PRACTICE EXAM 14: PE POWER SIMULATION (80 QUESTIONS)

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1. A 13.8 kV industrial facility has a three-phase fault level of 450 MVA and an SLG fault level of 520 MVA at the main bus. A 7,200 kvar capacitor bank is proposed for power factor correction. The bus serves twelve six-pulse VFDs totaling 3,000 HP. The engineer calculates the resonant harmonic order as h_r = √(450,000/7,200) = 7.91. Additionally, the high SLG-to-three-phase MVA ratio indicates the system is solidly grounded with low Z_0. Considering both the harmonic resonance risk and the grounding characteristic, what is the engineer's primary concern and recommended action?

A. The resonance at 7.91 is safely between the 7th and 11th harmonics; no action is needed

B. The low Z_0 causes high capacitor bank inrush current during switching; pre-insertion resistors are the only concern

C. The resonance at 7.91 is close to the 7th harmonic from six-pulse VFDs, but far enough that a simple harmonic study can confirm acceptability

D. The resonance at 7.91 is dangerously close to the 7th harmonic characteristic of six-pulse VFDs; detuning reactors (6% or 7%) should be installed to shift resonance below the 5th harmonic, and the low Z_0 requires verifying the capacitor bank switching device and fusing are rated for the elevated SLG fault current

2. A three-phase, 480V, solidly grounded wye system has a 3,000 kVA service transformer (Z = 5.75%) fed from a utility with 800 MVA of short-circuit capacity at 13.8 kV primary. The 480V switchboard feeds two MCCs through cable runs. MCC-1 is 200 feet away (350 kcmil copper in steel conduit, R = 0.0367 Ω/1000 ft, X = 0.0407 Ω/1000 ft). MCC-2 is 500 feet away (same cable). What is the approximate ratio of the available fault current at MCC-2 to that at MCC-1?

A. MCC-2 has approximately the same fault current as MCC-1 because both are served from the same transformer

B. MCC-2 has approximately 60–70% of MCC-1's fault current because the longer cable adds significantly more impedance

C. MCC-2 has approximately 90% of MCC-1's fault current

D. MCC-2 has approximately 40% of MCC-1's fault current because cable impedance increases linearly with length

3. Per NEC 430.52(C)(1), a 500 HP, 460V, three-phase Design B motor has a Table 430.250 FLA of 590A. An inverse-time breaker is selected. The Table 430.52 maximum is 250% = 1,475A → next standard 1,600A. The motor trips the 1,600A breaker during starting. Exception 1 permits up to 400% = 2,360A → next standard not exceeding 2,360A. What is the maximum standard breaker size?

A. 2,000A

B. 2,500A

C. 1,800A

D. 2,360A (exact value — not a standard size)

4. A CT with a ratio of 2000:5 and accuracy class C400 is connected to a transformer differential relay. The total CT burden (external + winding) is 5.0 Ω. During a 30,000A internal fault, the CT secondary current is 75A (15× rated). The voltage across the total burden is 375V. At 20× rated secondary current (100A), the C400 rating guarantees accuracy up to 400V. At the actual 15× operating point, is 375V within the CT's capability?

A. No — 375V exceeds the C400 rating regardless of the current level

B. No — the CT's accuracy at 15× rated is proportionally less than at 20× rated

C. Yes — at 15× rated, the CT core can produce more voltage than at 20× rated because less of the excitation characteristic is consumed; 375V is within the CT's capability at this operating point

D. Yes — but only if the CT has a knee-point voltage above 400V

5. A 345 kV, 320-mile transmission line has Z = 0.065 + j0.68 Ω/mile and Y = $j4.8 \times 10^{-6}$ S/mile per phase. The line is energized from the sending end with the receiving end open. At what approximate line length does the Ferranti effect voltage rise reach 10%?

A. 350 miles

B. 250 miles

C. 150 miles

D. 400 miles

6. Per NEC 250.122(B), the EGC must be proportionally increased when phase conductors are upsized. A 200A circuit originally requires 3/0 AWG copper (167,800 CM), increased to 350 kcmil (350,000 CM) for a long run. The minimum EGC from Table 250.122 for 200A is 6 AWG (26,240 CM). Calculate the required EGC size.

A. 6 AWG (26,240 CM — no increase required)

B. 3 AWG (52,620 CM)

C. 2 AWG (66,360 CM)

D. 4 AWG copper (54,740 CM) — increase ratio = 350,000/167,800 = 2.086; EGC = 26,240 × 2.086 = 54,740 CM → next standard size is 3 AWG (52,620 CM) or 4 AWG (41,740 CM)

7. A balanced three-phase, 4,160V system feeds a 4,000 kW load at 0.78 lagging PF through a feeder with $Z = 0.50 + j2.40\ \Omega$ per phase. The engineer evaluates installing a 2,800 kvar capacitor bank at the load bus versus installing a 2,000 HP synchronous motor at 0.80 leading PF ($\eta = 95\%$) that also serves a new mechanical load. What is the synchronous motor's net reactive power contribution, and how does the voltage improvement at the load bus compare to the capacitor bank?

A. Motor delivers 1,175 kvar; both options provide similar voltage improvement, but the motor also serves a mechanical load — the motor is the better choice when additional shaft output is needed

B. Motor delivers 2,800 kvar; identical voltage improvement

C. Motor delivers 500 kvar; capacitor bank provides far superior voltage improvement

D. Motor absorbs reactive power at leading PF; no voltage improvement

8. A three-phase, 480Y/277V panelboard serves a commercial office with 60% linear fluorescent lighting and 40% nonlinear LED driver loads (by current). Each phase draws a total of 200A fundamental and 35A of third-harmonic current. The neutral current is 3 × 35 = 105A. Per NEC 310.15(C)(1), must the neutral be counted as a current-carrying conductor?

A. No — the 40% nonlinear load does not constitute a "major portion" of the total

B. Yes — any amount of harmonic current on the neutral requires it to be counted

C. Yes — the neutral carries 105A, which is a significant current requiring derating consideration; per NEC 310.15(C)(1), when a major portion of the load consists of nonlinear loads producing harmonic currents, the neutral must be counted

D. No — the neutral current is less than the phase current so it does not affect derating

9. A 100 MVA synchronous generator has X"_d = 0.18 pu, X_2 = 0.20 pu, X_0 = 0.07 pu. The generator is grounded through a 0.5 Ω resistor. The base impedance is Z_base = $V^2/S = (13.8)^2/100$ = 1.904 Ω. The per-unit neutral resistance is R_n = 0.5/1.904 = 0.263 pu. In the zero-sequence network, 3R_n = 0.789 pu. What is the total zero-sequence impedance Z_0_network, and how does this grounding affect the SLG fault current compared to a solidly grounded system?

A. Z_0_network = 0.07 + j0 = 0.07 pu; same as solidly grounded

B. Z_0_network = 0.07 + 0.789 = 0.859 pu (predominantly resistive); the SLG fault current is dramatically reduced compared to solidly grounded because 3R_n dominates the zero-sequence impedance

C. Z_0_network = 0.789 pu (only the resistance counts); identical to solidly grounded

D. Z_0_network = j0.07 + 0.789 = 0.792 pu; the grounding resistor reduces SLG current to approximately 30% of the solidly grounded value

10. A three-phase, 4,160V, low-resistance grounded system has a 200A NGR rated for 10 seconds. The system has 8A of total distributed zero-sequence capacitive charging current. A bolted SLG fault occurs. The relay engineer must set the ground-fault relay pickup above the capacitive charging but below the NGR current, while accounting for CT error and safety margin. What is the recommended relay pickup?

A. 8A (equal to the capacitive charging — to detect any fault above background)

B. 16A (2× the capacitive charging — provides margin for CT error and unbalance)

C. 100A (50% of NGR rating — standard practice for LRG systems)

D. 20–25A (approximately 2.5–3× the capacitive charging, providing adequate margin above background while maintaining sensitivity for high-impedance ground faults at 10–12% of the NGR rating)

11. Per NEC 110.26(A)(1), the minimum working space depth for equipment rated 601V to 2,500V under Condition 3 (exposed live parts on both sides) is what distance?

A. 5 feet

B. 4 feet

C. 6 feet

D. 3 feet

12. A 750 kVA, 4,160V/480V transformer has open-circuit losses of 2,200 W and full-load copper losses of 8,000 W. The transformer's percent impedance is 5.5% with X/R = 6. The transformer operates at 75% load with 0.88 lagging PF for 16 hours and at 40% load with 0.75 PF for 8 hours. What is the all-day efficiency, and at what loading does maximum efficiency occur?

A. η_allday = 96.5%; max efficiency at 75% load

B. η_allday = 97.8%; max efficiency at 40% load

C. η_allday = 97.5%; max efficiency at 52.4% load (where P_core = P_Cu)

D. η_allday = 98.2%; max efficiency at 100% load

13. A protection coordination study requires coordinating a 200A expulsion fuse on a 13.8 kV lateral with an upstream 51 feeder relay (IEEE extremely inverse, TD = 2.5, pickup = 5A on 600:5 CT). At the maximum fault current of 6,000A, the fuse total clearing time is 0.012 seconds. The relay operates in 0.18 seconds at this current. The CTI = 0.168 seconds. A new motor is added, increasing the maximum fault to 10,000A. At 10,000A, the fuse clears in 0.005 seconds and the relay operates in 0.10 seconds. What is the new CTI, and is coordination maintained?

A. CTI = 0.168 seconds; unchanged

B. CTI = 0.095 seconds; coordination is LOST — below the 0.20-second minimum for relay-fuse coordination

C. CTI = 0.20 seconds; exactly at the minimum — marginally acceptable

D. CTI = 0.12 seconds; coordination is adequate for extremely inverse characteristics

14. A distance relay on a 230 kV line has Zone 1 at 85% reach (Z_line = 6 + j65 Ω). A three-phase fault occurs at 70% of the line through a fault resistance of 0 Ω. The pilot protection scheme (DCB) is active with a healthy communication channel. Both terminals see the fault as forward (into the line). What is the protection response?

A. Zone 1 at the near end trips instantaneously; the remote end trips on Zone 2 after 0.35 seconds

B. Zone 1 at both ends trips instantaneously because 70% is within Zone 1 reach at both terminals (Zone 1 at each end covers 85% of the line from each direction)

C. Both terminals trip on Zone 2 after the time delay

D. The DCB scheme allows both terminals to trip simultaneously with high-speed clearing because neither terminal sends a blocking signal (both see the fault as forward)

15. A three-phase, 460V, 6-pole, 400 HP induction motor drives a centrifugal pump through a VFD. At 60 Hz (1,170 RPM full-load speed), the motor delivers 298 kW to the pump. A system study shows the pump only needs 75% of design flow during 70% of operating hours (6,000 hours/year). Using the affinity laws, the reduced-flow speed is 75% of full speed = 877.5 RPM. What is the pump power at reduced speed, and what are the annual energy savings at $0.082/kWh?

A. P_reduced = 125.5 kW; savings = $85,362/year

B. P_reduced = 223.5 kW; savings = $29,142/year

C. P_reduced = 55.8 kW; savings = $119,594/year

D. P_reduced = 167.6 kW; savings = $64,239/year

16. Per NEC 480.9(A), ventilation in battery rooms must limit hydrogen below 1% by volume. A large UPS installation uses 480 vented lead-acid cells charging at a rate producing 0.006 ft^3 of hydrogen per cell per hour. The room is 5,000 ft^3. What ventilation rate (ACH) maintains hydrogen below 1%, and what safety margin does 2× this rate provide?

A. Required = 0.058 ACH; 2× = 0.115 ACH — provides a 50% margin

B. Required = 0.288 ACH; 2× = 0.576 ACH — provides a 50% margin

C. Required = 0.058 ACH; 2× = 0.115 ACH — reduces hydrogen to 0.5% volume (doubles the safety margin to 50% of LEL)

D. Required = 5.76 ACH; 2× = 11.52 ACH — industrial battery rooms require high ventilation rates

17. A 230 kV, 180-mile transmission line has a characteristic impedance of 365 Ω and an SIL of 145 MW. The line is loaded at 300 MW during peak hours and 60 MW during off-peak hours. A 100 Mvar switched shunt reactor is installed at the receiving end. During which operating condition should the reactor be switched ON, and what happens if it is left on during peak loading?

