PRACTICE EXAM 25: PE POWER SIMULATION (80 QUESTIONS)

---

1. A 13.8 kV industrial bus has a three-phase fault level of 580 MVA. An existing 8,400 kvar capacitor bank produces h_r = √(580,000/8,400) = 8.31. The bus serves only eighteen-pulse and AFE VFDs with negligible low-order harmonics. A proposed plant expansion will simultaneously add: (1) a 3,000 HP six-pulse VFD compressor, (2) a 1,500 HP six-pulse VFD pump, AND (3) a 4,200 kvar additional capacitor bank for PF correction. The new total capacitor = 12,600 kvar. The new h_r = √(580,000/12,600) = 6.79. The engineer must evaluate the COMBINED effect of adding new harmonic sources AND shifting resonance simultaneously. What is the critical assessment?

A. The new h_r of 6.79 is safely between the 5th and 7th and poses no resonance risk

B. Only the six-pulse compressor matters — the pump is too small to affect harmonics

C. The expansion creates a perfect storm: h_r drops from 8.31 (safe) to 6.79 (between the 5th and 7th) while simultaneously adding two six-pulse drives that inject major 5th and 7th harmonic currents; the amplification factors at h = 5 (AF = 2.62) and h = 7 (AF = 5.82) mean the six-pulse harmonics will be amplified 2.6× and 5.8× respectively; detuning reactors MUST be installed on the ENTIRE 12,600 kvar bank before EITHER the new drives or the additional capacitors are energized — the sequence of energization is critical

D. The AFE drives will cancel the new six-pulse harmonics through active filtering

2. A three-phase, 480V system has a 4,000 kVA transformer (Z = 5.50%, X/R = 10) feeding a switchboard. The switchboard has an available fault current of 53,200A. A 600-foot cable of 3/0 AWG copper in PVC conduit (R = 0.0766, X = 0.0532 Ω/1000 ft) feeds a remote MCC. At the MCC, twelve 50 HP motors (FLA = 65A each, total = 780A) contribute 4 × 780 = 3,120A first-cycle. An IEEE 1584 arc flash study at the switchboard shows 22 cal/cm² at 0.15-second clearing. The engineer calculates the MCC fault current AND must verify whether the dramatic reduction in fault current changes the IEEE 1584 electrode configuration from "VCB" to "VCBB" (which further reduces calculated energy). What is the approximate total MCC fault current?

A. Cable reduces transformer to approximately 7,200A; motors add 3,120A = 10,320A total; at this reduced current, the IEEE 1584 model produces significantly lower arc flash energy AND the electrode configuration may change, compounding the reduction — the MCC requires its own detailed arc flash calculation using the correct IEEE 1584 parameters for its specific fault level

B. 53,200A (cable is negligible for 3/0 at 600 feet)

C. 3,120A (motor contribution only)

D. 30,000A

3. Per NEC 430.52(C)(1), a 100 HP, 460V motor (FLA = 124A) uses a dual-element time-delay fuse at 175% = 217A → next standard 225A. The motor starts successfully. The plant adds a second identical 100 HP motor on the same branch circuit (not permitted — but the electrician did it anyway). The combined FLA = 248A through the single 225A fuse. Per NEC 430.24, what is the fundamental code violation BEYOND the undersized fuse?

A. The fuse rating exceeds the combined motor FLA, so no violation exists

B. Two motors on a single branch circuit is permitted for motors under 125 HP

C. NEC 430.24 governs feeder calculations, not branch circuits — but that's not the issue

D. NEC 430.53(A) requires that each motor on a group installation have individual branch-circuit short-circuit and ground-fault protection; placing two motors on a single branch circuit without individual OCPDs means neither motor has dedicated branch-circuit protection — a fault on one motor is not isolated from the other, and the 225A fuse cannot selectively protect either motor; this is a fundamental NEC Article 430 Part V violation

4. A CT with a ratio of 5000:5 and accuracy class C800 serves a generator differential relay. The total burden is 2.0 Ω. During a 100,000A internal fault (20× rated), the CT secondary = 100A. Burden voltage = 200V. The CT is well within its C800 capability. However, the generator is connected to a bus that has X/R = 40 (extremely high — typical for large generators). The DC time constant $\tau = X/(2\pi fR) = 40/377 = 0.106$ seconds ≈ 6.4 cycles. The DC offset persists for $3\tau \approx 19$ cycles. What is the CT challenge during these 19 cycles?

A. No challenge — C800 CTs handle any DC offset regardless of X/R ratio

B. The DC offset at X/R = 40 drives the CT core flux to approximately 3× the symmetrical peak during the first several cycles; the core saturates severely for 19 cycles (0.32 seconds); during saturation, the relay sees distorted, reduced-magnitude secondary current that may cause: (1) delayed detection of internal faults, (2) false restraint in the differential element; modern generator differential relays use waveform recognition algorithms to operate through CT saturation, but older relays may fail to detect the internal fault for 0.32 seconds — adding significant fault damage to the generator windings

C. The DC offset only affects the first half-cycle and has no sustained impact

D. The relay automatically doubles its sensitivity during DC offset periods

5. A 345 kV, 500-mile transmission line with SIL = 310 MW must transmit 600 MW. A 50% distributed series compensation at three locations is installed. Effective X = 0.50 × X_line. Additionally, both a ±300 Mvar STATCOM at the midpoint AND a ±200 Mvar SVC at the receiving end are installed. During a double-circuit contingency (loss of a parallel line), the remaining line must carry the full 600 MW. The receiving-end voltage drops to 0.85 pu. The STATCOM at the midpoint operates at 0.85 pu voltage and the SVC at the receiving end at 0.85 pu. Compare their reactive outputs.

A. STATCOM output = 0.85 × 300 = 255 Mvar (current maintained, Q reduced proportionally to V); SVC output = $0.85^2 \times 200 = 144.5$ Mvar (thyristor-controlled output proportional to V^2); the STATCOM provides 110 Mvar MORE support than the SVC at this voltage — a 76% advantage; this difference is critical during contingencies where every Mvar of voltage support directly impacts transient stability margins

B. Both devices provide identical output regardless of voltage

C. The SVC provides more output because its thyristors can overload during contingencies

D. Neither device can operate at 0.85 pu voltage

6. Per NEC 250.122(B), a 1,200A circuit has two parallel 750 kcmil per phase (1,500,000 CM total), increased to two parallel 1,000 kcmil (2,000,000 CM total) for voltage drop. Table 250.122 requires 3/0 AWG (167,800 CM) for 1,200A. What is the proportionally increased EGC?

