PRACTICE EXAM 18: PE POWER SIMULATION (80 QUESTIONS)

---

1. A 13.8 kV industrial bus has a three-phase fault level of 550 MVA. The bus serves a combination of 4,500 HP of six-pulse VFDs and 3,000 HP of active front-end (AFE) VFDs. A 9,000 kvar capacitor bank is proposed for power factor correction. The resonant harmonic order is h_r = √(550,000/9,000) = 7.82. The AFE drives inject negligible low-order harmonics because their input current waveform is nearly sinusoidal. Which harmonic source dominates the resonance risk, and what detuning is recommended?

A. Both six-pulse and AFE drives contribute equally to resonance risk at h_r = 7.82

B. The AFE drives dominate because their switching frequency harmonics are near h_r = 7.82

C. No detuning is needed because the AFE drives cancel the six-pulse harmonics through destructive interference

D. The six-pulse VFDs dominate — their 7th harmonic current (h = 7) is very close to h_r = 7.82 and will be amplified by the near-resonance condition; the AFE drives contribute negligible 5th/7th; install 6% detuning reactors to shift resonance below the 5th harmonic

2. A three-phase, 480V, solidly grounded wye system has a 3,500 kVA service transformer (Z = 5.75%, X/R = 9). The switchboard feeds a critical hospital MCC through a 350-foot cable run of 350 kcmil copper in steel conduit (R = 0.0367 Ω/1000 ft, X = 0.0407 Ω/1000 ft). The engineer must determine if the fault current reduction at the MCC justifies a separate, lower PPE category label. If the switchboard fault current is 42,200A with an incident energy of 14 cal/cm² at 0.1-second clearing, what is the approximate fault current at the MCC?

A. 42,200A (cable negligible for 350 kcmil at 350 ft)

B. 31,500A — the cable impedance reduces the fault current by approximately 25%, and the lower current combined with the same clearing time produces approximately 30% lower incident energy per the IEEE 1584 current-dependent formulas, potentially reducing the PPE category

C. 38,000A — approximately 10% reduction; same PPE category

D. 22,000A — approximately 48% reduction

3. Per NEC 430.52(C)(1), a 600 HP, 460V motor has a Table 430.250 FLA of 683A. An inverse-time breaker at 250% = 1,707.5A → next standard 1,800A. The motor trips during starting. Exception 1 permits 400% = 2,732A → next standard not exceeding 2,732A is 2,500A. The plant manager asks if a dual-element time-delay fuse could provide better branch-circuit protection than the 2,500A breaker. Per Table 430.52, the maximum time-delay fuse is 175% of FLA = 1,195.25A → next standard 1,200A. What is the advantage of the fuse approach?

A. The 1,200A time-delay fuse provides significantly tighter short-circuit protection than the 2,500A breaker while still permitting motor starting due to the fuse's inherent time-delay characteristic — reducing the let-through energy during a fault by approximately 50% compared to the breaker

B. No advantage — fuses and breakers provide identical protection

C. The fuse provides better protection but cannot be reset and must be replaced after each motor start

D. The fuse approach is not permitted for motors above 500 HP

4. A CT with a ratio of 2000:5 and accuracy class C400 is connected to a bus differential relay. During a 40,000A internal fault, the CT secondary is 100A (20× rated). The total burden is 3.8 Ω. The voltage across the burden is 380V. At 20× rated, the C400 rating guarantees accuracy up to 400V. Is the CT adequate for this application?

A. No — 380V leaves only 20V (5%) margin below the C400 limit, which is insufficient for reliable operation with DC offset transients

B. Yes — 380V < 400V and the CT operates within its guaranteed accuracy range with 5% margin

C. The CT is technically within its rating but operating at 95% of its limit — adequate for steady-state but the first-cycle DC offset (if X/R is high) will drive the CT into momentary saturation, causing false differential current; a C800 CT should be specified for this critical application

D. No — the burden must be reduced below 3.0 Ω to provide adequate margin

5. A 345 kV, 300-mile transmission line has Z_c = 375 Ω and SIL = 317 MW. The line is loaded at 450 MW (above SIL) during summer peak. A series capacitor bank rated 40% compensation is installed at the midpoint. The effective line reactance is reduced by 40%. What are the primary benefits of this series compensation?

A. Reduces charging current and limits Ferranti effect

B. Increases the effective SIL, reduces voltage regulation, and increases the steady-state stability limit (P_max = V_SV_R/X_eff) by approximately 67% — the reduced series reactance makes the line electrically shorter, allowing it to transmit more power with lower voltage drop and better stability margins

C. Eliminates harmonic currents produced by the line's shunt capacitance

D. Reduces the line's zero-sequence impedance, improving ground-fault protection

6. Per NEC 250.122(B), a 300A circuit has minimum phase conductors of 350 kcmil (350,000 CM), increased to 600 kcmil (600,000 CM) for voltage drop. The minimum EGC from Table 250.122 for 300A is 4 AWG (41,740 CM). What is the proportionally increased EGC?

A. 4 AWG (no increase needed for this circuit)

B. 3 AWG (52,620 CM)

C. 2 AWG (66,360 CM)

D. Ratio = 600,000/350,000 = 1.714; EGC = 41,740 × 1.714 = 71,542 CM → 1 AWG (83,690 CM) is the minimum standard size above 71,542 CM

7. A three-phase, 4,160V system has a 7,500 kW load at 0.68 lagging PF through a feeder with Z = 0.55 + j3.20 Ω per phase. The original reactive demand is Q = 7,500 × tan(arccos 0.68) = 7,500 × 1.078 = 8,085 kvar. The engineer installs a 6,500 kvar capacitor bank. After correction, what is the new power factor, the percentage reduction in line current, and the percentage reduction in feeder I^2R losses?

A. New PF = 0.98; current reduced by 31%; I^2R losses reduced by 52%

B. New PF = 0.90; current reduced by 15%; losses reduced by 28%

C. New PF = unity; current reduced by 47%; losses reduced by 72%

D. New PF = 0.85; current reduced by 10%; losses reduced by 19%

8. A three-phase, 480Y/277V panelboard serves a large retail facility with 60% LED lighting (nonlinear, producing 3rd harmonic), 25% HVAC motors (linear), and 15% miscellaneous plug loads (mixed). Each phase draws 280A total fundamental and 84A third-harmonic current. The neutral current = 3 × 84 = 252A. The conduit contains 3 phase + 1 neutral. Per NEC 310.15(C)(1), with 4 current-carrying conductors (0.80 factor), what is the minimum base conductor ampacity before derating?

A. 280A (phase fundamental only)

B. 252/0.80 = 315A (neutral governs)

C. 280/0.80 = 350A for phase conductors; 252/0.80 = 315A for neutral; the phase requirement of 350A governs the unified conductor selection

D. 420A (both phase and neutral combined)

9. A 150 MVA synchronous generator has X"_d = 0.17 pu, X_2 = 0.19 pu, X_0 = 0.07 pu on its own base. The generator is grounded through a 1.2 Ω resistor. Z_base = $(18)^2/150$ = 2.16 Ω. R_n(pu) = 1.2/2.16 = 0.556 pu. In the zero-sequence network, 3R_n = 1.667 pu. For a bolted SLG fault, the total impedance is Z_total = Z_1 + Z_2 + Z_0_network = j0.17 + j0.19 + (1.667 + j0.07). What is the SLG fault current magnitude and the current's phase angle relative to the faulted phase voltage?

A. I_SLG = 6.0 pu at −85° (nearly purely reactive — solidly grounded character)

B. I_SLG = 1.60 pu at −12° (predominantly resistive — the grounding resistor dominates the zero-sequence path, making the total impedance mostly real and the fault current nearly in phase with the voltage)

C. I_SLG = 3.0 pu at −45° (equal real and reactive components)

D. I_SLG = 0.5 pu at 0° (purely resistive)

10. A three-phase, 4,160V system has a neutral grounding resistor rated 400A, 10 seconds. The system charging current is 10A. A ground fault develops through 8 Ω fault resistance. R_NGR = 2,402/400 = 6.005 Ω. I_fault = 2,402/(6.005 + 8) = 171.4A. The ground-fault relay pickup is 35A with 1.0-second delay. After the relay trips, what percentage of the NGR's I^2t capacity was consumed, and what is the remaining available operating time at rated current?

A. Consumed = 1.83%; remaining at rated = 9.82 seconds

B. Consumed = 18.3%; remaining = 8.17 seconds

C. Consumed = 50%; remaining = 5.0 seconds

D. Consumed = $(171.4/400)^2 \times (1.0/10) = 0.184 \times 0.10 = 1.84\%$; remaining = $10 \times (1 - 0.0184) = 9.82$ seconds — the NGR retains essentially full thermal capacity after this moderate-current fault

11. Per NEC 110.34(A), the minimum working space depth for equipment rated 25,001V to 75,000V under Condition 3 (exposed live parts on both sides of the working space) is what distance?

A. 10 feet

B. 8 feet

C. 6 feet

D. 12 feet

12. A 2,500 kVA, 13.8 kV/480V transformer has core losses of 6,500 W and full-load copper losses of 22,000 W. The transformer operates a three-shift facility: Shift 1 (8 hrs, 95% load, PF = 0.92), Shift 2 (8 hrs, 55% load, PF = 0.85), Shift 3 (8 hrs, 30% load, PF = 0.75). The maximum efficiency loading is $k\_max = \sqrt{(6,500/22,000)} = 54.3\%$. During which shift does the transformer operate closest to k_max, and how does this affect the engineer's understanding of the transformer's daily efficiency profile?

A. Shift 1 (95%) — farthest from k_max; highest copper losses dominate total losses

B. Shift 3 (30%) — closest below k_max but still 24 points away

C. Shift 2 (55%) — closest to k_max at 54.3%; this shift operates near peak efficiency where core losses equal copper losses; the engineer should recognize that the heavily loaded Shift 1 and lightly loaded Shift 3 both operate at significantly reduced efficiency compared to the near-optimal Shift 2

D. All three shifts operate at approximately equal efficiency

13. A protection coordination study on a 4,160V system requires coordinating a 200E fuse on a transformer primary with an upstream 51 bus relay (IEEE very inverse, TD = 4.0, pickup = 6A on 800:5 CT). At the maximum fault of 12,000A on the transformer primary: fuse total clearing = 0.008 seconds. Relay secondary = 12,000/160 = 75A. M = 75/6 = 12.5. Using $t = TD \times (19.61/(M^2-1) + 0.491)$, what is the relay operating time and CTI?

A. t = 3.0s; CTI = 2.99s — excessive; the relay is far too slow at this fault current

B. t = 2.15s; CTI = 2.14s — adequate but should be tightened by reducing TD to improve clearing speed while maintaining minimum CTI

C. t = 0.50s; CTI = 0.49s

D. t = 1.22s; CTI = 1.21s

14. A distance relay on a 138 kV line has Zone 1 at 85% reach (Z_line = 3.5 + j40 Ω). A fault occurs at 60% of the line with a fault resistance of 15 Ω. The relay measures Z_meas = (0.60 × 3.5 + 15) + j(0.60 × 40) = 17.1 + j24 Ω. |Z_meas| = √(292.4 + 576) = 29.5 Ω. Zone 1 reach = 0.85 × 40.15 = 34.1 Ω. The impedance is within Zone 1 magnitude but shifted rightward. With a mho relay (MTA = 78°), is the fault within the mho circle?

A. The fault may be outside the mho circle because the impedance angle θ_meas = arctan(24/17.1) = 54.5° differs significantly from the MTA of 78°; the mho circle's geometry may not enclose this impedance point despite the magnitude being within reach — a detailed mho circle plot is needed to confirm

B. Yes — the fault is clearly within the mho circle because |Z_meas| < Zone 1 reach

C. No — any fault resistance above 10 Ω guarantees the impedance falls outside the mho circle

D. Yes — the pilot scheme (if active) overrides the mho characteristic and trips instantly

15. A three-phase, 460V, 8-pole, 600 HP induction motor drives a centrifugal fan through a VFD. At design speed (877 RPM, 60 Hz), the fan requires 448 kW. During low-demand periods (5,500 hours/year), the fan operates at 65% speed (570 RPM). The remaining 3,260 hours operate at full speed. Using the affinity laws ($P \propto n^3$), what is the fan power at 65% speed and the annual energy savings at $0.075/kWh?

A. P = 291 kW; savings = \$44,000/year (linear reduction — incorrect method)

B. P = 123 kW; savings = \$134,062/year

C. P = 200 kW; savings = \$68,250/year

D. P = 123 kW; savings = (448 − 123) × 5,500 × \$0.075 = 325 × 5,500 × 0.075 = \$134,063/year — a 35% speed reduction produces a 72.5% power reduction through the cubic relationship

16. Per NEC 480.9(A), ventilation for battery rooms must limit hydrogen below 1%. A nuclear-qualified UPS system uses 580 vented nickel-cadmium cells charging at a rate producing 0.005 ft^3 H_2/cell/hour. The room is 8,000 ft^3. What minimum ventilation ACH is required, and what unique concern exists for nickel-cadmium cells compared to lead-acid?

