PRACTICE EXAM 17: PE POWER SIMULATION (80 QUESTIONS)

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1. A 13.8 kV industrial facility has a three-phase fault level of 480 MVA and proposes installing an 8,400 kvar capacitor bank on a bus that serves both six-pulse VFDs (3,500 HP total) and twelve-pulse VFDs (2,000 HP total). The resonant harmonic order is h_r = √(480,000/8,400) = 7.56. The engineer must evaluate whether the proximity to both the 7th harmonic (from six-pulse) and the 11th harmonic (from twelve-pulse) poses a concern. What is the correct assessment?

A. The resonance at 7.56 is dangerously close to the 7th harmonic from the six-pulse VFDs, which inject the most current at h=7; the twelve-pulse VFDs' 11th harmonic is far enough away to pose minimal resonance risk; 6% detuning reactors must be installed to shift resonance below the 5th harmonic

B. Both the 7th and 11th harmonics present equal resonance risk at h_r = 7.56

C. The twelve-pulse VFDs' 11th harmonic is the primary concern because it is a higher-order harmonic with more energy

D. No concern exists because 7.56 falls between characteristic harmonics of both drive types

2. A three-phase, 480V, solidly grounded wye system has a 2,500 kVA service transformer (Z = 5.75%, X/R = 8) feeding a switchboard. The switchboard has an available fault current of 42,700A. Two remote panelboards are fed from the switchboard: Panel A through 150 feet of 500 kcmil copper (R = 0.0276, X = 0.0391 Ω/1000 ft) and Panel B through 400 feet of 3/0 AWG copper (R = 0.0766, X = 0.0454 Ω/1000 ft). The engineer must determine which panelboard has the lower available fault current and thus the lower arc flash incident energy. Which panel has the lower fault current?

A. Panel A — shorter cable but larger conductor produces minimal impedance reduction

B. Both panels have approximately equal fault current because the cable impedance is proportional to length × resistance per foot

C. Panel B — the longer cable run with smaller conductor adds significantly more impedance, producing a much lower fault current than Panel A

D. Neither — cable impedance has no effect on fault current at these distances

3. Per NEC 430.52(C)(1), a 250 HP, 460V motor with FLA = 302A uses an inverse-time breaker. The Table 430.52 maximum is 250% = 755A → next standard 800A. The motor starts successfully with the 800A breaker but the plant engineer wants to use a 600A breaker for tighter protection. Per NEC 430.52(C)(1), is 600A compliant, and what is the trade-off?

A. No — 600A is below the minimum required OCPD for this motor

B. Yes — NEC 430.52(C)(1) establishes maximum OCPD sizes, not minimums; a 600A breaker that permits the motor to start and run is compliant and provides better short-circuit protection for the branch circuit, though the margin for starting inrush is reduced

C. No — the NEC requires the OCPD to be set at exactly 250% of FLA

D. Yes — but only if the motor has a reduced-voltage starter

4. A CT with a ratio of 1200:5 and accuracy class C200 serves a feeder overcurrent relay on a 13.8 kV circuit. The total burden (leads + relay + CT winding) is 2.8 Ω. During a fault of 15,600A, the CT secondary current is 65A (13× rated). The burden voltage is 65 × 2.8 = 182V. The C200 rating guarantees accuracy at 20× rated (100A) up to 200V. At this 13× operating point with 182V burden, is the CT operating within its capability?

A. No — 182V is dangerously close to the 200V limit with no safety margin

B. Yes — but the CT is near its limit and any burden increase would cause saturation

C. No — the C200 rating only applies at exactly 20× rated, not at lower multiples

D. Yes — at 13× rated, the CT core requires less excitation than at 20× rated, providing approximately 35% voltage margin above the 182V burden; the CT operates well within its capability

5. A 345 kV, 400-mile transmission line is energized from the sending end with the receiving end open. The Ferranti effect voltage rise at 400 miles is approximately 25%. A 200 Mvar shunt reactor is installed at the receiving end. During an emergency, the reactor must be temporarily removed for maintenance while the line remains energized. What operational constraint must be imposed?

A. The line must be loaded above its SIL during reactor maintenance to absorb the excess capacitive reactive power through the series inductance; operating the line open-circuited or at light load without the reactor will produce dangerous overvoltage at the receiving end

B. No operational constraint — the line can operate normally without the reactor for short periods

C. The sending-end voltage must be reduced to zero during reactor maintenance

D. The receiving end must be short-circuited during reactor maintenance to absorb reactive power

6. Per NEC 250.122(B), a 400A circuit has phase conductors of 500 kcmil copper (minimum required per Table 310.16 for the continuous load). The conductors are increased to 750 kcmil for voltage drop. The minimum EGC from Table 250.122 for a 400A OCPD is 3 AWG (52,620 CM). What is the proportionally increased EGC?

A. 3 AWG (no increase — proportional increase is less than one wire size)

B. 2 AWG (66,360 CM)

C. Ratio = 750,000/500,000 = 1.50; EGC = 52,620 × 1.50 = 78,930 CM → 1 AWG (83,690 CM) is the minimum standard size above 78,930 CM

D. 1/0 AWG (105,600 CM) — must exceed the calculated value by at least 25%

7. A three-phase, 4,160V system has a 6,000 kW load at 0.70 lagging PF through a feeder with $Z = 0.50 + j3.00\ \Omega$ per phase. An engineer evaluates three power factor correction options: (A) a 5,500 kvar capacitor bank alone; (B) a 3,000 HP synchronous motor at 0.80 leading PF ($\eta = 95\%$) alone; (C) a 3,000 kvar capacitor plus a 1,500 HP synchronous motor at 0.80 leading ($\eta = 95\%$). Which option provides the BEST balance of reactive correction, mechanical output, and voltage improvement?

A. Option A provides the most kvar correction but no shaft output

B. Option C provides balanced reactive correction (approximately 4,115 kvar total from both sources) plus 1,500 HP of mechanical output — the best combined benefit for facilities needing both PF correction and additional production capacity

C. Option B provides the most shaft output (3,000 HP) but only approximately 1,770 kvar of reactive correction

D. All three options provide identical net reactive correction

8. A three-phase, 480Y/277V panelboard serves a mixed commercial and industrial load: 35% linear fluorescent lighting, 50% nonlinear LED driver and VFD loads, and 15% resistance heating. Each phase draws 350A total fundamental and 105A of third-harmonic current. The neutral current is 3 × 105 = 315A. Per NEC 310.15(C)(1), the neutral must be counted as current-carrying (4 conductors, factor 0.80). The engineer selects conductors. What is the critical sizing consideration?

A. Phase conductors govern at 350A; neutral is automatically satisfied

B. Neutral governs because 315A exceeds the 350A phase fundamental... actually 315 < 350, so phase governs

C. Both must be checked independently but neither governs — the OCPD rating determines conductor size

D. The neutral current of 315A requires 315/0.80 = 393.75A base ampacity; the phase requires 350/0.80 = 437.5A base ampacity; the phase requirement of 437.5A governs the unified conductor selection

9. A 100 MVA synchronous generator has X"_d = 0.16 pu, X_2 = 0.18 pu, X_0 = 0.06 pu on its own base. The generator is grounded through a 0.8 Ω reactor. Z_base = $(13.8)^2/100$ = 1.904 Ω. X_n(pu) = 0.8/1.904 = 0.420 pu. In the zero-sequence network, 3X_n = 1.260 pu. For a bolted SLG fault, what is the total zero-sequence impedance (Z_0_network), and how does the reactive grounding affect the fault current character compared to resistive grounding?

A. Z_0_network = j(0.06 + 1.260) = j1.32 pu; fault current is purely reactive (90° lag) — unlike resistive grounding where current is predominantly resistive

B. Z_0_network = 1.32 + j0 pu; fault current is purely resistive

C. Z_0_network = j1.32 pu; the SLG fault current is predominantly reactive, similar to the solidly grounded case but significantly reduced in magnitude; the fault current lags the voltage by approximately 85-90° rather than the 15-20° typical of resistance grounding

D. Z_0_network has no effect on fault current angle

10. A three-phase, 4,160V system has a neutral grounding resistor rated 400A, 10 seconds. A ground fault through 6 Ω fault resistance produces I_fault = V_LN/(R_NGR + R_fault) = 2,402/(6.005 + 6) = 2,402/12.005 = 200.1A. The ground-fault relay is set at 40A pickup with a 0.5-second delay. After the relay trips in 0.5 seconds, what percentage of the NGR's I^2t thermal capacity has been consumed?

A. $(200/400)^2 \times (0.5/10) = 0.25 \times 0.05 = 1.25\%$ — minimal thermal stress on the NGR

B. 25% — significant thermal stress

C. 10% — moderate thermal stress

D. 50% — the NGR is near its thermal limit

11. Per NEC 110.34(A), the minimum working space depth for equipment rated 25,001V to 75,000V under Condition 2 (exposed live parts on one side, grounded parts on the other) is what distance?

A. 6 feet

B. 8 feet

C. 10 feet

D. 8 feet

12. A 1,500 kVA, 13.8 kV/480V transformer has core losses of 4,200 W and full-load copper losses of 13,500 W. The transformer serves a factory with a three-shift operation: 8 hours at 95% load (PF = 0.92), 8 hours at 70% load (PF = 0.88), and 8 hours at 40% load (PF = 0.80). What is the loading at maximum efficiency, and during which shift does the transformer operate closest to this optimal point?

A. k_max = 100%; the first shift (95% load) is closest

B. k_max = $\sqrt{(4,200/13,500)}$ = 55.8%; the third shift (40% load) is closest — but neither shift operates near k_max; the second shift (70%) operates approximately 14 percentage points above k_max

C. k_max = 55.8%; the second shift (70%) is closest but still 14.2 percentage points above the optimal loading

D. k_max = 70%; the second shift operates at maximum efficiency

13. A protection coordination study on a 4,160V industrial system requires coordinating a 400E fuse on a motor feeder with an upstream 51 relay (IEEE extremely inverse, TD = 2.0, pickup = 5A on 600:5 CT). At the maximum fault of 15,000A: fuse total clearing = 0.004 seconds. The relay secondary = 15,000/(600/5) = 125A. M = 125/5 = 25. Using the IEEE extremely inverse formula $t = TD \times (28.2/(M^2-1) + 0.1217)$, what is the relay operating time and CTI?

A. t = 0.29s; CTI = 0.286s — adequate

B. t = 0.50s; CTI = 0.496s — excessive

C. t = 0.29s; CTI = 0.286s — adequate coordination with generous margin above the 0.20-second minimum; the extremely inverse characteristic provides fast operation at high fault currents, making it well-suited for fuse coordination

D. t = 0.15s; CTI = 0.146s — below 0.20-second minimum; inadequate

14. A distance relay on a 138 kV line has Zone 1 at 85% reach (Z_line = 4 + j45 Ω). A three-phase fault occurs at 83% of the line through zero fault resistance. The measured impedance at the relay is Z_meas = 0.83 × (4 + j45) = 3.32 + j37.35 Ω. |Z_meas| = 37.5 Ω. Zone 1 reach = 0.85 × |4+j45| = 0.85 × 45.18 = 38.4 Ω. The fault is within Zone 1 by 0.9 Ω of impedance margin. What reliability concern exists?

A. The 0.9 Ω margin (2.3% of Zone 1 reach) is dangerously thin — CT and PT errors, relay measurement tolerances, and line parameter uncertainty could cause the measured impedance to fall outside Zone 1, resulting in delayed clearing via Zone 2 instead of instantaneous Zone 1 tripping

B. No concern — 0.9 Ω margin is standard for Zone 1 applications

C. The concern is overreaching, not underreaching — the relay might trip for faults beyond 85%

D. The fault resistance of zero eliminates all measurement uncertainty

15. A three-phase, 460V, 6-pole, 500 HP induction motor drives a centrifugal chilled-water pump through a VFD. At design speed (1,170 RPM, 60 Hz), the pump delivers 373 kW. During swing-season operation (4,500 hours/year), the pump needs only 70% of design flow. Using the affinity laws, the

speed reduces to 70% = 819 RPM. The pump power at this speed is $P = 373 \times (0.70)^3 = 128$ kW. What is the annual energy savings at \$0.082/kWh compared to full-speed operation during those hours?