A. 3/0 AWG (no increase)

B. 4/0 AWG (211,600 CM) — close but below the calculated value

C. 250 kcmil (250,000 CM)

D. Ratio = 2,000,000/1,500,000 = 1.333; EGC = 167,800 × 1.333 = 223,767 CM → 250 kcmil (250,000 CM) is the minimum standard size above 223,767 CM; 4/0 AWG at 211,600 CM falls below the requirement

7. A three-phase, 4,160V system has a 25,000 kW load at 0.62 lagging PF. Q = 25,000 × 1.270 = 31,750 kvar. The engineer installs a 24,000 kvar capacitor bank, a 7,000 HP synchronous motor at 0.80 leading PF (η = 94%), a 3,500 HP synchronous motor at 0.85 leading (η = 95%), AND a 2,000 HP synchronous motor at 0.90 leading (η = 95%). What is the new bus PF?

A. PF = 0.85

B. SM1: P=5,558, Q_1=4,169; SM2: P=2,750, Q_2=1,707; SM3: P=1,571, Q_3=761; total correction=24,000+4,169+1,707+761=30,637; net Q=31,750−30,637=1,113; P_total=34,879; PF=34,879/34,897=0.999 — five correction sources virtually eliminate reactive demand while adding 12,500 HP; the engineer should reduce the capacitor bank by approximately 1,100 kvar to maintain exactly 0.95 PF and avoid leading PF issues

C. PF = 0.92

D. PF = 0.95

8. A three-phase, 480Y/277V panelboard serves a cryptocurrency mining facility with 100% nonlinear GPU power supplies. Each phase: 800A fundamental, 320A 3rd harmonic (40%), 160A 5th (20%), 80A 7th (10%), 40A 9th (5%). Phase RMS = $\sqrt{(800^2+320^2+160^2+80^2+40^2)}$ = $\sqrt{(640{,}000+102{,}400+25{,}600+6{,}400+1{,}600)}$ = $\sqrt{776{,}000}$ = 880.9A. Neutral = 3×(320+40) = 1,080A (triplens: 3rd + 9th). Neutral-to-phase ratio = 1,080/880.9 = 1.226. With 4 conductors (0.80 factor): phase base = 1,101.1A; neutral base = 1,350A. Which governs?

A. Neutral governs at 1,350A — this is the most extreme neutral-over-phase scenario in the entire exam series; the 100% nonlinear load with high triplen content produces a neutral that is 22.6% larger than the phase RMS and 68.8% larger than the phase fundamental; the neutral conductor must be sized for 1,350A base ampacity, dominating the entire conductor selection

B. Phase governs at 1,101.1A because phase always governs in commercial installations

C. Both require 1,200A base ampacity (average of phase and neutral)

D. The OCPD determines sizing regardless of harmonic content

9. A 300 MVA synchronous generator has X"_d = 0.22 pu, X_2 = 0.24 pu, X_0 = 0.09 pu. Solidly grounded: I_SLG = 5.45 pu; I_3Φ = 4.55 pu. SLG exceeds 3Φ by 19.8%. The engineer evaluates a comprehensive grounding strategy: (1) solid ground during commissioning tests for maximum fault detection, (2) reactor ground (3X_n = 0.40 pu) during normal operation for moderate SLG current, (3) auto-switch to HRG (3R_n = 50 pu) upon ground-fault detection for minimum damage. What are the SLG currents for each mode?

A. All three modes produce identical fault current

B. Solid: 5.45 pu; reactor: 3.09 pu; HRG: 0.06 pu — but the modes cannot be switched dynamically

C. Solid: I_SLG = 3/(0.22+0.24+0.09) = 5.45 pu (maximum detection sensitivity); Reactor: I_SLG = 3/j(0.55+0.40) = 3.16 pu (moderate current for reliable relay operation during normal service); HRG: I_SLG = 3/50 = 0.06 pu (minimum damage after fault detection and location); the three-mode strategy provides maximum detection during testing, reliable detection during operation, AND minimum damage during fault isolation — the most comprehensive grounding approach in the exam series

D. HRG during commissioning provides the best fault detection

10. A three-phase, 4,160V system has an NGR rated 400A, 10 seconds. Five ground faults occur over a 4-hour period with varying resistance and clearing times: Fault 1 (R_f = 0, 0.5s), Fault 2 (R_f = 5Ω, 1.0s, 10 min after F1), Fault 3 (R_f = 15Ω, 1.5s, 30 min after F2), Fault 4 (R_f = 25Ω, 2.0s, 60 min after F3), Fault 5 (R_f = 50Ω, 2.0s, 120 min after F4). Calculate the cumulative I^2t as a percentage of NGR capacity.

A. F1: 400A, $(1.0)^2 \times (0.5/10)$ = 5.0%. F2: 218A, $(0.545)^2 \times (1.0/10)$ = 2.97%. F3: 104A, $(0.260)^2 \times (1.5/10)$ = 1.01%. F4: 77A, $(0.193)^2 \times (2.0/10)$ = 0.74%. F5: 43A, $(0.108)^2 \times (2.0/10)$ = 0.23%. Total ≈ 9.95% — ten percent consumed from five diverse faults; the decreasing current with each event (increasing R_f) means each contributes less despite longer clearing

B. 50% consumed — the five faults exhaust half the NGR capacity

C. 100% — five faults always exhaust the NGR

D. F1 = 5.0%; F2 = 2.97%; F3 = 1.01%; F4 = 0.74%; F5 = 0.23%; cumulative = 9.95%; the 10-minute to 120-minute intervals between faults provide substantial cooling; the actual thermal stress is even lower than 9.95%; but the PATTERN of five ground faults in 4 hours indicates a severe systemic problem — probably contaminated insulators, water intrusion, or cable insulation failure requiring immediate shutdown and comprehensive investigation

11. Per NEC 110.26(A)(3), the headroom in working spaces around electrical equipment operating at 600V or less must be at least what dimension?

A. 6 feet or the height of the equipment, whichever is greater

B. 6.5 feet or the height of the equipment, whichever is greater

C. 7 feet

D. 8 feet

12. A 7,500 kVA, 13.8 kV/480V transformer has core losses = 18,000 W and full-load copper losses = 58,000 W. k_max = √(18,000/58,000) = 55.7%. The transformer serves a three-shift steel mill: Shift 1 (8 hrs, 100% load, PF = 0.92), Shift 2 (8 hrs, 70% load, PF = 0.88), Shift 3 (8 hrs, 40% load, PF = 0.80). The engineer is considering adding a second identical transformer in parallel to share the load. Each transformer would then operate at half the current loading. What is the impact on all-day efficiency?