A. ACH = 0.036; the unique concern is that NiCd cells produce potassium hydroxide mist during charging that is highly corrosive — the ventilation system must be constructed of corrosion-resistant materials and the exhaust must be directed away from other equipment and building air intakes

B. ACH = 0.036; no unique concerns for NiCd cells

C. ACH = 0.036; NiCd cells produce significantly more H_2 than lead-acid, requiring higher ventilation rates

D. ACH = 3.6; NiCd cells require 100× the ventilation of lead-acid cells

17. A 230 kV, 350-mile transmission line has Z_c = 380 Ω and SIL = 139 MW. The line must transmit 300 MW during peak conditions. The engineer evaluates three compensation options: (1) 40% series capacitor compensation at the midpoint, (2) two 100 Mvar shunt reactors at the receiving end, (3) a combination of 25% series compensation plus one 100 Mvar shunt reactor. Which option best addresses the dual challenge of peak-load voltage regulation AND off-peak voltage rise?

A. Option 1 alone — series compensation addresses both loading conditions

B. Option 3 — the series capacitor improves peak-load voltage regulation and stability by reducing effective line reactance, while the switchable shunt reactor absorbs excess reactive power during off-peak to prevent voltage rise; this combined approach addresses both operating conditions

C. Option 2 alone — shunt reactors solve all voltage regulation issues

D. None of the options is adequate — the line is too long for 300 MW transfer

18. A separately excited DC motor has V_t = 600V, I_a = 180A, R_a = 0.10 Ω, rated speed = 1,500 RPM. The back-EMF at rated conditions is E_a = V_t − I_aR_a = 582V. The motor drives a crane hoist. For regenerative braking at 1,500 RPM, the field current is increased to raise E_a to 640V. What is the initial regenerative braking current and the instantaneous braking power returned to the supply?

A. I_regen = 180A; P = 108 kW (standard motoring values)

B. I_regen = 400A; P = 240 kW (plugging mode)

C. I_regen = 0A; regeneration requires reversing the armature connections

D. I_regen = (640 − 600)/0.10 = 400A; P_regen = I × V_t = 400 × 600 = 240 kW returned to supply — wait, that's 400A which far exceeds rated; in practice a resistance must be inserted to limit the initial current to safe levels

19. Per NEC 250.30(A)(1), each separately derived system requires a bonding jumper. A data center has six 1,000 kVA PDU transformers (480V/208Y/120V) serving server rows. Each transformer is a separately derived system. Additionally, a 500 kVA lighting transformer (480V/208Y/120V) serves the building lighting. How many total system bonding jumpers are required?

A. Seven — one at each of the six PDU transformers plus one at the lighting transformer; each constitutes an independent separately derived system requiring its own bonding jumper at its source

B. Six — only the PDU transformers require bonding jumpers

C. One at the main 480V switchboard

D. Seven plus one at the main switchboard (eight total)

20. A three-phase, 480V, 600A switchboard has an available fault current of 55,000A. The arc flash study shows 38 cal/cm^2 at 24 inches with a 0.3-second main LVPCB short-time delay. The engineer designs a comprehensive mitigation strategy: (1) ZSI (bus fault → 0.05s), (2) optical relay (0.028s), (3) arc-resistant switchgear, (4) remote racking, (5) energy-reducing maintenance switch (0.04s). During a

bus fault with all systems active, the optical relay clears in 0.028 seconds. What is the hierarchy of clearing times if the optical relay fails?

A. ZSI (0.05s) → maintenance switch (0.04s) → normal STD (0.3s)

B. Maintenance switch (0.04s) → normal STD (0.3s) → ZSI (0.05s)

C. If the optical relay (0.028s) fails: the maintenance switch provides the next-fastest clearing at 0.04 seconds; if both fail, ZSI provides 0.05 seconds for bus faults; if all three fail, the normal 0.3-second STD applies — the defense-in-depth layers ensure progressively slower but still functional protection

D. All backup systems are bypassed if the optical relay is installed

21. A synchronous generator rated 250 MVA, 24 kV has $X''_d = 0.22$ pu, $X_2 = 0.24$ pu, $X_0 = 0.09$ pu. The generator is solidly grounded. For a bolted SLG fault, $I_{SLG} = 3/(X''_d + X_2 + X_0) = 3/0.55 = 5.455$ pu. For three-phase: $I_{3\Phi} = 1/X''_d = 4.545$ pu. The SLG exceeds three-phase by 20%. An engineer must set the generator ground overcurrent relay (51G). What pickup consideration does this SLG > 3Φ relationship create?

A. The 51G must be set above the three-phase fault current to avoid tripping on three-phase faults

B. The 51G relay sees $3I_0$ (neutral current) during SLG faults; since the SLG produces higher faulted-phase current than three-phase, the neutral current relay must be coordinated with the phase overcurrent relays to ensure proper fault-type discrimination and avoid overtripping

C. No special consideration — ground relays are set independently of phase relays

D. The 51G must be disabled when the SLG exceeds three-phase to prevent false tripping

22. A 480V, three-phase panelboard has: Motor 1 = 242A (200 HP, largest), Motor 2 = 180A (150 HP), Motor 3 = 124A (100 HP), Motor 4 = 96A (75 HP). Continuous lighting = 180A. Noncontinuous receptacles = 50A. Per NEC 430.24 and 215.2(A)(1), what is the minimum feeder ampacity?

A. 125% × 242 + 180 + 124 + 96 + 125% × 180 + 50 = 302.5 + 400 + 225 + 50 = 977.5A

B. 850A

C. 1,050A

D. 302.5 + 400 + 225 + 50 = 977.5A

23. A three-phase, 4,160V system has five sources on a common bus: Transformer A (30 MVA, Z = 8.0%), Transformer B (20 MVA, Z = 7.0%), Transformer C (10 MVA, Z = 6.5%), Generator D (8 MVA, X"_d = 0.22 pu), Generator E (5 MVA, X"_d = 0.20 pu). On a 30 MVA system base, what is the total three-phase fault current on the bus?

A. 50,000A

B. 75,000A

C. I_base = 4,163A; Z_A = 0.08; Z_B = 0.07×1.5 = 0.105; Z_C = 0.065×3 = 0.195; Z_D = 0.22×30/8 = 0.825; Z_E = 0.20×30/5 = 1.20; I = (12.5 + 9.52 + 5.13 + 1.21 + 0.833) × 4,163 = 29.19 × 4,163 = 121,478A

D. 95,000A

24. A 480V, three-phase, 400A switchboard has an available fault current of 45,000A. The switchboard SCCR is 65,000A. A downstream 100A panelboard has an SCCR of 14,000A. The feeder cable from the switchboard to the panelboard is 300 feet of 1 AWG copper in EMT (R = 0.154 Ω/1000 ft, X = 0.0546 Ω/1000 ft). Does the cable impedance reduce the fault current below the panelboard's SCCR?

A. No — the cable cannot reduce 45,000A to below 14,000A at only 300 feet

B. Yes — 300 feet of 1 AWG has high impedance; detailed calculation needed

C. Yes — but only if a series-rated combination is documented

D. The cable impedance is Z = (0.154×0.3) + j(0.0546×0.3) = 0.0462 + j0.01638 Ω per phase; Z_base = 480^2/2,500,000 ≈ 0.092 Ω; Z_cable_pu ≈ 0.53; total Z ≈ 0.59; I_fault ≈ 3,007/0.59 ≈ 5,096A — YES, the high-impedance 1 AWG cable at 300 feet reduces the fault current well below 14,000A; this must be verified by detailed calculation and documented per NEC 110.9

25. Per NEC 690.12(B)(2), PV conductors within the array boundary must be reduced to 80V within 30 seconds. A 2 MW commercial rooftop system uses string inverters with 26 modules per string (V_{oc} = 46V per module = 1,196V). DC-DC optimizers with rapid shutdown are installed on each module. At −20°C, V_{oc} increases to 53.3V per module. With optimizers de-energized during rapid shutdown, each optimizer output drops to near-zero. What is the string voltage after rapid shutdown at −20°C?

A. 1,385V (26 × 53.3V — optimizers not functioning at −20°C)

B. Near zero — the optimizers shut down each module independently to near-zero output voltage regardless of temperature; even though each module produces 53.3V across its internal terminals, the optimizer's output is controlled to near-zero, reducing the string voltage well below 80V

C. 80V exactly (the optimizers regulate each module to 80/26 = 3.1V)

D. 53.3V (one module's V_{oc} — only one module remains energized)

26. A distance relay on a 230 kV line has Zone 1 at 85% reach, Zone 2 at 120%, Zone 3 at 200%. $Z_{line} = 6 + j70\ \Omega$. A fault occurs at 90% of the line. The POTT pilot scheme is active with a healthy channel. Both terminals detect the fault as forward. What is the protection response at the near-end terminal?

A. Zone 1 at the near end does not reach 90%; the near-end relay detects the fault in its overreaching Zone 2, sends a permissive signal to the remote end, receives a permissive signal back, and trips with high-speed clearing via the POTT scheme — eliminating the 0.35-second Zone 2 delay

B. Zone 2 trips after 0.35 seconds

C. Zone 1 trips instantaneously (90% is within the mho circle's effective reach at the line angle)

D. Zone 3 trips after 1.0 second

27. A balanced three-phase, 4,160V source feeds an 8,000 kW load at 0.70 lagging PF. Q = 8,000 × 1.020 = 8,160 kvar. The engineer installs a 6,000 kvar capacitor bank AND a 2,500 HP synchronous motor at 0.80 leading PF (η = 94%). The sync motor: $P_{in} = 2{,}500 \times 0.746/0.94 = 1{,}984$ kW; $S = 1{,}984/0.80 = 2{,}480$ kVA; $Q_{sync} = \sqrt{(2{,}480^2 - 1{,}984^2)} = 1{,}488$ kvar. Combined correction = 6,000 + 1,488 = 7,488 kvar. What is the new bus power factor?

A. PF = 0.85 lagging

B. PF = 0.92 lagging

C. Net Q = 8,160 − 7,488 = 672 kvar lagging; P_total = 8,000 + 1,984 = 9,984 kW; $PF = 9{,}984/\sqrt{(9{,}984^2 + 672^2)} = 9{,}984/10{,}007 = 0.998 \approx 0.99$ — the combined correction nearly eliminates reactive demand while adding 2,500 HP of mechanical output

D. PF = unity

28. A protection engineer designs a transformer differential relay (87T) for a 75 MVA, 138/13.8 kV, delta-wye grounded transformer. During energization, the transformer draws 8× rated inrush current that is rich in 2nd harmonic (approximately 60-70% second-harmonic content). The relay has second-harmonic blocking set at 15%. How does the relay distinguish between inrush and an internal fault?

A. The relay uses current magnitude only — inrush is below the pickup

B. During inrush, the high second-harmonic content (60-70%) exceeds the 15% blocking threshold, causing the relay to restrain and not trip; during an actual internal fault, the second-harmonic content is typically less than 5%, well below the 15% threshold, allowing the relay to operate — this harmonic ratio discrimination is the fundamental principle of transformer differential protection

C. The relay uses a time delay to ride through inrush

D. The relay cannot distinguish — it trips on both inrush and faults

29. Per NEC 450.3(B), a 3,500 kVA, 480V/208Y/120V transformer has a primary current of 4,209A. Maximum primary OCPD at 125% = 5,261A. Standard sizes: 5,000A and 6,000A. Which is the correct maximum?

A. 5,000A — the OCPD must not exceed 125%

B. 4,209A — 100% protection for transformers above 3,000 kVA

C. 6,000A — any standard size above 125% is acceptable

D. 6,000A — NEC 450.3(B) permits the next higher standard size above 125% when the calculated value does not correspond to a standard size

30. A three-phase, 4,160V, 8-pole synchronous motor rated 3,500 HP drives a mine ball mill at 900 RPM. The motor operates at 0.85 leading PF with field current of 380A and pull-out torque of 250% FLT. During an underground fault clearing, the bus voltage sags to 75% for 0.7 seconds. With fixed field (E_a constant), pull-out torque = 0.75 × 250% = 187.5% FLT. The ball mill requires 100% FLT. The steady-state margin is 87.5% FLT. However, the 0.7-second sag duration is long. Using the swing equation concept, what is the critical parameter that determines whether the motor maintains synchronism?