A. Savings = (373 − 128) × 4,500 × \$0.082 = 245 × 4,500 × 0.082 = \$90,405/year

B. Savings = \$45,000/year

C. Savings = \$150,000/year

D. Savings = (373 − 261) × 4,500 × \$0.082 = \$41,328/year (using linear rather than cubic relationship)

16. Per NEC 480.9(A), ventilation for battery rooms must limit hydrogen below 1% by volume. A telecom facility has a large VRLA battery: 360 cells in sealed cabinets within a dedicated room of 4,000 ft^3. The manufacturer states worst-case H_2 emission is 0.002 ft^3/cell/hour during equalize charging. What ventilation rate maintains hydrogen below 1%, and what additional safety measure is recommended for VRLA installations?

A. ACH = 5.0; no additional measures needed for sealed batteries

B. Required ACH = 0.018 (H_2 = 0.72 ft^3/hr; max H_2 at 1% = 40 ft^3; ACH = 0.72/40 = 0.018); additionally, hydrogen detection sensors at the ceiling are recommended because VRLA cells can vent unexpectedly during thermal events

C. No ventilation required for VRLA — they produce zero hydrogen

D. ACH = 1.0; carbon monoxide detectors required

17. A 230 kV, 300-mile transmission line has Z_c = 370 Ω and SIL = 143 MW. During a severe winter storm, the load drops to 40 MW. The receiving-end voltage begins to rise. Two switched shunt reactors (80 Mvar each) and a static VAR compensator (SVC) rated ±100 Mvar are installed at the receiving end. What is the optimal reactive compensation strategy for this emergency light-load condition?

A. Switch on both reactors only — the combined 160 Mvar absorption should control the voltage rise

B. Switch on one reactor (80 Mvar) and use the SVC in absorbing mode to fine-tune voltage — this provides both coarse correction (reactor) and continuous regulation (SVC) while reserving the second reactor for additional contingencies

C. Use the SVC alone — its ±100 Mvar range is sufficient to handle the voltage rise

D. Switch on both reactors and the SVC in maximum absorbing mode — use all available reactive absorption

18. A three-phase, 13.8 kV system has a delta-wye grounded transformer bank ($Z_1 = j6.5\%$, $Z_0 = j5.0\%$ on its base). A 13.8 kV source has Z_1_src = j2.0% on the transformer base. A bolted SLG fault occurs on the 480V secondary bus. On a 10 MVA system base, the engineer must determine whether I_SLG exceeds I_3Φ. What is the key factor that determines this relationship?

A. The transformer's X/R ratio

B. Whether Z_0_total (transformer only, since delta blocks source Z_0) is less than Z_1_total (transformer + source); when Z_0_total < Z_1_total, the SLG exceeds the three-phase fault because the total SLG impedance is less than 3 × Z_1_total

C. The secondary voltage level

D. The transformer's MVA rating

19. Per NEC 250.30(A)(1), each separately derived system requires a system bonding jumper. A hospital has a 2,000 kVA normal service transformer (13.8 kV/480V) and a 1,500 kVA emergency generator. Both feed a common 480V emergency bus through an automatic transfer switch. The generator constitutes a separately derived system when it is the sole source. How many system bonding jumpers are required for this configuration?

A. One at the service transformer only — the generator is not a separately derived system because it connects to the same grounding electrode

B. Two — one at the service transformer secondary and one at the generator; the ATS switching determines which source is the active separately derived system at any given time

C. Two — one at the service transformer and one at the generator; each is a separately derived system requiring its own bonding jumper at its source per NEC 250.30(A)(1)

D. Three — one at each source plus one at the ATS

20. A three-phase, 480V, 800A switchboard has an available fault current of 50,000A and a main LVPCB with 0.30-second short-time delay. The arc flash study shows 33 cal/cm² at 24 inches. The engineer designs a layered mitigation strategy: ZSI (bus fault → 0.05s), optical arc relay (0.030s), arc-resistant switchgear, and remote racking. For a bus fault during maintenance, the optical relay clears in 0.030 seconds. What is the calculated incident energy, and what is the worker's effective exposure with the arc-resistant enclosure?

A. E_calc = 33 × (0.030/0.30) = 3.3 cal/cm²; the worker's effective exposure at the front is near zero because the arc-resistant enclosure redirects the arc blast energy through exhaust plenums away from the worker

B. E_calc = 33 cal/cm²; unchanged by any mitigation

C. E_calc = 3.3 cal/cm²; the worker must wear PPE Category 1

D. E_calc = 0 cal/cm²; the optical relay prevents any arc from forming

21. A synchronous generator rated 200 MVA, 22 kV has X"_d = 0.20 pu, $X_2 = 0.22$ pu, $X_0 = 0.08$ pu. The generator is solidly grounded. For a bolted SLG fault at the terminals, a bolted three-phase fault, and a bolted line-to-line fault, calculate all three subtransient fault currents and rank them. Which fault type produces the highest current for relay and equipment rating purposes?

A. I_SLG > I_3Φ > I_LL for equipment on the faulted phase; but I_3Φ determines the equipment symmetrical rating because it flows in all three phases simultaneously

B. I_3Φ > I_SLG > I_LL always — three-phase is the standard rating basis

C. I_LL > I_SLG > I_3Φ in solidly grounded systems

D. I_SLG = 6.0 pu > I_3Φ = 5.0 pu > I_LL = 4.13 pu; the SLG produces the highest current in the faulted phase because X_0 (0.08) is much less than X"_d (0.20); for equipment ratings, the three-phase fault current is typically used for symmetrical interrupting ratings, but the SLG value must be checked for single-phase duties and ground-fault protection settings

22. A 480V, three-phase panelboard has: Motor 1 = 180A (150 HP), Motor 2 = 124A (100 HP), Motor 3 = 65A (50 HP). Continuous lighting = 160A. Noncontinuous receptacles = 70A. Per NEC 430.24 and 215.2(A)(1): minimum feeder ampacity = 125% × largest motor + other motors + 125% × continuous lighting + noncontinuous. What is the calculation?

A. 225 + 189 + 200 + 70 = 684A

B. 125% × 180 + 124 + 65 + 125% × 160 + 70 = 225 + 189 + 200 + 70 = 684A

C. 414 + 200 + 70 = 684A

D. 750A

23. A three-phase, 4,160V system has four sources: Transformer A (25 MVA, Z = 7.5%), Transformer B (15 MVA, Z = 6.0%), Generator C (8 MVA, X"_d = 0.22 pu), Generator D (5 MVA, X"_d = 0.20 pu). On a 25 MVA system base, the per-unit impedances are: Z_A = 0.075, Z_B = 0.10, X_C = 0.6875, X_D = 1.0. What is the total three-phase fault current on the bus?

A. I_base = 3,471A; I_total = (1/0.075 + 1/0.10 + 1/0.6875 + 1/1.0) × 3,471 = (13.33 + 10.0 + 1.45 + 1.0) × 3,471 = 25.78 × 3,471 = 89,465A

B. 50,000A

C. 70,000A

D. 45,000A

24. A 480V, three-phase, 225A panelboard has an available fault current of 35,000A. The panelboard SCCR is 22,000A. An upstream 225A Class RK1 fuse limits let-through to 10,000A peak (6,500A RMS) at 35,000A available. Per NEC 110.10, the installation requires equipment capable of withstanding the available fault current. Can the fuse-panelboard combination satisfy this requirement?

A. No — the panelboard SCCR must independently meet or exceed the available fault current of 35,000A regardless of upstream protection

B. Yes — any current-limiting fuse automatically satisfies NEC 110.10

C. Yes — when the specific fuse-panelboard combination is tested, listed, and documented as a series-rated system per NEC 240.86, the let-through of 6,500A is well below the 22,000A SCCR; the combination must be properly labeled with the series combination rating

D. No — Class RK1 fuses cannot be used in series-rated combinations

25. Per NEC 690.12, a PV system on a hospital building uses microinverters at each module. Each microinverter converts DC to 240V single-phase AC at the module level. When rapid shutdown is initiated, each microinverter ceases power conversion. The remaining module DC voltage is V_oc = 42V per module. The maximum string length is one module per microinverter (no series strings). Is this system compliant with NEC 690.12(A) (outside array boundary) and 690.12(B)(2) (within array boundary)?

A. Compliant with 690.12(A) only — the AC output drops to zero immediately, but the module DC conductors remain at 42V

B. Non-compliant — microinverters do not qualify as rapid shutdown devices

C. Compliant with both — but only for hospital occupancies

D. Compliant with both 690.12(A) and 690.12(B)(2) — the AC output ceases immediately (outside boundary), and each module's DC conductors carry only 42V (below the 80V array boundary threshold); microinverters are recognized rapid shutdown devices per UL 1741

26. A three-phase, 480V system has two parallel transformers: T1 = 2,000 kVA (Z = 5.75%, X/R = 7) and T2 = 1,000 kVA (Z = 6.50%, X/R = 6). Both have identical ratios and configurations. The engineer must determine the total available fault current and verify whether a downstream 225A MCCB (22 kA AIC) is adequate. On a 2,000 kVA common base: Z_T1 = 0.0575 pu, Z_T2 = 0.065 × 2 = 0.13 pu. What is the total fault current?

A. 31,374A (T1 alone)

B. I_T1 = 2,406/0.0575 = 41,843A; I_T2 = 1,203/0.065 = 18,508A; Total = 60,351A; the 22 kA MCCB is grossly inadequate

C. 50,000A

D. 22,000A — exactly at the MCCB rating

27. A distance relay on a 230 kV line has Zone 1 at 85% reach, Zone 2 at 120% (0.35s delay), Zone 3 at 200% (1.0s delay). The line impedance is Z_line = 5 + j60 Ω. A bolted three-phase fault occurs at 118% of the protected line (on the adjacent line). The pilot scheme (POTT) has a communication channel failure. What is the protection response at the near-end terminal?

A. Zone 2 at 120% covers 118% → Zone 2 operates after 0.35 seconds as backup protection for the adjacent line's primary relay; total clearing time ≈ 0.35 + breaker time ≈ 0.433 seconds

B. Zone 1 trips instantaneously

C. Zone 3 trips after 1.0 second

D. No zone detects the fault

28. A three-phase, 480V, 400A panelboard has an available fault current of 28,000A. An IEEE 1584 arc flash study shows 15.2 cal/cm² at 24 inches with a 0.25-second clearing time. The engineer proposes a three-layer mitigation strategy: (1) maintenance mode switch (clearing = 0.05 seconds), (2) optical arc relay (clearing = 0.015 seconds), (3) arc-resistant panel enclosure. With all three active and the optical relay overriding during maintenance, what is the calculated incident energy and the worker's effective exposure?

A. E_calc = 15.2 cal/cm²; worker exposure = 15.2 cal/cm² (no reduction)

B. E_calc = 3.04 cal/cm²; worker exposure = 3.04 cal/cm² (maintenance switch only)

C. E_calc = 0.912 cal/cm²; worker exposure = 0.912 cal/cm² (optical relay, no arc-resistant benefit)

D. E_calc = 0.912 cal/cm² (optical relay: 15.2 × 0.015/0.25); worker exposure near zero because the arc-resistant enclosure redirects all thermal energy away from the front of the equipment

29. Per NEC 450.3(B), a 2,500 kVA, 480V/208Y/120V transformer has a primary current of 3,007A. At 125%: 3,758.75A. The next standard size above is 4,000A. The engineer also installs secondary overcurrent protection at 125% of secondary rated current (6,940A × 1.25 = 8,675A → 8,000A standard fuse). With both primary and secondary protection, is the installation code-compliant?

A. Yes — but the secondary OCPD must not exceed 125% of secondary rated current, and 8,000A exceeds this for some transformer configurations

B. Yes — NEC 450.3(B) Table permits primary protection at the next standard above 125% (4,000A) when secondary protection is also provided; this is the standard dual-protection approach for large transformers

C. No — both primary and secondary protection at 125% is redundant and not permitted

D. No — secondary protection must be at 100% of rated current

30. A three-phase, 4,160V, 6-pole synchronous motor rated 2,000 HP drives a mine hoist at 1,200 RPM. The motor operates at 0.85 leading PF with a field current of 300A and has a pull-out torque of 240% FLT. During a mine emergency, the motor must operate at 110% of rated torque for 30 seconds while a system voltage sag reduces the bus voltage to 88% for the same duration. With fixed field (E_a constant), pull-out torque = 0.88 × 240% = 211.2% FLT. Does the motor maintain synchronism during this combined overload and voltage sag?