A. Paralleling two transformers at half load each: each operates at approximately 50% load (near k_max = 55.7%); the TOTAL core losses DOUBLE (two transformers × 18,000 = 36,000 W) while total copper losses at half current per transformer DROP to 1/4 of the single-transformer value per unit × 2 units = 1/2 of original copper losses; the trade-off: doubled core losses versus halved copper losses; for the heavily loaded Shift 1, the copper loss reduction dominates and efficiency improves; for the lightly loaded Shift 3 (now at 20% per transformer), the doubled core losses dominate and efficiency worsens — the net impact depends on the load profile but is often slightly NEGATIVE for variable-load applications

B. Paralleling always improves efficiency regardless of loading

C. Paralleling has no effect on efficiency

D. Paralleling always worsens efficiency

13. A protection coordination study on a 13.8 kV system requires coordinating four devices in series: (1) motor fuse (400E, TC = 0.003s at 15,000A), (2) feeder relay R1 (EI, TD = 1.0, pickup = 5A on 400:5), (3) bus section relay R2 (VI, TD = 3.0, pickup = 6A on 800:5), (4) main relay R3 (VI, TD = 5.5, pickup = 8A on 1200:5). At the maximum motor fault of 15,000A, calculate all three relay operating times and CTIs.

A. R1 too slow; R2 adequate; R3 grossly excessive

B. All three relays are optimally coordinated

C. R1: M = 375/5 = 75; t_1 = 1.0×(28.2/5,624+0.1217) = 0.127s; CTI_fuse-R1 = 0.124s — BELOW 0.20s minimum (FAIL); R2: M = 93.75/6 = 15.63; t_2 = 3.0×(19.61/243+0.491) = 1.716s; CTI_R1-R2 = 1.589s (adequate but excessive); R3: M = 62.5/8 = 7.81; t_3 = 5.5×(19.61/60+0.491) = 4.497s; CTI_R2-R3 = 2.781s (grossly excessive); two problems: CTI fuse-R1 is inadequate (increase R1 TD to 1.3), and R3 is grossly slow (reduce TD to 2.5)

D. All CTIs are adequate — no adjustments needed

14. A distance relay on a 345 kV line (Z_line = 12+j140 Ω) has Zone 1 at 85%, Zone 2 at 120% (0.35s). A fault at 84% through 25 Ω resistance (the highest fault resistance in the exam series). Z_meas = (0.84×12+25)+j(0.84×140) = 35.08+j117.6 Ω. |Z_meas| = 122.7 Ω. Zone 1 reach = 0.85×140.5 = 119.4 Ω. The measured impedance EXCEEDS Zone 1 reach by 2.8%. What protection provides high-speed clearing?

A. Zone 1 can still reach this fault through the mho circle's geometry at the line angle

B. Zone 2 detects the fault but cannot provide high-speed clearing without a pilot scheme

C. No protection can detect this high-resistance fault

D. The fault is 2.8% beyond Zone 1 reach — Zone 1 cannot operate; Zone 2 at 120% (168.6 Ω) covers the fault; with POTT active, the near end sends a permissive signal and receives one from the remote end (which sees the fault at 16% within its Zone 1); both terminals trip with high-speed clearing via the pilot scheme; this is the highest-resistance fault scenario in the exam series, demonstrating that pilot protection is ESSENTIAL for resistive faults near the Zone 1 boundary

15. A three-phase, 460V, 4-pole, 600 HP induction motor drives a centrifugal chiller via VFD. Design: 448 kW at 1,770 RPM. Seven operating modes representing a full year of chiller operation: 100% (600

hr), 95% (900 hr), 85% (1,500 hr), 75% (2,000 hr), 60% (1,800 hr), 45% (1,200 hr), 25% (760 hr). VFD efficiency varies: 97%, 97%, 96%, 95%, 93%, 89%, 82%. Motor efficiency varies: 96.5%, 96%, 95%, 93%, 88%, 80%, 65%. What is the total annual SUPPLY energy?

A. 1,800,000 kWh (ideal affinity law)

B. 100%: 448/(0.965×0.97)×600=287,191; 95%: 383.7/(0.96×0.97)×900=370,774; 85%: 275.1/(0.95×0.96)×1,500=452,580; 75%: 189.0/(0.93×0.95)×2,000=427,870; 60%: 96.8/(0.88×0.93)×1,800=212,878; 45%: 40.8/(0.80×0.89)×1,200=68,764; 25%: 7.0/(0.65×0.82)×760=9,984; total≈1,830,041 kWh; including losses at each point adds approximately 15% over the ideal affinity-law-only estimate — the light-load efficiency collapse at 25% speed (motor at 65%, VFD at 82%) adds disproportionate losses; this is the most comprehensive VFD energy calculation in the exam series

C. 2,500,000 kWh (full-speed estimate)

D. 1,400,000 kWh

16. Per NEC 480.9(A), a large hospital critical-power UPS system has 1,500 vented lead-acid cells in a dedicated room of 20,000 ft^3. Charging at 0.009 ft^3 H_2/cell/hour. The room also contains the UPS inverter modules (300 kVA each × 6 modules = 1,800 kVA total) which generate significant heat. What ACH is required for H_2 management, and what ADDITIONAL ventilation consideration exists for the combined battery + UPS room?

A. H_2 = 1,500 × 0.009 = 13.5 ft^3/hr; max H_2 = 200 ft^3; ACH_H_2 = 0.0675; however, the six 300 kVA UPS modules generate approximately 5-8% losses = 90-144 kW of heat in the same room; the ventilation system must handle BOTH hydrogen dilution AND thermal management; the thermal load likely requires 5-10× higher ACH than the hydrogen calculation alone; the combined design must address: H_2 dilution to below 1%, thermal management to maintain battery room below 77°F (25°C) per IEEE 484, and UPS module cooling — the thermal requirement almost certainly governs the total ventilation capacity

B. ACH = 0.0675 (H_2 only); UPS heat is negligible

C. ACH = 10.0 (UPS cooling only); H_2 is negligible

D. Separate rooms are required for batteries and UPS modules

17. A 230 kV, 500-mile transmission line with SIL = 140 MW must carry 400 MW during peak and 15 MW during off-peak. The line has 50% distributed series compensation, three 120 Mvar switched shunt reactors (two at receiving end, one at midpoint), and a ±250 Mvar STATCOM at the midpoint. During the off-peak transition (load drops from 400 to 15 MW over 45 minutes), what is the reactive compensation strategy?

A. All devices operate identically during peak and off-peak

B. As load decreases below SIL (140 MW): (1) at 180 MW, switch ON midpoint reactor (120 Mvar); (2) STATCOM continuously absorbs to smooth transitions; (3) at 100 MW, switch ON first receiving-end reactor; (4) at 50 MW, switch ON second receiving-end reactor; (5) at 15 MW, all three reactors ON (360 Mvar total absorption) plus STATCOM fine-tuning; the STATCOM provides continuous fast-response regulation between discrete reactor steps, preventing the voltage spikes from mechanical switching; the 45-minute transition allows sequential switching without urgency — but the automation must prevent operator error in the switching sequence

C. Only the STATCOM operates; reactors remain off at all times

D. All three reactors switch on simultaneously when load drops below 200 MW

18. A separately excited DC motor (V_t = 600V, I_a = 350A, R_a = 0.03 Ω, rated speed 1,800 RPM) drives a paper winder requiring precise tension control. E_a = 600 − 10.5 = 589.5V. The winder requires constant torque from 300 RPM to 1,800 RPM (6:1 speed range using armature voltage control), then constant power from 1,800 to 3,600 RPM (2:1 range using field weakening). At 300 RPM: E_a = 589.5 × (300/1,800) = 98.25V. V_t = 98.25 + 10.5 = 108.75V. At 3,600 RPM with 50% field: E_a = 0.50 × 589.5 × (3,600/1,800) = 589.5V. V_t = 589.5 + 10.5 = 600V. What is the output power at 300 RPM and 3,600 RPM?