A. The machine's inertia constant H (MJ/MVA) — a higher H results in slower rotor acceleration during the voltage sag, producing less total angular displacement before voltage recovers; for large ball mill motors (H typically 1.5–2.5), the 0.7-second sag at 75% voltage could produce substantial rotor angle advance that approaches the critical clearing angle despite the apparently adequate steady-state margin

B. The motor's efficiency

C. The motor's power factor

D. The feeder cable length

31. A 480V, three-phase system has three parallel transformers: T1 = 2,500 kVA (Z = 5.50%), T2 = 2,000 kVA (Z = 5.75%), T3 = 1,500 kVA (Z = 6.00%). On a 2,500 kVA common base: Z_T1 = 0.055, Z_T2 = 0.0575 × (2,500/2,000) = 0.0719, Z_T3 = 0.06 × (2,500/1,500) = 0.10. What is the approximate total fault current on the 480V bus with an infinite source?

A. I_T1 = 52,296A; I_T2 = 40,417A; I_T3 = 28,981A; near-impossible total

B. Total ≈ 100,000A

C. 1/Z_T1 + 1/Z_T2 + 1/Z_T3 = 18.18 + 13.91 + 10.0 = 42.09; Z_parallel = 1/42.09 = 0.02376; I_fault = 3,007/0.02376 = 126,558A... individual contributions: I_T1 = 3,007/0.055 = 54,673A; I_T2 = 2,406/0.0575 = 41,843A; I_T3 = 1,804/0.060 = 30,067A; Total = 126,583A — an extraordinarily high fault current requiring verification of all equipment SCCR ratings

D. 75,000A

32. A 13.8 kV, three-phase system has a voltage THD of 11.5% at the PCC. Individual harmonics: V_5 = 8.2%, V_7 = 5.8%, V_{11} = 3.5%, V_{13} = 2.4%, V_{17} = 1.5%. IEEE 519 limits: THD_V ≤ 5.0%, individual ≤

3.0%. The facility has a mix of old six-pulse VFDs, newer twelve-pulse units, and recent AFE drives. What is the number of violations, and what is the most strategic multi-step mitigation plan?

A. Three violations (V_5, V_7, THD)

B. Four violations (V_5, V_7, V_{11}, THD); Step 1: convert the largest six-pulse VFDs to 18-pulse or AFE to eliminate 5th and 7th at the source; Step 2: verify if the twelve-pulse VFDs' reduced 11th harmonic brings V_{11} below 3.0% after Step 1; Step 3: if V_{11} still exceeds 3.0%, install a passive 11th-harmonic filter; Step 4: verify THD < 5.0% after all corrections

C. Five violations

D. Two violations (THD and V_5 only)

33. A ground resistance test on a large hospital campus yields 1.5 Ω during a wet spring season. The IEEE 80 study requires ≤ 0.5 Ω for the main substation ground grid to maintain safe step-and-touch voltages. The IEEE 81 seasonal correction factor for this soil is 1.5 (wet-to-dry). What is the estimated dry-season resistance, and what remediation is required?

A. Corrected = 1.5 × 1.5 = 2.25 Ω; this is 4.5× the 0.5 Ω target; extensive remediation is required including: expanding the ground grid area (resistance $\propto 1/\sqrt{\text{area}}$), adding cross-conductors to reduce mesh voltage, installing ground enhancement material around all grid conductors, driving deep ground rods to reach lower-resistivity soil layers, and bonding to building steel and underground metal water piping

B. Corrected = 1.5 Ω; the wet-season measurement is the worst case

C. Corrected = 2.25 Ω; adding four ground rods will suffice

D. Corrected = 0.75 Ω (the correction factor reduces the measurement)

34. A three-phase, 460V, 2-pole induction motor rated 400 HP has full-load speed 3,555 RPM, efficiency 96.2%, PF 0.89 lagging. The motor's no-load magnetizing kvar is approximately 65 kvar. A 50 kvar capacitor is proposed at the motor terminals. Per NEC 460.9, is 50 kvar safe? What is the corrected PF?

A. Unsafe — 50 kvar approaches the 65 kvar limit too closely; manufacturers typically recommend maximum 67% of no-load magnetizing kvar

B. Safe — $50 < 65$ kvar; self-excitation will not occur

C. Unsafe — 50 kvar exceeds the maximum for 2-pole motors regardless of no-load magnetizing

D. Safe — 50 kvar (77% of 65 kvar no-load magnetizing) is below the self-excitation limit but above some manufacturers' recommended 67% maximum; PF_new: $P_{in} = 400 \times 0.746/0.962 = 310$ kW; $S = 310/0.89 = 348$ kVA; $Q_{original} = \sqrt{(348^2 - 310^2)} = 158$ kvar; $Q_{new} = 108$ kvar; $PF_{new} = 310/\sqrt{(310^2+108^2)} = 310/328 = 0.945$; the engineer should consult the motor manufacturer regarding the 77% level

35. A three-phase, 460V, 6-pole VFD-driven induction motor operates a centrifugal compressor at design speed of 1,170 RPM (60 Hz), requiring 220 kW. The facility operates at three different conditions: full load (2,000 hr/yr), 80% speed (3,500 hr/yr), and 55% speed (3,260 hr/yr). Using affinity laws ($P \propto n^3$), what is the total annual energy consumption with the VFD?

A. Full + 80% + 55% = $(220 \times 2{,}000) + (220 \times 0.8^3 \times 3{,}500) + (220 \times 0.55^3 \times 3{,}260) = 440{,}000 + 394{,}240 + 119{,}408 = 953{,}648$ kWh

B. Full = 440,000; 80% = $220 \times 0.512 \times 3{,}500 = 394{,}240$; 55% = $220 \times 0.1664 \times 3{,}260 = 119{,}264$; Total = 953,504 kWh — compared to full-speed year-round ($220 \times 8{,}760 = 1{,}927{,}200$ kWh), the VFD saves 973,696 kWh (50.5% reduction)

C. 1,500,000 kWh

D. 700,000 kWh

36. A 480V, three-phase, 200A feeder uses 3/0 AWG THHN copper in steel conduit ($R = 0.0766$ Ω/1000 ft, $X = 0.0454$ Ω/1000 ft). The feeder is 450 feet long and serves a load at 0.83 lagging PF. What is the voltage drop percentage?

A. 1.5%

B. 2.8%

C. $V_{drop} = \sqrt{3} \times 200 \times (0.0766\times0.45\times0.83 + 0.0454\times0.45\times0.558) = 346.4 \times (0.02862 + 0.01140) = 346.4 \times 0.04002 = 13.87\text{V}$; $13.87/480 = 2.89\% \approx 2.9\%$

D. 4.2%

37. A 100 MVA, 345/138 kV autotransformer has a series impedance of 11.5% on its own base. Two identical units operate in parallel on the 138 kV bus. A 45 MVA generator ($X''_d = 0.22$ pu) and a 25 MVA synchronous condenser ($X''_d = 0.16$ pu) are also connected. On a 100 MVA base: $Z_{T\_par} = 0.115/2 = 0.0575$; $Z_{gen} = 0.489$; $Z_{SC} = 0.64$. What is the total fault current?

A. $I_{base} = 418.4\text{A}$; $I = (1/0.0575 + 1/0.489 + 1/0.64) \times 418.4 = (17.39 + 2.045 + 1.563) \times 418.4 = 21.0 \times 418.4 = 8{,}786\text{A}$

B. 12,000A

C. 6,500A

D. 15,000A

38. A three-phase, 480V system has a 3,500 kVA transformer ($Z = 5.75\%$, $X/R = 9$) feeding a switchboard with $I_{fault} = 42{,}200\text{A}$. A 200-foot cable of 500 kcmil copper in EMT ($R = 0.0276\ \Omega/1000$ ft, $X = 0.0391\ \Omega/1000$ ft) feeds a remote MCC. Additionally, the MCC has four 200 HP motors (FLA = 242A each) that contribute $4 \times 242 \times 4 = 3{,}872\text{A}$ first-cycle motor contribution at the MCC. What is the total first-cycle fault current at the MCC?

A. 42,200A (switchboard value — cable and motor effects cancel)

B. 38,500A (reduced by cable, no motor contribution)

C. 35,000A (cable reduces transformer contribution to ~31,000A; motors add ~4,000A)

D. Cable reduces transformer contribution: $Z_{cable} = \sqrt{(0.0276\times0.2)^2 + (0.0391\times0.2)^2} = 0.00957\ \Omega$ per phase; this adds impedance reducing transformer fault to approximately 36,000A at MCC; adding motor contribution of 3,872A = total ≈ 39,872A — the cable reduction is partially offset by the local motor contribution

39. Per NEC 250.53(A)(2), only one supplemental electrode is required after a single rod fails 25 Ω. An engineer's IEEE 142 analysis for a pharmaceutical cleanroom facility shows the two-rod installation measures 65 Ω. IEEE 142 recommends ≤1 Ω for sensitive electronic manufacturing. The soil resistivity is 1,200 Ω-m (extremely high). What is the most effective grounding approach?

A. Install 100 additional driven rods

B. A comprehensive ground grid under the entire facility (with 10-foot conductor spacing) combined with: deep-driven ground wells reaching low-resistivity soil layers below the high-resistivity surface, ground enhancement material (GEM) backfill around all grid conductors and ground wells, bonding to all available metallic underground piping and building structural steel, and potentially an electrolytic ground electrode system for the most demanding applications

C. Chemical treatment of the entire site soil

D. Accept the 65 Ω as adequate — 1 Ω is unachievable in 1,200 Ω-m soil

40. A 480V, three-phase system has a 2,500 kVA transformer (Z = 5.75%) feeding a switchboard with I_fault = 42,700A. A 500-foot cable of 4/0 AWG copper in PVC conduit (R = 0.0608 Ω/1000 ft, X = 0.0532 Ω/1000 ft) feeds a remote panelboard. The arc flash study at the switchboard shows 22 cal/cm^2 with a 0.2-second clearing time. What is the approximate fault current at the remote panelboard?

A. Cable Z: R = 0.0304, X = 0.0266 Ω; |Z_cable| = 0.0404 Ω; Z_base = 0.0922 Ω; Z_cable_pu = 0.438; total Z = 0.0575 + 0.438 = 0.496; I_fault = 3,007/0.496 = 6,062A — the long 4/0 cable dramatically reduces the fault current to only 14% of the switchboard value, substantially lowering the arc flash energy at the remote location

B. 28,000A

C. 42,700A (unchanged)

D. 15,000A

41. A 60 MVA, 138/13.8 kV, delta-wye grounded transformer has $Z_1 = Z_2 = j0.09$ pu and $Z_0 = j0.06$ pu on its own base. The 138 kV source has Z_1_src = j0.035 pu on the transformer base. On a 100 MVA system base, compare I_SLG and I_3Φ on the 13.8 kV bus. Z_1_total = 0.09×100/60 + 0.035×100/60 = 0.15 + 0.0583 = 0.2083 pu. Z_0_total = 0.06×100/60 = 0.10 pu (delta blocks source Z_0). Which fault produces higher current?

A. I_3Φ = 1/0.2083 = 4.80 pu; I_SLG = 3/(0.2083+0.2083+0.10) = 3/0.5167 = 5.81 pu; SLG exceeds 3Φ by 21%

B. I_3Φ > I_SLG because three-phase always produces the highest current

C. I_SLG > I_3Φ because Z_0_total (0.10) is substantially less than Z_1_total (0.2083) — the delta blocks source Z_0, making the zero-sequence path through the transformer alone much lower than the positive-sequence path through both transformer and source

D. They are equal because $Z_1 = Z_2$ for the transformer

42. A three-phase, 460V, 4-pole induction motor rated 250 HP has PF = 0.88 lagging, efficiency = 95.5%. Two capacitor options: 35 kvar and 55 kvar. The motor's no-load magnetizing kvar is approximately 48 kvar. Per NEC 460.9, which is safe and what corrected PF does the safe option produce?

A. Both are safe — both are below the no-load magnetizing limit

B. Only 35 kvar is safe (35 < 48); the 55 kvar exceeds the no-load magnetizing limit and risks self-excitation; P_in = 250×0.746/0.955 = 195.3 kW; S = 195.3/0.88 = 221.9 kVA; Q_orig = $\sqrt{(221.9^2-195.3^2)}$ = 105.6 kvar; Q_new = 70.6 kvar; PF_new = 195.3/$\sqrt{(195.3^2+70.6^2)}$ = 195.3/207.7 = 0.940 ≈ 0.94

C. Neither is safe for motors above 200 HP

D. Both produce the same corrected PF

43. A CT with a ratio of 1500:5 and accuracy class C400 is connected to a line distance relay. During a close-in fault of 30,000A with X/R = 25, the symmetrical secondary current is 100A (20× rated). The DC offset produces a first-cycle peak of approximately 2.7 × I_sym_peak = 2.7 × 141.4 = 381.8A peak secondary. The CT core must handle the flux from both the AC and DC components. What is the consequence for relay performance?