A. Yes — 211.2% pull-out exceeds 110% load with a margin of 101.2% FLT; the combined overload and voltage sag leaves adequate margin, but the power angle increases significantly and the motor's thermal capacity for the 30-second overload must also be verified

B. No — 110% overload during a voltage sag always causes loss of synchronism

C. Yes — but only if the field current is simultaneously increased

D. No — the margin is insufficient for the 30-second duration

31. A 480V, three-phase system has three parallel transformers feeding a common bus: T1 = 2,000 kVA (Z = 5.50%), T2 = 1,500 kVA (Z = 5.75%), T3 = 1,000 kVA (Z = 6.00%). All have identical ratios and configurations. On a 2,000 kVA common base: Z_T1 = 0.055, Z_T2 = 0.0575 × (2,000/1,500) = 0.0767, Z_T3 = 0.06 × (2,000/1,000) = 0.12. The parallel impedance is Z_p = 1/(1/0.055 + 1/0.0767 + 1/0.12). What percentage of a combined 3,000 kVA load does T1 carry?

A. T1 carries 50% because it is the largest transformer

B. T1 carries approximately 33% (equal shares)

C. 1/Z_T1 = 18.18; 1/Z_T2 = 13.04; 1/Z_T3 = 8.33; sum = 39.55; T1 share = 18.18/39.55 = 46.0% — T1 carries the most because it has the lowest per-unit impedance on the common base

D. T1 carries 37.5%

32. A 13.8 kV, three-phase system has a measured voltage THD of 10.2% at the PCC. Individual harmonics: V_5 = 7.5%, V_7 = 5.2%, V_{11} = 3.1%, V_{13} = 2.3%. IEEE 519 limits for <69 kV: THD_V ≤ 5.0%, individual ≤ 3.0%. The facility has a mix of old six-pulse and new eighteen-pulse VFDs. What is the total number of violations, and what is the most cost-effective first step?

A. Two violations (V_5 and THD only)

B. Three violations (V_5, V_7, THD)

C. Four violations (V_5, V_7, V_{11}, THD)

D. Four violations — V_5 (7.5%), V_7 (5.2%), V_{11} (3.1%) all exceed the 3.0% individual limit, and THD (10.2%) exceeds 5.0%; the most cost-effective first step is retrofitting the remaining six-pulse VFDs to 18-pulse or AFE, which eliminates 5th and 7th at the source and will likely bring V_{11} and THD into compliance as a secondary benefit

33. A ground resistance test on a large pharmaceutical campus yields 0.8 Ω using the fall-of-potential method during spring (wet season). The IEEE 80 design target is 0.5 Ω for the substation ground grid. The IEEE 81 seasonal correction factor for wet-to-dry is 1.6 for this soil type. What is the estimated worst-case dry season resistance, and does the grid meet the specification?

A. Corrected = 0.8 × 1.6 = 1.28 Ω; the grid FAILS the 0.5 Ω specification by a significant margin — extensive remediation including grid expansion, additional conductors, and ground enhancement material is required

B. Corrected = 0.8 Ω; seasonal correction not needed

C. Corrected = 1.28 Ω; marginally meets the specification

D. Corrected = 0.5 Ω; the grid meets the specification exactly

34. A three-phase, 460V, 2-pole induction motor rated 350 HP has a full-load speed of 3,555 RPM, efficiency of 96%, and PF of 0.89 lagging. The motor's no-load magnetizing kvar is approximately 55 kvar. A 40 kvar capacitor is proposed for the motor terminals. Per NEC 460.9, is this safe, and what is the corrected power factor?

A. Safe — 40 kvar < 55 kvar no-load magnetizing; self-excitation will not occur; corrected PF ≈ 0.96 (original Q ≈ P_in × tan(arccos 0.89) ≈ 272 × 0.512 = 139 kvar; Q_new = 99 kvar → PF_new ≈ 0.94)

B. Unsafe — 40 kvar exceeds the maximum for 2-pole motors

C. Safe — but the corrected PF would be unity, which is not recommended

D. Unsafe — any capacitor above 30 kvar on a 350 HP motor causes self-excitation

35. A three-phase, 460V, 6-pole VFD-driven induction motor operates a centrifugal blower at design speed of 1,170 RPM (60 Hz), consuming 180 kW. During summer peak (3,000 hours/year), the blower operates at 85% speed (994.5 RPM). During shoulder seasons (4,000 hours/year), the blower operates at 60% speed (702 RPM). During winter (1,760 hours/year), the blower operates at design speed. What is the total annual energy consumption with the VFD versus full-speed operation year-round, and what is the annual savings at $0.078/kWh?

A. VFD annual energy = 900,000 kWh; full-speed = 1,576,800 kWh; savings = $52,750/year

B. VFD annual energy = 1,200,000 kWh; full-speed = 1,576,800 kWh; savings = $29,390/year

C. VFD annual energy = 1,400,000 kWh; savings = $13,790/year

D. Summer: P = 180 × 0.85^3 = 110.6 kW × 3,000 = 331,668 kWh; Shoulder: P = 180 × 0.60^3 = 38.9 kW × 4,000 = 155,520 kWh; Winter: 180 × 1,760 = 316,800 kWh; VFD total = 803,988 kWh; Full-speed = 180 × 8,760 = 1,576,800 kWh; Savings = 772,812 kWh × $0.078 = $60,279/year

36. A 480V, three-phase, 200A feeder uses 250 kcmil THHN copper in EMT (R = 0.0541 Ω/1000 ft, X = 0.0442 Ω/1000 ft). The feeder is 500 feet long and serves a balanced load at 0.85 lagging PF. What is the voltage drop percentage?

A. 1.5%

B. V_drop = √3 × 200 × (0.0541×0.500×0.85 + 0.0442×0.500×0.527) = 346.4 × (0.02299 + 0.01165) = 346.4 × 0.03464 = 12.0V; 12.0/480 = 2.5%

C. 3.8%

D. 4.5%

37. A 100 MVA, 230/69 kV autotransformer has a series impedance of 9.5% on its own base. Two identical units operate in parallel. A 40 MVA synchronous generator (X"_d = 0.22 pu) and a 30 MVA synchronous condenser (X"_d = 0.16 pu) are connected to the 69 kV bus. On a 100 MVA base, what is the total three-phase fault current on the 69 kV bus?

A. I_base = 836.7A; Z_T_par = 0.095/2 = 0.0475; Z_gen = 0.22×100/40 = 0.55; Z_SC = 0.16×100/30 = 0.533; I = (1/0.0475 + 1/0.55 + 1/0.533) × 836.7 = (21.05 + 1.82 + 1.88) × 836.7 = 24.75 × 836.7 = 20,708A

B. 15,000A

C. 25,000A

D. 10,500A

38. A three-phase, 480V system has a 3,000 kVA transformer (Z = 5.75%) feeding a switchboard. The switchboard bus fault current = 36,130A. A 250-foot cable of 350 kcmil copper in steel conduit (R = 0.0367, X = 0.0407 Ω/1000 ft) feeds a remote MCC. What is the approximate available fault current at the MCC?

A. 36,130A (unchanged)

B. 30,000A

C. 26,800A

D. 18,500A

39. Per NEC 250.53(A)(2), only one supplemental electrode is required when a single rod fails to achieve 25 Ω. However, the engineer's IEEE 142 study for a semiconductor fabrication facility shows the two-rod installation measures 52 Ω and recommends ≤1 Ω. What is the engineering approach to achieve this aggressive target?

A. Add additional driven rods until 1 Ω is achieved

B. Install a chemical ground enhancement compound around the existing rods

C. Reduce the target to 5 Ω — 1 Ω is unachievable

D. Install a comprehensive ground grid beneath the building (grid of bare copper conductors at 10-foot spacing buried 18-24 inches deep) combined with ground enhancement material, driven ground rods at grid intersections, and connections to building steel — a ground grid is the only practical way to achieve ≤1 Ω in most soil conditions for large facilities

40. A 480V, three-phase system has a 2,000 kVA transformer (Z = 5.75%, X/R = 7) feeding a switchboard with I_fault = 31,374A. The switchboard feeds a remote panelboard through 300 feet of 4/0 AWG copper in EMT (R = 0.0608, X = 0.0478 Ω/1000 ft). The arc flash study at the switchboard shows 18 cal/cm² with a 0.2-second clearing time. What is the approximate fault current and incident energy at the remote panelboard (same clearing time)?

A. I ≈ 31,374A; E ≈ 18 cal/cm² (cable is negligible for 300 feet with 4/0)

B. I ≈ 14,500A; E ≈ 6.5 cal/cm² — the reduced fault current at the remote panel significantly lowers the arc flash energy per the IEEE 1584 current-dependent formula; separate PPE category labeling may be warranted

C. I ≈ 25,000A; E ≈ 12 cal/cm²

D. I ≈ 8,000A; E ≈ 2.5 cal/cm²

41. A 60 MVA, 138/13.8 kV, delta-wye grounded transformer has $Z_1 = Z_2 = j0.085$ pu and $Z_0 = j0.065$ pu on its own base. The 138 kV source has Z_1_src = j0.03 pu on the transformer base. On a 100 MVA system base, compare I_SLG and I_3Φ on the 13.8 kV bus. Which is larger, and by what approximate percentage?

A. I_SLG exceeds I_3Φ by approximately 15% because Z_0_total (0.1083 pu, transformer only) is less than Z_1_total (0.1917 pu, transformer + source); the delta blocks source Z_0, creating a lower zero-sequence path

B. I_3Φ exceeds I_SLG by 15%

C. They are equal because $Z_0 \approx Z_1$ for the transformer

D. I_3Φ always exceeds I_SLG in delta-wye transformer configurations

42. A three-phase, 460V, 4-pole induction motor rated 200 HP has a power factor of 0.88 lagging at full load with an efficiency of 95%. Two capacitor options are available: 30 kvar and 50 kvar. The motor's no-load magnetizing kvar is approximately 40 kvar. Per NEC 460.9, which capacitor option is safe, and what corrected PF does each produce?

A. Both are safe — neither exceeds the 40 kvar no-load magnetizing limit

B. Only the 30 kvar is safe (30 < 40); the 50 kvar exceeds the no-load magnetizing limit and risks self-excitation

C. Only the 30 kvar is safe; corrected PF ≈ 0.95; the 50 kvar option exceeds the motor's no-load magnetizing kvar of 40 kvar and could cause dangerous self-excitation overvoltage when the motor is disconnected from the supply

D. Neither is safe for motors above 150 HP

43. A CT with a ratio of 3000:5 and accuracy class C800 serves a transformer differential relay. During an external through-fault of 45,000A with X/R = 20, one CT saturates to 65% of expected output during the first three cycles due to DC offset. The expected secondary current per CT is 75A. The differential relay has a 30% slope. What is the false differential current, and does the relay correctly restrain?

A. False differential = 0A (all CTs produce identical output)

B. False differential = 26.25A (75A − 48.75A saturated); restraint current = 75A; slope threshold = 22.5A; since 26.25A > 22.5A, the relay may FALSE TRIP — the 30% slope is insufficient for this level of CT saturation

C. False differential = 7.5A; well below the slope threshold — relay correctly restrains

D. False differential = 26.25A; relay slope of 30% = 22.5A threshold; since 26.25A > 22.5A, the relay trips — a FALSE TRIP; the slope should be increased to at least 35% to accommodate this CT saturation scenario

44. A balanced three-phase, 208Y/120V panelboard serves a data center with a mix of servers (nonlinear, 3rd harmonic dominant) and HVAC units (linear motors). Phase currents: 250A fundamental (180A servers + 70A HVAC), 72A third-harmonic per phase (from servers only), 25A fifth-harmonic per phase (from servers). Calculate the true-RMS phase current, the neutral current, and the neutral-to-phase ratio.

A. I_phase = 250A; I_neutral = 216A; ratio = 0.86

B. I_phase = $\sqrt{(250^2 + 72^2 + 25^2)}$ = 261.8A; I_neutral = 3 × 72 = 216A; ratio = 216/261.8 = 0.825 — the neutral is 82.5% of the phase RMS, requiring careful sizing but not exceeding the phase current

C. I_phase = 347A; I_neutral = 216A; ratio = 0.62

D. I_phase = 261.8A; I_neutral = 291A; ratio = 1.11

45. Per NEC Article 517.17(A), a hospital's isolated power system LIM alarms at 5 mA. An operating suite has two isolated power panels: Panel A serves Room 1 (total hazard current = 3.9 mA, 11 devices) and Panel B serves Room 2 (total hazard current = 4.4 mA, 13 devices). A new electrosurgical unit with 0.8 mA leakage needs to be connected in Room 2. The biomedical engineer has three options: (1) connect to Panel B, (2) connect to Panel A via a long extension from Room 1's outlets, (3) install a third isolated power panel. Which is the best engineering decision?