A. 300 RPM: P = 34.6 kW; 3,600 RPM: P = 206.3 kW

B. Both operating points produce the same output power of 206.3 kW

C. 300 RPM: P = 206.3 kW; 3,600 RPM: P = 34.6 kW

D. 300 RPM: P = E_a × I_a = 98.25 × 350 = 34,388W = 34.4 kW (constant torque at 1/6 speed = 1/6 rated power); 3,600 RPM: P = 589.5 × I_a; but I_a at 3,600 RPM with field weakening: V_t = 600V, E_a = 589.5V, I_a = (600−589.5)/0.03 = 350A; P = 589.5 × 350 = 206,325W = 206.3 kW (same as rated power — this is the constant-power region); the motor provides 34.4 kW at 300 RPM and 206.3 kW at 3,600 RPM, demonstrating the constant-torque (P ∝ speed) and constant-power regions of DC motor operation

19. Per NEC 250.30(A)(1), the largest facility in the exam series: a semiconductor campus with 10 × 5,000 kVA service transformers, 8 × 3,000 kW emergency generators, 6 × 2,000 kW fire pump generators, 4 × 3,000 kW CHP generators, 30 × 1,000 kVA PDU transformers, 16 × 500 kVA isolation transformers, 10 × 300 kVA UPS transformers, and 2 × 150 kVA instrument isolation transformers. How many bonding jumpers?

A. Eighty-six — 10+8+6+4+30+16+10+2 = 86 bonding jumpers; this is the most complex grounding installation in the exam series; each jumper must be sized per NEC 250.30(A)(2) based on the derived system's overcurrent protection; the facility requires a comprehensive bonding jumper schedule as part of the electrical design documentation, with each jumper tested during commissioning and annually thereafter

B. Fifty (service transformers and generators only)

C. Thirty (PDU transformers only)

D. Forty-eight (excludes fire pump and CHP generators)

20. A three-phase, 480V, 4,000A main-tie-main switchgear configuration serves the largest facility in the exam series. Bus A: 5,000 kVA transformer (Z = 5.50%, I_A = 109,345A). Bus B: 4,000 kVA transformer (Z = 5.75%, I_B = 83,670A). With tie closed: combined = 193,015A. Motor contribution from both buses = 20,000A. Grand total = 213,015A. The engineer must design BOTH the arc flash mitigation AND the bus bracing for this extreme fault level. With AQD (4 ms), optical relay (6 ms), ZSI (50 ms), maintenance switch (40 ms), arc-resistant switchgear, and permanent-magnet trip with redundant fiber-optic trip path, what is the calculated arc energy during the 4 ms before AQD activation?

A. E_AQD = 0 (the AQD prevents any arc from forming)

B. The AQD cannot help because the fault current is too high

C. Original E = 72 cal/cm² at 0.30s; E_AQD ≈ 72 × (0.004/0.30) = 0.96 cal/cm² — the arc exists for only 4 ms before the AQD quenches it by creating a bolted fault; this sub-1.0 cal/cm² energy combined with the arc-resistant enclosure produces effectively zero worker exposure; the seven-layer defense (AQD + optical + ZSI + maintenance switch + arc-resistant + PM trip + fiber trip) at the highest fault current in the exam series represents the absolute state of the art in arc flash protection engineering

D. E = 72 cal/cm² (unchanged by any mitigation)

21. A synchronous generator rated 600 MVA, 26 kV (the largest in the exam series) has X"_d = 0.25 pu, X_2 = 0.27 pu, X_0 = 0.12 pu. Solidly grounded: I_SLG = 4.69 pu, I_3Φ = 4.0 pu. SLG exceeds 3Φ by 17.3%. The engineer implements the most advanced hybrid grounding: reactor (3X_n = 0.25 pu) during first 150 ms for fault detection, then auto-switch to resistance (3R_n = 8.0 pu) for moderate fault current during feeder isolation (0.5-2.0 seconds), then auto-switch to HRG (3R_n = 50 pu) for indefinite operation on the remaining grounded but faulted system. What are the three I_SLG values?

A. All three produce the same current

B. Mode 1 (reactor): I = 3/j(0.64+0.25) = 3.37 pu (reactive — relay detects and locates fault); Mode 2 (resistance): I = 3/√(8.0^2+0.64^2) = 0.374 pu (resistive — moderate current clears faulted feeder); Mode 3 (HRG): I = 0.06 pu (minimal damage for continued operation); this three-stage system provides the maximum operational flexibility: fast detection → controlled clearing → safe continued operation

C. Reactor produces higher current than solid grounding

D. HRG provides the best fault detection capability

22. A 480V, three-phase panelboard has the most complex motor load in the exam series: Motor 1 = 862A (750 HP), Motor 2 = 683A (600 HP), Motor 3 = 590A (500 HP), Motor 4 = 477A (400 HP), Motor 5 = 414A (350 HP). Continuous lighting = 400A. Noncontinuous HVAC = 150A. Per NEC 430.24 and 215.2(A)(1), what is the minimum feeder conductor ampacity?

A. 3,500A

B. 3,000A

C. 4,000A

D. 125%×862 + 683+590+477+414 + 125%×400 + 150 = 1,077.5+2,164+500+150 = 3,891.5A — the most demanding feeder calculation in the exam series; this requires at least eight parallel 500 kcmil per phase at 75°C (8×380=3,040A — still inadequate!) or six parallel 750 kcmil at 90°C (6×535=3,210A — still inadequate); bus duct rated for 4,000A is the practical solution

23. A three-phase, 4,160V bus has the most sources in the exam series: twelve parallel sources. On a 80 MVA base: six transformers (Z = 0.025, 0.03, 0.04, 0.05, 0.06, 0.08), three generators (Z = 0.20, 0.35,

0.50), two synchronous condensers (Z = 0.60, 0.80), one 80 MVA BESS inverter (Z = 4.0). I_base = 11,104A. What is the total fault current?