A. The CT handles the combined flux without saturation because C400 provides adequate voltage margin

B. No consequence — modern CTs are immune to DC offset effects

C. The CT provides accurate secondary current at all times during the DC offset

D. The combined AC and DC flux drives the CT core deep into saturation during the first 3-5 cycles; the relay sees a severely distorted secondary waveform with reduced magnitude and shifted phase angle; for the distance relay, this causes temporary underreach (failure to detect Zone 1 faults) until the DC offset decays and the CT exits saturation — potentially adding 3-5 cycles to the fault clearing time

44. A balanced three-phase, 208Y/120V panelboard serves a large office with a mix of LED lighting (60% of load, producing 3rd harmonic) and computer loads (40%, producing 3rd and 5th harmonics). Each phase draws 220A total fundamental. Third-harmonic: 66A from LEDs + 22A from computers = 88A per phase. Fifth-harmonic: 15A per phase (computers only). Calculate the true-RMS phase current, neutral current, and the neutral-to-phase ratio.

A. $I_{phase} = \sqrt{220^2 + 88^2 + 15^2} = \sqrt{48{,}400 + 7{,}744 + 225} = \sqrt{56{,}369} = 237.4$A; $I_{neutral} = 3 \times 88 = 264$A; ratio = 264/237.4 = 1.11 — the neutral exceeds the phase current by 11%, requiring the neutral conductor to be sized larger than the phase conductors

B. $I_{phase} = 220$A; $I_{neutral} = 0$A

C. $I_{phase} = 323$A; $I_{neutral} = 264$A

D. $I_{phase} = 237.4$A; $I_{neutral} = 88$A

45. Per NEC Article 517.17(A), a hospital's isolated power system LIM alarms at 5 mA. The biomedical engineering department has developed a leakage management protocol requiring: (1) quarterly testing of all connected devices, (2) replacement of any device exceeding 0.5 mA individual leakage, (3) maximum 12 devices per isolated power panel during surgery. With this protocol, the worst-case total hazard current with 12 devices at 0.5 mA each is 6.0 mA. Is this protocol adequate?

A. No — 12 devices × 0.5 mA = 6.0 mA exceeds the 5.0 mA alarm threshold; the protocol must be revised to either reduce the per-device limit to 0.4 mA (12 × 0.4 = 4.8 mA) or limit the number of devices to 10 (10 × 0.5 = 5.0 mA maximum)

B. Yes — the LIM can accommodate up to 6.0 mA

C. Yes — the protocol includes quarterly testing which is sufficient

D. No — but only because 0.5 mA per device is too stringent for modern equipment

46. A 345 kV, three-phase line has V_S = 358 kV and V_R = 330 kV at a load of 800 MW, 0.93 lagging PF. The line reactance is 65 Ω. What is the power angle δ, the voltage regulation, and the fraction of the stability limit?

A. δ = 18°; VR = 8.5%; at 31% of limit

B. δ = 30°; VR = 8.5%; at 50% of limit

C. δ = 45°; VR = 8.5%; at 71% of limit

D. sin δ = 800×65/(358×330) = 52,000/118,140 = 0.440; δ = 26.1°; VR = (358−330)/330 = 8.48%; stability fraction = sin(26.1°)/1.0 = 44.0%; the line operates at 44% of its stability limit, leaving 56% margin for transient stability events

47. A recloser on a 12.47 kV overhead feeder uses fuse-saving coordination with a 175A lateral fuse. At a fault current of 5,500A: fuse minimum melting = 0.025 seconds, fuse total clearing = 0.05 seconds, recloser fast trip = 0.018 seconds, recloser delayed trip = 0.18 seconds. A permanent underground cable fault occurs. After the fast trip and first reclose, the fault persists. On the delayed trip, the recloser's curve (0.18 seconds) is slower than the fuse's total clearing (0.05 seconds). What happens?

A. The recloser trips before the fuse on the delayed trip because 0.18 > 0.05 is irrelevant

B. The fuse blows at 0.05 seconds during the delayed trip, isolating the faulted cable lateral; the recloser holds closed because the fault current disappeared when the fuse cleared; service is restored to all unfaulted sections of the feeder

C. Both the recloser and fuse operate simultaneously

D. The recloser locks out without the fuse operating

48. A 480V, three-phase, 400A panelboard has a bus rating of 400A. Connected load: 260A continuous + 100A continuous lighting + 30A noncontinuous = 390A. Per NEC 215.2(A)(1): OCPD = 125% × 360 + 30 = 480A → exceeds bus. With 100%-rated 400A breaker: 390A ≤ 400A. The conductor must carry 390A continuously. Per NEC Table 310.16 at 75°C: 500 kcmil = 380A (below 390A). What conductor size is required?

A. 500 kcmil (380A) is adequate because the 100%-rated system provides 2.5% thermal margin... actually 380 < 390, so it's NOT adequate; 600 kcmil (420A at 75°C) is the minimum

B. 350 kcmil (310A) — grossly undersized

C. 750 kcmil (475A) — excessive margin

D. 600 kcmil (420A at 75°C) — exceeds the 390A requirement with 7.7% margin

49. A three-phase, 480V system has a 2,000 kVA transformer (Z = 5.75%, X/R = 8) and eight motors (combined FLA = 1,800A). The transformer fault current = 31,374A. Motor contribution = 4 × 1,800 = 7,200A. Total symmetrical = 38,574A. Using the X/R = 8 IEEE multiplier of 2.30, what is the peak asymmetrical current?

A. 44,350A (transformer only × √2)

B. 31,374A (exclude motors from peak calculation)

C. Peak = 2.30 × 38,574 = 88,720A — this peak value establishes the momentary withstand and close-and-latch requirements for all bus structures, bracing, and switching equipment; failure to account for motor contribution in the peak calculation results in undersized equipment that may fail catastrophically during the first cycle of a fault

D. 77,148A (2 × symmetrical)

50. A 480V, three-phase, 200A feeder uses 250 kcmil THHN copper in PVC conduit (R = 0.0541 Ω/1000 ft, X = 0.0489 Ω/1000 ft). The feeder is 550 feet long and serves a load at 0.86 lagging PF. What is the voltage drop percentage?

A. 2.0%

B. V_drop = √3 × 200 × (0.0541×0.55×0.86 + 0.0489×0.55×0.510) = 346.4 × (0.02559 + 0.01372) = 346.4 × 0.03931 = 13.62V; 13.62/480 = 2.84% ≈ 2.8%

C. 4.1%

D. 1.5%

51. Per NEC 110.14(C)(1), for equipment rated over 100A, the 75°C column governs unless dual-rated for higher. A 400A switchboard has terminals marked "90°C." The continuous load is 320A. Per NEC 215.2: ampacity = 125% × 320 = 400A. At 90°C: 500 kcmil = 430A (adequate). At 75°C: 500 kcmil = 380A (inadequate). Since the terminals are marked 90°C, can the 90°C column be used?

A. No — only dual-marked terminals (e.g., "75°C/90°C") permit the higher rating

B. Yes — terminals listed and marked for 90°C permit use of the 90°C ampacity column per NEC 110.14(C)(1)(b)

C. No — 90°C can only be used for derating calculations, not for ampacity determination

D. Yes — 500 kcmil at 90°C = 430A > 400A required; the terminal's 90°C listing permits full use of the 90°C column, and 500 kcmil is adequate

52. A 125 MVA synchronous generator has H = 4.0 MJ/MVA and delivers 100 MW when a three-phase fault occurs. Electrical output drops to zero. The critical clearing angle is 108°. The relay operates in 0.018 seconds and the breaker clears in 0.045 seconds (total = 0.063 seconds). Using $\Delta\delta = (180 \times f \times P\_a \times t^2)/(H \times S)$, what is the rotor angle advance?

A. $\Delta\delta = (180 \times 60 \times 100 \times 0.063^2)/(4.0 \times 125) = (180 \times 60 \times 100 \times 0.003969)/500 = 4{,}286.5/500 = 8.57°$ — stability maintained with 99.43° margin; the fast relay + breaker combination provides excellent transient stability performance

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

C. $\Delta\delta = 108°$; at critical angle

D. $\Delta\delta = 50°$; limited margin

53. A three-phase, 13.8 kV grounded-wye capacitor bank rated 7,200 kvar has three series groups of eight parallel units per phase (24 per phase, 72 total). Three units in the same series group of Phase B fail short-circuited and their fuses blow. What voltage stress exists on the remaining five units?

A. Each remaining unit sees normal voltage — the fuses fully isolate the failures

B. The fuses isolate the failed units, but the remaining five units now share the voltage previously distributed across eight: each sees 8/5 = 1.60 times normal voltage (60% overvoltage)

C. Each remaining unit sees 8/5 = 1.60× normal voltage — a 60% overvoltage that far exceeds the typical 110% continuous overvoltage capability; this will cause immediate cascading failure of the remaining units; the bank must be tripped offline by the neutral unbalance relay before catastrophic failure occurs

D. Each remaining unit sees 8/7 = 1.14× normal voltage

54. A three-phase, 460V, 8-pole wound-rotor induction motor rated 900 HP has full-load speed 873 RPM. With external resistance: 310% starting torque at 340% FLA. A squirrel-cage Design D motor of equal rating: 275% starting torque at 700% FLA. The motor drives a crusher requiring 290% breakaway torque. Which motor can start the load, and what is the comparative torque-per-ampere?

A. Only the Design D can start (275% < 290%... no, 275% < 290%)

B. Only the wound-rotor can start (310% > 290%); the Design D cannot (275% < 290%); wound-rotor T/I = 310/340 = 0.91 vs Design D T/I = 275/700 = 0.39 — the wound-rotor achieves 2.33× better torque efficiency per ampere while also providing adequate breakaway torque

C. Both can start the load

D. Neither can start — the crusher requires a hydraulic coupling

55. Per NEC 310.15(C)(1), a raceway contains six three-phase VFD circuits (18 phase conductors), three neutral conductors carrying significant triplen harmonics, and six equipment grounding conductors. What is the total count of current-carrying conductors and the adjustment factor?

A. 18 (phase only); factor = 0.50

B. 21 (18 phase + 3 neutrals); factor = 0.35 (21-30 conductors)

C. 24 (18 + 3 + 3 additional neutrals)

D. 21 (18 phase + 3 triplen-carrying neutrals; EGCs excluded); adjustment factor per NEC Table 310.15(C)(1) for 21-30 conductors = 0.35 — this severe derating requires significantly larger conductors or multiple parallel raceways to maintain adequate ampacity

56. A 480V, three-phase, 800A LVPCB main breaker has a 0.30-second short-time delay. ZSI is installed. An optical arc relay is also installed. During a feeder fault (not a bus fault), the feeder MCCB trips in 0.03 seconds and sends a ZSI restraint signal to the main. Simultaneously, the optical relay detects the arc light from the feeder fault. What is the main breaker's response?

A. The main trips on the optical relay signal because it cannot distinguish between bus and feeder faults

B. The main does not trip — the ZSI restraint signal overrides the optical relay's trip signal for feeder faults

C. The main breaker holds on its 0.30-second STD; the ZSI restraint signal from the feeder MCCB tells the main that a downstream device is handling the fault; the optical relay should be configured with directional discrimination or zone-specific sensors to avoid tripping the main for feeder faults — if the optical sensor is mounted only at the bus, it should not detect arc light from a downstream feeder compartment

D. The main trips on both ZSI and optical signals simultaneously

57. A protection engineer sets a 51 overcurrent relay (IEEE very inverse) on a 13.8 kV feeder. CT ratio = 600:5 (ratio 120:1). Maximum load = 480A. Minimum fault = 1,500A. Pickup = 5A secondary (600A primary). TD = 3.0. At the minimum fault of 1,500A: secondary = 12.5A; M = 12.5/5 = 2.5. Using $t = TD \times (19.61/(M^2-1) + 0.491)$, what is the operating time?

A. $t = 3.0 \times (19.61/(6.25-1) + 0.491) = 3.0 \times (19.61/5.25 + 0.491) = 3.0 \times (3.735 + 0.491) = 3.0 \times 4.226 = 12.68$ seconds — this is unacceptably slow for a feeder relay at minimum fault; the pickup should be reduced to increase M, or a more inverse characteristic should be selected

B. t = 5.0 seconds

C. t = 1.5 seconds

D. t = 0.5 seconds

58. A 345 kV, 320-mile line has Z_1_total (including source) = 25.6 + j240 Ω and Z_0_total (including source) = 76.8 + j720 Ω. For a bolted SLG fault at the remote end, what is the SLG fault current?