A. Option 3 (install a third panel) — adding a new panel distributes the hazard current across three systems, providing the most headroom for future device additions; Panel B at 4.4 mA cannot safely accept the 0.8 mA device (would reach 5.2 mA), and Option 2 uses extension cords which are generally prohibited in operating rooms

B. Option 1 — 5.2 mA is acceptably close to 5.0 mA

C. Option 2 — extension cords are permitted in operating rooms during emergency procedures

D. Any option is acceptable because the 5 mA limit is a guideline, not a hard requirement

46. A 345 kV, three-phase line has V_S = 355 kV and V_R = 332 kV at a load of 700 MW, 0.94 lagging PF. Line reactance = 68 Ω. What is the power angle δ, the voltage regulation, and the line's operating point as a fraction of its stability limit?

A. δ = 18°; VR = 6.9%; at 31% of stability limit

B. δ = 30°; VR = 6.9%; at 50% of stability limit

C. P = V_S × V_R × sin δ / X → 700 = 355 × 332 × sin δ / 68 = 1,733.5 × sin δ; sin δ = 0.4039; δ = 23.8°; VR = (355−332)/332 = 6.93%; at sin(23.8°)/1.0 = 40.4% of stability limit

D. δ = 45°; VR = 10%; at 71% of stability limit

47. A recloser on a 12.47 kV overhead feeder uses fuse-saving coordination with a 125A lateral fuse. At a fault current of 3,800A: fuse minimum melting = 0.035 seconds, fuse total clearing = 0.07 seconds, recloser fast trip = 0.025 seconds, recloser delayed trip = 0.22 seconds. A temporary fault occurs on the lateral during a thunderstorm. The recloser fast-trips, de-energizes, and recloses. The temporary fault has cleared. What is the net result?

A. The fuse blows because the recloser was too slow

B. The recloser locks out after multiple trips

C. The lateral remains de-energized for safety during the storm

D. Service is fully restored without any fuse operation — the recloser fast-trip (0.025s) operated before the fuse minimum melting (0.035s), saving the fuse; after the dead time, the recloser recloses and the temporary fault is gone; the fuse is intact and all customers retain service

48. A 480V, three-phase, 400A panelboard has a bus rating of 400A. The load is: 250A continuous + 80A continuous + 40A noncontinuous = 370A. Per NEC 215.2(A)(1): OCPD = 125% × 330 + 40 = 452.5A → exceeds 400A bus. Using a 100%-rated 400A breaker: 370A ≤ 400A. But the conductor must handle continuous thermal duty. What minimum conductor ampacity is required with the 100%-rated system?

A. 452.5A (standard NEC calculation regardless of breaker type)

B. 370A — the conductor must carry the actual total load continuously; with a 100%-rated system where the breaker and conductors are both designed for 100% continuous operation, the 125% adder is eliminated

C. 400A (matching the bus rating)

D. 330A (continuous load only)

49. A three-phase, 480V system has a 2,500 kVA transformer (Z = 5.75%, X/R = 8). The available symmetrical fault current at the switchboard is 42,700A. Six motors on the bus have combined FLA = 1,400A, contributing 5,600A first-cycle. Total symmetrical = 48,300A. What is the peak asymmetrical current using the X/R = 8 multiplier of 2.30?

A. 42,700A (transformer only — exclude motor contribution)

B. Peak = 2.30 × 48,300 = 111,090A — this value determines the momentary withstand and close-and-latch rating required for all bus structures and switching equipment

C. Peak = 68,265A (√2 × 48,300)

D. Peak = 96,600A (2× symmetrical)

50. A 480V, three-phase, 200A feeder uses 350 kcmil THHN copper in PVC conduit (R = 0.0367, X = 0.0489 Ω/1000 ft). The feeder is 350 feet long and serves a load at 0.90 lagging PF. What is the voltage drop percentage?

A. 1.2%

B. 2.8%

C. 3.5%

D. V_drop = √3 × 200 × (0.0367×0.35×0.90 + 0.0489×0.35×0.436) = 346.4 × (0.01156 + 0.00746) = 346.4 × 0.01902 = 6.59V; 6.59/480 = 1.37% ≈ 1.4%

51. Per NEC 110.14(C)(1), for equipment rated over 100A, the 75°C column governs unless terminals are listed for higher temperature. A 600A switchboard has terminals marked "75°C only." The continuous load requires a minimum conductor ampacity of 500A (after 125% calculation). At 75°C: 700 kcmil = 460A (insufficient), 750 kcmil = 475A (insufficient), two 500 kcmil in parallel = 2 × 380A = 760A. What is the minimum conductor configuration?

A. Two parallel sets of 500 kcmil per phase (760A total at 75°C) satisfy the 500A requirement with 52% margin; each set must be identically routed, terminated, and sized per NEC 310.10(G)

B. 750 kcmil (475A at 75°C) — close enough to 500A with the standard 5% tolerance

C. Single 1,000 kcmil (75°C = 545A)

D. 900 kcmil (75°C = 520A) if available as a standard conductor size

52. A 150 MVA synchronous generator has H = 5.0 MJ/MVA and delivers 130 MW when a three-phase fault reduces electrical output to zero. The critical clearing angle is 100°. The relay operates in 0.02 seconds and the breaker clears in 0.04 seconds (total = 0.06 seconds). Using $\Delta\delta = (180 \times f \times P\_a \times t^2)/(H \times S)$, what is the rotor angle advance?

A. $\Delta\delta = 25°$; stability marginal

B. $\Delta\delta = 50°$; stability uncertain

C. $\Delta\delta = (180 \times 60 \times 130 \times 0.06^2)/(5.0 \times 150) = (180 \times 60 \times 130 \times 0.0036)/750 = 5{,}054.4/750 = 6.74°$; stability maintained with 93.26° margin

D. $\Delta\delta = 100°$; at critical clearing — must trip faster

53. A three-phase, 13.8 kV grounded-wye capacitor bank rated 5,400 kvar has two series groups of six parallel units per phase (12 per phase, 36 total). Two units in the same series group of Phase A fail short-circuited and their fuses blow. What voltage stress now exists on the remaining four units in that series group?

A. No change — the fuses completely isolate the failed units

B. Each remaining unit now sees 6/4 = 1.50 times normal voltage (50% overvoltage) — this exceeds the typical 110% continuous overvoltage rating of capacitor units and will likely cause cascading failures in the remaining units unless the bank is immediately de-energized

C. Each remaining unit sees 6/5 = 1.20 times normal voltage

D. The bank automatically compensates for the lost units

54. A three-phase, 460V, 8-pole wound-rotor induction motor rated 800 HP has a full-load speed of 873 RPM. With external rotor resistance, the motor achieves 300% starting torque at 330% FLA. The motor drives a crusher requiring 270% breakaway torque. A plant engineer proposes using a standard Design B squirrel-cage motor instead (150% starting torque at 600% FLA). Can the Design B motor start this crusher?

A. Yes — if the voltage dip during starting is less than 5%

B. No — the Design B motor's starting torque is only 150% FLT at rated voltage

C. Yes — with a soft starter to boost starting torque

D. No — 150% < 270% breakaway; the Design B motor cannot start the crusher; additionally, the Design B motor's 600% FLA starting current produces a much larger voltage dip than the wound-rotor's 330% FLA, further reducing the available starting torque below 150% due to the V^2 torque relationship

55. Per NEC 310.15(C)(1), a raceway contains five three-phase VFD circuits (15 phase conductors), five neutral conductors (all carrying significant triplen harmonics), and five equipment grounding conductors. How many current-carrying conductors are counted, and what is the adjustment factor?

A. 15 phase conductors only; factor = 0.50

B. 20 (15 phase + 5 neutrals); factor = 0.50

C. 20 (15 phase + 5 harmonic-carrying neutrals); factor = 0.50 per NEC Table 310.15(C)(1) for 10–20 conductors; the five EGCs are excluded from the count

D. 25 (all conductors); factor = 0.40

56. A 480V, three-phase, 800A LVPCB main breaker has a short-time delay of 0.25 seconds. ZSI is installed with ten feeder breakers. An optical arc relay is also installed. During a bus fault: ZSI (no restraint → 0.05s) and optical relay (0.030s) both detect the fault. The optical relay's trip signal reaches the breaker trip coil approximately 2 ms after arc detection. The ZSI logic processes restraint status in approximately 8 ms. Which signal controls the trip?

A. The optical relay signal controls because it arrives at the trip coil first (approximately 0.002s detection + trip signal transmission vs ZSI's 0.008s processing time); the breaker mechanism begins opening upon receiving the first trip signal, producing a total clearing time of approximately 0.030 seconds

B. ZSI controls because it is hardwired into the breaker trip unit

C. Both signals arrive simultaneously

D. The slowest signal controls — the breaker waits for both trip commands

57. A protection engineer must set a 51 overcurrent relay (IEEE extremely inverse) on a 13.8 kV feeder. CT ratio = 400:5. Maximum load = 320A. Minimum fault = 1,000A. The engineer selects pickup = 5A (primary = 400A) with TD = 2.5. At the minimum fault of 1,000A: secondary = 12.5A; M = 12.5/5 = 2.5. Using $t = TD \times (28.2/(M^2-1) + 0.1217)$, what is the relay operating time?

A. t = 5.2 seconds — too slow for this application

B. t = 3.8 seconds

C. t = 1.0 seconds

D. $t = 2.5 \times (28.2/(6.25-1) + 0.1217) = 2.5 \times (28.2/5.25 + 0.1217) = 2.5 \times (5.371 + 0.1217) = 2.5 \times 5.493 = 13.73$ seconds — extremely slow at this low fault multiple; the pickup should be reduced or a different relay characteristic selected for better sensitivity at low fault multiples

58. A 345 kV, 280-mile line has $Z_1 = 22.4 + j210\ \Omega$ total and $Z_0 = 67.2 + j630\ \Omega$ total. Source: Z_1_src = j14 Ω, Z_0_src = j21 Ω. For a bolted SLG fault at the remote end, what is |Z_1_total| and |Z_0_total|, and what is the SLG fault current magnitude (I_SLG = 3V_f/|Z_total_sum|)?

A. $|Z_1\_total| = 224.4\ \Omega$; $|Z_0\_total| = 651.6\ \Omega$; I_SLG = 450A

B. $|Z_1\_total| = \surd(22.4^2 + 224^2) = 225.1\ \Omega$; $|Z_0\_total| = \surd(67.2^2 + 651^2) = 654.5\ \Omega$; |Sum| = |44.8+j(224+224+651)| = |44.8+j1,099| = 1,100 Ω; I_SLG = 3 × 199,186V/1,100 = 543A

C. I_SLG = 1,200A

D. I_SLG = 800A

59. Per NEC Article 700.10(B)(1), emergency wiring must be independent from normal wiring. A hospital routes emergency conduit and normal conduit through the same 2-hour fire-rated shaft. Each system is in separate metallic conduit. Is this installation compliant with NEC 700.10(B)(1)?

A. Yes — separate metallic conduits within a 2-hour fire-rated shaft provide both physical separation of the wiring systems and fire protection; the shaft's fire rating provides additional protection against simultaneous loss of both systems during a fire event

B. No — emergency and normal wiring cannot share the same shaft under any circumstances

C. Yes — but only if the shaft is 4-hour fire-rated

D. No — but this can be resolved by routing the normal conduit outside the shaft

60. A three-phase, 480V, 225A panelboard has a continuous lighting load of 175A and a noncontinuous HVAC load of 35A. The panelboard bus is rated 225A. Per NEC 215.2(A)(1): OCPD = 125% × 175 + 35 = 253.75A → next standard = 300A. This exceeds the 225A bus. Using a 100%-rated 225A breaker: load = 210A ≤ 225A. Is this resolution compliant?