A. I = (40.0+33.33+25.0+20.0+16.67+12.50+5.0+2.857+2.0+1.667+1.25+0.25) × 11,104 = 160.52 × 11,104 = 1,782,494A — twelve sources produce nearly 1.8 MILLION amperes symmetrical; this is physically impossible for a single 4,160V bus and demonstrates the absolute necessity of bus splitting, current-limiting reactors, and possibly separate substations to manage fault levels within equipment ratings

B. 800,000A

C. 1,000,000A

D. 500,000A

24. A 480V, three-phase, 225A panelboard (SCCR = 10,000A) is fed from a switchboard with 75,000A available. The cable is 600 feet of 2 AWG copper in EMT (R = 0.194, X = 0.0573 Ω/1000 ft). Three motors at the panelboard (FLA = 300A total) contribute 1,200A. Does the cable naturally protect the panelboard?

A. No — the cable cannot reduce 75,000A to below 10,000A

B. Cable cannot overcome this extreme available fault current

C. Z_cable: R = 0.1164, X = 0.03438 Ω; Z_base = 0.0922; Z_cable_pu = 0.1214/0.0922 = 1.317; total Z = 0.0575+1.317 = 1.375; I_transformer = 3,007/1.375 = 2,187A; motor = 1,200A; total = 3,387A — below 10,000A SCCR; the extreme impedance of 2 AWG at 600 feet reduces the fault to only 4.5% of switchboard value; the installation is code-compliant BUT the engineer must verify voltage drop acceptability at this conductor size and distance, AND verify breaker trip characteristics at the reduced fault level

D. 10,000A exactly (at the SCCR limit)

25. Per NEC 690.12, the most complex PV scenario in the exam series: a 5 MW commercial installation uses 100 string inverters. Half the strings (50) have module-level rapid shutdown devices; the other half (50) do not. All strings have 22 modules (V_oc = 48V = 1,056V per string). At −20°C: V_oc = 55.1V → string = 1,212V. The system is rated 1,000V DC. What NEC violations exist?

A. NEC 690.12(B)(2) violation only — the 50 strings without RSDs exceed 80V within the array boundary during rapid shutdown

B. TWO violations: (1) NEC 690.7(A) — the temperature-corrected string voltage of 1,212V exceeds the 1,000V DC system rating for ALL 100 strings regardless of RSD installation; (2) NEC 690.12(B)(2) — the 50 strings without RSDs cannot reduce voltage below 80V within the array boundary; BOTH violations must be corrected: reduce string length to 18 modules (18×55.1=991.8V) AND install RSDs on the remaining 50 strings

C. No violations — the RSDs on half the strings make the entire system compliant

D. Only the NEC 690.7 violation for the strings without RSDs

26. A three-phase, 480V system has five parallel transformers: T1 = 4,000 kVA (Z = 5.50%), T2 = 3,500 kVA (Z = 5.75%), T3 = 3,000 kVA (Z = 6.00%), T4 = 2,500 kVA (Z = 6.25%), T5 = 2,000 kVA (Z = 6.50%). Individual contributions: I_T1 = 84,800A, I_T2 = 70,956A, I_T3 = 58,333A, I_T4 = 46,603A, I_T5 = 35,840A. Total = 296,532A. Motor (FLA = 6,000A) = 24,000A. Grand total = 320,532A. X/R ≈ 8.3. Multiplier = 2.32. Peak?

A. Peak = 2.32 × 320,532 = 743,634A — the highest peak asymmetrical current in the entire 2,000-question exam series; at nearly three-quarters of a million amperes peak, the electromagnetic forces proportional to $I^2\_peak = 5.53 \times 10^{11}\ A^2$ are beyond any standard bus construction capability; this configuration requires custom-designed isolated-phase bus with structural engineering analysis, reinforced concrete barriers, and mechanical design rivaling seismic-rated structures

B. 453,200A (√2 × total)

C. 641,064A (2× total)

D. 320,532A (no asymmetry)

27. A distance relay on a 230 kV line (Z_line = 9+j105 Ω) has Zone 1 at 85%, Zone 2 at 120%. A permanent fault at 84% through 25 Ω resistance with the DCB pilot scheme active and healthy. The near end: Zone 1 cannot reach (|Z_meas| exceeds reach). Zone 2 covers the fault. The remote end: 16% from its terminal (within Zone 1). Both see forward. Neither sends blocking. What happens?

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

B. Only the remote end trips on Zone 1

C. The fault resistance prevents any relay detection

D. Both terminals trip with high-speed clearing — the DCB scheme enables the near end to trip instantaneously via Zone 2 (no blocking received) while the remote end trips on Zone 1; the 25 Ω fault resistance prevents Zone 1 at the near end but does NOT prevent Zone 2 detection; this is the most demanding distance relay scenario in the exam series: highest resistance, near Zone 1 boundary, requiring pilot scheme for reliable clearing

28. A transformer differential relay (87T) for a 400 MVA, 345/138/13.8 kV three-winding autotransformer with tertiary delta faces the most complex CT balancing challenge in the exam series. During a HV-side SLG fault, zero-sequence current flows in the HV (wye-grounded) and LV (wye-grounded) CTs but NOT in the tertiary (delta) CTs because the delta circulates zero-sequence internally. The relay must handle this asymmetry across THREE windings. What is the solution?

A. Use identical CT ratios on all three windings

B. The relay must compensate for zero-sequence current appearing in both HV and LV CTs but not in the tertiary; modern numerical relays accomplish this through: (1) internal zero-sequence filtering on the HV and LV CT inputs, (2) independent magnitude and phase compensation for each winding's CT ratio and connection, (3) inrush restraint using second-harmonic blocking from all three CT sets simultaneously; without proper three-winding compensation, any SLG fault creates false differential that exceeds the operate threshold — this is the most complex relay configuration in the exam series

C. Zero-sequence filtering on the HV side only is sufficient

D. Three-winding transformers do not require differential protection

29. Per NEC 450.3(B), a 3,000 kVA, 13.8 kV/480V transformer has primary current = 125.5A. At 125% = 156.9A → next standard = 175A. The transformer has dual secondaries: a 480V main secondary (2,500 kVA) and a 480V auxiliary secondary (500 kVA). Per NEC 450.3(B), does each secondary require its own OCPD?

A. Each secondary winding that serves loads requires its own overcurrent protection; the 2,500 kVA secondary (rated 3,007A) and the 500 kVA secondary (rated 601A) each need independent OCPDs sized per NEC 450.3(B); the 175A primary OCPD alone does NOT adequately protect either secondary winding from overloads or faults on its individual bus — a fault on the 500 kVA secondary drawing 601A represents only 5.7% overload on the primary (125.5A → 133A) and would not be detected by the 175A primary fuse

B. Only the larger secondary requires an OCPD

C. No secondary OCPDs are needed because the primary provides adequate protection

D. Both secondaries share a single OCPD

30. A three-phase, 4,160V, 6-pole synchronous motor rated 8,000 HP (the largest in the exam series) drives a mine hoist at 1,200 RPM. Pull-out = 280% FLT. H = 4.0 MJ/MVA (the highest motor H in the series — massive flywheel). S = 6,986 kVA. During a severe grid event, voltage sags to 68% for 1.5 seconds. Pull-out = 190.4% FLT. Load = 90% FLT. Margin = 100.4% FLT. What is the stability assessment?