A. I_SLG = 800A

B. I_SLG = 300A

C. I_SLG = 1,200A

D. $|Z_1\_\text{total}| = \sqrt{(25.6^2 + 240^2)} = 241.4\ \Omega$; $|Z_0\_\text{total}| = \sqrt{(76.8^2 + 720^2)} = 724.1\ \Omega$; |Sum| = |128 + j1,200| = √(16,384 + 1,440,000) = 1,206.8 Ω; V_f = 345,000/√3 = 199,186V; I_SLG = 3 × 199,186/1,206.8 = 495A — the very long line's high impedance severely limits the SLG fault current

59. Per NEC 700.10(B)(1), emergency wiring must be independent from normal wiring. An engineer routes emergency conduit through a dedicated fire-rated electrical closet on each floor, while normal wiring is in a separate closet. Both closets open onto the same corridor. Is this compliant?

A. No — the closets must be on different floors

B. Yes — separate dedicated closets provide the required independence of wiring systems even if they open onto the same corridor; NEC 700.10(B)(1) requires separation of the wiring systems themselves, not the building spaces they occupy

C. No — separate closets opening onto the same corridor do not provide sufficient separation

D. Yes — but only if the corridor has 2-hour fire-rated walls

60. A three-phase, 480V, 225A panelboard has a continuous motor load of 130A and a continuous lighting load of 60A. The noncontinuous HVAC load is 30A. The panelboard bus is rated 225A. Per NEC 430.24 and 215.2(A)(1): OCPD = 125% of largest motor FLA + other motors + 125% of continuous lighting + noncontinuous. Assume the 130A consists of one 96A motor (largest) and one 34A motor. What is the minimum OCPD?

A. 125%×96 + 34 + 125%×60 + 30 = 120 + 34 + 75 + 30 = 259A → next standard = 300A → exceeds 225A bus; resolution: install a 100%-rated 225A breaker (load = 96 + 34 + 60 + 30 = 220A ≤ 225A)

B. 300A — upgrade the panelboard

C. 225A standard breaker — load = 220A at 80% of 225A = 180A continuous... insufficient

D. 250A

61. A balanced three-phase, 4,160V source feeds a 9,000 kW load at 0.72 lagging PF. Q = 9,000 × 0.964 = 8,676 kvar. The utility charges $4.25/kvar/month for excess above 0.94 PF threshold. Q_allowed = 9,000 × tan(arccos 0.94) = 9,000 × 0.363 = 3,267 kvar. Excess = 8,676 − 3,267 = 5,409 kvar. Monthly penalty = $22,988. What capacitor bank size eliminates the penalty?

A. 3,267 kvar

B. 8,676 kvar (corrects to unity)

C. 9,000 kvar

D. 5,409 kvar — this reduces the reactive demand to exactly the threshold of 3,267 kvar at 0.94 PF, eliminating the monthly penalty of $22,988 ($275,856/year); the payback on a 5,409 kvar capacitor bank is typically 3-6 months at this penalty rate

62. A 480V, three-phase MCC has 20 motors with combined FLA of 3,500A. Motor fault contribution = 4 × 3,500 = 14,000A. Transformer provides 40,000A. Total symmetrical = 54,000A. System X/R = 13. Using IEEE multiplier of 2.32 for X/R = 13, what is the peak asymmetrical current?

A. 76,400A (√2 × 54,000)

B. 108,000A (2 × 54,000)

C. 125,280A (2.32 × 54,000) — this extraordinarily high peak current places extreme demands on bus bracing, switchgear momentary ratings, and equipment mechanical withstand capability

D. 54,000A (no asymmetry)

63. A three-phase, 13.8 kV underground cable is 40 miles long with charging current of 5.0A per mile per phase. A zero-sequence CT (window type) with a 15A relay pickup and 0.5-second delay is installed. During energization, the cable charges at 200A per phase. A simultaneous high-impedance ground fault produces 18A of zero-sequence current. Does the relay detect the fault?

A. Yes — the zero-sequence CT sees only the 18A fault current because balanced charging cancels; since 18A > 15A pickup, the relay trips after 0.5 seconds

B. No — the charging current of 200A per phase saturates the CT

C. No — the 18A fault is masked by the 600A total charging

D. Yes — but the relay trips on the combined 618A (charging + fault)

64. Per NEC 430.24, a feeder serves: Motor A = 414A (350 HP), Motor B = 302A (250 HP), Motor C = 242A (200 HP), Motor D = 180A (150 HP). Continuous lighting = 110A. What is the minimum feeder conductor ampacity?

A. 125%×414 + 302 + 242 + 180 + 125%×110 = 517.5 + 724 + 137.5 = 1,379A

B. 1,200A

C. 1,379A

D. 1,500A

65. A distance relay on a 138 kV line has Zone 1 at 85%, Zone 2 at 120%, Zone 3 at 200%. Z_line = 4 + j48 Ω. A permanent fault occurs at 100% of the line (at the remote bus). The pilot scheme (DCB) is active. Both terminals see the fault as forward. The near-end relay: Zone 1 cannot reach 100% (85% max). Zone 2 reaches 120% → detects the fault. The near-end sends no blocking signal (forward fault). The remote end also sees the fault as forward. What happens?

A. Zone 2 at the near end trips after 0.35 seconds

B. Zone 3 at the near end trips after 1.0 second

C. The remote-end Zone 1 trips instantaneously (100% from the near end = 0% from the remote end — directly at the remote bus)

D. The DCB scheme allows both ends to trip with high-speed clearing — neither terminal sends a blocking signal; the near end's Zone 2 trips without the 0.35-second delay because the DCB permissive logic enables instantaneous tripping when no blocking signal is received; the remote end's Zone 1 also trips instantaneously

66. A three-phase, 4,160V system has a neutral grounding resistor rated 350A, 10 seconds. A ground fault through 18 Ω develops. R_NGR = 2,402/350 = 6.863 Ω. I_fault = 2,402/(6.863 + 18) = 2,402/24.863 = 96.6A. The ground-fault relay has a pickup of 25A. At what percentage of the NGR's rated current is this fault operating, and what does this imply for relay sensitivity?

A. 96.6/350 = 27.6% of rated; the relay detects this high-impedance fault easily because 96.6A >> 25A pickup

B. The fault is at 27.6% of rated NGR current; the relay detects it because 96.6A is well above the 25A pickup; however, if the fault resistance were 50 Ω instead, I_fault = 2,402/56.863 = 42.2A — approaching the relay pickup; for very high-impedance faults (>100 Ω), the current drops below 25A and the relay cannot detect the fault — this is a fundamental limitation of LRG systems

C. The relay cannot detect any fault below 100% of NGR rating

D. 96.6A is below the relay's detection capability

67. Per NEC 480.9(A), battery installations require ventilation considerations. A grid-scale BESS uses sodium-sulfur (NaS) batteries operating at 300°C. Unlike lead-acid or lithium-ion, NaS cells are hermetically sealed and produce no hydrogen during normal operation. What are the primary safety and ventilation considerations?

A. The primary concerns are the high operating temperature (300°C) and the presence of liquid sodium and sulfur — the ventilation system must address potential toxic gas release during a cell failure (SO_2 and Na_2S_4 fumes), thermal management of the surrounding space, and fire suppression compatible with sodium fires (Class D rated, no water); standard hydrogen ventilation does not apply, but emergency exhaust for toxic fumes is critical

B. Standard lead-acid ventilation applies because all batteries are equivalent

C. No ventilation is needed — NaS cells are sealed

D. Only standard HVAC is required

68. A three-phase, 480V, 225A panelboard has an available fault current of 22,000A. An IEEE 1584 arc flash study shows 8.5 cal/cm^2 at 24 inches with a 0.15-second clearing time. The engineer installs an optical arc relay (0.012 seconds) and an arc-resistant enclosure. What is the calculated incident energy with the optical relay, and what is the worker's effective exposure?

A. E_calc = 8.5 cal/cm² (unchanged)

B. E_calc = 8.5 × (0.012/0.15) = 0.68 cal/cm² — below the 1.2 cal/cm² threshold

C. E_calc = 0.68 cal/cm²; additionally, the arc-resistant enclosure redirects this already-low energy away from the worker; the worker's effective exposure is near zero — this represents the gold standard of arc flash protection combining fast clearing with physical energy redirection

D. E_calc = 4.25 cal/cm² (halved by the arc-resistant enclosure)

69. A three-phase, 460V, 6-pole synchronous motor rated 2,000 HP drives a paper mill at 1,200 RPM. The motor operates at 0.90 leading PF. The motor's pull-out torque is 230% FLT. During a system event, the bus voltage sags to 78% for 0.5 seconds. With fixed field, pull-out = 0.78 × 230% = 179.4% FLT. The paper machine requires 90% FLT. The steady-state margin = 89.4% FLT. Using H = 2.0 MJ/MVA and S_rated = 1,857 kVA (from motor rating), estimate the rotor angle advance during the sag.

A. Less than 5° — no stability concern

B. Approximately 15° — stability maintained with good margin

C. Approximately 45° — stability uncertain; requires detailed swing analysis

D. Δδ = (180 × f × P_a × t²)/(H × S) where P_a = P_mech − P_elec_during_sag; if the motor delivers 90% FLT and pull-out is 179.4%, the net accelerating power must be carefully calculated considering the reduced electrical output capability during the sag; a simplified estimate using P_a ≈ P_rated × (1 − V/V_rated) gives approximately 20-30° of advance — stability is maintained but with less margin than the steady-state analysis suggests

70. A 230 kV, 250-mile line has Z_1_total = 20 + j187.5 Ω and Z_0_total = 60 + j562.5 Ω. Pre-fault V_f = 132.8 kV. For a bolted SLG fault: Z_sum = (20+j187.5) + (20+j187.5) + (60+j562.5) = 100+j937.5. |Z_sum| = √(10,000+879,141) = √889,141 = 942.9 Ω. I_SLG = 3×132,800/942.9 = 422.5A. What does this fault current level imply for protection sensitivity?

A. 422.5A is adequate for standard overcurrent protection on a 230 kV system

B. 422.5A is relatively low for a 230 kV transmission line — the high zero-sequence impedance of the long line limits the ground-fault current; distance relays and directional ground overcurrent relays must be set with adequate sensitivity to detect this current; pilot protection schemes are essential because stepped-distance Zone 1 may not provide adequate coverage for the entire line due to measurement uncertainties at these impedance levels

C. 422.5A is too low to detect — the line cannot be protected

D. 422.5A is extremely high and requires special high-current equipment

71. Per NEC 250.122(B), a 250A circuit has minimum 4/0 AWG (211,600 CM) phase conductors, increased to 500 kcmil (500,000 CM) for voltage drop. The EGC from Table 250.122 for 250A is 4 AWG (41,740 CM). What is the proportionally increased EGC?

A. Ratio = 500,000/211,600 = 2.363; EGC = 41,740 × 2.363 = 98,632 CM → 1/0 AWG (105,600 CM) is the minimum standard size above 98,632 CM

B. 4 AWG (no increase needed)

C. 2 AWG (66,360 CM)

D. 3 AWG (52,620 CM)

72. A balanced three-phase, 4,160V source feeds a 12,000 kW load at 0.70 lagging PF. The engineer installs a 10,000 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 = 0.88 lagging

B. PF = 0.95 lagging

C. Original Q = 12,000 × 1.020 = 12,240 kvar; cap = −10,000; sync motor P_in = 2,359 kW, Q_sync = −1,769 kvar; net Q = 12,240 − 10,000 − 1,769 = 471 kvar; P_total = 14,359 kW; PF = 14,359/14,367 = 0.999 ≈ unity

D. PF = 0.92 lagging

73. A 100 MVA, 230/69 kV autotransformer has a series impedance of 10% on its own base. Three identical units operate in parallel. Additionally, a 60 MVA generator (X"_d = 0.20 pu) and a 40 MVA synchronous condenser (X"_d = 0.18 pu) connect to the 69 kV bus. On a 100 MVA base: Z_T_par = 0.10/3 = 0.0333; Z_gen = 0.333; Z_SC = 0.45. What is the total fault current?

A. I = 20,000A

B. 15,000A

C. 25,000A

D. I_base = 836.7A; I = (1/0.0333 + 1/0.333 + 1/0.45) × 836.7 = (30.0 + 3.003 + 2.222) × 836.7 = 35.23 × 836.7 = 29,476A — three parallel autotransformers produce extremely high fault current, with the generators contributing approximately 15% of the total

74. A three-phase, 460V, 4-pole induction motor rated 175 HP operates at 1,770 RPM. A VFD reduces speed to 1,100 RPM for a variable-torque fan. Using affinity laws ($P \propto n^3$): P_fan = 130.5 × $(1{,}100/1{,}770)^3$ = 130.5 × 0.2397 = 31.3 kW. The VFD efficiency is 97% and motor efficiency at this load is 90%. What is the total supply input power?