A. No — even with a 100%-rated breaker, the load of 210A leaves insufficient thermal margin

B. Yes — but only if ambient temperature derating is applied to verify the breaker's 100% rating at the actual installation temperature

C. Yes — 210A ≤ 225A satisfies NEC 215.2 (OCPD ≥ load) and NEC 408.36 (OCPD ≤ bus); the conductor must be sized for ≥210A with a 100%-rated system

D. No — the conductor ampacity must still be 253.75A per the standard calculation

61. A balanced three-phase, 4,160V source feeds a 5,500 kW load at 0.73 lagging PF. The total reactive demand is Q = 5,500 × tan(arccos 0.73) = 5,500 × 0.935 = 5,143 kvar. The utility penalizes $3.75/kvar/month for excess above a 0.95 PF threshold. What are the allowed kvar at 0.95 PF, the excess, the monthly penalty, and the capacitor bank size to eliminate the penalty?

A. Q_allowed = 1,808 kvar; excess = 3,335 kvar; penalty = $12,506/month; capacitor = 3,335 kvar

B. Q_allowed = 0; penalty = $19,286/month

C. Q_allowed = 2,500 kvar; excess = 2,643 kvar; penalty = $9,911/month

D. Q_allowed = 5,500 × tan(arccos 0.95) = 5,500 × 0.3287 = 1,808 kvar; excess = 5,143 − 1,808 = 3,335 kvar; penalty = 3,335 × $3.75 = $12,506/month; a 3,335 kvar capacitor bank eliminates the penalty and pays for itself within months at this penalty rate

62. A 480V, three-phase MCC has 15 motors with combined FLA of 2,500A. During a fault, motors contribute 4 × 2,500 = 10,000A first-cycle. The transformer provides 38,000A. Total symmetrical = 48,000A. System X/R = 12. What is the approximate peak asymmetrical current?

A. 67,900A (√2 × total)

B. Peak = 2.30 × 48,000 = 110,400A (IEEE multiplier for X/R = 12 ≈ 2.30) — this extremely high peak dictates the mechanical bracing requirements for the MCC bus structures

C. 96,000A (2× total)

D. 48,000A (no asymmetry)

63. A three-phase, 13.8 kV underground cable system is 35 miles long with charging current of 4.5A per mile per phase. A zero-sequence CT (window type) with a 20A relay pickup is installed. During normal energization, the cable charges at 4.5 × 35 = 157.5A per phase (472.5A total three-phase). Does the relay trip on energization?

A. No — the zero-sequence CT measures only residual current; balanced three-phase charging produces zero residual; the relay sees 0A during normal energization regardless of the magnitude of the individual phase charging currents

B. Yes — 157.5A per phase far exceeds the 20A pickup

C. Yes — the total charging of 472.5A overwhelms the CT

D. No — but only because the charging current is capacitive and the relay is set for resistive faults

64. Per NEC 430.24, a feeder serves: Motor A = 361A (300 HP), Motor B = 242A (200 HP), Motor C = 180A (150 HP), Motor D = 124A (100 HP). Continuous lighting = 75A. What is the minimum feeder conductor ampacity?

A. 125% × 361 + 242 + 180 + 124 + 125% × 75 = 451.25 + 546 + 93.75 = 1,091A

B. 950A

C. 1,091A

D. 1,200A

65. A distance relay on a 69 kV line has Zone 1 at 80% reach, Zone 2 at 120%, Zone 3 at 200%. The line impedance is Z_line = 2 + j20 Ω. A fault occurs at 95% of the line. The pilot scheme (DCB) is active with a healthy communication channel. Both terminals see the fault as forward. What is the protection response?

A. The DCB scheme allows both terminals to trip with high-speed clearing — since both terminals see the fault as forward, neither sends a blocking signal; the 95% fault exceeds Zone 1 at the near end (80%) but is within Zone 1 at the far end (95% from near = 5% from far); the far-end Zone 1 trips instantaneously and the near end trips via DCB permissive action

B. Zone 2 at the near end trips after 0.35 seconds; far end Zone 1 trips instantaneously

C. Both ends trip on Zone 2 after 0.35 seconds

D. No protection operates because the fault is between Zone 1 and Zone 2 reach

66. A three-phase, 4,160V system has a neutral grounding resistor rated 350A, 10 seconds. A ground fault through 15 Ω fault resistance develops. R_NGR = 2,402/350 = 6.863 Ω. What is the fault current and the relay operating considerations?

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

B. I = 350A; relay operates at standard setting

C. I = 2,402/(6.863 + 15) = 2,402/21.863 = 109.9A ≈ 110A; the relay pickup must be set well below 110A to reliably detect this fault — if the relay pickup is 100A, the margin is only 10% and the fault may go undetected during system voltage variations

D. I = 55A; relay cannot detect the fault

67. Per NEC 480.9(A), ventilation considerations apply to all battery installations. A utility-scale battery energy storage system (BESS) uses lithium-ion NMC (nickel-manganese-cobalt) cells in a containerized enclosure. Unlike LFP batteries, NMC cells have higher energy density but also higher thermal runaway risk. What are the ventilation and safety system requirements?

A. Standard HVAC ventilation only — NMC cells are inherently stable

B. The containerized NMC BESS requires: (1) active thermal management (HVAC or liquid cooling) to maintain cell temperature within operating limits, (2) smoke and gas detection systems, (3) emergency ventilation/exhaust for thermal runaway off-gases, (4) fire suppression (clean agent or water mist), and (5) deflagration venting if the container is sealed — NMC thermal runaway produces flammable and toxic gases at higher rates than LFP

C. No ventilation — the container is sealed and self-contained

D. Identical to lead-acid battery room ventilation

68. A three-phase, 480V, 225A panelboard has an available fault current of 15,000A. An IEEE 1584 arc flash study shows 3.2 cal/cm² at 18 inches with a main breaker clearing time of 0.05 seconds. An optical arc relay (0.010 seconds) is proposed. What is the new incident energy, and does it drop below the 1.2 cal/cm² threshold?

A. E = 3.2 × (0.01/0.05) = 0.64 cal/cm^2; YES — below 1.2 cal/cm^2

B. E = 1.6 cal/cm^2; above the threshold

C. E = 3.2 cal/cm^2 (unchanged)

D. E = 0.64 cal/cm^2; below the 1.2 cal/cm^2 arc flash boundary threshold — standard daily work clothing without specific arc-rated PPE may be adequate at the 18-inch working distance; however, the engineer should verify this against the specific IEEE 1584 calculation parameters

69. A three-phase, 460V, 6-pole synchronous motor rated 1,500 HP drives a paper machine at 1,200 RPM. The motor operates at 0.90 leading PF with 96% efficiency. The motor's pull-out torque is 220% FLT. The paper machine requires 85% FLT during normal operation. During a voltage sag to 80% for 0.4 seconds (fixed field), the pull-out torque drops to 0.80 × 220% = 176% FLT. What is the stability margin, and what is the transient stability concern?

A. Margin = 91% FLT; no concern — voltage sag is within the motor's capability

B. Margin = 176% − 85% = 91% FLT; the steady-state margin is large, but the concern is rotor angle dynamics during the 0.4-second sag

C. Margin = 176% − 85% = 91% FLT; adequate in steady-state, but during the 0.4-second sag the power angle increases continuously; after voltage recovery, the rotor oscillates and the return-swing peak could approach the pull-out angle if the machine's inertia constant H is low; a swing equation analysis should confirm stability

D. No concern — 91% margin guarantees stability under all conditions

70. A 230 kV, 220-mile line has Z_1_total (including source) = 17.6 + j176 Ω and Z_0_total (including source Z_0 through non-delta path) = 52.8 + j528 Ω. For a bolted SLG fault, |Z_1_total| ≈ 176.9 Ω and |Z_0_total| ≈ 530.6 Ω. The ratio $|Z_0|/|Z_1| = 3.0$. The pre-fault line-to-neutral voltage is 132.8 kV. What is the SLG fault current?

A. I_SLG = 3 × V_f / |Z_1_total + Z_2_total + Z_0_total| = 3 × 132,800 / |88 + j880| where $Z_2 = Z_1$; |sum| = $\sqrt{(88^2 + 880^2)}$ = 884.4 Ω; I_SLG = 398,400/884.4 = 450.5A

B. I_SLG = 1,000A

C. I_SLG = 225A

D. I_SLG = 750A

71. Per NEC 250.122(B), a 200A circuit has minimum phase conductors of 3/0 AWG (167,800 CM). The conductors are increased to 500 kcmil (500,000 CM) for voltage drop. The minimum EGC from Table 250.122 for 200A is 6 AWG (26,240 CM). What is the proportionally increased EGC?

A. 6 AWG (no increase needed)

B. 4 AWG (41,740 CM)

C. 2 AWG (66,360 CM)

D. Ratio = 500,000/167,800 = 2.98; EGC = 26,240 × 2.98 = 78,195 CM → 1 AWG (83,690 CM) is the minimum standard size above 78,195 CM

72. A balanced three-phase, 4,160V source feeds a 10,000 kW load at 0.68 lagging PF. The engineer installs an 8,000 kvar capacitor bank and a 3,000 HP synchronous motor at 0.80 leading PF ($\eta = 95\%$). What is the new combined bus power factor?

A. PF = 0.90 lagging

B. PF ≈ 0.99 — the original Q = 10,000 × tan(arccos 0.68) = 10,782 kvar; capacitor = −8,000 kvar; sync motor P_in = 2,364 kW, Q_sync = −1,773 kvar; combined Q = 10,782 − 8,000 − 1,773 = 1,009 kvar; P_total = 12,364 kW; PF = $12{,}364/\sqrt{(12{,}364^2 + 1{,}009^2)}$ = 12,364/12,405 = 0.997 ≈ 0.99

C. PF = 0.95 lagging

D. PF = unity

73. A 100 MVA, 345/138 kV autotransformer has a series impedance of 10% on its own base. Two identical units operate in parallel. A 50 MVA generator (X"_d = 0.20 pu) and a 30 MVA synchronous condenser (X"_d = 0.15 pu) are on the 138 kV bus. On a 100 MVA base: Z_T_par = 0.05, Z_gen = 0.40, Z_SC = 0.50. What is the total fault current?

A. I = (20.0 + 2.5 + 2.0) × 418.4 = 24.5 × 418.4 = 10,251A

B. 8,000A

C. I_base = 418.4A; I = (1/0.05 + 1/0.40 + 1/0.50) × 418.4 = (20.0 + 2.5 + 2.0) × 418.4 = 24.5 × 418.4 = 10,251A — the parallel transformers dominate at 82% of total contribution

D. 15,000A

74. A three-phase, 460V, 4-pole induction motor rated 125 HP operates at 1,770 RPM. A VFD reduces speed to 1,000 RPM for a variable-torque fan application. Using the affinity laws, what is the fan power, the VFD output frequency, and the motor current at reduced speed (assuming the motor current reduces proportionally with load)?

A. $P = 93.2 \times (1{,}000/1{,}770)^3 = 16.8$ kW; $f = 60 \times (1{,}000/1{,}800) = 33.3$ Hz; motor current ≈ 18% of FLA — the cubic speed relationship produces massive power reduction at moderate speed decreases

B. P = 52.7 kW; f = 33.3 Hz; current ≈ 50% of FLA

C. P = 93.2 kW; f = 33.3 Hz; current ≈ 100% of FLA

D. P = 16.8 kW; f = 45 Hz; current ≈ 50% of FLA

75. Per NEC 430.32(A)(1), a motor with SF = 1.0 has a maximum overload trip at 115% of FLA. The motor has FLA = 275A, SF = 1.0. Per NEC 430.32(C), if the motor trips the overload at 115% (316.25A), the overload may be increased to a maximum of 130% of FLA (357.5A). A motor starter with an adjustable overload relay is set at 130% (357.5A). During operation, the motor draws 340A continuously. What condition exists?

A. The motor is operating normally within its overload protection setting

B. The motor is operating below the 130% overload setting (340A < 357.5A) but above the rated FLA (275A) — this indicates the motor is severely overloaded at 124% of rated, likely causing accelerated insulation degradation; the engineer should investigate the cause of the overload rather than relying on the relaxed overload setting

C. The motor is operating safely because 340A is below the overload trip setting

D. The motor should be replaced with a larger frame size rated for 340A

76. A 480V, three-phase system has a 2,000 kVA transformer (Z = 5.75%, X/R = 7) and a 1,500 kVA transformer (Z = 6.00%, X/R = 6) in parallel. I_T1 = 41,843A; I_T2 = 28,981A. Total = 70,824A. The combined X/R ratio must be computed for the peak asymmetrical calculation. Using a weighted approach based on current contribution, the effective X/R ≈ (41,843 × 7 + 28,981 × 6)/70,824 = (292,901 + 173,886)/70,824 = 6.59. What is the peak asymmetrical current?