A. Unstable despite the high H

B. Marginally stable — detailed simulation needed

C. With H = 4.0 (highest in the exam series), the massive flywheel provides extraordinary resistance to angular acceleration; even with the severe 1.5-second sag at 68%, the angle advance is moderate (estimated 20-35°); the generous 100.4% FLT margin combined with the extreme inertia ensures stability; the flywheel is specifically engineered for mine hoist applications where grid disturbances are frequent; this is the most optimistic stability assessment in the exam series — the highest H combined with adequate margin ensures survival through severe sags

D. Cannot be determined without computational simulation

31. A 480V, three-phase system has five parallel transformers with combined symmetrical fault = 320,532A. Weighted X/R = 8.3. Multiplier = 2.32. Peak = 743,634A. Bus spacing = 6 inches (0.152 m). Using $F = \mu_0 I^2\_\text{peak}/(2\pi d)$: $F = (2\times10^{-7} \times 743{,}634^2)/0.152$. What is the force per meter, and what is the practical engineering response?

A. $F = (2\times10^{-7} \times 5.53\times10^{11})/0.152 = 110{,}600/0.152 = 727{,}632$ N/m ≈ 728 kN/m (163,500 lbs/foot) — this is the highest electromagnetic force calculation in the entire exam series; at 163,500 lbs/foot, the force exceeds the structural capacity of any conceivable bus arrangement at 6-inch spacing; the ONLY solution is to split the bus into multiple sections with current-limiting reactors between them, reducing the fault current at any single bus to manageable levels

B. F = 10,000 N/m — manageable with heavy-duty bracing

C. F = 50,000 N/m — requires specialized construction

D. F = 728 kN/m — this is the highest force in the exam series; the practical response is that five parallel 480V transformers of this combined capacity should NEVER share a single bus; the system must be redesigned with bus-section splitting, current-limiting reactors, or separate switchgear lineups to reduce the combined fault current to levels that standard or heavy-duty bus construction can safely withstand

32. A 13.8 kV system has the most severe harmonic environment in the 2,000-question exam series: THD = 18.5%. Harmonics: V_5 = 13.2%, V_7 = 9.0%, V_{11} = 6.2%, V_{13} = 4.5%, V_{17} = 2.8%, V_{19} = 2.0%. IEEE 519: individual ≤ 3.0%, THD ≤ 5.0%. Six individual violations (V_5, V_7, V_{11}, V_{13} exceed 3.0%) plus THD. The facility has 60 six-pulse VFDs totaling 18,000 HP. What comprehensive remediation addresses ALL violations?

A. Replace all 60 VFDs (cost-prohibitive at $4M+)

B. Install a large active harmonic filter (AHF) at the 13.8 kV bus; the AHF dynamically measures and cancels ALL harmonics simultaneously; combined with converting the 10 largest six-pulse VFDs to 18-pulse (eliminating the dominant harmonic sources), the two-pronged approach addresses ALL violations: the VFD conversions remove the largest harmonic injections (reducing THD by approximately 40-50%), and the AHF cancels the remainder; estimated cost: $800K for AHF + $600K for 10 VFD conversions = $1.4M total (35% of full replacement) — this is the most cost-effective comprehensive solution

C. Install passive filters for all individual harmonics (five separate filters)

D. Accept the violations and pay penalties

33. A ground resistance test on the most challenging site in the exam series: a remote arctic research station on permafrost (ρ = 10,000 Ω-m frozen, thawing layer ρ = 500 Ω-m for 3 months/year at 2-foot depth). IEEE 80 target = 5.0 Ω. Driven rods in permafrost measure 250 Ω. What grounding approach can achieve the target?

A. The combination of: (1) a ground grid in the thawed active layer (2-foot depth) using ground enhancement material (GEM) to maintain conductivity through freeze-thaw cycles, (2) deep thermosyphon-type ground electrodes that penetrate to unfrozen ground below the permafrost (if accessible, typically 50-200 feet), (3) building structural steel and underground piping connections, (4) electrolytic ground electrodes that maintain conductivity in frozen soil by releasing ions, AND (5) a counterpoise system of radial conductors extending outward from the station; achieving 5 Ω in permafrost is extremely challenging and may require accepting higher resistance with compensating safety measures (insulating mats, step potential mitigation)

B. Standard driven rods will achieve 5 Ω once the ground thaws

C. Chemical treatment of the permafrost eliminates the resistivity problem

D. 5 Ω is achievable with two standard driven rods

34. A three-phase, 460V, 2-pole induction motor rated 1,000 HP (the largest motor with a capacitor question in the exam series) has $\eta = 97.2\%$, PF = 0.91. No-load magnetizing = 125 kvar. A 100 kvar capacitor is proposed (80% of no-load mag). The motor operates on a VFD across a 3:1 speed range (600-1,800 RPM). At 1,800 RPM (full speed, constant V/f): magnetizing = 125 kvar; capacitor at 80% = safe. At 600 RPM (1/3 speed, cubic-law pump load = 3.7% of rated power): magnetizing drops to approximately 60% of full value = 75 kvar. Is the 100 kvar capacitor safe at 600 RPM?

A. Yes — the VFD maintains constant V/f, keeping magnetizing constant at all speeds

B. Yes — reduced speed actually increases the motor's magnetizing requirement

C. At 600 RPM with reduced magnetizing of 75 kvar, the 100 kvar capacitor is at 133% of no-load magnetizing — well above the self-excitation threshold; if the VFD trips, the coasting motor with 100 kvar connected WILL self-excite, producing dangerous overvoltage; the capacitor must be interlocked with the VFD and automatically disconnected during any VFD trip or speed reduction below the safe threshold (approximately 85% speed where magnetizing = 100 kvar)

D. The capacitor is only dangerous below 400 RPM

35. A three-phase, 460V, 8-pole VFD-driven motor operates a mine ventilation fan at the most complex operating profile in the exam series: eight modes spanning emergency maximum ventilation to standby monitoring. 100% (400 hr), 95% (600 hr), 90% (1,000 hr), 80% (1,800 hr), 65% (2,000 hr), 50% (1,500 hr), 35% (800 hr), 20% (660 hr). Design: 450 kW at 877 RPM. Using $P \propto n^3$, what is the VFD total annual energy?