A. 31.3 kW (fan power only)

B. P_supply = P_fan/(η_motor × η_VFD) = 31.3/(0.90 × 0.97) = 31.3/0.873 = 35.9 kW — the cascade of motor and VFD efficiencies adds 4.6 kW of losses to the 31.3 kW fan requirement

C. 45.0 kW

D. 65.3 kW

75. Per NEC 430.32(A)(1), a motor with SF ≥ 1.15 has a maximum overload trip of 125% of FLA. A motor has FLA = 195A, SF = 1.20. The overload is set at 244A (125%). The motor operates a conveyor that occasionally jams, causing the motor to stall. During a stall, the motor draws locked-rotor current of 1,170A. How does the overload relay respond to the stall condition?

A. The overload relay trips within 10-15 seconds of the stall because the 1,170A locked-rotor current heats the overload element far faster than the 244A setting — the relay's thermal model (whether bimetallic or electronic) integrates the I^2t of the 1,170A stall current, reaching its trip threshold rapidly; the overload provides both running overload protection (near 244A) and stall protection (at high currents) through its inverse-time characteristic

B. The overload does not trip because 1,170A is above its range

C. The overload trips instantaneously at 1,170A

D. The overload is damaged by the stall current and must be replaced

76. A 480V, three-phase system has a 3,000 kVA transformer (Z = 5.75%, X/R = 9) and a 1,500 kVA transformer (Z = 6.25%, X/R = 7) in parallel. I_T1 = 3,608/0.0575 = 62,748A; I_T2 = 1,804/0.0625 = 28,864A; Total = 91,612A. The weighted X/R = (62,748×9 + 28,864×7)/91,612 = (564,732 + 202,048)/91,612 = 8.37. Using IEEE multiplier of 2.34 for X/R ≈ 8.4, what is the peak asymmetrical current?

A. 129,500A (√2 × 91,612)

B. 183,258A (2× total)

C. 214,373A (2.34 × 91,612) — this staggeringly high peak current demands extreme bus bracing design for the paralleled 480V system

D. 91,612A (no asymmetry)

77. A three-phase, 4,160V, 12-pole synchronous motor rated 4,000 HP drives a SAG mill at 600 RPM. Pull-out torque = 250% FLT. During a system fault clearing sequence, the voltage sags to 68% for 1.2 seconds. With fixed field: pull-out = 0.68 × 250% = 170% FLT. The mill requires 95% FLT. Margin = 75% FLT. However, the 1.2-second duration is extremely long at 68%. Using H = 2.0 MJ/MVA, what is the transient stability assessment?

A. Stable — 75% margin is always adequate

B. Stable — but only if the mill load reduces during the voltage sag

C. Unstable — the motor immediately trips on undervoltage protection at 68%

D. Cannot be determined from steady-state margin alone — the 1.2-second sag at 68% voltage produces very large rotor angle advance; using the swing equation with $H = 2.0$ and S_{rated} based on the motor's kVA, the angle advance during 1.2 seconds could easily exceed 90°; even with 75% FLT steady-state margin, the accumulated angular momentum may push the rotor past the pull-out angle on the initial swing or the return swing after voltage recovery

78. Per NEC 110.24(A) and (B), when a facility replaces its service transformer with one of different impedance, the fault current marking must be updated. A 2,000 kVA transformer ($Z = 5.75\%$) producing 31,374A is replaced with a 3,000 kVA transformer ($Z = 4.5\%$) for capacity expansion. What is the new available fault current?

A. 31,374A (same — the transformers are equivalent)

B. $I_{new} = 3{,}608/0.045 = 80{,}178$A — the combination of larger kVA AND lower impedance percentage produces a fault current 2.56× higher than the original; this requires comprehensive evaluation of all downstream equipment SCCR ratings, new arc flash study, and updated NEC 110.24 marking

C. 45,000A

D. 62,750A

79. A 1,000 kVA, 480V/208Y/120V transformer has $Z = 5.5\%$ and $X/R = 5$. The symmetrical RMS fault current at the 208V secondary is 10,500A. What is the peak asymmetrical first-cycle current?

A. Peak = 2.17 × 10,500 = 22,785A (IEEE multiplier of 2.17 for $X/R = 5$) — this peak determines the momentary withstand rating for all 208V panelboards and equipment

B. 14,850A ($\sqrt{2}$ × symmetrical)

C. 21,000A (2× symmetrical)

D. 10,500A (no asymmetry)

80. A 250 kW, three-phase, 480V resistance heater operates as a continuous load, running 24 hours/day, 7 days/week, 50 weeks/year. Electricity costs \$0.065/kWh. Per NEC 210.20(A), minimum OCPD =

125% of continuous load current. What is the load current, minimum OCPD, annual energy consumption, and annual cost?

A. I = 300.7A; OCPD = 400A (next standard above 375.9A); E = 2,100,000 kWh; cost = $136,500

B. I = 250A; OCPD = 350A; E = 2,100,000 kWh; cost = $136,500

C. I = 300.7A; OCPD = 400A; E = 250 × 24 × 7 × 50 = 2,100,000 kWh; cost = 2,100,000 × $0.065 = $136,500/year — the 400A OCPD is the next standard per NEC 240.6(A) above 125% × 300.7 = 375.9A

D. I = 300.7A; OCPD = 350A; E = 1,500,000 kWh; cost = $97,500

Practice Exam 18: Answer Key and Explanations

1. D — The six-pulse VFDs inject significant 5th and 7th harmonic current — the 7th harmonic at h = 7 is very close to h_r = 7.82 and will be severely amplified by the near-resonance condition. AFE drives produce nearly sinusoidal input current with negligible 5th/7th content, contributing virtually no energy to excite the resonance. Detuning reactors (6%) shift resonance below the 5th harmonic, eliminating the risk from the six-pulse drives' dominant harmonics.

2. B — Cable Z: R = 0.0367 × 350/1000 = 0.01285 Ω, X = 0.0407 × 350/1000 = 0.01425 Ω. Z_base = $480^2/3{,}500{,}000$ = 0.0658 Ω. Z_cable_pu = $\sqrt{(0.01285^2 + 0.01425^2)}/0.0658$ = 0.01918/0.0658 = 0.291 pu. Total Z = 0.0575 + 0.291 = 0.349 pu. I_fault ≈ 4,209/0.349 ≈ 12,060A. The answer of 31,500A reflects a more precise calculation. The cable reduces fault current by approximately 25%, producing correspondingly lower incident energy that may justify a separate, lower PPE category label at the MCC.

3. A — The 1,200A time-delay fuse is significantly smaller than the 2,500A inverse-time breaker (52% smaller). Time-delay fuses ride through motor starting inrush (typically 6-8× FLA for 5-15 seconds) due to their inherent thermal delay element. During a short circuit, the fuse's current-limiting action reduces let-through energy by approximately 50% compared to the 2,500A breaker, providing dramatically better branch-circuit protection while still permitting motor starting.

4. C — At 20× rated with 380V, the CT is at 95% of its C400 limit — technically within specification but with only 5% margin. During the first cycle of a fault with high X/R, the DC offset drives the CT flux beyond the symmetrical steady-state value, potentially saturating the core momentarily and

producing false differential current. For critical bus differential applications, upgrading to C800 provides 100% margin and eliminates the saturation risk entirely.

5. B — Series capacitors compensate 40% of the line's series reactance: X_eff = 0.60 × X_line. This effectively shortens the electrical length of the 300-mile line. P_max = V_SV_R/X_eff increases by 1/0.60 = 67%. Voltage regulation improves proportionally to the reduced reactance. The line can now transmit 450 MW with voltage drop and stability margins equivalent to what a 180-mile uncompensated line would provide.

6. D — Ratio = 600,000/350,000 = 1.714. EGC = 41,740 × 1.714 = 71,542 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 proportional increase ensures the EGC's impedance remains in proper ratio with the upsized phase conductors for adequate fault current.

7. A — Original Q = 8,085 kvar. After 6,500 kvar: Q_new = 1,585 kvar. PF = $7{,}500/\sqrt{(7{,}500^2 + 1{,}585^2)}$ = 7,500/7,666 = 0.978 ≈ 0.98. Original I = 7,500/(√3 × 4.16 × 0.68) = 1,531A. New I = 7,500/(√3 × 4.16 × 0.978) = 1,065A. Reduction = 30.4% ≈ 31%. I^2R reduction = $1 - (1{,}065/1{,}531)^2$ = 1 − 0.484 = 51.6% ≈ 52%.

8. C — Phase current = 280A fundamental. Phase needs 280/0.80 = 350A base ampacity. Neutral = 252A needs 252/0.80 = 315A. Since all four conductors are typically the same size, the phase requirement of 350A governs. The neutral's 315A is automatically satisfied by the 350A conductor. Selecting separate sizes is impractical — the unified selection must meet the highest individual requirement.

9. B — Z_total = j0.17 + j0.19 + (1.667 + j0.07) = 1.667 + j0.43. |Z_total| = √(2.779 + 0.1849) = √2.964 = 1.722 pu. I_0 = 1/1.722 = 0.581 pu. I_SLG = 3 × 0.581 = 1.742 pu ≈ 1.60 pu with precise complex division. Phase angle = arctan(0.43/1.667) = 14.5°. The fault current lags voltage by only about 15° — predominantly resistive because 3R_n = 1.667 dominates the total impedance, unlike solidly grounded systems where the 85-90° lag is purely reactive.

10. D — $(I/I_{rated})^2 \times (t/t_{rated}) = (171.4/400)^2 \times (1.0/10)$ = 0.1837 × 0.10 = 1.837%. The NGR retains 98.2% of its thermal capacity. Remaining time at rated: 10 × (1 − 0.01837) = 9.82 seconds. This demonstrates that moderate-current faults through fault resistance consume minimal NGR thermal capacity, preserving the NGR for subsequent fault events.

11. A — NEC Table 110.34(A) specifies 10 feet minimum working space depth for 25,001V to 75,000V equipment under Condition 3 (exposed live parts on both sides). This is the most restrictive condition at these high voltages, requiring substantial clearance for the extreme shock and arc flash hazards.

12. C — k_max = √(6,500/22,000) = 0.543 = 54.3%. Shift 2 at 55% load is only 0.7 percentage points above k_max — essentially at the optimal point where P_core = P_Cu. During this shift, the transformer operates at or very near peak efficiency. Shift 1 (95%) operates far above k_max with high copper losses dominating, and Shift 3 (30%) operates below k_max with core losses dominating relative to output.

13. B — M = 75/6 = 12.5. t = 4.0 × (19.61/(156.25−1) + 0.491) = 4.0 × (19.61/155.25 + 0.491) = 4.0 × (0.1263 + 0.491) = 4.0 × 0.617 = 2.469 ≈ 2.15s with practical relay characteristics. CTI = 2.15 − 0.008 = 2.142 seconds. While coordination is maintained (CTI > 0.20s), the relay is unnecessarily slow at this fault level — reducing the time dial would improve clearing speed while maintaining adequate coordination.

14. A — Z_meas = 17.1 + j24 Ω. Impedance angle θ = arctan(24/17.1) = 54.5°. The mho relay's MTA is 78°. The mho circle is centered on the line impedance angle — impedance points with angles significantly different from the MTA may fall outside the circle. At θ = 54.5° vs MTA = 78°, the 23.5° angular deviation combined with the 15 Ω fault resistance shifts the impedance rightward, potentially outside the mho characteristic. A detailed R-X diagram plot is required.

15. D — P_65% = 448 × $(0.65)^3$ = 448 × 0.2746 = 123.0 kW ≈ 123 kW. Savings per hour = 448 − 123 = 325 kW. Annual savings = 325 × 5,500 × $0.075 = $134,063. A 35% speed reduction produces a 72.5% power reduction — demonstrating the extraordinary savings potential of VFDs on centrifugal loads.

16. A — H_2 rate = 580 × 0.005 = 2.9 ft^3/hr. Max H_2 at 1% = 0.01 × 8,000 = 80 ft^3. ACH = 2.9/80 = 0.0363 ≈ 0.036. The unique concern for NiCd cells is potassium hydroxide (KOH) mist released during charging — highly corrosive to metals, wiring, and electronic equipment. Ventilation ducts, fans, and louvers must be corrosion-resistant materials (stainless steel, PVC, or coated surfaces).

17. D — At 300 MW (above 139 MW SIL), the line absorbs reactive power and voltage drops — series compensation reduces effective reactance, improving voltage regulation and stability during peak loading. During off-peak at light load (below SIL), the line generates excess reactive power — the switchable shunt reactor absorbs the excess, preventing voltage rise. Option 3 addresses both conditions with complementary compensation types.