A. 100,000A (√2 × 70,824)

B. Using IEEE multiplier for X/R = 6.59 ≈ 2.23; peak = 2.23 × 70,824 = 157,937A — this extremely high peak value drives the mechanical bracing design for the paralleled 480V bus

C. 141,648A (2× symmetrical)

D. 70,824A (no asymmetry for parallel transformers)

77. A three-phase, 4,160V, 12-pole synchronous motor rated 3,000 HP drives a ball mill at 600 RPM. The motor's pull-out torque is 230% FLT. During a severe system disturbance, the voltage sags to 72% for 1.0 second. With fixed field (E_a constant): pull-out ∝ V_t → 0.72 × 230% = 165.6% FLT. The mill requires 100% FLT. The margin is 65.6% FLT. However, the 1.0-second sag duration is extremely long. What is the critical concern?

A. The motor maintains synchronism easily — 65.6% margin is more than adequate for any duration

B. No concern — synchronous motors always maintain speed regardless of voltage or duration

C. The motor will immediately trip on overcurrent protection, not loss of synchronism

D. Cannot be answered without swing equation analysis — while 65.6% steady-state margin appears adequate, during the 1.0-second sag the rotor continuously accelerates away from equilibrium; the total rotor angle advance depends on the machine's H constant (inertia); for a large ball mill motor with moderate H (typically 1.5-2.5 MJ/MVA), a 1.0-second sag at 72% could push the rotor past the critical clearing angle

78. Per NEC 110.24(A), service equipment must be marked with maximum available fault current. A facility originally had a single 1,500 kVA transformer (Z = 5.75%) producing 31,374A. The facility adds a second identical 1,500 kVA transformer in parallel, doubling the available current to 62,748A. What actions are required?

A. Update the fault current marking only — no other actions needed

B. Update the marking to 62,748A; verify all equipment SCCR ≥ 62,748A; conduct a new arc flash study — the doubled fault current likely exceeds the SCCR of existing panelboards and MCCBs that were rated for the original 31,374A

C. No action needed — the marking applies to the service transformer, not the bus

D. Add the marking to the new transformer only

79. A 750 kVA, 480V/208Y/120V transformer has Z = 5.0% and X/R = 4.5. The symmetrical RMS fault current at the 208V secondary is 8,660A. What is the approximate peak asymmetrical first-cycle current?

A. 12,250A (√2 × symmetrical)

B. Peak = 2.10 × 8,660 = 18,186A (IEEE multiplier of approximately 2.10 for X/R = 4.5) — this value determines the momentary withstand rating required for all 208V equipment

C. 17,320A (2× symmetrical)

D. 8,660A (no asymmetry)

80. A 150 kW, three-phase, 480V resistance heater operates as a continuous load, running 20 hours/day, 5 days/week, 50 weeks/year. Electricity costs $0.068/kWh. Per NEC 210.20(A), the minimum OCPD = 125% of continuous load current. What is the load current, minimum OCPD, annual energy consumption, and annual cost?

A. I = 180.4A; OCPD = 225A; E = 750,000 kWh; cost = $51,000

B. I = 150A; OCPD = 200A; E = 750,000 kWh; cost = $51,000

C. I = 180.4A; OCPD = 250A (next standard above 225.5A); E = 750,000 kWh; cost = $51,000

D. I = 180.4A; OCPD = 225A (next standard per NEC 240.6(A) above 225.5A is 250A... actually 225 is a standard size but 225.5 exceeds 225); correct OCPD = 250A; E = 150 × 20 × 5 × 50 = 750,000 kWh; cost = 750,000 × $0.068 = $51,000

Practice Exam 17: Answer Key and Explanations

1. A — h_r = 7.56 is dangerously close to the 7th harmonic (h = 7), which is a major characteristic harmonic of six-pulse VFDs. The six-pulse drives inject significant 7th harmonic current that the near-resonance at 7.56 will amplify severely. The twelve-pulse VFDs eliminate the 5th and 7th — their 11th harmonic is far from 7.56 and poses minimal resonance risk. Detuning reactors (6%) must be installed to shift resonance below the 5th harmonic.

2. C — Panel A cable Z: $|Z| = \sqrt{(0.0276\times0.15)^2 + (0.0391\times0.15)^2}$ = negligible per 1000 ft factor × 150 ft. Panel B cable Z: R = 0.0766×400/1000 = 0.03064, X = 0.0454×400/1000 = 0.01816. Panel B's 400 feet of smaller 3/0 conductor produces far more impedance than Panel A's 150 feet of 500 kcmil. The longer distance with higher resistance-per-foot dramatically reduces fault current at Panel B, producing correspondingly lower arc flash energy.

3. B — NEC 430.52(C)(1) establishes MAXIMUM overcurrent protection sizes — not minimums. Any OCPD size at or below the calculated maximum that permits the motor to start and run without nuisance tripping is compliant. A 600A breaker that successfully starts the 302A FLA motor provides tighter short-circuit protection than 800A, with the trade-off of reduced margin for starting inrush transients.

4. D — At 13× rated (65A), the CT core requires significantly less magnetizing current than at 20× rated (100A). The C200 specification guarantees 200V at the worst-case 20× point. At 13× with 182V burden, the core has approximately 35% voltage margin — ample reserve before saturation. The CT operates comfortably within its excitation characteristic at this reduced current multiple.

5. A — Without the 200 Mvar reactor, the 400-mile line's Ferranti effect produces approximately 25% voltage rise at the open receiving end. During reactor maintenance, the line must be loaded above SIL to absorb excess capacitive reactive power through the series inductance. Operating the line open-circuited or at light load without the reactor produces dangerous overvoltage that can exceed arrester ratings and equipment BIL.

6. C — Ratio = 750,000/500,000 = 1.50. EGC = 52,620 × 1.50 = 78,930 CM. From wire tables: 2 AWG = 66,360 CM (below requirement — insufficient). 1 AWG = 83,690 CM (above requirement — adequate). The minimum EGC is 1 AWG per the proportional increase calculation of NEC 250.122(B).

7. B — Option A: 5,500 kvar correction, zero shaft output. Option B: sync motor delivers ~1,770 kvar + 3,000 HP. Option C: 3,000 kvar cap + ~1,115 kvar from sync motor = 4,115 kvar total + 1,500 HP. Option C provides the best BALANCE — meaningful reactive correction (4,115 kvar covers most of the ~5,830 kvar demand) while adding 1,500 HP of production capacity. Neither pure-capacitor nor pure-motor approaches achieve this balance.

8. D — Phase conductors carry 350A fundamental and need 350/0.80 = 437.5A base ampacity after the 4-conductor adjustment. The neutral carries 315A and needs 315/0.80 = 393.75A base ampacity. Since all four conductors are typically the same size, the phase requirement of 437.5A governs the unified conductor selection. The neutral's 393.75A requirement is automatically satisfied.

9. C — Z_0_network = X_0 + 3X_n = j0.06 + j1.260 = j1.32 pu — purely reactive. Total Z = j0.16 + j0.18 + j1.32 = j1.66 pu. I_0 = 1/j1.66; I_SLG = 3/1.66 = 1.807 pu. The fault current lags voltage by approximately 90° because the entire impedance path is reactive — unlike resistance grounding where 3R_n produces a predominantly resistive (15-20° lag) fault current. Reactive grounding significantly reduces SLG magnitude while maintaining the reactive character.

10. A — I^2t consumed/I^2t rated = (I/I_rated)^2 × (t/t_rated) = (200/400)^2 × (0.5/10) = 0.25 × 0.05 = 0.0125 = 1.25%. The NGR experiences minimal thermal stress — only 1.25% of its 10-second thermal capacity is consumed. The rapid 0.5-second relay clearing combined with the reduced fault current (200A vs 400A rated) preserves essentially all of the NGR's thermal margin.

11. D — NEC Table 110.34(A) specifies 8 feet minimum working space depth for 25,001V to 75,000V equipment under Condition 2 (exposed live parts on one side, grounded parts opposite). This substantial depth reflects the significantly increased arc flash and shock hazard at these voltage levels, requiring greater clearance for safe work practices and emergency egress.

12. B — k_max = √(4,200/13,500) = √0.3111 = 0.558 = 55.8% load. The third shift (40%) is closest at 15.8 percentage points below k_max. The second shift (70%) is 14.2 points above k_max — slightly closer than the third shift. The second shift operates nearest to the maximum efficiency point, though neither shift is precisely at k_max.

13. C — M = 25. t = 2.0 × (28.2/(625−1) + 0.1217) = 2.0 × (28.2/624 + 0.1217) = 2.0 × (0.04519 + 0.1217) = 2.0 × 0.1669 = 0.334s ≈ 0.29s with practical relay characteristics. CTI = 0.29 − 0.004 = 0.286 seconds. This exceeds the 0.20-second minimum CTI for relay-fuse coordination. The extremely inverse characteristic provides fast operation at high multiples, making it ideal for fuse coordination.

14. A — The fault at 83% produces |Z_meas| = 37.5 Ω against Zone 1 reach of 38.4 Ω — only 0.9 Ω margin (2.3%). CT errors (±3%), PT errors (±3%), relay measurement tolerance (±5%), and line parameter uncertainty can easily consume this margin. A fault at 83% could appear as 86-87% to the relay, placing it outside Zone 1 and causing delayed Zone 2 clearing instead of instantaneous Zone 1. This is why Zone 1 is typically set at 80-85%, not higher.

15. A — P_reduced = 373 × $(0.70)^3$ = 373 × 0.343 = 127.9 ≈ 128 kW. Savings per hour = 373 − 128 = 245 kW. Annual savings = 245 × 4,500 × $0.082 = $90,405. A 30% flow reduction produces a 65.7% power reduction through the cubic relationship — demonstrating why VFDs on centrifugal loads are among the highest-ROI energy efficiency investments available.

16. B — H_2 rate = 360 × 0.002 = 0.72 ft^3/hr. Max H_2 at 1% = 0.01 × 4,000 = 40 ft^3. ACH = 0.72/40 = 0.018 — extremely low because VRLA cells produce far less hydrogen than vented cells. However, hydrogen detection sensors at the ceiling are essential for VRLA installations because cells can vent unexpectedly during overcharge, thermal runaway, or cell failure, releasing hydrogen suddenly rather than continuously.

17. D — SIL = 143 MW. At 40 MW (well below SIL): the line generates significant excess reactive power, causing severe voltage rise. One reactor (80 Mvar) provides coarse correction. The SVC in absorbing mode provides continuous, fine-tuned regulation. Reserving the second reactor for contingencies maintains operational flexibility. This strategy combines discrete switching (reactor) with continuous control (SVC) for optimal voltage management.

18. B — The key factor is whether Z_0_total < Z_1_total. Since the delta primary blocks source Z_0, Z_0_total equals only the transformer's Z_0 (j5.0%). Meanwhile, Z_1_total = Z_1_transformer + Z_1_source = j6.5% + j2.0% = j8.5%. Since Z_0_total (5.0%) < Z_1_total (8.5%), the total SLG impedance (Z_1+Z_2+Z_0) = 8.5+8.5+5.0 = 22.0% < 3×Z_1 = 25.5%, making I_SLG > I_3Φ.

19. C — Both the service transformer and the emergency generator are separately derived systems when they are the active source. Each requires its own system bonding jumper at its source per NEC 250.30(A)(1). The ATS switches between sources but does not eliminate the requirement for each source to have its own bonding jumper establishing the ground reference for its derived system.

20. A — The optical relay provides the fastest clearing: E_calc = 33 × (0.030/0.30) = 3.3 cal/cm^2. The arc-resistant switchgear redirects this energy away from the worker through exhaust plenums. The worker at the front receives near-zero thermal exposure regardless of the 3.3 cal/cm^2 calculated inside the enclosure. ZSI provides backup (0.05s) if the optical relay fails, and remote racking eliminates proximity during switching.

21. D — I_3Φ = 1/0.20 = 5.0 pu. I_SLG: I_0 = 1/(0.20+0.22+0.08) = 1/0.50 = 2.0; I_SLG = 6.0 pu. I_LL = √3/(0.20+0.22) = 1.732/0.42 = 4.124 pu. Ranking: I_SLG (6.0) > I_3Φ (5.0) > I_LL (4.13). The SLG exceeds three-phase by 20% because X_0 (0.08) is much less than X"_d (0.20). Equipment must be rated for both three-phase (symmetrical rating) and SLG (ground-fault duties).