A. Switch ON during peak loading (300 MW) to support voltage; leaving it on during off-peak causes overvoltage

B. Switch ON during off-peak (60 MW, below SIL) to absorb excess reactive power and prevent voltage rise; leaving it on during peak loading (300 MW, above SIL) worsens the voltage drop because the reactor absorbs reactive power that the system needs

C. Keep the reactor on at all times for steady-state stability improvement

D. Switch OFF at all times — shunt reactors are only for transient overvoltage suppression

18. A three-phase, 13.8 kV system has a delta-wye grounded transformer. A bolted SLG fault on the wye secondary produces a zero-sequence current of I_0 = 3,500A. This zero-sequence current circulates within the delta primary winding. An engineer measures the current in one of the delta primary LINE conductors and finds it is 1,200A (the through-fault value). The engineer expected to see I_0/turns_ratio reflected in the primary. Why is the measured line current different from the expected zero-sequence reflection?

A. The engineer's measurement is wrong — the primary line current should equal I_0/n

B. The zero-sequence current circulates within the delta but does NOT flow in the primary lines; the 1,200A line current is entirely composed of positive-sequence and negative-sequence components reflected through the transformer

C. The delta winding is damaged and allowing zero-sequence current to leak into the line

D. The 1,200A represents only half the zero-sequence current because the delta splits it between two phases

19. A three-phase, 480V, 800A switchboard has an available fault current of 52,000A. An arc flash study calculates 28 cal/cm^2 at 24 inches with the existing 0.3-second short-time delay. The engineer evaluates five mitigation options: (1) reduce STD to 0.1 seconds; (2) enable ZSI for bus faults (0.05 seconds); (3) install arc-resistant switchgear; (4) install remote racking; (5) install an optical arc-flash relay that trips in 0.035 seconds. For a bus fault, rank options 1, 2, and 5 by decreasing incident energy.

A. Option 5 produces the lowest energy (3.3 cal/cm^2), then option 2 (4.7 cal/cm^2), then option 1 (9.3 cal/cm^2)

B. All three produce identical energy because the fault current is unchanged

C. Option 1 produces the lowest energy because short-time delay directly controls clearing time

D. Option 5 (0.035s → 3.3 cal/cm^2) < option 2 (0.05s → 4.7 cal/cm^2) < option 1 (0.1s → 9.3 cal/cm^2) — the optical relay provides the fastest clearing and lowest incident energy

20. Per NEC 250.30(A)(1), a separately derived system requires a system bonding jumper at the source. A multi-tenant commercial building has eight individual 225 kVA, 480V/208Y/120V dry-type transformers, each serving a tenant space. All eight transformers are fed from a common 13.8 kV primary switchgear through individual fused switches. How many system bonding jumpers are required?

A. One at the primary switchgear

B. Eight — one at each transformer secondary, because each transformer is a separately derived system requiring its own bonding jumper per NEC 250.30(A)(1)

C. Four — one for each pair of transformers

D. None — the primary switchgear's grounding system provides the bond for all derived systems

21. A synchronous generator rated 150 MVA, 18 kV has X"_d = 0.22 pu, X'_d = 0.33 pu, X_d = 1.80 pu, X_2 = 0.24 pu, X_0 = 0.10 pu. The generator is solidly grounded. Compare the bolted SLG subtransient fault current to the three-phase subtransient fault current and the line-to-line fault current. Rank them from highest to lowest.

A. I_3Φ > I_LL > I_SLG (three-phase is always the highest)

B. I_SLG > I_3Φ > I_LL (SLG exceeds three-phase in this solidly grounded system with low X_0)

C. I_SLG > I_LL > I_3Φ (SLG is highest, then LL, then three-phase)

D. I_3Φ > I_SLG > I_LL (three-phase is highest because X"_d is the lowest impedance)

22. A 480V, three-phase panelboard has a continuous motor load of 250A and a continuous lighting load of 100A. The noncontinuous receptacle load is 40A. Per NEC 215.2(A)(1) and 430.24, the minimum feeder conductor ampacity = 125% of largest motor FLA + 100% of other motors + 125% of continuous non-motor + 100% of noncontinuous. If the 250A represents the combined motor load (largest motor = 96A, remaining = 154A), what is the minimum feeder ampacity?

A. 120 + 154 + 125 + 40 = 439A

B. 120 + 154 + 100 + 40 = 414A

C. 312.5 + 154 + 125 + 40 = 631.5A

D. 120 + 250 + 125 + 40 = 535A

23. A three-phase, 4,160V system has two transformers and one generator feeding a common bus. Transformer 1: 10 MVA, Z = 7% on its base. Transformer 2: 5 MVA, Z = 6% on its base. Generator: 3 MVA, X"_d = 0.20 pu on its base. On a 10 MVA system base, the per-unit impedances are: Z_T1 = 0.07, Z_T2 = 0.12, X"_gen = 0.667. What is the total three-phase fault current on the 4,160V bus (assuming infinite primary sources for both transformers)?

A. 14,286 A + 8,333 A + 1,500 A = 24,119 A

B. 1,388 A (base current only)

C. 18,500 A

D. I_T1 = 1/0.07 × 1,388 = 19,829A; I_T2 = 1/0.12 × 1,388 = 11,567A; I_gen = 1/0.667 × 1,388 = 2,081A; Total = 33,477A

24. A 480V, three-phase, 400A feeder breaker (MCCB, 35 kA AIC) protects a cable run to a remote MCC. The available fault current at the breaker terminals is 42,000A — exceeding the breaker's 35 kA rating. A 400A Class L fuse is proposed upstream. The fuse limits let-through to 22,000A RMS at 42,000A available. Per NEC 240.86, is this a series-rated installation, and what documentation is required?

A. Yes, it's a series-rated installation; no special documentation is needed because the let-through is below the breaker's rating

B. Yes, it's a series-rated installation; the specific fuse-breaker combination must be tested, listed, and documented per NEC 240.86, and the downstream equipment must be labeled with the series combination rating

C. No, series rating is not permitted for feeder breakers above 200A

D. Yes, but only if both devices are from the same manufacturer

25. Per NEC 690.12(B)(2), PV conductors within the array boundary must be reduced to 80V within 30 seconds. A system uses 18 modules per string (V_oc = 48V per module = 864V per string) with DC-DC power optimizers that have listed rapid shutdown capability. At −15°C, V_oc per module increases to 55.2V (temperature coefficient = −0.30%/°C, ΔT = 40°C). With optimizers de-energized during rapid shutdown, each module produces near-zero output. Is the system compliant at all temperatures?

A. Yes — the optimizers shut down each module independently to near-zero voltage regardless of temperature; the module's V_oc still exists on the module leads but the optimizer's output voltage is near zero, reducing the string voltage below 80V

B. No — at −15°C, each module's V_oc of 55.2V means even one module exceeds 80V

C. No — the string voltage of 993.6V at −15°C far exceeds 600V code limits

D. Yes — but only for systems with fewer than 15 modules per string

26. A 1,000 kVA, 13.8 kV/480V, delta-wye grounded transformer has $Z_1 = Z_2 = j0.06$ pu and $Z_0 = j0.06$ pu on its own base. The 13.8 kV source has Z_1_src = j0.01 pu on the transformer base. On a 10 MVA system base, a bolted three-phase fault and a bolted SLG fault occur on the 480V bus. Compare the two fault currents and explain why they differ or are equal.

A. I_3Φ = I_SLG because $Z_1 = Z_2 = Z_0$ for the transformer and the delta blocks source Z_0

B. I_3Φ > I_SLG because the source impedance adds to Z_1 and Z_2 for the SLG but not for the three-phase

C. I_3Φ < I_SLG when source impedance is included, because the total (Z_1+Z_2+Z_0) is less than 3×(Z_1_total) due to the delta blocking source Z_0 from the zero-sequence network

D. I_3Φ > I_SLG because all three sequence impedances are in series for SLG, always producing lower current

27. A three-phase, 480V, 225A panelboard has an available fault current of 22,000A and a main MCCB clearing time of 0.08 seconds. An arc flash study shows 3.8 cal/cm^2 at 18 inches. The engineer proposes adding a maintenance mode switch that reduces clearing to 0.02 seconds. Additionally, an optical arc-flash relay is proposed that trips in 0.010 seconds. If both are implemented (the optical relay overrides the maintenance switch during maintenance), what is the incident energy?

A. 3.8 cal/cm^2 (unchanged)

B. 0.95 cal/cm^2 (proportional to maintenance switch only)

C. 0.475 cal/cm^2 (proportional to optical relay: 0.010/0.08 × 3.8)

D. 0.475 cal/cm^2 — the optical relay's 0.010-second clearing produces the lowest incident energy, below the 1.2 cal/cm^2 arc flash boundary threshold

28. A three-phase, 460V, 8-pole wound-rotor induction motor rated 600 HP has a full-load speed of 873 RPM. The motor starts a loaded ball mill requiring 300% breakaway torque. With external rotor resistance, the motor achieves 320% starting torque at 400% FLA. Without external resistance, the squirrel-cage equivalent would produce 150% starting torque at 650% FLA. Calculate the torque-per-ampere improvement factor of the wound-rotor start versus the squirrel-cage start.

A. Improvement factor = 2.0× (wound-rotor is twice as effective)

B. Improvement factor = 3.47× (wound-rotor achieves 0.80 %FLT/%FLA vs squirrel-cage's 0.23 %FLT/%FLA)

C. Improvement factor = 1.5× (moderate improvement)

D. No improvement — wound-rotor and squirrel-cage have equal torque-per-ampere ratios

29. Per NEC 450.3(B), a 3,000 kVA, 480V/208Y/120V transformer has a rated primary current of 3,608A. At 125% of rated primary current, the maximum OCPD = 4,510A. The next standard size per NEC 240.6(A) is 4,000A (below 4,510A) or 5,000A (above 4,510A). Which is the correct maximum primary OCPD?

A. 5,000A — NEC 450.3(B) permits the next higher standard size above 125% when the calculated value does not correspond to a standard size

B. 4,000A — the OCPD must not exceed 125% of rated current

C. 3,608A — primary protection must be at 100% of rated current for transformers above 1,000 kVA

D. 6,000A — transformers above 2,000 kVA may use 167% primary protection

30. A three-phase, 4,160V, 10-pole synchronous motor rated 2,500 HP drives a cement ball mill at 720 RPM. The motor operates at 0.85 leading PF with a field current of 280A. During a system fault clearing, the bus voltage experiences a 0.3-second sag to 78% of nominal. The motor's pull-out torque at rated voltage is 220% FLT. With fixed field current (E_a constant), pull-out torque is proportional to V_t. At 78% voltage, pull-out = 0.78 × 220% = 171.6% FLT. The ball mill requires 95% FLT continuously. Does the motor maintain synchronism, and what is the stability margin?

A. No — 171.6% is close to 100% and the motor may oscillate out of synchronism

B. Yes — margin = 171.6% − 95% = 76.6% FLT; but the power angle increases significantly and the 0.3-second sag may cause transient instability depending on the machine's inertia

C. Yes — synchronous motors maintain constant speed regardless of voltage

D. No — any voltage below 85% causes immediate loss of synchronism

31. A 480V, three-phase system has three parallel transformers: T1 = 2,000 kVA (Z = 5.75%), T2 = 1,500 kVA (Z = 5.50%), T3 = 1,000 kVA (Z = 6.00%). All have identical voltage ratios and angular displacements. On a 2,000 kVA common base, which transformer has the lowest per-unit impedance and carries the most load?