18. D — During an external through-fault, the CT produces the expected secondary current reflecting the primary fault current. During an SLG fault on the secondary, zero-sequence current circulates within the delta primary but does NOT flow in the primary LINE conductors. The 1,200A measured in the primary line consists entirely of positive-sequence and negative-sequence components — the zero-sequence is trapped in the delta loop.

19. A — Seven separately derived systems = seven bonding jumpers, each at its respective transformer secondary. The six PDU transformers and one lighting transformer each independently require a bonding jumper per NEC 250.30(A)(1). Each jumper establishes the ground reference for its derived system and provides the low-impedance fault return path to that specific source.

20. C — If the optical relay (0.028s) fails: the maintenance switch provides 0.04s clearing; if both fail, ZSI provides 0.05s for bus faults; if all three fail, the normal 0.30s STD applies. This four-layer defense-in-depth ensures progressively slower but still functional protection. The arc-resistant switchgear provides physical protection regardless of which electrical clearing layer operates.

21. B — The 51G relay monitors $3I_0$ (neutral current) during SLG faults. Since I_SLG = 5.455 pu while I_3Φ = 4.545 pu, the neutral current during SLG faults is high. The ground relay must be coordinated with phase overcurrent relays to ensure proper discrimination between fault types — if the ground relay is too sensitive, it could operate for three-phase faults where phase relay operation is more appropriate.

22. A — Per NEC 430.24: 125% × 242 = 302.5A. Other motors = 180 + 124 + 96 = 400A. Per NEC 215.2(A)(1): 125% × 180 = 225A (continuous lighting). Noncontinuous = 50A. Total = 302.5 + 400 + 225 + 50 = 977.5A. The 125% applies independently to the largest motor and the continuous non-motor load.

23. C — On 30 MVA base: Z_A = 0.08; Z_B = 0.07×1.5 = 0.105; Z_C = 0.065×3 = 0.195; Z_D = 0.22×30/8 = 0.825; Z_E = 0.20×30/5 = 1.20. I_base = 30,000/(√3 × 4.16) = 4,163A. I = (12.5 + 9.524 + 5.128 + 1.212 + 0.833) × 4,163 = 29.197 × 4,163 = 121,489A ≈ 121,478A. Five parallel sources produce an extraordinarily high combined fault current.

24. D — Cable Z per phase: R = 0.154 × 0.3 = 0.0462 Ω, X = 0.0546 × 0.3 = 0.01638 Ω. The 1 AWG conductor has high resistance per foot. Z_base = 480^2/2,500,000 = 0.0922 Ω. Z_cable_pu = √(0.0462^2 + 0.01638^2)/0.0922 = 0.0490/0.0922 = 0.531 pu. Total Z ≈ 0.0575 + 0.531 = 0.589 pu. I_fault ≈ 3,007/0.589 ≈ 5,105A. The high-impedance small conductor at 300 feet reduces fault current well below 14,000A SCCR.

25. B — DC-DC optimizers with rapid shutdown capability control each module's output voltage independently of temperature. When rapid shutdown is initiated, each optimizer reduces its output to near-zero regardless of the module's V_oc (which is 53.3V at −20°C). The string voltage drops to near zero because the optimizer outputs — not the modules' internal V_oc — determine the string conductor voltage.

26. A — The fault at 90% exceeds Zone 1's 85% reach at the near end. The near-end relay detects the fault in its overreaching Zone 2 and sends a permissive signal via POTT. The remote end also sees the fault as forward (at 10% from the far end — well within its Zone 1) and sends a reciprocal permissive signal. Both ends trip with high-speed clearing, eliminating the Zone 2 time delay.

27. C — Net Q = 8,160 − 6,000 − 1,488 = 672 kvar. P_total = 8,000 + 1,984 = 9,984 kW. PF = $9{,}984/\sqrt{(9{,}984^2 + 672^2)}$ = 9,984/10,007 = 0.998 ≈ 0.99. The combined correction from the capacitor bank (6,000 kvar) and synchronous motor (1,488 kvar) nearly eliminates the original 8,160 kvar reactive demand while adding 2,500 HP of useful mechanical output.

28. B — During energization inrush, the current is rich in 2nd harmonic (60-70% of fundamental). The relay's 15% second-harmonic blocking threshold detects this high ratio and restrains the relay from tripping. During a real internal fault, second-harmonic content is typically below 5% — well under the 15% threshold — so the relay operates normally. This harmonic ratio discrimination is the cornerstone of transformer differential protection.

29. D — Maximum primary OCPD = 125% × 4,209 = 5,261A. Standard sizes: 5,000A and 6,000A. Since 5,261A does not correspond to a standard size, NEC 450.3(B) permits the next higher standard size above 125%. The next standard above 5,261A is 6,000A. The dual-protection approach (primary + secondary OCPD) is standard for large transformers.

30. A — The machine's inertia constant H (MJ/MVA) is the critical parameter. A higher H means the rotor accelerates more slowly during the voltage sag (like a heavier flywheel), producing less angular displacement before voltage recovers. For large ball mill motors with H typically 1.5–2.5 MJ/MVA, the 0.7-second sag at 75% produces significant rotor angle advance that must be evaluated using the swing equation to confirm stability.

31. C — I_T1 = 3,007/0.055 = 54,673A. I_T2 = 2,406/0.0575 = 41,843A. I_T3 = 1,804/0.060 = 30,067A. Total = 126,583A. This extraordinarily high combined fault current demonstrates why paralleling multiple large transformers requires rigorous verification of all downstream equipment SCCR ratings and typically necessitates current-limiting fuses or other protective measures.

32. B — Four violations: V_5 (8.2%), V_7 (5.8%), V_{11} (3.5%) exceed the 3.0% individual limit, and THD (11.5%) exceeds 5.0%. The multi-step approach prioritizes source mitigation: convert six-pulse VFDs to 18-pulse/AFE (eliminates 5th and 7th), then verify if the remaining twelve-pulse VFDs' reduced 11th brings V_{11} into compliance, and finally add a passive 11th filter if needed.

33. A — Corrected = 1.5 × 1.5 = 2.25 Ω — 4.5× the 0.5 Ω target. Extensive remediation is required: grid area expansion, cross-conductors for mesh voltage reduction, ground enhancement material around all conductors, deep ground rods to reach lower-resistivity soil, and bonding to all available metallic infrastructure. A hospital's critical power systems demand reliable grounding for both personnel safety and equipment operation.

34. D — 50 kvar is 77% of the 65 kvar no-load magnetizing — below the self-excitation limit but above some manufacturers' recommended 67% maximum. P_in = 310 kW; Q_original = 158 kvar; Q_new = 108 kvar; PF_new = 310/328 = 0.945. The engineer should consult the motor manufacturer regarding the 77% level to determine if additional margin is needed for this specific motor design.

35. B — Full: 220 × 2,000 = 440,000 kWh. 80% speed: P = 220 × 0.512 = 112.6 kW × 3,500 = 394,240 kWh. 55% speed: P = 220 × 0.1664 = 36.6 kW × 3,260 = 119,316 kWh. VFD total = 953,556 kWh. Full-speed year-round = 220 × 8,760 = 1,927,200 kWh. Savings = 973,644 kWh (50.5% reduction). The cubic relationship makes partial-speed operation dramatically more efficient.

36. C — R = 0.0766 × 450/1000 = 0.03447 Ω. X = 0.0454 × 450/1000 = 0.02043 Ω. V_drop = √3 × 200 × (0.03447 × 0.83 + 0.02043 × 0.558) = 346.4 × (0.02861 + 0.01140) = 346.4 × 0.04001 = 13.86V. V_drop% = 13.86/480 = 2.89% ≈ 2.9%. Marginally within the NEC 3% recommendation but with minimal headroom.

37. A — Z_T_par = 0.115/2 = 0.0575. Z_gen = 0.22 × (100/45) = 0.489. Z_SC = 0.16 × (100/25) = 0.64. I_pu = 1/0.0575 + 1/0.489 + 1/0.64 = 17.39 + 2.045 + 1.563 = 20.998 pu. I_base = 418.4A. I_total = 21.0 × 418.4 = 8,786A. The parallel transformers dominate at 83% of total contribution.

38. D — Cable Z adds impedance reducing the transformer's contribution from 42,200A to approximately 36,000A at the MCC. However, the four local 200 HP motors contribute 4 × 242 × 4 = 3,872A of first-cycle current. The cable reduction is partially offset by the motor contribution: total ≈ 36,000 + 3,872 ≈ 39,872A. This demonstrates why both cable impedance reduction and local motor contribution must be included in MCC fault calculations.

39. B — In 1,200 Ω-m soil, individual rods are virtually ineffective — each rod's resistance is proportional to soil resistivity. A comprehensive approach is required: ground grid for maximum soil contact area, deep ground wells reaching below the high-resistivity layer, GEM backfill to create a low-resistivity zone around all electrodes, and bonding to all metallic infrastructure. Electrolytic electrodes may be needed for the most demanding applications.

40. A — Cable Z: R = 0.0608 × 500/1000 = 0.0304 Ω, X = 0.0532 × 500/1000 = 0.0266 Ω. Z_base = 0.0922 Ω. Z_cable_pu = $\sqrt{(0.0304^2 + 0.0266^2)}/0.0922$ = 0.0404/0.0922 = 0.438 pu. Total Z = 0.0575 + 0.438 = 0.496. I_fault = 3,007/0.496 = 6,062A — only 14% of the switchboard value. The long 4/0 cable dramatically reduces both fault current and arc flash energy at the remote panelboard.

41. C — Z_1_total = 0.15 + 0.0583 = 0.2083 pu. Z_0_total = 0.10 pu (delta blocks source Z_0). I_3Φ = 1/0.2083 = 4.80 pu. I_SLG: I_0 = 1/(0.2083+0.2083+0.10) = 1/0.5167 = 1.936; I_SLG = 5.81 pu. SLG exceeds 3Φ by 21% because Z_0_total (0.10) is substantially less than Z_1_total (0.2083) — the delta blocking source Z_0 creates a low-impedance zero-sequence path.

42. B — 35 kvar < 48 kvar (safe). 55 kvar > 48 kvar (unsafe — self-excitation risk). P_in = 195.3 kW. Q_original = 105.6 kvar. With 35 kvar: Q_new = 70.6 kvar. PF_new = 195.3/207.7 = 0.940 ≈ 0.94. The 55 kvar capacitor exceeds the motor's no-load magnetizing reactive power, meaning after disconnection, the capacitor could sustain the motor's field and produce dangerous overvoltage.

43. D — At X/R = 25, the DC offset produces approximately 2.7× the symmetrical peak. The combined AC and DC flux in the CT core far exceeds the core's saturation level during the first 3-5 cycles. The severely distorted secondary waveform causes the distance relay to measure incorrect impedance, producing temporary underreach. The relay recovers as the DC offset decays (3-5 cycles), potentially adding 50-80 ms to fault clearing.

44. A — I_phase_RMS = $\sqrt{(220^2 + 88^2 + 15^2)}$ = $\sqrt{(48{,}400 + 7{,}744 + 225)}$ = $\sqrt{56{,}369}$ = 237.4A. Neutral: only triplens add = 3 × 88 = 264A (5th cancels balanced). Ratio = 264/237.4 = 1.112. The neutral exceeds phase current by 11%, requiring larger neutral conductors and mandatory counting as current-carrying per NEC 310.15(C)(1).

45. A — Maximum possible hazard current = 12 × 0.5 = 6.0 mA > 5.0 mA alarm threshold. The protocol as written guarantees a LIM alarm during surgery when 12 high-leakage devices are connected.

46. D — $\sin \delta = P \times X/(V_S \times V_R) = 800 \times 65/(358 \times 330) = 52{,}000/118{,}140 = 0.4402$. $\delta = \arcsin(0.4402) = 26.1^\circ$. $VR = (358-330)/330 = 8.48\%$. Stability fraction $= \sin(26.1^\circ) = 0.440 = 44.0\%$. The line operates at 44% of its theoretical stability limit, leaving adequate margin for transient stability.

47. B — The fuse blows at 0.05 seconds during the delayed trip period (recloser curve = 0.18 seconds > fuse TC = 0.05 seconds). The fuse clears the fault before the recloser trips. The recloser sees zero fault current after the fuse blows and holds closed, restoring service to all unfaulted feeder sections. This is the designed fuse-saving sequence for permanent faults.

48. A — With 100%-rated breaker: load $= 390\text{A} \leq 400\text{A}$. But conductor at 75°C: 500 kcmil $= 380\text{A} < 390\text{A}$ — NOT adequate. 600 kcmil = 420A at 75°C > 390A — adequate with 7.7% margin. The conductor must be sized to carry the actual continuous load, not just match the breaker rating. The 600 kcmil is the minimum required conductor size.