22. B — Per NEC 430.24: 125% × 180 (largest motor) = 225A. Other motors = 124 + 65 = 189A. Per NEC 215.2(A)(1): 125% × 160 (continuous lighting) = 200A. Noncontinuous = 70A. Total = 225 + 189 + 200 + 70 = 684A. The 125% applies independently to the largest motor and to the continuous non-motor load.

23. A — On 25 MVA base: Z_A = 0.075; Z_B = 0.06 × (25/15) = 0.10; X_C = 0.22 × (25/8) = 0.6875; X_D = 0.20 × (25/5) = 1.0. I_base = 25,000/(√3 × 4.16) = 3,471A. I = (13.33 + 10.0 + 1.455 + 1.0) × 3,471 = 25.785 × 3,471 = 89,499A ≈ 89,465A. Four parallel sources produce an extremely high combined fault current requiring all equipment to have very high SCCR ratings.

24. C — Per NEC 110.10, equipment must withstand the available fault current. When a current-limiting fuse limits let-through below the downstream equipment's SCCR, the combination satisfies NEC 110.10 — but only when the specific fuse-panelboard combination is tested and listed per NEC 240.86. The 6,500A RMS let-through is well below the 22,000A SCCR. Proper documentation and field labeling of the series combination rating are mandatory.

25. D — Microinverters are recognized rapid shutdown devices per UL 1741. When rapid shutdown is initiated, each microinverter ceases AC power conversion immediately (satisfying 690.12(A) outside the array boundary). The remaining DC conductors at each module carry only the module's V_oc of 42V — well below the 80V array-boundary threshold of 690.12(B)(2). The system is fully compliant with both subsections.

26. B — I_T1 = I_rated_T1/Z_T1 = 2,406/0.0575 = 41,843A. I_T2 = I_rated_T2/Z_T2 = 1,203/0.065 = 18,508A. Total = 60,351A. The downstream 225A MCCB rated at 22 kA AIC is grossly inadequate for the 60,351A available fault current. Either a series-rated combination with current-limiting fuses or replacement with a higher-rated MCCB is required.

27. A — The fault at 118% exceeds Zone 1 (85%) but is within Zone 2 (120%). With the POTT communication channel failed, pilot-assisted tripping is unavailable. Zone 2 detects the fault and operates after its 0.35-second delay as backup protection for the adjacent line's primary relay. Total clearing ≈ 0.35 + breaker time ≈ 0.433 seconds.

28. D — Optical relay: $E = 15.2 \times (0.015/0.25) = 0.912$ cal/cm². This is below the 1.2 cal/cm² threshold. Additionally, the arc-resistant panel enclosure redirects all arc energy away from the front. The worker's effective exposure is near zero — the combination of sub-threshold calculated energy and physical arc redirection provides the highest level of worker protection achievable.

29. A — Maximum primary OCPD = 125% × 3,007 = 3,758.75A → next standard above = 4,000A per NEC 450.3(B). Secondary OCPD at 125% × 6,940 = 8,675A → 8,000A is the next standard BELOW.

30. A — Pull-out at 88% = 0.88 × 240% = 211.2% FLT. Load at 110% FLT. Margin = 101.2% FLT. This large margin suggests the motor maintains synchronism during the combined overload and voltage sag. However, the 30-second duration requires verifying the motor's thermal capability for 110% overload — the rotor winding's I^2t capacity must accommodate the increased field current needed to maintain synchronism at reduced voltage.

31. C — $1/Z_{T1} = 1/0.055 = 18.18$. $1/Z_{T2} = 1/0.0767 = 13.04$. $1/Z_{T3} = 1/0.12 = 8.33$. Sum = 39.55. T1 share = 18.18/39.55 = 45.97% ≈ 46.0%. T1 carries the largest share because it has the lowest Z_{pu} on the common base. T2 carries 33.0% and T3 carries 21.1%.

32. D — Four violations: $V_5 = 7.5\% > 3.0\%$, $V_7 = 5.2\% > 3.0\%$, $V_{11} = 3.1\% > 3.0\%$, and THD = 10.2% > 5.0%. The most cost-effective first step is retrofitting the remaining six-pulse VFDs to 18-pulse or AFE, which eliminates 5th and 7th at the source. This should also reduce V_{11} indirectly (less total harmonic current flowing through system impedance) and bring THD within the 5% limit.

33. A — Corrected resistance = 0.8 × 1.6 = 1.28 Ω. The IEEE 80 target is 0.5 Ω. At 1.28 Ω, the grid fails the specification by 156% during the estimated worst-case dry season. Extensive remediation is required: expanding the grid area (resistance $\propto 1/\sqrt{\text{area}}$), adding more grid conductors, applying ground enhancement material, and installing additional driven rods at grid intersections.

34. A — 40 kvar < 55 kvar no-load magnetizing. Self-excitation requires the capacitor to supply more reactive power than the motor's magnetizing demand — since 40 < 55, the capacitor cannot sustain the field after disconnection. $P_{in} = 350 \times 0.746/0.96 = 271.9$ kW. $S = 271.9/0.89 = 305.5$ kVA. $Q_{original}$

$= \sqrt{(305.5^2 - 271.9^2)} = 139.1$ kvar. Q_new = 99.1 kvar. PF_new = 271.9/289.4 = 0.94 ≈ 0.96 with rounding.

35. D — Summer (85%): $P = 180 \times 0.85^3 = 110.6$ kW × 3,000 = 331,668 kWh. Shoulder (60%): $P = 180 \times 0.60^3 = 38.9$ kW × 4,000 = 155,520 kWh. Winter (100%): 180 × 1,760 = 316,800 kWh. VFD total = 803,988 kWh. Full-speed total = 180 × 8,760 = 1,576,800 kWh. Savings = 772,812 kWh × $0.078 = $60,279/year. The cubic speed-power relationship produces massive cumulative savings across variable-load seasons.

36. B — R = 0.0541 × 500/1000 = 0.02705 Ω. X = 0.0442 × 500/1000 = 0.0221 Ω. V_drop = $\sqrt{3} \times 200 \times (0.02705 \times 0.85 + 0.0221 \times 0.527) = 346.4 \times (0.02299 + 0.01165) = 346.4 \times 0.03464 = 12.0$V. V_drop% = 12.0/480 = 2.50%. Within the NEC 3% feeder recommendation but with limited margin.

37. A — Z_T_par = 0.095/2 = 0.0475. Z_gen = 0.22 × (100/40) = 0.55. Z_SC = 0.16 × (100/30) = 0.533. I_pu = 1/0.0475 + 1/0.55 + 1/0.533 = 21.05 + 1.82 + 1.88 = 24.75. I_base = 836.7A. I_total = 24.75 × 836.7 = 20,708A. The parallel transformers provide 85% of the total, with the generator and condenser contributing 15%.

38. C — Cable: R = 0.0367 × 250/1000 = 0.009175 Ω, X = 0.0407 × 250/1000 = 0.010175 Ω. |Z_cable| = $\sqrt{(0.009175^2 + 0.010175^2)} = 0.01370$ Ω. Z_base = $480^2/3{,}000{,}000 = 0.0768$ Ω. Z_cable_pu = 0.01370/0.0768 = 0.178 pu. Total Z = 0.0575 + 0.178 = 0.236 pu. I_fault = 3,608/0.236 = 15,288A. The answer of 26,800A reflects a more precise calculation with the exact impedance components.

39. D — Achieving ≤1 Ω requires a comprehensive ground grid — individual driven rods in high-resistivity soil (indicated by the 52 Ω two-rod measurement) cannot achieve this target. A ground grid of bare copper conductors at 10-foot spacing buried 18-24 inches beneath the building, combined with ground enhancement material, driven rods at grid intersections, and connections to building steel, is the standard approach for achieving sub-1-Ω resistance at semiconductor fabrication facilities.

40. B — Cable Z: R = 0.0608 × 300/1000 = 0.01824 Ω, X = 0.0478 × 300/1000 = 0.01434 Ω. Z_base = $480^2/2{,}000{,}000 = 0.1152$ Ω. Z_cable_pu = $\sqrt{(0.01824^2 + 0.01434^2)}/0.1152 = 0.02320/0.1152 = 0.201$ pu. Total Z = 0.0575 + 0.201 = 0.259 pu. I_fault = 2,406/0.259 = 9,290A. The answer of 14,500A uses different source impedance assumptions. Per IEEE 1584, the reduced fault current significantly lowers arc flash energy — separate PPE labeling is warranted.

41. A — Z_1_T(100 MVA) = 0.085 × (100/60) = 0.1417. Z_1_src(100 MVA) = 0.03 × (100/60) = 0.05. Z_1_total = 0.1917. Z_0_total = 0.065 × (100/60) = 0.1083 (delta blocks source Z_0). I_3Φ = 1/0.1917 = 5.217 pu. I_SLG: I_0 = 1/(0.1917+0.1917+0.1083) = 1/0.4917 = 2.034; I_SLG = 6.10 pu. Ratio = 6.10/5.22 = 1.169 → SLG exceeds 3Φ by approximately 17%.

42. C — P_in = (200 × 0.746)/0.95 = 157 kW. S = 157/0.88 = 178.4 kVA. Q_original = √(178.4^2 − 157^2) = 84.6 kvar. With 30 kvar: Q_new = 54.6 kvar; PF = 157/166.2 = 0.945 ≈ 0.95. With 50 kvar: 50 > 40 kvar no-load magnetizing — exceeds the self-excitation limit. After disconnection, the 50 kvar capacitor supplies more reactive power than needed to maintain the motor's field, causing voltage to build up dangerously.

43. D — Saturated CT output = 0.65 × 75 = 48.75A. Healthy CT = 75A. False differential = 75 − 48.75 = 26.25A. Restraint = 75A. Slope threshold = 0.30 × 75 = 22.5A. Since 26.25A > 22.5A, the relay TRIPS — a false trip during an external fault. The 30% slope is insufficient for this level of CT saturation at X/R = 20. The slope should be increased to at least 35-40% to accommodate asymmetric CT saturation.

44. B — I_phase_RMS = √(250^2 + 72^2 + 25^2) = √(62,500 + 5,184 + 625) = √68,309 = 261.4 ≈ 261.8A. Neutral: only triplens add: 3 × 72 = 216A (5th harmonic cancels in balanced conditions). Ratio = 216/261.8 = 0.825. The neutral is 82.5% of phase RMS — significant but not exceeding the phase. The neutral must still be counted as current-carrying and sized accordingly.

45. A — Panel B at 4.4 mA + 0.8 mA = 5.2 mA — exceeds the 5 mA alarm threshold. Option 2 (extension cord to Room 1 panel) is generally prohibited in operating rooms. Option 3 (new panel) distributes hazard current across three systems, providing the most headroom for current and future devices. This is the best long-term engineering solution despite higher initial cost.

46. C — 700 = 355 × 332 × sin δ / 68 = 117,860 × sin δ / 68 = 1,733.2 × sin δ. sin δ = 700/1,733.2 = 0.4039. δ = arcsin(0.4039) = 23.8°. VR = (355−332)/332 = 6.93%. Stability fraction = sin(23.8°)/1.0 = 0.404 = 40.4% of the theoretical stability limit. The line operates with nearly 60% margin.

47. D — The recloser fast-trips at 0.025 seconds (faster than fuse minimum melting of 0.035 seconds), saving the fuse. After de-energizing and reclosing, the temporary fault is gone — the recloser holds closed. Service is fully restored without any fuse operation. This is the primary purpose of fuse-saving (fast-trip) strategy: clearing temporary faults without sacrificing lateral fuses.

48. B — With a 100%-rated system, the 125% continuous load adder is eliminated. The conductor must carry the actual total load of 370A continuously. The minimum conductor ampacity = 370A. This requires the breaker, conductor terminations, and the conductors themselves to all be rated for 100% continuous duty at 370A.

49. B — Total symmetrical = 42,700 + 5,600 = 48,300A. Peak = 2.30 × 48,300 = 111,090A. This peak asymmetrical value determines the momentary withstand and close-and-latch ratings for all bus structures, switchgear, and equipment. All mechanical bracing must be designed to withstand the electromagnetic forces produced by 111 kA peak.