A. T1 (Z = 0.0575 pu) carries the most because it has the lowest Z_pu at its own base

B. T1 (Z = 0.0575 pu on the 2,000 kVA base) carries the most because it has the lowest per-unit impedance — T2 = 0.0733 pu, T3 = 0.12 pu on the same base

C. T3 carries the most because its smaller kVA means it reaches capacity first

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

32. A 13.8 kV, three-phase system has a measured voltage THD of 7.5% at the PCC. Individual harmonics: V_5 = 5.2%, V_7 = 3.5%, V_{11} = 2.0%, V_{13} = 1.4%. IEEE 519 limits for systems below 69 kV: THD_V ≤ 5.0%, individual ≤ 3.0%. How many violations exist, and what is the recommended engineering approach?

A. One violation (THD only); install a passive harmonic filter tuned to the 5th

B. Three violations (THD, V_5, V_7); the 5th and 7th both exceed 3.0% individual limits and the THD exceeds 5.0%

C. Two violations (V_5 and THD); install an active harmonic filter

D. Four violations — THD, V_5, V_7, V_{11} all exceed limits; complete system redesign required

33. A ground resistance test on an industrial facility yields 12 Ω during dry summer conditions. The specification requires ≤ 5 Ω year-round. The engineer proposes three remediation options: (1) add 4 supplemental ground rods; (2) install a ground ring around the building; (3) apply chemical ground enhancement material around existing electrodes. Rank the options by effectiveness for this high-resistivity site.

A. Option 1 (ground rods) is most effective because rods reach deeper soil with lower resistivity

B. Option 2 (ground ring) is most effective because it maximizes electrode surface area in contact with soil, followed by Option 3, then Option 1

C. Option 3 (chemical enhancement) is most effective because it reduces local soil resistivity

D. All three options are equally effective and interchangeable

34. A 230 kV transmission line has a total positive-sequence impedance of $Z_1 = 15 + j180\ \Omega$ and zero-sequence impedance of $Z_0 = 45 + j540\ \Omega$. Source impedances: $Z_{1}\_\text{src} = j12\ \Omega$, $Z_{0}\_\text{src} = j18\ \Omega$. For a bolted SLG fault at the remote end, what is the total impedance magnitude $|Z_{1}\_\text{total} + Z_{2}\_\text{total} + Z_{0}\_\text{total}|$, and is the SLG current higher or lower than the three-phase fault current?

A. |Sum| = 750 Ω; SLG is higher than three-phase

B. |Sum| = 550 Ω; SLG equals three-phase

C. |Sum| = 750 Ω; SLG is lower than three-phase because Z_0 is much larger than Z_1

D. |Sum| = 1,110 Ω; SLG is lower than three-phase

35. Per NEC 110.14(C)(1), for equipment rated over 100A or marked for conductors 1 AWG through 750 kcmil, the 75°C column governs unless the terminal is listed and marked for higher temperature. A 600A switchboard has terminals marked "75°C only." The engineer installs 500 kcmil THWN-2 (90°C rated) conductors. The 75°C ampacity of 500 kcmil is 380A; the 90°C ampacity is 430A. For a continuous load of 440A (after applying 125%), what is the minimum conductor size?

A. 750 kcmil (75°C ampacity = 475A ≥ 440A) — the 75°C column must be used because the terminals are rated 75°C only

B. 500 kcmil using the 90°C column (430A < 440A — non-compliant)

C. 600 kcmil (75°C ampacity = 420A < 440A — also non-compliant; 750 kcmil needed)

D. 500 kcmil is adequate because the 90°C insulation provides thermal headroom even at 75°C terminals

36. A three-phase, 460V, 4-pole VFD-driven induction motor operates a centrifugal chiller compressor. At design conditions (1,770 RPM), the chiller delivers 500 tons of cooling. During mild weather, the chiller needs only 60% of design capacity. Using the affinity laws, the compressor speed can be reduced to 60% of rated (1,062 RPM). What is the approximate power savings compared to full-speed operation, and what is the VFD output frequency?

A. Power savings = 40%; frequency = 36 Hz

B. Power savings = 60%; frequency = 36 Hz

C. Power savings = 78.4%; frequency = 35.4 Hz (power reduces to $(0.6)^3$ = 21.6% of rated; savings = 78.4%)

D. Power savings = 40%; frequency = 30 Hz

37. A 480V, three-phase, 200A feeder uses 4/0 AWG THHN copper in EMT conduit. NEC Chapter 9 Table 9 lists R = 0.0608 Ω/1000 ft and X = 0.0478 Ω/1000 ft. The feeder is 600 feet long and serves a load at 0.82 lagging PF. What is the voltage drop percentage, and what conductor size would reduce it below 3%?

A. V_drop = 2.8%; 4/0 is adequate

B. V_drop = 4.2%; upsizing to 250 kcmil (R = 0.0431, X = 0.0445) reduces the drop to approximately 3.0%

C. V_drop = 5.1%; upsizing to 350 kcmil is required

D. V_drop = 1.5%; well within limits

38. A 100 MVA, 345/138 kV autotransformer has a series impedance of 12% on its own base. Two identical units operate in parallel. A 25 MVA synchronous generator with X"_d = 0.25 pu is also connected to the 138 kV bus. On a 100 MVA system base, the generator's subtransient reactance is 1.0 pu. With an infinite 345 kV source, what is the total fault current on the 138 kV bus?

A. 7,400 A

B. 8,370 A

C. 14,800 A

D. I_base(138 kV) = 418.4A; I_transformers = 1/0.06 × 418.4 = 6,973A; I_gen = 1/1.0 × 418.4 = 418A; total = 7,391A ≈ 7,400A

39. Per NEC 250.53(A)(2), a supplemental ground electrode is required when a single rod doesn't achieve 25 Ω. After installing the supplemental rod 6 feet from the first, the combined resistance is 38 Ω. The engineer installs a third rod 6 feet from the second. The combined resistance drops to 28 Ω. A fourth rod brings the combined to 20 Ω. Per the NEC, how many rods were actually REQUIRED by code?

A. Two rods — NEC 250.53(A)(2) requires only ONE supplemental electrode; the third and fourth rods were voluntary improvements not required by code

B. Four rods — because the resistance must achieve 25 Ω

C. Three rods — because each subsequent rod reduces resistance proportionally

D. Only one rod was required — the supplemental rod requirement does not depend on achieving any specific resistance

40. A three-phase, 480V system has a 2,000 kVA transformer (Z = 5.75%) with an available fault current of 31,374A at the switchboard. The switchboard feeds a panelboard through 350 feet of 250 kcmil copper in EMT (R = 0.0541 Ω/1000 ft, X = 0.0442 Ω/1000 ft). What is the approximate available fault current at the panelboard?

A. 31,374A (unchanged — cable impedance at 350 feet is negligible)

B. 28,500A

C. 22,800A

D. 15,200A

41. A three-phase, 4,160V, 6-pole synchronous motor rated 1,500 HP drives a compressor at 1,200 RPM. The motor operates at 0.80 leading PF with an efficiency of 95.5%. The motor's capability curve shows it can supply a maximum of 1,200 kvar at the current real power loading. An operator accidentally opens the DC field circuit breaker. What happens immediately and over the next few seconds?

A. The motor continues at synchronous speed with no noticeable change

B. The motor immediately stalls because synchronous motors cannot run without field excitation

C. The motor speed drops gradually as the residual magnetism decays

D. The motor loses synchronism almost immediately because without field excitation, the synchronous torque drops to zero; the motor may briefly operate as an induction motor using rotor cage bars (if present) or may stall completely if the load exceeds the induction motor pull-in capability

42. A 480V, three-phase, 600A switchboard has an available fault current of 55,000A. The switchboard SCCR is 65,000A. An arc flash study shows 32 cal/cm² at 24 inches with a 0.3-second main breaker

clearing time. The engineer implements ZSI (bus fault clearing = 0.05 seconds) and installs arc-resistant switchgear. For a bus fault during maintenance, what is the worker's effective exposure?

A. 32 cal/cm² — arc-resistant switchgear does not reduce the calculated incident energy

B. 5.3 cal/cm² — proportional to the ZSI clearing time of 0.05/0.3 × 32

C. Effectively near zero at the worker's position — the arc-resistant switchgear redirects the arc blast away from the front, and even the reduced 5.3 cal/cm² energy is directed to the exhaust plenum rather than toward the worker

D. 32 cal/cm² at the worker's position, but the arc-resistant enclosure prevents physical burns

43. Per NEC Article 517.17(A), the line isolation monitor (LIM) in a hospital isolated power system alarms at 5 mA total hazard current. A new operating suite has three operating rooms sharing an isolated power panel with 30 outlets. The background leakage from 18 connected devices totals 4.2 mA. The biomedical engineer determines that additional devices cannot be connected without risking a LIM alarm. What is the recommended engineering solution?

A. Install a second isolated power panel to distribute the leakage current across two independent LIM-monitored systems, reducing the per-system hazard current

B. Increase the LIM alarm threshold from 5 mA to 10 mA

C. Replace the LIM with a ground-fault circuit interrupter

D. Disconnect five of the oldest devices to reduce background leakage

44. A balanced three-phase, 4,160V source feeds two parallel loads: a 3,500 kW motor load at 0.78 lagging PF and a 2,000 kvar capacitor bank. Additionally, a 1,000 HP synchronous motor at 0.80 leading PF ($\eta = 94\%$) is connected to the same bus. What is the combined bus power factor with all three loads energized?

A. 0.92 lagging

B. 0.85 lagging

C. 0.96 lagging

D. 0.78 lagging (unchanged because the capacitor and synchronous motor cancel each other)

45. A three-phase, 460V, 2-pole induction motor rated 200 HP has a full-load speed of 3,540 RPM. The motor's air gap power is 160 kW (total three-phase). What is the slip, rotor copper loss, and developed mechanical power?

A. s = 1.67%; P_RCL = 2.67 kW; P_mech = 157.3 kW

B. s = 1.67%; P_RCL = 2.67 kW; P_mech = 157.3 kW (verified: n_s = 3,600, slip = (3,600−3,540)/3,600 = 1.67%; P_RCL = 0.0167 × 160 = 2.67 kW; P_mech = 160 − 2.67 = 157.3 kW)

C. s = 3.33%; P_RCL = 5.33 kW; P_mech = 154.7 kW

D. s = 0.83%; P_RCL = 1.33 kW; P_mech = 158.7 kW

46. A 138 kV circuit breaker has a rated symmetrical interrupting current of 40 kA. It was tested at a standard X/R of 17. The system X/R at the breaker location is 25. The ANSI derating factor for X/R = 25 vs tested X/R = 17 is approximately 0.93. The available symmetrical fault current is 38 kA. Is the breaker adequately rated?

A. Yes — 38 kA < 40 kA rated

B. No — the derated capability is 40 × 0.93 = 37.2 kA, which is less than the 38 kA available

C. Yes — the derating factor only applies to asymmetrical current, not symmetrical

D. No — but the breaker is adequate if the fault is line-to-line rather than three-phase

47. Per NEC 430.24, a feeder serves the following motors and a continuous lighting panel: Motor A: 200 HP (FLA = 242A), Motor B: 100 HP (FLA = 124A), Motor C: 75 HP (FLA = 96A), Motor D: 50 HP (FLA = 65A). Continuous lighting: 85A. What is the minimum feeder conductor ampacity?

A. 125% × 242 + 124 + 96 + 65 + 125% × 85 = 302.5 + 285 + 106.25 = 693.75A

B. 590A

C. 800A

D. 750A

48. A three-phase, 13.8 kV underground cable system is 20 miles long with a charging current of 4.0A per mile per phase. A ground-fault relay uses a zero-sequence CT (window type) with a pickup of 25A.

The cable is energized at rated voltage with no connected load. A high-impedance ground fault develops, producing 30A of zero-sequence current. Does the relay correctly detect the fault?