A. 2,500,000 kWh

B. 100%: 180,000; 95%: 450×0.857×600=231,435; 90%: 450×0.729×1,000=328,050; 80%: 450×0.512×1,800=414,720; 65%: 450×0.274×2,000=246,780; 50%: 450×0.125×1,500=84,375; 35%: 450×0.0429×800=15,435; 20%: 450×0.008×660=2,376; VFD=1,503,171; full=450×8,760=3,942,000; savings=2,438,829 kWh (61.9%) — eight modes produce 62% reduction; the three lowest modes (35%, 20%) contribute only 1.2% of VFD energy despite 16.7% of hours

C. 1,000,000 kWh

D. 2,000,000 kWh

36. A 480V, three-phase, 200A feeder uses 750 kcmil THHN copper in EMT (R = 0.0196, X = 0.0373 Ω/1000 ft) — the largest conductor for a 200A feeder in the exam series. The feeder is 1,000 feet long (the longest in the series) and serves a load at 0.85 lagging PF. What is the voltage drop?

A. 1.5%

B. 2.0%

C. 3.5%

D. V_drop = √3 × 200 × (0.0196×1.0×0.85 + 0.0373×1.0×0.527) = 346.4 × (0.01666+0.01966) = 346.4 × 0.03632 = 12.58V; 12.58/480 = 2.62% — within the NEC 3% recommendation despite the extreme 1,000-foot distance, because the 750 kcmil conductor provides very low resistance; this demonstrates that oversizing conductors can maintain voltage drop compliance even at extreme distances

37. A 100 MVA, 345/138 kV autotransformer has Z = 10%. Three units in parallel. A 80 MVA generator (X"_d = 0.18 pu), 60 MVA sync condenser (X"_d = 0.12 pu), 40 MVA sync motor (X"_d = 0.20 pu), 50 MVA solar (eff Z = 1.0), 30 MVA wind (eff Z = 1.2), and 25 MVA BESS (eff Z = 1.5) are on the 138 kV bus. On 100 MVA base: total inverter-based = 105 MVA. What is the combined inverter contribution percentage?

A. Z_T_par = 0.0333; Z_gen = 0.225; Z_SC = 0.20; Z_SM = 0.50; Z_solar = 2.0; Z_wind = 4.0; Z_BESS = 6.0; I_pu = (30.0+4.444+5.0+2.0+0.50+0.25+0.167) = 42.36; inverter contribution = (0.50+0.25+0.167)/42.36 = 2.17%; despite 105 MVA of inverter-based resources (37% of connected capacity), they contribute only 2.17% of fault current — the highest inverter penetration AND lowest percentage contribution in the entire exam series; this is the defining protection challenge of the modern grid transition

B. Inverter contribution = 10%

C. Inverter contribution = 20%

D. Inverter contribution = 37% (proportional to capacity)

38. A three-phase, 480V system has the most extreme parallel transformer configuration in the exam series: a 5,000 kVA (Z = 5.50%) and a 4,500 kVA (Z = 5.75%) in parallel. I_T1 = 6,014/0.055 = 109,345A. I_T2 = 5,413/0.0575 = 94,139A. Total = 203,484A. Motors (FLA = 5,500A) = 22,000A. Grand total = 225,484A. X/R ≈ 9.5. Multiplier = 2.37. Peak?

A. 318,900A (√2)

B. 450,968A (2×)

C. Peak = 2.37 × 225,484 = 534,397A — over half a million amperes peak; the 5,000 + 4,500 kVA combination is the largest two-transformer parallel in the exam series; bus bracing for 534 kA peak requires custom isolated-phase bus construction with structural analysis comparable to seismic engineering

D. 225,484A (no asymmetry)

39. Per NEC 250.53(A)(2), an engineer designs grounding for the most demanding facility in the exam series: a 200 MW data center campus in sandy desert soil (ρ = 3,000 Ω-m surface, dropping to 100 Ω-m at the water table 80 feet below). IEEE 80 target = 0.5 Ω. The surface ground grid measures 50 Ω with two supplemental rods. What comprehensive strategy achieves the target?

A. Additional driven rods in the sandy surface layer (diminishing returns)

B. The engineer must implement a multi-layer approach exploiting the soil stratification: (1) a large ground grid (covering the entire campus footprint) with 5-foot conductor spacing for step-and-touch potential control, (2) twenty or more deep ground wells drilled 100+ feet to reach the 100 Ω-m water table, each with bare copper conductor and GEM backfill, (3) electrolytic ground electrodes for areas where drilling is impractical, (4) bonding to all underground utilities (water, storm drainage — NOT cathodically protected gas lines), (5) building structural steel and foundation reinforcing (Ufer grounds); the deep wells provide the primary resistance reduction while the surface grid provides safety — achieving 0.5 Ω requires dozens of deep wells in parallel

C. Chemical treatment of the desert soil

D. Accept 50 Ω — the target is unachievable

40. A 480V, three-phase system has a 5,000 kVA transformer (Z = 5.50%) feeding a switchboard. A 1,500-foot cable of 3/0 AWG copper (the longest cable run in the exam series) feeds a remote panelboard. R = 0.0766 × 1.5 = 0.1149 Ω/phase. X = 0.0532 × 1.5 = 0.0798 Ω/phase. Z_base = 480^2/5,000,000 = 0.0461 Ω. Z_cable_pu = $\sqrt{(0.1149^2+0.0798^2)}$/0.0461 = 0.1399/0.0461 = 3.035. Total Z = 0.055+3.035 = 3.090. I = 6,014/3.090 = 1,946A. At this remarkably low fault current, what is the most critical concern?

A. 1,946A may be insufficient for some protective devices to clear faults within acceptable time

B. The fault current is adequate for all standard protective devices

C. The panelboard SCCR is the primary concern

D. At 1,946A — only 3.2% of the switchboard's fault current — the most critical concern is whether protective devices can clear faults fast enough: (1) a 100A breaker at 19.5× will likely reach instantaneous trip; (2) a 225A breaker at 8.6× may fall in the time-overcurrent region (0.1-1.0 seconds) rather than instantaneous (0.02-0.05 seconds), dramatically increasing both clearing time and arc flash energy; (3) a 400A breaker at 4.9× may take 5-30 seconds to clear — potentially creating a dangerous arc flash situation despite the low fault current; the engineer must verify EVERY protective device's time-current curve at 1,946A

41. A 75 MVA, 138/13.8 kV, delta-wye grounded transformer has Z_1 = j0.09 pu, Z_0 = j0.035 pu on its own base (the lowest Z_0 in the exam series). The 138 kV source has Z_1_src = j0.06 pu. On 100 MVA base: Z_1_total = (0.09+0.06)×100/75 = 0.20. Z_0_total = 0.035×100/75 = 0.0467. I_3Φ = 5.0 pu. I_SLG = 3/(0.20+0.20+0.0467) = 3/0.4467 = 6.71 pu. SLG exceeds 3Φ by 34.3% — the highest ratio in the entire 2,000-question series. What drives this extreme exceedance?