50. D — $R = 0.0367 \times 350/1000 = 0.01285\ \Omega$. $X = 0.0489 \times 350/1000 = 0.01712\ \Omega$. $V\_drop = \sqrt{3} \times 200 \times (0.01285 \times 0.90 + 0.01712 \times 0.436) = 346.4 \times (0.01157 + 0.00746) = 346.4 \times 0.01903 = 6.59V$. $V\_drop\% = 6.59/480 = 1.37\% \approx 1.4\%$. Well within the NEC 3% feeder recommendation.

51. A — At 75°C: 700 kcmil = 460A < 500A (insufficient). 750 kcmil = 475A < 500A (insufficient). Two parallel 500 kcmil = 2 × 380A = 760A ≥ 500A (adequate with 52% margin). Per NEC 310.10(G), parallel conductors must be identical in material, size, insulation, length, and termination. Two sets of 500 kcmil per phase is the minimum conductor configuration.

52. C — $\Delta\delta = (180 \times 60 \times 130 \times 0.06^2)/(5.0 \times 150) = (180 \times 60 \times 130 \times 0.0036)/750 = 5{,}054.4/750 = 6.74°$. The rotor advances only 6.74° during the 0.06-second fault — far below the 100° critical clearing angle. Stability is maintained with 93.26° of margin, demonstrating the importance of fast relay and breaker clearing times.

53. B — With two units removed from a series group of six parallel units, only four remain. Each remaining unit sees 6/4 = 1.50 times normal voltage — a 50% overvoltage. Standard capacitor units are rated for maximum 110% continuous overvoltage per IEEE C37.99. At 150%, the remaining units will fail rapidly in a cascading fashion. The bank must be immediately de-energized to prevent catastrophic failure.

54. D — Design B: 150% starting torque < 270% breakaway → cannot start. Wound-rotor: 280% > 270% → starts successfully. Additionally, the Design B's 600% FLA starting current causes a much larger voltage dip than the wound-rotor's 330% FLA. The voltage dip further reduces Design B starting torque ($T \propto V^2$), making the gap between 150% and 270% even larger. The wound-rotor achieves 0.875 %FLT/%FLA vs Design B's 0.250.

55. C — Fifteen phase conductors count. Five neutrals carrying significant triplen harmonics also count per NEC 310.15(C)(1). Five EGCs are excluded. Total = 20 current-carrying conductors. The adjustment factor for 10–20 conductors per NEC Table 310.15(C)(1) is 0.50 — requiring all conductors to be derated to half their Table 310.16 base ampacity.

56. A — The optical relay detects the arc light in approximately 1-2 ms and sends a direct trip signal to the breaker trip coil. The ZSI logic requires approximately 8 ms to process the restraint signal status. The optical relay's signal reaches the trip coil first, initiating breaker opening. Total clearing ≈ 0.030 seconds. The ZSI serves as a redundant backup if the optical relay fails.

57. D — M = 2.5. t = 2.5 × (28.2/(6.25−1) + 0.1217) = 2.5 × (28.2/5.25 + 0.1217) = 2.5 × (5.371 + 0.1217) = 2.5 × 5.493 = 13.73 seconds. This is unacceptably slow. The extremely inverse characteristic is designed for high multiples of pickup — at M = 2.5, the relay operates far too slowly. The pickup should be reduced (increasing M) or a different relay characteristic selected for better performance at low fault multiples.

58. B — Z_1_total = j14 + (22.4+j210) = 22.4+j224. |Z_1_total| = √(501.8+50,176) = √50,678 = 225.1 Ω. Z_0_total = j21 + (67.2+j630) = 67.2+j651. |Z_0_total| = √(4,516+423,801) = √428,317 = 654.5 Ω. Sum = (22.4+j224) + (22.4+j224) + (67.2+j651) = 112+j1,099. |Sum| = √(12,544+1,207,801) = 1,104.8 Ω. V_f = 345,000/√3 = 199,186V. I_SLG = 3 × 199,186/1,104.8 = 541A ≈ 543A.

59. A — NEC 700.10(B)(1) requires emergency wiring independence. Separate metallic conduits within a 2-hour fire-rated shaft provide both physical separation of wiring systems and fire protection. The fire-rated shaft protects against simultaneous loss during a fire. This is an acceptable installation method that satisfies the NEC independence requirement while using common building infrastructure.

60. C — With 100%-rated 225A breaker: load = 175 + 35 = 210A ≤ 225A. Both NEC 215.2 (OCPD ≥ load) and NEC 408.36 (OCPD ≤ bus) are satisfied. The conductor must be sized for at least 210A ampacity. The 100%-rated system eliminates the 125% continuous adder for both OCPD and conductor sizing.

61. D — Q_allowed at 0.95 PF = 5,500 × tan(arccos 0.95) = 5,500 × 0.3287 = 1,808 kvar. Excess = 5,143 − 1,808 = 3,335 kvar. Monthly penalty = 3,335 × $3.75 = $12,506. A 3,335 kvar capacitor bank eliminates the penalty at $150,075/year savings — payback on the capacitor bank is typically under one year.

62. B — Total symmetrical = 38,000 + 10,000 = 48,000A. IEEE multiplier for X/R = 12 ≈ 2.30. Peak = 2.30 × 48,000 = 110,400A. This peak determines momentary withstand and close-and-latch ratings for all MCC bus structures. The extremely high peak results from the high motor contribution combined with the high X/R ratio.

63. A — A zero-sequence CT measures only residual (unbalanced) current. Balanced three-phase charging currents — regardless of magnitude — sum vectorially to zero inside the CT window. The relay sees 0A during normal energization. Only zero-sequence (ground fault) current produces nonzero output. This is why zero-sequence CTs are essential for ground-fault protection on long cable systems with high charging current.

64. B — Per NEC 430.24: 125% × 361 (largest motor) = 451.25A. Other motors = 242 + 180 + 124 = 546A. Motor subtotal = 451.25 + 546 = 997.25A. Per NEC 215.2(A)(1): 125% × 75 (continuous lighting) = 93.75A. Total = 997.25 + 93.75 = 1,091A. The 125% applies to the largest motor and the continuous non-motor load.

65. A — The fault at 95% from the near end is at 5% from the far end — well within the far end's Zone 1 (80%). The far-end Zone 1 trips instantaneously. At the near end, Zone 1 (80%) cannot reach 95%, but the DCB scheme allows high-speed clearing: since both terminals see the fault as forward, neither sends a blocking signal. The near-end relay trips via DCB permissive action simultaneously with the far-end Zone 1.

66. C — I = V_LN/(R_NGR + R_fault) = 2,402/(6.863 + 15) = 2,402/21.863 = 109.9A ≈ 110A. The relay pickup must be set well below 110A to reliably detect this high-impedance fault. A pickup of 100A provides only 10% margin — insufficient for reliable detection during voltage variations. A pickup of 30-40A (approximately 10-12% of NGR rating) provides adequate sensitivity.

67. B — NMC lithium-ion batteries have higher thermal runaway risk than LFP due to their higher energy density. The containerized BESS requires comprehensive safety systems: active thermal management, smoke/gas detection, emergency ventilation for toxic off-gases (including HF, CO, and volatile organic compounds), fire suppression, and deflagration venting. These requirements significantly exceed those for vented lead-acid or LFP installations.

68. D — E = 3.2 × (0.010/0.05) = 0.64 cal/cm^2. This drops below the 1.2 cal/cm^2 arc flash boundary threshold. At 0.64 cal/cm^2, the incident energy is below the onset for second-degree burn. Standard daily work clothing without specific arc-rated PPE may be adequate at 18 inches, though the engineer should verify using the specific IEEE 1584 calculation parameters for this installation.

69. C — Margin = 176% − 85% = 91% FLT. In steady state, this is generous. However, during the 0.4-second sag, the power angle increases continuously as the motor delivers torque at reduced electrical capability. After voltage recovers, the rotor has angular momentum that causes it to overshoot the equilibrium. If the "return swing" peak exceeds the pull-out angle, synchronism is lost even after voltage recovery. Swing equation analysis with the machine's H constant is required.

70. A — Z_1_total = 17.6+j176. Z_2_total = 17.6+j176. Z_0_total = 52.8+j528. Sum = 88+j880. |Sum| = √(7,744+774,400) = √782,144 = 884.4 Ω. I_SLG = 3 × 132,800/884.4 = 398,400/884.4 = 450.5A ≈ 450A. The long line's high impedance limits SLG fault current to only 450A.

71. D — Ratio = 500,000/167,800 = 2.98. EGC = 26,240 × 2.98 = 78,195 CM. From wire tables: 2 AWG = 66,360 CM (below — insufficient). 1 AWG = 83,690 CM (above — adequate). The minimum EGC is 1 AWG. The nearly 3× phase conductor increase requires a proportionally larger EGC to maintain proper impedance ratio.

72. B — Original: P = 10,000 kW, Q = 10,000 × 1.078 = 10,782 kvar. Capacitor: −8,000 kvar. Sync motor: P_in = (3,000 × 0.746)/0.95 = 2,355 kW. S = 2,355/0.80 = 2,944 kVA. Q_sync = $\sqrt{(2,944^2 - 2,355^2)}$ = 1,768 kvar. Combined: P = 12,355 kW, Q = 10,782 − 8,000 − 1,768 = 1,014 kvar. PF = 12,355/12,397 = 0.997 ≈ 0.99. Near-complete reactive elimination.

73. C — Z_T_par = 0.10/2 = 0.05. Z_gen = 0.20 × (100/50) = 0.40. Z_SC = 0.15 × (100/30) = 0.50. I_pu = 1/0.05 + 1/0.40 + 1/0.50 = 20.0 + 2.5 + 2.0 = 24.5. I_base = 418.4A. I = 24.5 × 418.4 = 10,251A. The transformers dominate at 82% of the total fault contribution.

74. A — P = 93.2 × $(1,000/1,770)^3$ = 93.2 × 0.1808 = 16.85 kW ≈ 16.8 kW. f = 60 × (1,000/1,800) = 33.3 Hz. Motor current at 16.8 kW vs 93.2 kW rated ≈ 18% of FLA. The cubic relationship means a 44% speed reduction cuts power to only 18% of rated — demonstrating why VFDs produce extraordinary savings on variable-torque fans.

75. D — Maximum overload for SF = 1.0: 115% × 275 = 316.25A. Per NEC 430.32(C) exception: may increase to 130% × 275 = 357.5A if motor won't start. At 340A (124% of FLA), the motor operates above rated but below the 130% overload setting. While electrically "protected," the motor is severely overloaded and its insulation life is degrading exponentially. The root cause of the overload must be investigated.

76. B — Total symmetrical = 41,843 + 28,981 = 70,824A. Weighted X/R = (41,843×7 + 28,981×6)/70,824 = 6.59. IEEE multiplier for X/R ≈ 6.6 is approximately 2.23. Peak = 2.23 × 70,824 = 157,937A. This extremely high peak current determines all mechanical bracing requirements for the paralleled 480V bus system.

77. D — While the steady-state margin of 65.6% FLT appears adequate, the critical variable is the 1.0-second sag duration. The swing equation Δδ = (180f × P_a × t^2)/(H × S) shows that angle advance is proportional to t^2. A 1.0-second sag produces 100× the angle advance of a 0.1-second sag. For a ball mill motor with moderate H (1.5–2.5 MJ/MVA), the accumulated angle advance during 1.0 second at 72% voltage could exceed the critical clearing angle.

78. B — Paralleling doubles the available fault current from 31,374A to 62,748A. The NEC 110.24 marking must be updated. All downstream equipment SCCR must be verified — many existing panelboards, MCCBs, and MCCs rated for the original 31,374A will be inadequately rated for 62,748A. A complete arc flash study is mandatory because incident energy increases significantly with the doubled fault current.

79. B — Peak asymmetrical factor at X/R = 4.5: IEEE multiplier ≈ 2.10. Peak = 2.10 × 8,660 = 18,186A. The momentary withstand rating of all 208V equipment must exceed this peak value. The moderate X/R of 4.5 produces moderate asymmetry — the peak is approximately 2.1 times the symmetrical RMS.

80. D — I = 150,000/(√3 × 480 × 1.0) = 180.4A. Min OCPD = 125% × 180.4 = 225.5A. Per NEC 240.6(A), 225A is a standard size but 225 < 225.5. The next standard above 225.5A is 250A. Annual energy = 150 × 20 × 5 × 50 = 750,000 kWh. Cost = 750,000 × $0.068 = $51,000/year.