A. No — the charging current masks the fault current in the zero-sequence CT

B. Yes — but the relay also sees 80A of charging current, causing it to trip immediately on energization before any fault occurs

C. Yes — the zero-sequence CT sees only the 30A fault current (balanced charging cancels); since 30A exceeds the 25A pickup, the relay operates correctly

D. No — 30A is too close to the 25A pickup for reliable detection

49. A 480V, three-phase, 400A panelboard has a bus rating of 400A. The total connected load is: 280A continuous motor + 60A continuous lighting + 50A noncontinuous receptacles = 390A total. Per NEC 215.2(A)(1), minimum OCPD = 125% × (280+60) + 50 = 475A. A 100%-rated 400A breaker eliminates the 125% adder: 280+60+50 = 390A ≤ 400A. But the conductor must still handle the thermal load. With a 100%-rated breaker, what minimum conductor ampacity is required?

A. 390A (matching the total load)

B. 475A (the standard NEC 215.2 calculation still applies to conductor sizing even with a 100%-rated breaker)

C. 400A (matching the breaker and bus rating)

D. 340A (motor load at 100% + lighting at 100% + receptacles at 100%, minus 50A margin)

50. A recloser on a 12.47 kV overhead feeder coordinates with a 100A lateral fuse using fuse-saving strategy. At a fault current of 3,000A: fuse minimum melting = 0.06 seconds, fuse total clearing = 0.12 seconds, recloser fast trip = 0.04 seconds, recloser delayed trip = 0.35 seconds. A permanent fault occurs on the lateral. Describe the complete protection sequence.

A. The fuse blows immediately on the first occurrence because it is faster than the recloser

B. The recloser and fuse both operate on the first trip, isolating everything

C. The recloser fast-trips (0.04s < fuse min melt 0.06s), de-energizes the line, recloses into the permanent fault; on the delayed trip (0.35s > fuse total clear 0.12s), the fuse blows and isolates the lateral; the recloser holds and restores service to unfaulted sections

D. The recloser locks out after four trips without the fuse ever operating

51. A three-phase, 480V system has a 1,500 kVA transformer (Z = 5.75%, X/R = 7) and five motors totaling 800A FLA. The transformer fault current is 31,374A. The motors contribute 4 × 800 = 3,200A first-cycle. The total first-cycle symmetrical fault current is 34,574A. What is the peak asymmetrical current using the X/R = 7 multiplier?

A. 48,860A (√2 × symmetrical)

B. 78,000A (2.268 × symmetrical, using the X/R = 7 factor)

C. 34,574A (no asymmetry for combined sources)

D. 62,000A

52. A 345 kV, 200-mile transmission line has a sending-end voltage of 350 kV and a receiving-end voltage of 335 kV. The line reactance is 65 Ω. The power angle is 22°. What is the transmitted real power and the approximate voltage regulation?

A. P = 758 MW; VR = 10.5%

B. P = 500 MW; VR = 3.2%

C. P = 600 MW; VR = 4.5%

D. P = 758 MW; VR = 4.5%

53. Per NEC 250.30(A)(1) Exception, the system bonding jumper may be installed at the first disconnecting means rather than at the source when a supply-side bonding jumper connects the source to the first disconnect. A 500 kVA transformer is located in an outdoor vault 100 feet from the indoor switchboard (first disconnecting means). The supply-side bonding jumper from the transformer to the switchboard must be sized how?

A. Per NEC Table 250.102(C)(1), based on the largest ungrounded supply conductor from the transformer to the switchboard — the same sizing rules as for a system bonding jumper

B. Per NEC Table 250.122, based on the overcurrent device rating

C. At 12.5% of the ungrounded conductor circular mil area

D. At any size not smaller than the equipment grounding conductor

54. A 100 MVA synchronous generator with H = 4.0 MJ/MVA delivers 80 MW when a three-phase fault reduces electrical output to zero. The critical clearing angle is 110°. The rotor accelerates at a rate determined by the swing equation. If the protective relay trips in 0.025 seconds and the breaker clears in 0.05 seconds (total 0.075 seconds), the rotor angle at clearing must be less than 110° for stability. Using the simplified acceleration formula: $\Delta\delta = (180 \times f \times P\_a)/(H \times S\_rated) \times t^2$, what is the approximate rotor angle advance during the 0.075-second fault?

A. 12.2° — well within the 110° critical clearing angle; stability is maintained with generous margin

B. 45° — stability is maintained but with limited margin

C. 110° — exactly at the critical clearing angle

D. 3.04° — minimal angle advance due to the very short clearing time

55. A three-phase, 460V, 8-pole wound-rotor motor rated 400 HP has external rotor resistance for starting. The motor's full-voltage, full-resistance starting current is 350% FLA, producing 280% starting torque. As the motor accelerates and resistance is removed in steps, the final step removes all external resistance. At what approximate speed does the motor transition from the wound-rotor characteristic to the normal squirrel-cage characteristic?

A. At standstill — the external resistance is removed immediately after the motor begins turning

B. Near synchronous speed — the external resistance is gradually removed during acceleration, and the final step occurs when the motor is near full speed, transitioning to normal induction motor operation with the rotor winding effectively short-circuited

C. At 50% of synchronous speed — the midpoint provides optimal transition

D. The transition never occurs because wound-rotor motors always operate with external resistance

56. A 480V, three-phase, 800A LVPCB main breaker has long-time, short-time (0.25s delay), and ground-fault trip functions. A 400A MCCB feeder breaker has a fixed instantaneous trip at 4,000A. ZSI is installed. A fault of 40,000A occurs on the bus (no feeder restraint signal). What is the main breaker's response, and what is the approximate incident energy reduction compared to the normal 0.25-second delay?

A. The main trips instantaneously because no ZSI restraint signal was received; energy reduces by approximately 80%

B. The main holds on its 0.25-second delay regardless of ZSI status

C. The main trips on its ground-fault element, not the short-time element

D. The main trips with no intentional delay (approximately 0.05s mechanical operating time); incident energy reduces from 0.25/0.25 × E to 0.05/0.25 × E = 20% of original, an 80% reduction

57. Per NEC 310.15(C)(1), temperature correction and conduit fill adjustment factors are applied to the conductor's base ampacity from Table 310.16. A conduit in a 40°C ambient contains eight 1/0 AWG THWN-2 copper conductors (90°C rated, base ampacity = 170A). Temperature correction for 90°C at 40°C = 0.91. Conduit fill for 7–9 conductors = 0.70. Equipment terminals are rated 75°C (75°C ampacity for 1/0 = 150A). What is the final adjusted ampacity?

A. 108.3A (170 × 0.91 × 0.70 = 108.3A)

B. 150A (75°C terminal limit governs because 150 > 108.3)

C. 170A (no adjustment needed for 90°C insulation)

D. 95.6A (150 × 0.91 × 0.70)

58. A three-phase, 13.8 kV system has a delta-connected 5,400 kvar capacitor bank and a system short-circuit capacity of 400 MVA. The resonant harmonic order is h_r = √(400,000/5,400) = 8.60. The facility has twelve-pulse VFDs whose lowest characteristic harmonics are the 11th and 13th. Is the resonant frequency a concern for this installation?

A. No — h_r = 8.60 is well below the 11th harmonic and above the 7th; the resonance falls between characteristic harmonics and poses minimal risk for twelve-pulse VFDs

B. Yes — the 7th harmonic from residual unbalance in the 12-pulse drives will excite resonance

C. Yes — resonance at 8.60 is close to the 11th harmonic and will amplify it

D. No — twelve-pulse VFDs produce zero harmonics by design

59. A 480V, three-phase panelboard with a 225A bus has a calculated load of 240A (per NEC 215.2 with 125% continuous adder). A 100%-rated 225A breaker reduces the calculation to 192A (without the 125% adder). However, the engineer must also verify the conductor ampacity. With a 100%-rated 225A breaker, what is the minimum conductor ampacity?

A. 225A (matching the breaker rating)

B. 192A (matching the load without the 125% adder, since the 100%-rated breaker and its associated wiring system are designed for continuous duty)

C. 240A (the standard NEC 215.2 calculation still governs conductor sizing)

D. 180A (the actual load current without any multipliers)

60. A 345 kV, three-phase line has a sending-end voltage of 360 kV and receiving-end voltage of 340 kV. The line reactance is 90 Ω. The power angle is 35°. What is the real power transmitted and the maximum power this line could transmit (at $\delta = 90°$)?

A. P = 780 MW; P_max = 1,360 MW

B. P = 1,000 MW; P_max = 2,000 MW

C. P = 390 MW; P_max = 680 MW

D. P = 780 MW; P_max = 1,360 MW

61. Per NEC Article 700.10(B)(1), emergency wiring must be kept independent from normal wiring. NEC 700.10(B)(5) provides an exception for assembly occupancies ≤1,000 persons: emergency wiring may share raceways with normal circuits when enclosed in 2 inches of concrete or using MI/fire-rated cable. An engineer applies this exception to a 500-person assembly hall. The emergency circuit uses Type MC-HL (hospital-listed) cable in a shared raceway with normal circuits. Is this compliant?

A. Yes — Type MC-HL cable meets the fire-rated cable requirement of NEC 700.10(B)(5)

B. No — only MI cable or listed electrical circuit protective systems qualify under this exception; standard MC cable does not

C. Yes — any metal-clad cable qualifies under this exception

D. No — the exception applies only to occupancies over 500 persons

62. A balanced three-phase, 208Y/120V panelboard serves a data center with 100% nonlinear server loads. Each phase draws 350A fundamental and 140A of third-harmonic current. The true-RMS phase current is $\sqrt{(350^2 + 140^2)} = 377A$. The neutral current is $3 \times 140 = 420A$. The conduit contains 3 phase and 1 neutral conductor. Per NEC 310.15(C)(1), 4 current-carrying conductors require a 0.80 adjustment factor. The engineer must select conductors. What minimum base ampacity (before derating) is required for BOTH the phase and neutral conductors?

A. Phase: 377/0.80 = 471A; Neutral: 420/0.80 = 525A — the neutral governs the conductor selection at 525A base ampacity

B. Phase: 350/0.80 = 437.5A; Neutral: 420/0.80 = 525A

C. Phase and neutral both at 471A (based on phase current only)

D. Phase: 471A; Neutral: 350A (neutral does not need derating)

63. A three-phase, 4,160V system has a neutral grounding resistor rated 400A, 10 seconds. A ground fault occurs through a fault resistance of 8 Ω. The system V_LN = 2,402V. The NGR resistance = 2,402/400 = 6.005 Ω. The fault resistance is in series with the phase conductor impedance in the fault circuit. What is the approximate ground-fault current?

A. 400A (the NGR limits current to its rated value regardless of fault resistance)

B. 200A (the fault resistance and NGR are in parallel)

C. 280A (the fault resistance is in series with the NGR, but on the same path)

D. I = V_LN/(R_NGR + R_fault) = 2,402/(6.005 + 8) = 2,402/14.005 = 171.5A — the fault resistance significantly reduces the ground-fault current below the NGR rating

64. A 480V, three-phase motor control center has 8 motors with a combined FLA of 1,200A. During a fault on the MCC bus, the motors contribute approximately 4 × FLA = 4,800A of first-cycle fault current. The utility source contributes 35,000A through the service transformer. The total first-cycle fault current is 39,800A. If the system X/R ratio is 9, what is the approximate peak asymmetrical fault current?

A. 56,300A

B. 89,550A (peak factor of 2.25 for X/R = 9)

C. 39,800A (no asymmetry)

D. 79,600A (2× symmetrical)

65. A protection engineer sets a distance relay (21) on a 138 kV line with Z_line = 4 + j48 Ω. Zone 1 = 85% reach. Zone 2 = 120% with 0.35-second delay. Zone 3 = 200% with 1.0-second delay. A fault occurs at 130% of the protected line (on the adjacent line). Which zone(s) at the near-end terminal can detect this fault?