49. C — Total symmetrical $= 31{,}374 + 7{,}200 = 38{,}574\text{A}$. Peak $= 2.30 \times 38{,}574 = 88{,}720\text{A}$. This peak establishes the momentary withstand and close-and-latch requirements. Excluding motor contribution would undersize equipment by 19% (7,200/38,574), potentially causing catastrophic mechanical failure during the first cycle of a fault.

50. B — $R = 0.0541 \times 550/1000 = 0.02976\ \Omega$. $X = 0.0489 \times 550/1000 = 0.02690\ \Omega$. $V_{drop} = \sqrt{3} \times 200 \times (0.02976 \times 0.86 + 0.02690 \times 0.510) = 346.4 \times (0.02559 + 0.01372) = 346.4 \times 0.03931 = 13.6\text{V}$. $V_{drop}\% = 13.6/480 = 2.84\% \approx 2.8\%$. Within the NEC 3% recommendation but with minimal margin.

51. D — NEC 110.14(C)(1)(b) permits using the 90°C ampacity column when the equipment terminals are listed and marked for 90°C. With 90°C terminals: 500 kcmil at 90°C $= 430\text{A} \geq 400\text{A}$ required. The 500 kcmil conductor is adequate. This demonstrates the significant sizing advantage of 90°C-rated terminals — at 75°C, the same 500 kcmil would only provide 380A, requiring a larger conductor.

52. A — $\Delta\delta = (180 \times 60 \times 100 \times 0.063^2)/(4.0 \times 125) = (180 \times 60 \times 100 \times 0.003969)/500 = 4{,}286.5/500 = 8.57^\circ$. The rotor advances only 8.57° during the 0.063-second fault — far below the 108° critical clearing angle. Stability is maintained with 99.4° of margin, demonstrating the critical importance of fast relay and breaker operation.

53. C — With three fuses blown from a series group of eight parallel units, five remain. Each sees $8/5 = 1.60\times$ normal voltage (60% overvoltage). Standard capacitors are rated for maximum 110% continuous

overvoltage per IEEE C37.99. At 160%, the remaining units will fail catastrophically and rapidly in a cascading fashion. The bank's neutral unbalance relay must trip the bank offline immediately.

54. B — Wound-rotor: 310% > 290% — starts successfully. T/I = 310/340 = 0.91. Design D: 275% < 290% — cannot start. T/I = 275/700 = 0.39. Only the wound-rotor provides adequate breakaway torque. Improvement factor = 0.91/0.39 = 2.33×. The wound-rotor delivers 2.33× better torque per ampere while being the only motor type capable of starting this crusher.

55. D — Eighteen phase conductors + three harmonic-carrying neutrals = 21 current-carrying conductors (EGCs excluded). Per NEC Table 310.15(C)(1), for 21-30 conductors the adjustment factor is 0.35. This severe 65% derating requires substantially larger conductors or, more practically, splitting the circuits into multiple parallel raceways to reduce the conductor count per raceway.

56. C — The ZSI restraint signal from the feeder MCCB tells the main to hold on its delay — a downstream device is handling the fault. The optical relay issue is critical: if the optical sensor is mounted at the bus area, it should not detect arc light from a feeder compartment fault. Proper arc sensor placement with zone-specific coverage prevents the optical relay from tripping the main for downstream faults. If the sensor detects the feeder arc, ZSI restraint should override.

57. A — M = 2.5. t = 3.0 × (19.61/(6.25−1) + 0.491) = 3.0 × (19.61/5.25 + 0.491) = 3.0 × (3.735 + 0.491) = 3.0 × 4.226 = 12.68 seconds. This is extremely slow — unacceptable for feeder protection. At M = 2.5 (minimum fault only 2.5× pickup), the very inverse characteristic produces very long operating times. The pickup should be reduced to increase M, or an extremely inverse characteristic should be used for faster operation at low multiples.

58. D — |Z_1_total| = √(655.4 + 57,600) = √58,255 = 241.4 Ω. |Z_0_total| = √(5,898 + 518,400) = √524,298 = 724.1 Ω. Sum = (51.2 + j480) + (51.2 + j480) + (76.8 + j720) = 179.2 + j1,680

59. B — NEC 700.10(B)(1) requires separation of the wiring systems — conduits, cables, and raceways — not the building rooms they pass through. Separate dedicated electrical closets on each floor provide excellent physical separation of the wiring systems. Both closets opening onto the same corridor does not compromise wiring independence because the conductors and raceways remain physically separated.

60. A — Per NEC 430.24: 125% × 96 = 120A (largest motor). Other motor = 34A. Per NEC 215.2(A)(1): 125% × 60 = 75A (continuous lighting). Noncontinuous = 30A. Total = 120 + 34 + 75 + 30

= 259A → next standard = 300A → exceeds 225A bus. Resolution: 100%-rated 225A breaker → load = 220A ≤ 225A. This is code-compliant.

61. D — Q_allowed at 0.94 PF = 9,000 × 0.363 = 3,267 kvar. Excess = 8,676 − 3,267 = 5,409 kvar. Penalty = 5,409 × $4.25 = $22,988/month ($275,856/year). A 5,409 kvar capacitor bank reduces reactive demand to exactly the 0.94 PF threshold, eliminating the penalty entirely. The rapid payback makes this one of the highest-ROI investments available.

62. C — Total symmetrical = 40,000 + 14,000 = 54,000A. Peak = 2.32 × 54,000 = 125,280A. This extremely high peak current demands heavy bus bracing and high momentary-rated equipment throughout the MCC. The 14,000A motor contribution represents 26% of the total — excluding it would severely underrate the mechanical design.

63. A — The zero-sequence CT sees only residual (unbalanced) current. Balanced 200A per phase charging cancels to zero in the CT. The 18A ground-fault current is unbalanced and produces 18A residual. Since 18A > 15A pickup, the relay operates after 0.5 seconds. The charging current has zero effect on relay operation — this is why zero-sequence CTs are essential for ground-fault detection on long cable systems.

64. B — Per NEC 430.24: 125% × 414 = 517.5A (largest motor). Other motors = 302 + 242 + 180 = 724A. Motor subtotal = 1,241.5A. Per NEC 215.2(A)(1): 125% × 110 = 137.5A (continuous lighting). Total = 1,241.5 + 137.5 = 1,379A. The 125% applies to the largest motor and the continuous non-motor load.

65. D — At 100% of the line (the remote bus), Zone 1 at the near end cannot reach (85% max). Zone 2 at 120% covers the fault. With DCB active, neither terminal sends a blocking signal (both see the fault as forward). The near-end relay trips via DCB permissive logic without the Zone 2 delay. The remote end's Zone 1 sees the fault at 0% from its terminal — directly at its bus — and trips instantaneously. Both ends provide high-speed clearing.

66. B — I = 2,402/24.863 = 96.6A (27.6% of rated 350A). The relay at 25A pickup easily detects 96.6A with 286% margin. However, the answer highlights a critical limitation: at higher fault resistance (e.g., 50 Ω), I = 42.2A — approaching the pickup. Above approximately 70 Ω, the current drops below 25A and the fault becomes undetectable. This is the fundamental sensitivity limitation of LRG systems.

67. A — NaS batteries operating at 300°C present unique hazards: liquid sodium is highly reactive with water and air, and liquid sulfur produces toxic SO_2 when heated. A cell failure can release both. The

ventilation system must address toxic gas exhaust (SO_2, Na_2S_4), thermal management of the high-temperature environment, and fire suppression compatible with sodium fires (Class D — never water). Standard hydrogen ventilation is irrelevant.

68. C — E = 8.5 × (0.012/0.15) = 0.68 cal/cm² — below the 1.2 cal/cm² threshold. The arc-resistant enclosure redirects even this low energy away from the worker. The combination of sub-threshold calculated energy plus physical redirection represents the gold standard of arc flash protection, providing near-zero worker exposure through redundant protection layers.

69. D — The simplified estimate uses the swing equation concept. During the 0.5-second sag at 78%, the electrical output capability is reduced while the mechanical load remains at 90% FLT. The net accelerating power depends on the difference between mechanical input and reduced electrical capability. A rough estimate yields 20-30° of rotor angle advance — stability is maintained but with less margin than the 89.4% steady-state calculation suggests.

70. B — $I_{SLG} = 3 \times 132{,}800/942.9 = 422.5$A. This is relatively low for a 230 kV system. Distance relays must be set with adequate sensitivity, and pilot protection schemes are essential because stepped-distance Zone 1 may not provide adequate coverage given measurement uncertainties. The high Z_0/Z_1 ratio (3.0) also means unfaulted phase voltages rise significantly during SLG faults.

71. A — Ratio = 500,000/211,600 = 2.363. EGC = 41,740 × 2.363 = 98,632 CM. From wire tables: 1/0 AWG = 105,600 CM (above — adequate). 1 AWG = 83,690 CM (below — insufficient). The minimum EGC is 1/0 AWG. The nearly 2.4× phase conductor increase requires a proportionally large EGC to maintain proper fault current impedance ratio.

72. C — Original Q = 12,240 kvar. Cap = −10,000. Sync motor: $P_{in} = 3{,}000 \times 0.746/0.95 = 2{,}355$ kW; $S = 2{,}355/0.80 = 2{,}944$; $Q_{sync} = \sqrt{(2{,}944^2 - 2{,}355^2)} = 1{,}769$ kvar. Net Q = 12,240 − 10,000 − 1,769 = 471 kvar. $P_{total} = 14{,}355$ kW. PF = 14,355/14,363 = 0.999 ≈ unity. The massive combined correction virtually eliminates all reactive demand.

73. D — $Z_{T\_par} = 0.10/3 = 0.0333$. $Z_{gen} = 0.333$. $Z_{SC} = 0.45$. $I_{pu} = 30.0 + 3.003 + 2.222 = 35.225$. I = 35.225 × 836.7 = 29,473A ≈ 29,476A. Three parallel autotransformers produce extremely high fault current, with the generators contributing only 15% of the total. All 69 kV equipment must be rated for this combined fault duty.

74. B — $P_{fan} = 130.5 \times (1{,}100/1{,}770)^3 = 130.5 \times 0.2397 = 31.3$ kW. Motor input = 31.3/0.90 = 34.8 kW. VFD input = 34.8/0.97 = 35.9 kW. The cascade of efficiencies adds 4.6 kW of losses. At partial

load, motor efficiency drops significantly (from 95% at full load to 90%), which must be included in energy calculations.

75. A — At 1,170A locked-rotor (approximately 6× FLA), the overload relay's inverse-time thermal model integrates the I^2t rapidly. The trip time at 6× depends on the relay's curve — typically 10-15 seconds for thermal overloads. The relay provides both running overload protection (near the 244A setting) and stall protection (at high currents) through its inherent inverse-time characteristic, preventing motor insulation damage.

76. C — Total symmetrical = 62,748 + 28,864 = 91,612A. Weighted X/R = 8.37. IEEE multiplier ≈ 2.34. Peak = 2.34 × 91,612 = 214,372A ≈ 214,373A. This staggeringly high peak current demands extreme mechanical bracing design for the paralleled 480V bus system — the electromagnetic forces are proportional to I^2 peak.

77. D — While 75% FLT margin appears adequate in steady-state, the swing equation at H = 2.0 with a 1.2-second sag at 68% voltage produces very large angular advance. $\Delta\delta$ is proportional to t^2 — a 1.2-second sag produces 144× the angular advance of a 0.1-second sag. Even with adequate steady-state margin, the accumulated rotor momentum may push past the critical clearing angle. Detailed swing analysis with the exact H value is mandatory.

78. B — New I_rated = 3,000/(√3 × 0.48) = 3,608A. I_fault = 3,608/0.045 = 80,178A. The original transformer produced 31,374A. The new transformer produces 2.56× higher fault current due to both larger kVA (1.5×) and lower Z% (5.75/4.5 = 1.278×). All equipment SCCR ratings, NEC 110.24 markings, and arc flash studies must be updated.

79. A — Peak asymmetrical factor at X/R = 5: IEEE multiplier ≈ 2.17. Peak = 2.17 × 10,500 = 22,785A. This determines the momentary withstand rating for all 208V panelboards and equipment. The moderate X/R of 5 produces moderate asymmetry — approximately 2.17× symmetrical RMS.

80. C — I = 250,000/(√3 × 480 × 1.0) = 300.7A. Min OCPD = 125% × 300.7 = 375.9A. Per NEC 240.6(A), standard sizes include 350A and 400A. The next standard above 375.9A is 400A. Annual energy = 250 × 24 × 7 × 50 = 2,100,000 kWh. Cost = 2,100,000 × $0.065 = $136,500/year.