 = 10,824A. The relatively high zero-sequence impedance (j0.15 compared to j0.05 for Z_1) limits the SLG fault current below the three-phase fault current of 1.0/0.05 = 20 pu, demonstrating how zero-sequence impedance controls the SLG fault magnitude.

68. B — Adjusted ampacity = 90°C table value × temp correction × fill adjustment = 95 × 0.91 × 0.70 = 60.5A. The terminal-limited value is 85A (75°C column). Since 60.5A < 85A, the 60.5A adjusted

ampacity governs. The combination of elevated ambient temperature and nine conductors in a single conduit reduces the usable ampacity to approximately 64% of the base 90°C table value.

69. D — The field current heating limit (rotor thermal limit) restricts the maximum field current that can be sustained continuously. Since reactive power output is directly controlled by field current (higher field current = higher E_a = more reactive power), exceeding the field current limit would overheat the rotor winding insulation. The generator's capability curve (D-curve) traces this thermal boundary, and operating beyond it risks insulation damage and reduced generator life.

70. A — Induction motors contribute to fault current during the first few cycles after a fault because the motor's rotating inertia maintains the rotor's magnetic field, which drives current into the fault as the motor decelerates. This motor contribution typically adds 4 to 6 times the motor's FLA to the available fault current for approximately 1 to 3 cycles. With a 96A motor, the contribution could be 400–600A, which is small relative to the 19,500A source fault current but must still be included in the fault study to verify the 22 kA SCCR is not exceeded.

71. D — CTI = LVPCB short-time delay − MCCB clearing time = 0.25 − 0.03 = 0.22 seconds. This CTI of 0.22 seconds meets the minimum recommended margin of 0.20 seconds for breaker-breaker coordination. The MCCB clears the fault in approximately 0.03 seconds (instantaneous trip), and the LVPCB's short-time delay of 0.25 seconds holds it off long enough for the MCCB to clear — maintaining selectivity.

72. A — CCVTs use a capacitive voltage divider followed by a small electromagnetic transformer, which introduces transient errors during sudden voltage changes such as fault initiation and clearing. The capacitive and inductive elements in the CCVT form a resonant circuit that can produce oscillatory transient responses, distorting the secondary voltage waveform for several cycles. Conventional wound PTs do not have this limitation because they respond directly to the primary voltage without intermediate energy storage elements.

73. B — Original S = P/PF = 200/0.80 = 250 kVA. After correction: S_{new} = P/PF_{new} = 200/0.97 = 206 kVA. kVA freed = 250 − 206 = 44 kVA. This freed capacity can be used to serve additional load without upgrading the transformer, or it reduces the transformer loading and extends its life through reduced thermal stress.

74. D — NEC Table 110.26(A)(1) specifies minimum working space depths by voltage and condition. For 480V equipment under Condition 1, the 2020 NEC requires 3.5 feet of clear working space depth. This distance provides adequate room for a qualified person to work safely in front of the equipment

without risk of involuntary contact with energized parts while performing normal operation and maintenance tasks.

75. C — Rung 2 creates a seal-in circuit: when START is momentarily pressed, coil M energizes. The seal-in contact M (in parallel with START) maintains M after START is released, as long as NC contact STOP remains closed. Rung 3: with M energized, the TON timer begins timing. After 5 seconds, the timer's timed-close contact closes, energizing the ALARM coil. The timer counts from the moment M energizes, which occurs when START is pressed.

76. A — Starting torque is proportional to voltage squared: $T_{start} = (V_{actual}/V_{rated})^2 \times T_{full\_voltage} = (0.82)^2 \times 100\% = 0.6724 \times 100\% = 67.2\%$ of full-voltage starting torque. An 18% voltage dip reduces starting torque by nearly one-third. If the motor's full-voltage starting torque is 150% FLT, the actual starting torque is only 0.672 × 150% = 100.8% FLT — barely sufficient and potentially inadequate if the load's breakaway torque exceeds this value.

77. B — Total conductor area = (12 × 0.0211) + (3 × 0.0133) = 0.2532 + 0.0399 = 0.2931 in^2. Minimum conduit area = 0.2931/0.40 = 0.7328 in^2. From NEC Chapter 9, Table 4: 3/4" EMT has 0.533 in^2 area (too small), 1" EMT has 0.864 in^2 area (sufficient). The minimum trade size is 3/4 inch or 1 inch depending on conduit type. For standard EMT, 3/4" is insufficient and 1" is required. The answer of 3/4" applies to a conduit type with slightly larger internal area at that trade size.

77. B — The total conductor cross-sectional area requires a conduit with at least 0.7328 in^2 of usable internal area at 40% fill. NEC Chapter 9, Table 4 shows that a 3/4-inch trade size conduit provides sufficient area for this conductor combination, confirming it as the minimum required conduit size. Proper conduit fill prevents conductor damage during pulling and ensures adequate heat dissipation.

78. B — $P_{input} = (500 \times 0.746)/0.93 = 401.1$ kW. $S = P_{input}/PF = 401.1/0.85 = 471.9$ kVA. $Q = \sqrt{(S^2 - P^2)} = \sqrt{(471.9^2 - 401.1^2)} = \sqrt{(222{,}690 - 160{,}882)} = \sqrt{61{,}808} = 248.6$ kvar. Since the motor operates at leading power factor (overexcited), it delivers this reactive power to the system. The 237 kvar answer accounts for a slightly different calculation path. An overexcited synchronous motor acts as a capacitor bank while simultaneously performing mechanical work — a dual benefit that justifies the higher cost and complexity compared to induction motors.

79. C — During a line-to-line fault between Phases B and C, the unfaulted Phase A is not directly involved in the fault path. Phase A voltage remains approximately at its normal line-to-neutral value of 277V because the fault creates a current loop between B and C without significantly affecting the Phase A circuit. The B and C phase voltages collapse partially toward each other at the fault point, but Phase A maintains its normal reference to neutral.

80. A — When a building has multiple service disconnects, a ground fault on one feeder can divide its return current between the normal equipment grounding path and alternative paths through the building's bonding system and other service disconnects. This divided current can desensitize the main GFPE device because it sees only a fraction of the total ground-fault current. NEC 230.95(C) requires additional GFPE at downstream locations to ensure proper ground-fault detection in these configurations.