A. Zone 1 only (85% reach detects faults up to 85% of the line)

B. Zone 2 only (120% reach covers up to 120% of the line, so 130% is beyond its reach)

C. Zone 3 only (200% reach covers 130% of the protected line plus the adjacent line)

D. Zone 2 and Zone 3 both detect the fault — Zone 2 at 120% cannot reach 130%, but Zone 3 at 200% covers 130%; Zone 3 operates after 1.0 seconds as backup for the adjacent line's protection

66. A three-phase, 480V, 225A panelboard has an available fault current of 20,000A. An IEEE 1584 arc flash study shows 4.2 cal/cm² at 18 inches with the existing main breaker (0.06-second clearing time). The engineer proposes installing a maintenance mode switch that reduces clearing time to 0.02 seconds. What is the new incident energy, and does this drop below the 1.2 cal/cm² arc flash boundary threshold?

A. E_new = 2.1 cal/cm²; above the 1.2 cal/cm² boundary — PPE Category 1 still required

B. E_new = 1.4 cal/cm²; above the 1.2 cal/cm² boundary — PPE Category 1 still required

C. E_new = 4.2 cal/cm² (unchanged)

D. E_new = 0.7 cal/cm²; below the 1.2 cal/cm² boundary — standard daily work clothing is sufficient at the arc flash boundary distance

67. A three-phase, 13.8 kV capacitor bank rated 3,600 kvar is grounded-wye connected. The bank has two series groups of five parallel units per phase (10 units per phase, 30 total). One unit fails open-circuited. What is the immediate effect on the affected phase?

A. The remaining healthy units in the same series group absorb the failed unit's reactive output, with no change in voltage per unit

B. The affected series group has reduced capacitance, causing its voltage to increase and the other series group's voltage to decrease — voltage redistribution between the two series groups occurs

C. The entire phase trips offline due to neutral current unbalance detection

D. The failed unit has no effect because capacitor banks automatically compensate for individual unit failures

68. Per NEC 480.9(A), ventilation for battery rooms applies to vented cells. A facility converts from vented lead-acid to sealed VRLA batteries. The VRLA cells are installed in the same room with the same ventilation system. The VRLA manufacturer states hydrogen emission is 0.001 ft³/cell/hour under

worst-case overcharge. The room has 200 cells and is 4,000 ft³. Does the existing ventilation system remain adequate?

A. Yes — VRLA cells produce approximately 5× less hydrogen than vented cells; the existing ventilation designed for vented cells provides excessive margin for VRLA

B. No — VRLA cells require double the ventilation of vented cells due to thermal runaway risk

C. Yes — but the ventilation should be verified against the manufacturer's specific requirements and the room should include hydrogen detection as an additional safety measure

D. No — VRLA batteries do not require any ventilation and the system should be decommissioned

69. A 230 kV, 160-mile transmission line has a total positive-sequence impedance of $Z_1 = 12.8 + j120\ \Omega$ and zero-sequence impedance of $Z_0 = 38.4 + j360\ \Omega$. Source impedances: Z_{1}_src = j10 Ω, Z_{0}_src = j15 Ω. For a bolted SLG fault at the remote end, what is the ratio $|Z_0$_total$|/|Z_1$_total$|$?

A. 1.0 (zero-sequence equals positive-sequence)

B. 2.0 (moderate zero-sequence impedance)

C. 4.0 (very high zero-sequence impedance)

D. 2.9 (the ratio of $|38.4+j375|/|12.8+j130| = 376.9/130.6 = 2.89 \approx 2.9$)

70. A 480V, three-phase, 600A switchboard has an available fault current of 45,000A and a main LVPCB with a 0.3-second short-time delay. An arc flash study shows 25 cal/cm² at 24 inches. ZSI is installed (bus fault clearing = 0.05 seconds). An optical arc-flash relay is also proposed (clearing time = 0.035 seconds). If both are implemented, which device controls the actual clearing time for a bus fault?

A. The slower device (ZSI at 0.05 seconds) controls because breakers cannot respond faster than their mechanical minimum

B. The faster device (optical relay at 0.035 seconds) controls because it sends a trip signal before the ZSI logic processes the restraint status

C. Both devices trip at 0.05 seconds because the breaker's mechanical time limits the response

D. The optical relay controls at 0.035 seconds because it provides an independent, direct trip path that bypasses the ZSI logic

71. Per NEC 250.122(B), a 300A circuit has 500 kcmil phase conductors (increased from the minimum 350 kcmil for voltage drop). The minimum EGC for 300A is 4 AWG (41,740 CM). What is the proportionally increased EGC size?

A. 3 AWG — ratio = 500,000/350,000 = 1.429; EGC = 41,740 × 1.429 = 59,627 CM → 3 AWG (52,620 CM) is too small; 2 AWG (66,360 CM) is the next adequate size

B. 4 AWG (no increase needed because the circuit is only 300A)

C. 1/0 AWG (must match the phase conductor size)

D. 6 AWG (standard EGC for all circuits up to 400A)

72. A balanced three-phase, 4,160V source feeds a 5,000 kW load at 0.70 lagging PF through a feeder with Z = 0.55 + j2.80 Ω per phase. The engineer installs a 4,000 kvar capacitor bank at the load bus. After the capacitor is energized, what is the new power factor and the approximate percentage reduction in feeder voltage drop?

A. New PF = 0.85; voltage drop reduced by 20%

B. New PF = 0.92; voltage drop reduced by 35%

C. New PF = 0.96; voltage drop reduced by approximately 45% because the reactive current reduction significantly reduces the dominant reactive voltage drop component through the high-reactance feeder

D. New PF = unity; voltage drop reduced by 50%

73. A 100 MVA, 345/138 kV autotransformer has a series impedance of 11% on its own base. The 138 kV bus also connects to a 50 MVA synchronous generator with X"_d = 0.20 pu on its own base. On a 100 MVA system base, the autotransformer Z = 0.11 pu and the generator X"_d = 0.40 pu. What is the total three-phase fault current on the 138 kV bus?

A. I_base = 418.4A; I_total = (1/0.11 + 1/0.40) × 418.4 = (9.09 + 2.50) × 418.4 = 11.59 × 418.4 = 4,849A

B. 7,500A

C. 9,800A

D. I_total = 11.59 pu × 418.4A = 4,849A

74. A three-phase, 460V, 4-pole induction motor rated 150 HP operates at full load with slip = 2.2%. A VFD operates the motor at 45 Hz using constant V/f control. The VFD output voltage is 345V. At 45 Hz, the motor's synchronous speed is 1,350 RPM. With the same 2.2% slip at 45 Hz, the actual operating speed is approximately 1,320 RPM. The motor drives a constant-torque conveyor load. What is the motor's approximate power output at this speed?

A. Full rated power (149 kW) because the torque is constant

B. 112 kW (proportional to speed: 149 × 1,320/1,770)

C. 149 kW (constant-torque means constant power)

D. 74.5 kW (power is proportional to the square of speed)

75. Per NEC 430.32(A)(1), a motor with SF ≥ 1.15 has a maximum overload trip of 125% of nameplate FLA, and a motor with SF < 1.15 has a maximum of 115%. A motor has nameplate FLA = 186A, SF = 1.10, and temperature rise = 40°C. What is the maximum overload setting?

A. 213.9A (115% of 186A)

B. 232.5A (125% of 186A)

C. 186A (100% — no overload margin for SF < 1.15)

D. 204.6A (110% of 186A)

76. A 480V, three-phase system has a 2,500 kVA transformer (Z = 5.75%) paralleled with a 1,500 kVA transformer (Z = 6.25%). Both have identical ratios and configurations. On a 2,500 kVA common base: $Z_1 = 0.0575$ pu, $Z_2 = 0.0625 \times (2{,}500/1{,}500) = 0.1042$ pu. The parallel impedance is Z_parallel = (0.0575 × 0.1042)/(0.0575 + 0.1042) = 0.0370 pu. What is the total available fault current?

A. 31,374A (single transformer only)

B. 62,748A

C. I_fault = I_rated/Z_parallel = 3,007/0.0370 = 81,270A

D. 45,200A

77. A three-phase, 13.8 kV system has a bolted three-phase fault current of 15,000A and a bolted SLG fault current of 18,750A. The system is solidly grounded. An engineer must verify that the zero-

sequence impedance is less than the positive-sequence impedance. Using the fault current ratio: $I\_SLG/I\_3\Phi = 3Z_1/(Z_1+Z_2+Z_0)$. With $Z_1 = Z_2$: $I\_SLG/I\_3\Phi = 3Z_1/(2Z_1+Z_0)$. Solving for Z_0/Z_1 gives what value?

A. $Z_0/Z_1 = 1.0$ (equal impedances)

B. $Z_0/Z_1 = 0.5$ (Z_0 is half of Z_1)

C. $Z_0/Z_1 = 2.0$ (Z_0 is twice Z_1)

D. $Z_0/Z_1 = 0.4$ ($I\_SLG/I\_3\Phi = 18{,}750/15{,}000 = 1.25$; solving: $3/(2 + Z_0/Z_1) = 1.25$; $2 + Z_0/Z_1 = 2.4$; $Z_0/Z_1 = 0.4$)

78. A 480V, three-phase panelboard has a continuous lighting load of 150A and a noncontinuous motor load of 90A. Per NEC 215.2(A)(1), minimum OCPD = 125% × 150 + 90 = 277.5A → next standard = 300A. The panelboard bus is rated 225A. Using a 100%-rated 225A breaker: load = 150 + 90 = 240A. Is 240A ≤ 225A?

A. No — 240A exceeds 225A; even with a 100%-rated breaker, the total load exceeds the bus and breaker rating; the panelboard must be upgraded to 250A or larger

B. Yes — 240A is within the 225A rating because the 100%-rated breaker has additional thermal headroom

C. No — but the noncontinuous load does not need to be counted at 100% for a 100%-rated breaker

D. Yes — the standard 80% rule (225 × 0.80 = 180A continuous) still applies, and 150A ≤ 180A

79. A three-phase, 4,160V system serves a 4,000 kW load at 0.75 lagging PF. The total reactive demand is Q = 4,000 × tan(arccos 0.75) = 4,000 × 0.882 = 3,528 kvar. The utility charges a reactive demand penalty of $3.50/kvar/month for kvar exceeding a 0.92 PF threshold. What is the allowed kvar at 0.92 PF, the excess kvar, and the monthly penalty?

A. Q_allowed = 4,000 × tan(arccos 0.92) = 1,704 kvar; excess = 3,528 − 1,704 = 1,824 kvar; penalty = 1,824 × $3.50 = $6,384/month

B. Q_allowed = 0 kvar; penalty = 3,528 × $3.50 = $12,348/month

C. Q_allowed = 3,528 kvar; no penalty

D. Q_allowed = 2,000 kvar; excess = 1,528 kvar; penalty = $5,348/month

80. A 500 kVA, 480V/208Y/120V, three-phase transformer has $Z = 4.5\%$ and $X/R = 4$. The symmetrical RMS fault current at the 208V secondary is 6,400A. What is the approximate peak asymmetrical current, and what determines the equipment's momentary withstand rating requirement?

A. Peak = 9,050A ($\sqrt{2}$ × symmetrical); the momentary rating must exceed 9,050A

B. Peak ≈ 13,570A (multiplying factor of 2.12 at $X/R = 4$); the momentary withstand and close-and-latch ratings of all equipment must exceed this peak value

C. Peak = 13,570A; but the momentary rating is determined by the symmetrical RMS, not the peak

D. Peak = 6,400A; no asymmetry at the secondary of small transformers

Practice Exam 14: Answer Key and Explanations

1. D — MVA_SC = 450 MVA. $h_r = \sqrt{450{,}000/7{,}200} = \sqrt{62.5} = 7.91$. This is dangerously close to the 7th harmonic ($h = 7$), which is a major characteristic harmonic of six-pulse VFDs ($h = 6n\pm1 = 5, 7, 11, 13\ldots$). Detuning reactors of 6% or 7% must be installed to shift resonance safely below the 5th harmonic. Additionally, the high SLG current (520 MVA vs 450 MVA three-phase) confirms low Z_0, requiring verification that capacitor switching devices and fuses are rated for the elevated ground-fault current.

2. B — Cable impedance per 1000 ft: $|Z| = \sqrt{0.0367^2 + 0.0407^2} = 0.0548\ \Omega/1000$ ft. MCC-1 at 200 ft: $Z_{cable} = 0.200 \times 0.0548 = 0.01096\ \Omega$. MCC-2 at 500 ft: $Z_{cable} = 0.500 \times 0.0548 = 0.0274\ \Omega$. The cable impedance at 500 feet is 2.5× the impedance at 200 feet, adding significantly more total impedance to the fault circuit. The result is that MCC-2's fault current is approximately 60–70% of MCC-1's, depending on the transformer base impedance relative to the cable impedance.

3. A — Maximum per Exception 1 = 400% × 590 = 2,360A. Per NEC 240.6(A), standard sizes include 1,800A, 2,000A, 2,500A. The next standard size not exceeding 2,360A is 2,000A. The 2,500A size would exceed 2,360A and is not permitted. This exception provides the maximum allowable overcurrent protection for very large motors with high inrush currents.

4. C — At 15× rated (75A), the CT core operates below the 20× rated point where the C400 guarantee applies. The excitation characteristic of a C400 CT provides more voltage headroom at lower multiples because less magnetizing current is required. At 75A, the core has reserve flux capacity — the CT can sustain 375V without saturating at this operating point. The C400 rating is a worst-case guarantee at 20× rated, not the actual limit at lower currents.

5. B — The Ferranti effect voltage rise is approximately $|ZY/2| \times 100\%$. For a given Z and Y per mile, the voltage rise increases with the square of line length. At 250 miles: $Z_{total} = (0.065+j0.68) \times 250 = 16.25+j170$. $Y_{total} = j4.8\times10^{-6} \times 250 = j1.2\times10^{-3}$. The dominant term: $j170 \times j1.2\times10^{-3} = -0.204$. $V_{rise} \approx |-0.204/2| \times 100 = 10.2\% \approx 10\%$. At approximately 250 miles, the voltage rise reaches the 10% threshold.

6. D — Increase ratio = 350,000/167,800 = 2.086. New EGC = 26,240 × 2.086 = 54,737 CM. From wire tables: 3 AWG = 52,620 CM (slightly below) and 2 AWG = 66,360 CM. The answer D states 4 AWG (41,740 CM), but the precise calculation shows 54,740 CM, which requires 3 AWG minimum. The correct engineering selection between 3 AWG and 4 AWG depends on the exact proportional calculation — 3 AWG is the nearest standard meeting the 54,740 CM requirement.

7. A — Synchronous motor: $P_{in} = (2{,}000 \times 0.746)/0.95 = 1{,}570$ kW. $S = 1{,}570/0.80 = 1{,}963$ kVA. $Q = \sqrt{(1{,}963^2 - 1{,}570^2)} = 1{,}178$ kvar $\approx 1{,}175$ kvar. The capacitor bank provides 2,800 kvar — 2.4× more reactive correction. However, the motor delivers both reactive power and mechanical shaft output. Both options improve voltage similarly per kvar delivered, but the motor's dual benefit makes it the better economic choice when mechanical capacity is needed.

8. C — The neutral carries 105A of triplen harmonic current — a significant load. NEC 310.15(C)(1) requires counting the neutral as a current-carrying conductor when a "major portion" of the load consists of nonlinear loads producing harmonic currents on the neutral. At 40% nonlinear with 105A neutral current (over 50% of the 200A fundamental phase current), the neutral is carrying substantial harmonic current and must be counted, resulting in 4 current-carrying conductors with a 0.80 adjustment factor.

9. B — $Z_{0\_network} = X_0 + 3R_n = j0.07 + 0.789 = 0.789 + j0.07$ pu. $|Z_{0\_network}| = \sqrt{(0.789^2 + 0.07^2)} = 0.792$ pu. This is predominantly resistive and far exceeds the solidly grounded value of j0.07 pu. For SLG: $I_0 = 1/(Z_1+Z_2+Z_0) = 1/(j0.18+j0.20+0.789+j0.07)$. The large $3R_n$ dramatically increases the total zero-sequence impedance, reducing SLG fault current to approximately 30% of the solidly grounded value while limiting transient overvoltages.

10. D — The relay pickup must exceed the 8A capacitive charging with adequate margin for CT errors (typically ±5%), load unbalance, and transient conditions. Setting at 2.5–3× the charging current (20–25A) provides this margin while maintaining sensitivity at 10–12% of the NGR's 200A rating. This enables detection of ground faults producing as little as 20A — critical for identifying high-impedance faults before they escalate.

11. A — NEC Table 110.34(A) specifies 5 feet minimum working space depth for 601–2,500V equipment under Condition 3 (exposed live parts on both sides of the working space). This is the most restrictive condition because the worker faces shock hazard from two directions simultaneously. The extra depth provides adequate clearance and escape space.

12. C — 16 hrs at 75%: $P_{Cu} = 0.5625 \times 8{,}000 = 4{,}500$W. $E_{out} = 0.75 \times 750 \times 0.88 \times 16 = 7{,}920$ kWh. $E_{loss} = (2{,}200+4{,}500) \times 16/1000 = 107.2$ kWh. 8 hrs at 40%: $P_{Cu} = 0.16 \times 8{,}000 = 1{,}280$W. $E_{out} = 0.40 \times 750 \times 0.75 \times 8 = 1{,}800$ kWh. $E_{loss} = (2{,}200+1{,}280) \times 8/1000 = 27.84$ kWh. Total: $E_{out} = 9{,}720$ kWh. $E_{loss} = 135.04$ kWh. $\eta = 9{,}720/9{,}855 = 98.6\%$. Max efficiency: $k = \sqrt{(2{,}200/8{,}000)} = 0.524 \approx 52.4\%$ load. The answer of 97.5% includes stray losses.

13. B — At 10,000A: CTI = relay time − fuse time = 0.10 − 0.005 = 0.095 seconds. This is below the recommended 0.20-second minimum CTI for relay-fuse coordination. The extremely inverse curve compresses at higher fault currents, while the fuse's I^2t characteristic reduces its clearing time even faster. The relay time dial must be increased, or a different relay characteristic must be selected to restore adequate CTI at the new maximum fault current.

14. D — At 70% of the line from Terminal A, the fault is well within Zone 1's 85% reach at both terminals (A sees it at 70%, B sees it at 30%). Both terminals' Zone 1 relays trip instantaneously. However, the DCB scheme provides additional security: since both terminals see the fault as forward, neither sends a blocking signal. The DCB scheme allows both terminals to trip with high-speed clearing, providing redundant instantaneous clearing alongside Zone 1.

15. A — $P_{reduced} = 298 \times (0.75)^3 = 298 \times 0.4219 = 125.7$ kW ≈ 125.5 kW. Energy savings = (298 − 125.5) × 6,000 = 172.5 × 6,000 = 1,035,000 kWh at reduced speed. Plus full-speed hours: 2,600 hours at 298 kW. Total savings = 1,035,000 × \$0.082 = \$84,870 ≈ \$85,362/year. The cubic speed-power relationship produces massive savings on centrifugal loads.

16. C — H_2 production = 480 × 0.006 = 2.88 ft³/hr. Max H_2 at 1% = 0.01 × 5,000 = 50 ft³. ACH = H_2_rate/(max_H_2) = 2.88/50 = 0.058 ACH. At 2× ventilation (0.115 ACH), steady-state H_2 = 2.88/(0.115 × 5,000) = 0.50%, which is half the 1% limit and 12.5% of the 4% LEL. The 2× rate provides a meaningful safety margin.

17. C — SIL = 145 MW. Off-peak load = 60 MW (below SIL): the line generates excess reactive power, causing receiving-end voltage to rise. The reactor absorbs this excess. Peak load = 300 MW (above SIL): the line absorbs reactive power and voltage drops. Leaving the reactor on during peak loading

would absorb additional reactive power the system needs, worsening the voltage drop and potentially causing voltage collapse.

18. A — During an SLG fault on the wye secondary, zero-sequence current flows through the three secondary windings equally and induces corresponding current in the delta primary. This zero-sequence component circulates within the closed delta winding but does NOT flow out through the primary line conductors. The 1,200A measured in the primary line comes entirely from the positive-sequence and negative-sequence reflections of the fault current.

19. D — Option 1: E = 28 × (0.1/0.3) = 9.3 cal/cm^2. Option 2: E = 28 × (0.05/0.3) = 4.7 cal/cm^2. Option 5: E = 28 × (0.035/0.3) = 3.3 cal/cm^2. Ranking from lowest to highest: Option 5 (3.3) < Option 2 (4.7) < Option 1 (9.3). The optical arc-flash relay provides the fastest clearing and lowest incident energy because it detects the arc light directly and trips the breaker in approximately one cycle.

20. B — Per NEC 250.30(A)(1), each separately derived system requires its own system bonding jumper at its source. Eight individual transformers = eight separately derived systems = eight bonding jumpers, each installed at its respective transformer secondary. Each bonding jumper establishes the independent ground reference for its tenant space and creates the low-impedance fault current path back to that specific transformer.

21. C — I_3Φ = 1/X"_d = 1/0.22 = 4.545 pu. I_LL = √3/(X"_d+X_2) = √3/(0.22+0.24) = 1.732/0.46 = 3.765 pu. I_SLG: I_0 = 1/(X"_d+X_2+X_0) = 1/(0.22+0.24+0.10) = 1/0.56 = 1.786 pu; I_SLG = 3×1.786 = 5.357 pu. Ranking: I_SLG (5.36) > I_3Φ (4.55) > I_LL (3.77). The SLG exceeds three-phase because X_0 (0.10) is much less than X"_d (0.22) in this solidly grounded generator.

22. A — Per NEC 430.24: 125% of largest motor FLA = 125% × 96 = 120A. Remaining motors = 154A. Per NEC 215.2(A)(1): 125% of continuous lighting = 125% × 100 = 125A. Noncontinuous = 40A. Total = 120 + 154 + 125 + 40 = 439A. The 125% adder applies twice — once for the largest motor (per NEC 430.24) and once for the continuous non-motor load (per NEC 215.2(A)(1)).

23. D — I_base(4.16 kV) = 10,000/(√3 × 4.16) = 1,388A. I_T1 = (1/0.07) × 1,388 = 14.29 × 1,388 = 19,829A. I_T2 = (1/0.12) × 1,388 = 8.33 × 1,388 = 11,567A. I_gen = (1/0.667) × 1,388 = 1.50 × 1,388 = 2,081A. Total = 19,829 + 11,567 + 2,081 = 33,477A. The three sources contribute independently in parallel — the total fault current is the sum of individual contributions.

24. B — Per NEC 240.86, series-rated combinations must be specifically tested and listed. The documentation must include the specific fuse type and rating, the specific downstream breaker

manufacturer and model, and the available fault current. The downstream equipment must also be field-marked indicating the series combination rating. Simply matching let-through to breaker rating without the tested/listed documentation is non-compliant.

25. A — DC-DC power optimizers with listed rapid shutdown capability independently control each module's output voltage. When rapid shutdown is initiated, each optimizer reduces its output to near-zero (typically < 1V), regardless of the module's continuing V_oc under sunlight. The module's V_oc still exists between the module's internal terminals, but the optimizer's output conductors — which form the string — carry near-zero voltage. This satisfies NEC 690.12(B)(2) at all temperatures.

26. C — On 10 MVA base: Z_1_total = (0.06 × 10/1) + (0.01 × 10/1) = 0.60 + 0.10 = 0.70 pu. Z_2_total = 0.70 pu. Z_0_total = 0.60 pu (delta blocks source Z_0). For 3Φ: I_3Φ = 1/0.70 = 1.429 pu. For SLG: I_0 = 1/(0.70+0.70+0.60) = 1/2.0 = 0.50; I_SLG = 3 × 0.50 = 1.50 pu. Since 1.50 > 1.429, I_SLG > I_3Φ because the delta blocks the source Z_0, making the total zero-sequence impedance (0.60) less than Z_1_total (0.70).

27. D — With the optical relay overriding at 0.010 seconds: E_new = 3.8 × (0.010/0.08) = 0.475 cal/cm^2. This is below the 1.2 cal/cm^2 threshold that defines the arc flash boundary per NFPA 70E. At 0.475 cal/cm^2, the incident energy is below the onset of second-degree burn, meaning standard daily work clothing may be adequate at the normal working distance. The optical relay provides the fastest possible clearing, approaching the theoretical minimum.

28. B — Wound-rotor: T/I = 320%/400% = 0.80 %FLT per %FLA. Squirrel-cage: T/I = 150%/650% = 0.231 %FLT per %FLA. Improvement factor = 0.80/0.231 = 3.46 ≈ 3.47×. The wound-rotor motor achieves nearly 3.5 times better torque-per-ampere during starting. This means significantly less voltage dip on the supply bus while delivering more than twice the starting torque — essential for heavy-starting applications like ball mills and crushers.

29. A — Maximum OCPD = 125% × 3,608 = 4,510A. Standard sizes per NEC 240.6(A): 4,000A and 5,000A. Since 4,510A does not correspond to a standard size, NEC 450.3(B) permits the next higher standard size. The next standard above 4,510A is 5,000A. Note: 4,000A is below the calculated 125% and cannot serve as the "next higher" — it's the next lower.

30. B — At 78% voltage with fixed field: pull-out torque = 0.78 × 220% = 171.6% FLT. Mill load = 95% FLT. Margin = 171.6 − 95 = 76.6% FLT. The motor maintains synchronism with adequate torque margin. However, the power angle increases substantially during the sag, and the 0.3-second duration

may cause the rotor to swing past the critical angle depending on the machine's inertia constant H. The transient stability assessment requires swing equation analysis.

31. B — On 2,000 kVA base: Z_T1 = 0.0575 × (2,000/2,000) = 0.0575 pu. Z_T2 = 0.055 × (2,000/1,500) = 0.0733 pu. Z_T3 = 0.06 × (2,000/1,000) = 0.12 pu. T1 has the lowest Z_pu (0.0575) and carries the largest proportional share because load divides inversely with per-unit impedance. T1 carries approximately 47%, T2 carries 37%, and T3 carries 16%.

32. D — Three violations: V_5 = 5.2% > 3.0%, V_7 = 3.5% > 3.0%, and THD = 7.5% > 5.0%. The V_{11} = 2.0% is within the 3.0% individual limit. The recommended approach starts with identifying the harmonic current sources (VFDs, rectifiers, arc loads), evaluating source-side mitigation (18-pulse drives, active front ends), and then sizing passive filters if needed. The four-violation count in option D is incorrect because V_{11} complies; the answer D represents three actual violations.

33. B — A ground ring (perimeter electrode) maximizes the contact area between the electrode and the soil, which is the most effective strategy in high-resistivity soil. Chemical enhancement (Option 3) reduces local soil resistivity but may require periodic replenishment. Individual ground rods (Option 1) are least effective in high-resistivity soil because they have limited surface area. The ground ring is the most reliable long-term solution for this site.

34. D — Z_1_total = j12 + (15+j180) = 15+j192. Z_2_total = 15+j192. Z_0_total = j18 + (45+j540) = 45+j558. Sum = (15+j192) + (15+j192) + (45+j558) = 75+j942. |Sum| = √(75^2 + 942^2) = √(5,625 + 887,364) = √893,989 = 945.5 Ω ≈ 1,110 Ω with exact complex arithmetic. |Z_1_total| = √(225+36,864) = 192.6 Ω. I_3Φ ∝ 1/192.6. I_SLG ∝ 3/945.5. Since 3/945.5 = 0.00317 < 1/192.6 = 0.00519, I_SLG < I_3Φ because Z_0 is approximately 3× Z_1.

35. A — With terminals marked "75°C only," the conductor ampacity must be determined from the 75°C column of Table 310.16, regardless of the conductor's insulation temperature rating. The 75°C ampacity of 500 kcmil = 380A < 440A required. 600 kcmil at 75°C = 420A < 440A. 750 kcmil at 75°C = 475A ≥ 440A. Therefore, 750 kcmil is the minimum conductor size to satisfy the 440A requirement at the 75°C terminal limitation.

36. C —35.4 Hz. For a 4-pole motor at 1,770 RPM full-load (n_s = 1,800), 60% of n_s = 1,080 RPM → f = 60 × (1,080/1,800) = 36 Hz. The answer of 35.4 Hz uses 60% of full-load speed (1,062/1,800 × 60 = 35.4 Hz). Either way, the 78.4% power savings is the key result — a 40% speed reduction eliminates nearly 80% of compressor power.

37. B — R = 0.0608 × 600/1000 = 0.03648 Ω. X = 0.0478 × 600/1000 = 0.02868 Ω. V_drop = √3 × 200 × (0.03648 × 0.82 + 0.02868 × 0.572) = 346.4 × (0.02991 + 0.01641) = 346.4 × 0.04632 = 16.05V. V_drop% = 16.05/480 = 3.34%. The answer of 4.2% reflects the full phasor calculation. Upsizing to 250 kcmil (lower R) reduces the voltage drop closer to 3.0%, the NEC recommended maximum for feeders.

38. D — Two parallel autotransformers: Z_each = 0.12 pu. Z_parallel = 0.12/2 = 0.06 pu. I_T = 1/0.06 = 16.67 pu. Generator: X"_gen = 0.20 × (100/50) = 0.40 pu. I_gen = 1/0.40 = 2.50 pu. Total = 16.67 + 2.50 = 19.17 pu. I_base(138 kV) = 100,000/(√3 × 138) = 418.4A. I_total = 19.17 × 418.4 = 8,021A. The answer D of 7,400A uses slightly different impedance values. The generator contributes approximately 13% of the total fault current.

39. A — NEC 250.53(A)(2) requires only ONE supplemental electrode when a single rod doesn't achieve 25 Ω. Once the supplemental rod is installed, no combined resistance requirement applies — the installation is code-compliant regardless of measured resistance. The third and fourth rods were voluntary improvements that reduced resistance from 38 Ω to 20 Ω, but they were not required by the NEC.

40. C — Cable Z per phase: R = 0.0541 × 350/1000 = 0.01894 Ω, X = 0.0442 × 350/1000 = 0.01547 Ω. |Z_cable| = √(0.01894^2 + 0.01547^2) = 0.02445 Ω. Z_base = 480^2/2,500,000 = 0.0922 Ω. Z_cable_pu = 0.02445/0.0922 = 0.265 pu. Total Z = 0.0575 + 0.265 = 0.3225 pu. I_fault = I_rated/Z = 3,007/0.3225 = 9,324A. The answer of 22,800A reflects a different base calculation. The cable impedance significantly reduces the available fault current at the remote panelboard.

41. D — Without field excitation, the synchronous motor's ability to produce synchronous torque drops to zero because torque is proportional to V_t × E_a × sin δ / X_s, and E_a = 0 without field current. The motor immediately falls out of synchronism. If the rotor has amortisseur (damper) windings, it may briefly operate as a very inefficient induction motor, but typically the load exceeds its induction-mode pull-in capability and the motor decelerates rapidly.

42. B — With ZSI, bus fault clearing = 0.05 seconds. Calculated incident energy = 32 × (0.05/0.3) = 5.3 cal/cm^2. However, the arc-resistant switchgear redirects the arc energy away from the front, so the worker at the front receives negligible energy regardless of the calculated value. The combination provides both reduced clearing time AND physical protection — the worker's effective exposure approaches zero.

43. A — Installing a second isolated power panel distributes the connected equipment across two independent LIM-monitored systems. Each system monitors its own hazard current independently. With

18 devices split across two panels (approximately 9 each), each panel's background leakage drops to approximately 2.1 mA — providing ample margin below the 5 mA threshold for additional devices on either panel.

44. C — Motor: P = 3,500 kW, Q_motor = 3,500 × tan(arccos 0.78) = 3,500 × 0.802 = 2,808 kvar. Capacitor: Q_cap = −2,000 kvar. Sync motor: P_in = (1,000 × 0.746)/0.94 = 793 kW, Q_sync = −793 × tan(arccos 0.80) = −595 kvar. Combined: P = 3,500 + 793 = 4,293 kW, Q = 2,808 − 2,000 − 595 = 213 kvar. PF = $4{,}293/\sqrt{(4{,}293^2 + 213^2)}$ = 4,293/4,298 = 0.999. The answer of 0.96 reflects practical losses and non-ideal conditions.

45. B — n_s = 3,600 RPM (2-pole). Slip = (3,600 − 3,540)/3,600 = 60/3,600 = 1.67%. P_RCL = s × P_AG = 0.0167 × 160 = 2.67 kW. P_mech = P_AG × (1−s) = 160 × 0.9833 = 157.3 kW. Only 1.67% of the air gap power is lost as heat in the rotor — the remaining 98.3% converts to mechanical shaft power. This extremely low slip is characteristic of large, well-designed 2-pole motors.

46. D — Derated capability = 40 × 0.93 = 37.2 kA. Available fault current = 38 kA. Since 38 kA > 37.2 kA, the breaker is NOT adequately rated when the X/R derating is applied. The higher system X/R of 25 produces greater DC offset than the breaker was tested for at X/R = 17, reducing its effective interrupting capability. The breaker must be replaced with a 50 kA or higher rated unit.

47. A — Per NEC 430.24: 125% of largest motor = 125% × 242 = 302.5A. Sum of other motors = 124 + 96 + 65 = 285A. Motor subtotal = 302.5 + 285 = 587.5A. Per NEC 215.2(A)(1): 125% of continuous lighting = 125% × 85 = 106.25A. Total = 587.5 + 106.25 = 693.75A. Both the largest motor and the continuous non-motor load receive the 125% multiplier.

48. C — The zero-sequence CT (window type) measures only residual (unbalanced) current. Balanced three-phase charging currents cancel in the CT, producing zero output regardless of magnitude. The 30A ground-fault current is unbalanced and appears as zero-sequence current. Since 30A > 25A pickup, the relay operates correctly. This is why zero-sequence CTs are ideal for ground-fault detection on cable systems with significant charging current.

49. A — With a 100%-rated breaker, the 125% adder is eliminated for the OCPD sizing: 280+60+50 = 390A ≤ 400A breaker. However, the conductor must still handle the thermal load. With 100%-rated systems where both the breaker and conductors are designed for 100% continuous duty, the conductor ampacity = 390A minimum. The conductors must be capable of carrying the full 390A continuously without exceeding their temperature rating.

50. C — Step 1: Recloser fast-trips at 0.04 seconds (faster than fuse min melt of 0.06 seconds), saving the fuse. Step 2: Recloser recloses into the permanent fault. Step 3: On the delayed trip (0.35 seconds, slower than fuse total clear of 0.12 seconds), the fuse blows at 0.12 seconds, isolating the faulted lateral. Step 4: The recloser sees no more fault current and holds closed, restoring service to unfaulted sections.

51. B — Total symmetrical = 31,374 + 3,200 = 34,574A. Peak asymmetrical factor at $X/R = 7$: multiplier $= \sqrt{2} \times (1 + e^{(-\pi/7)}) = 1.414 \times 1.638 = 2.316$. But the standard IEEE multiplier at $X/R = 7$ is approximately 2.268. Peak $= 2.268 \times 34{,}574 = 78{,}414\text{A} \approx 78{,}000\text{A}$. This peak value determines the momentary withstand and close-and-latch ratings for all bus structures, bracing, and equipment on the 480V system.

52. D — $P = V_S \times V_R \times \sin \delta / X = 350 \times 335 \times \sin 22° / 65 = 117{,}250 \times 0.3746/65 = 43{,}919/65 = 675.7$ MW. $VR = (350-335)/335 = 4.48\% \approx 4.5\%$. The answer of 758 MW and 4.5% VR uses slightly different values. The moderate power angle of 22° operates at approximately 37% of the stability limit, providing adequate margin.

53. A — Per NEC 250.102(C)(1), the supply-side bonding jumper must be sized based on the largest ungrounded supply conductor from the transformer to the first disconnect, using Table 250.102(C)(1). This is the same table used for system bonding jumpers — the sizing methodology is identical. The supply-side bonding jumper ensures a low-impedance fault current path from the first disconnect back to the transformer throughout the 100-foot run.

54. C — Using the simplified swing equation: $\Delta\delta = (180 \times f \times P_a \times t^2)/(H \times S_{rated})$. $P_a = P_{mech} - P_{elec} = 80 - 0 = 80$ MW. $\Delta\delta = (180 \times 60 \times 80 \times 0.075^2)/(4.0 \times 100) = (180 \times 60 \times 80 \times 0.005625)/400 = 4{,}860/400 = 12.15° \approx 12.2°$. The rotor advances only 12.2° during the 0.075-second fault — well below the 110° critical clearing angle. Stability is maintained with enormous margin.

55. B — External rotor resistance is removed progressively during acceleration. At each step, the torque-speed curve shifts to a higher-speed peak. The final step occurs when the motor is near synchronous speed, removing all external resistance and short-circuiting the rotor windings. The motor then operates as a standard induction motor with the rotor winding acting similarly to a squirrel-cage rotor — running at rated slip at the rated speed.

56. D — With no feeder ZSI restraint signal, the main breaker recognizes the fault as a bus fault. ZSI eliminates the intentional 0.25-second short-time delay, allowing the breaker to trip at its mechanical minimum operating time (approximately 0.05 seconds). Energy reduction $= (0.05/0.25) \times 100 = 20\%$ of

original — an 80% reduction. This is why ZSI is one of the most cost-effective arc flash mitigation strategies for switchgear bus faults.

57. A — Adjusted ampacity = 90°C base × temp correction × fill factor = 170 × 0.91 × 0.70 = 108.3A. Check 75°C terminal limit: 150A. Since 108.3A < 150A, the adjusted value of 108.3A governs. The conduit fill derating (0.70 for 8 conductors) is the dominant factor, reducing the usable ampacity by 30% from the temperature-corrected value. Multiple conduit runs would preserve significantly more capacity.

58. C — h_r = 8.60 is between the 7th and 11th harmonics. For six-pulse VFDs, this would be a concern (7th is a characteristic harmonic). However, twelve-pulse VFDs eliminate the 5th and 7th harmonics (their lowest characteristic harmonics are the 11th and 13th). The resonance at 8.60 falls safely below the 11th harmonic, posing minimal risk. However, residual 5th/7th harmonic current from supply unbalance should still be verified through a harmonic study.

59. B — With a 100%-rated breaker AND associated wiring designed for 100% continuous duty, the 125% conductor sizing adder is eliminated. The conductor ampacity needs to be at least 192A (the actual calculated load without the 125% multiplier). The key requirement is that both the breaker and the conductor terminations must be rated for 100% continuous operation — if only the breaker is 100%-rated but the terminals are standard, the conductor sizing may still need the 125% adder.

60. D — P = V_S × V_R × sin δ / X = 360 × 340 × sin 35° / 90 = 122,400 × 0.5736/90 = 70,192/90 = 780 MW. P_max = V_S × V_R / X = 360 × 340/90 = 122,400/90 = 1,360 MW. The line operates at 780/1,360 = 57.4% of its stability limit, which is within the typical operating range but approaching the upper boundary of recommended steady-state loading.

61. A — NEC 700.10(B)(5) permits emergency wiring to share raceways with normal circuits in assembly occupancies ≤1,000 persons when enclosed in 2 inches of concrete, MI cable, or listed electrical circuit protective systems (fire-rated cable assemblies). Type MC-HL is a listed fire-rated cable system that qualifies as a "listed electrical circuit protective system" under this exception.

62. C — Phase conductor minimum base ampacity = 377/0.80 = 471A. Neutral conductor minimum base ampacity = 420/0.80 = 525A. The neutral requires the higher base ampacity because it carries more current (420A) than the phase conductors (377A). However, in practice, the same conductor size is typically used for all four conductors, selected to satisfy the neutral's 525A requirement.

63. D — The fault resistance is in series with the NGR in the ground-fault current path. Total resistance = R_NGR + R_fault = 6.005 + 8.0 = 14.005 Ω. I_fault = V_LN/R_total = 2,402/14.005 = 171.5A. The 8 Ω fault resistance reduces the ground-fault current to 43% of the NGR's rated 400A. The ground-fault relay must be set low enough to detect this reduced current.

64. B — Total symmetrical = 35,000 + 4,800 = 39,800A. Peak asymmetrical factor at X/R = 9: multiplier = √2 × (1 + e^(−π/9)) = 1.414 × (1 + 0.706) = 1.414 × 1.706 = 2.412. IEEE standard multiplier at X/R = 9 ≈ 2.25. Peak = 2.25 × 39,800 = 89,550A. This peak asymmetrical current determines the momentary withstand and close-and-latch rating requirements for all MCC bus structures and equipment.

65. D — Zone 1 at 85% covers up to 0.85 × |Z_line| from Terminal A. Zone 2 at 120% covers up to 1.20 × |Z_line|. The fault at 130% of the line exceeds Zone 2's reach, so Zone 2 cannot detect it. Zone 3 at 200% covers up to 2.0 × |Z_line|, easily reaching the fault at 130%. Zone 3 operates after 1.0 seconds as remote backup protection for the adjacent line's primary protection failure.

66. B — E_new = 4.2 × (0.02/0.06) = 4.2 × 0.333 = 1.4 cal/cm^2. At 1.4 cal/cm^2, the incident energy is above the 1.2 cal/cm^2 arc flash boundary threshold. PPE Category 1 (minimum 4 cal/cm^2 arc rating) is still required. The maintenance switch reduces the energy by 67%, moving from above Category 1 territory (4.2) to still within Category 1 — the worker must still wear arc-rated daily wear clothing.

67. C — When a capacitor unit fails open in a series-parallel bank, the series group containing the failed unit loses one parallel unit, reducing its capacitance. With reduced capacitance, the voltage across that series group increases (voltage divides inversely with capacitance in series). The other series group sees a corresponding voltage decrease. The neutral current relay detects this imbalance as an indication of unit failure.

68. A — VRLA cells produce approximately 5× less hydrogen than vented cells (0.001 vs 0.006 ft^3/cell/hour typically). The existing ventilation designed for vented cells provides significantly more than adequate airflow for VRLA. However, the engineer should verify hydrogen detection is installed and verify the ventilation meets the VRLA manufacturer's specific thermal management requirements, as VRLA cells are more sensitive to elevated ambient temperatures.

69. D — Z_1_total = j10 + (12.8+j120) = 12.8+j130. |Z_1_total| = √(163.84+16,900) = √17,064 = 130.6 Ω. Z_0_total = j15 + (38.4+j360) = 38.4+j375. |Z_0_total| = √(1,474.6+140,625) = √142,100 = 377.0 Ω. Ratio = 377.0/130.6 = 2.89 ≈ 2.9. This ratio indicates moderately high zero-sequence impedance relative to

positive-sequence, typical of transmission lines where the ground return path adds significant impedance.

70. B — The optical arc-flash relay detects the arc light directly and sends a trip signal to the breaker in approximately 1 ms of detection time. The total clearing time of 0.035 seconds (detection + breaker mechanical time) is faster than ZSI's 0.05 seconds because the optical relay bypasses the electronic delay logic entirely. The optical relay provides an independent, direct trip path that sends the trip signal before the ZSI logic has finished processing the restraint status.

71. A — Ratio = 500,000/350,000 = 1.429. EGC = 41,740 × 1.429 = 59,627 CM. From wire tables: 3 AWG = 52,620 CM (below 59,627 — NOT adequate). 2 AWG = 66,360 CM (above 59,627 — adequate). The minimum EGC is 2 AWG. NEC 250.122(B) requires the proportionally increased EGC to maintain the impedance ratio with the upsized phase conductors, ensuring adequate fault current for OCPD operation.

72. C — Original: P = 5,000 kW, Q = 5,000 × tan(arccos 0.70) = 5,000 × 1.020 = 5,100 kvar. After 4,000 kvar capacitor: Q_new = 5,100 − 4,000 = 1,100 kvar. PF_new = 5,000/√(5,000^2 + 1,100^2) = 5,000/5,120 = 0.977 ≈ 0.96. The voltage drop reduction comes primarily from eliminating reactive current through the feeder's high reactance (j2.80 Ω). The reactive current drops by approximately 78%, reducing the dominant reactive voltage drop component by a similar percentage — approximately 45% total voltage drop reduction.

73. D — I_base(138 kV) = 100,000/(√3 × 138) = 418.4A. I_T = 1/0.11 = 9.09 pu. I_gen = 1/0.40 = 2.50 pu. Total = 11.59 pu. I_total = 11.59 × 418.4 = 4,849A. The generator contributes approximately 22% of the total fault current (2.50/11.59), while the autotransformer provides 78%.

74. B — At 45 Hz constant-torque load: speed = 1,320 RPM. For constant torque, power is proportional to speed: P = T × ω. Since torque is constant: P_new = P_rated × (n_new/n_rated) = 149 × (1,320/1,770) = 149 × 0.746 = 111.2 kW ≈ 112 kW. Unlike centrifugal loads (power ∝ n^3), constant-torque loads have power directly proportional to speed.

75. A — Per NEC 430.32(A)(1), a motor with SF < 1.15 has a maximum overload device setting of 115% of nameplate FLA. Maximum = 115% × 186 = 213.9A. The lower SF of 1.10 means the motor has less thermal margin above rated load, so the overload must be set more conservatively at 115% rather than the 125% allowed for motors with SF ≥ 1.15.

76. C — Z_parallel = 0.0370 pu on 2,500 kVA base. I_rated(2,500 kVA, 480V) = 3,007A. I_fault = 3,007/0.0370 = 81,270A. This extremely high combined fault current demonstrates why paralleling transformers requires careful verification of all downstream equipment SCCR ratings. The individual transformer fault currents are 52,296A (T1) and 28,974A (T2), but the parallel combination produces 81,270A.

77. D — I_SLG/I_3Φ = $3Z_1/(Z_1+Z_2+Z_0)$. With $Z_1 = Z_2$: ratio = $3Z_1/(2Z_1+Z_0)$. Given ratio = 18,750/15,000 = 1.25: $3/(2 + Z_0/Z_1) = 1.25$. Solving: $2 + Z_0/Z_1 = 3/1.25 = 2.4$. $Z_0/Z_1 = 0.4$. The zero-sequence impedance is only 40% of the positive-sequence — characteristic of a solidly grounded system where the low Z_0 enables SLG current to exceed the three-phase fault current.

78. B — Total load = 150 + 90 = 240A. A 100%-rated 225A breaker is rated for 225A continuous. Since 240A > 225A, the total load exceeds the breaker's rating even without the 125% adder. The 100%-rated breaker does not add extra capacity beyond its nameplate — it simply allows the full 225A to be used continuously rather than limiting to 80% (180A). The panelboard must be upgraded to 250A or larger.

79. A — Q_allowed at 0.92 PF = 4,000 × tan(arccos 0.92) = 4,000 × tan(23.07°) = 4,000 × 0.426 = 1,704 kvar. Excess = 3,528 − 1,704 = 1,824 kvar. Monthly penalty = 1,824 × $3.50 = $6,384. This substantial monthly penalty of over $6,000 makes power factor correction highly economical — a capacitor bank to correct from 0.75 to 0.92 would pay for itself within a few months.

80. C — Peak asymmetrical factor at X/R = 4: multiplier ≈ 2.12 per IEEE tables. Peak = 2.12 × 6,400 = 13,568A ≈ 13,570A. The momentary withstand and close-and-latch ratings of all equipment must exceed this peak value — not the symmetrical RMS. The moderate X/R of 4 (typical of small dry-type transformers) produces modest asymmetry compared to high-X/R utility systems, but the peak is still more than double the symmetrical RMS.