A. The source impedance creates the extreme ratio

B. The base conversion artificially inflates the ratio

C. The extremely low Z_0 (0.035 pu — the lowest in the entire exam series) creates Z_0_total = 0.0467 pu, which is only 23.3% of Z_1_total (0.20); this extreme disparity is the direct cause of the 34.3% SLG exceedance; the transformer has an unusually low zero-sequence impedance characteristic of certain three-limb core designs with low-reluctance zero-sequence flux paths; ALL equipment on the 13.8 kV bus must be rated for 6.71 pu (not 5.0 pu), and ground-fault protection must coordinate for this higher current

D. The delta winding has no effect on SLG fault current

42. A three-phase, 460V, 6-pole induction motor rated 800 HP (PF = 0.88, η = 96.5%) has no-load magnetizing = 100 kvar. A 75 kvar capacitor is installed (75% — safe at full load). The motor operates on a VFD. At full speed (constant V/f): safe. At 50% speed with cubic-law centrifugal load (12.5% power): magnetizing drops to approximately 55% = 55 kvar. The 75 kvar at 136% of reduced magnetizing is ABOVE self-excitation. Additionally, the VFD's PWM output at 4 kHz creates capacitor heating from high-frequency currents. What is the comprehensive engineering response?

A. The capacitor must be: (1) disconnected automatically when VFD speed drops below approximately 75% (where magnetizing drops to 75 kvar = capacitor value), (2) an output line reactor installed between VFD and motor to attenuate PWM harmonics that cause capacitor heating, (3) the capacitor switching contactor interlocked with the VFD run signal to disconnect before or simultaneously with VFD shutdown; this addresses both the speed-dependent self-excitation risk AND the PWM harmonic heating

B. The capacitor is safe at all VFD speeds and frequencies

C. Only the self-excitation risk needs to be addressed; PWM heating is negligible

D. Only the PWM heating needs to be addressed; self-excitation is impossible with a VFD

43. A CT with ratio 6000:5 and accuracy class C800 serves a line differential relay on a 500 kV circuit (the highest voltage in the exam series). During a 120,000A close-in fault with X/R = 45 (the highest in the series), the DC time constant = 0.119s ≈ 7.2 cycles. The DC offset persists for 3τ ≈ 21.5 cycles (0.36 seconds). The asymmetrical peak current = 2.85 × I_sym_peak = 2.85 × 169,705 = 483,660A in the primary. What CT and relay challenge does this create?

A. No challenge — C800 handles all conditions

B. The CT handles the fault within its rating under all conditions

C. The relay automatically compensates for any CT saturation at any X/R ratio

D. The combined AC and DC flux drives the CT core to approximately 3.5× its saturation level for 21.5 cycles (0.36 seconds); during this period, the relay sees severely distorted secondary current; the line differential relay must: (1) use CT saturation detection algorithms, (2) employ replica-current compensation to reconstruct the true primary current from the distorted secondary, (3) maintain security against false tripping from CT saturation during external faults; this is the most demanding CT scenario in the entire 2,000-question series — X/R = 45 produces the longest CT saturation duration of any exam scenario

44. A balanced three-phase, 208Y/120V panelboard serves the most extreme nonlinear load in the exam series: a cryptocurrency mining farm with 100% nonlinear GPU power supplies. Each phase: 1,000A fundamental, 400A 3rd (40%), 200A 5th (20%), 100A 7th (10%), 50A 9th (5%), 30A 11th (3%). Phase RMS = $\sqrt{(1{,}000^2+400^2+200^2+100^2+50^2+30^2)}$ = $\sqrt{(1{,}000{,}000+160{,}000+40{,}000+10{,}000+2{,}500+900)}$ = $\sqrt{1{,}213{,}400}$ = 1,101.5A. Neutral = 3×(400+50) = 1,350A. Neutral-to-phase ratio = 1,350/1,101.5 = 1.226. With 0.80 factor: neutral base = 1,687.5A.

A. This is the most extreme neutral scenario in the exam series — neutral base of 1,687.5A

B. The neutral of 1,350A (22.6% above phase RMS) with the 0.80 derating produces 1,687.5A — the highest neutral-driven conductor sizing requirement in the entire 2,000-question series; the neutral must be sized 53% larger than the phase after derating (1,687.5A vs 1,376.9A phase base); this requires dedicated oversized neutral conductors and demonstrates the critical importance of harmonic analysis in modern power system design

C. Phase governs because it always carries more total current

D. The OCPD determines all conductor sizing regardless of harmonics

45. Per NEC 517.17(A), the most complex hospital isolated power scenario in the exam series: a surgical suite has six operating rooms served by four isolated power panels. During a mass-casualty event, all six rooms operate at maximum capacity. Panel A = 4.8 mA, Panel B = 4.9 mA, Panel C = 4.7 mA, Panel D = 3.6 mA. Three additional devices (0.3 mA each = 0.9 mA total) must be connected for emergency procedures in Rooms A and B. No single panel except D can accept even one device without exceeding 5.0 mA. What is the optimal strategy?

A. Connect all three devices to Panel D: 3.6+0.9 = 4.5 mA (0.5 mA margin) — this is the safest single-panel solution because Panel D has the most headroom; distributing across panels would be marginally better for long-term headroom but takes longer to implement during a mass-casualty emergency; the priority during emergency is SPEED of connection while maintaining safety — Panel D accepts all three within the alarm threshold

B. One device to each of Panels A, B, and C (all exceed 5.0 mA — non-compliant)

C. Install a fifth panel before connecting any devices

D. The devices cannot be connected to any panel

46. A 345 kV, three-phase line (the highest-power scenario in the exam series) has V_S = 375 kV, V_R = 345 kV at 1,500 MW, 0.86 lagging PF. Line X_eff = 38 Ω (after 50% compensation from X_original = 76 Ω). What is the power angle, stability fraction, and margin?

A. δ = 15°; stability = 26%; margin = 74%

B. δ = 25°; stability = 42%; margin = 58%

C. δ = 35°; stability = 57%; margin = 43%

D. sin δ = 1,500×38/(375×345) = 57,000/129,375 = 0.4406; δ = 26.1°; stability = 44.1%; margin = 55.9%; WITHOUT compensation: sin δ = 1,500×76/129,375 = 0.881; δ = 61.8°; stability = 88.1%; margin = 11.9%; the series compensation improved the margin from 11.9% to 55.9% — a nearly 5× improvement; without compensation, the line would be dangerously close to its stability limit; this is the highest-power, most stability-critical scenario in the entire exam series

47. A recloser on a 12.47 kV feeder coordinates with a 300A lateral fuse (the largest fuse in the exam series). At 12,000A: fuse MM = 0.010s, fuse TC = 0.020s, recloser fast = 0.007s, recloser delayed = 0.040s. A permanent cable fault occurs. Fast trip: 0.007s < 0.010s → fuse saved. After reclose: delayed (0.040s) vs fuse TC (0.020s). Fuse clears at 0.020s. Margin = 0.020s (100% of fuse TC). At minimum fault of 2,500A: fuse MM = 0.08s, fuse TC = 0.16s, recloser fast = 0.04s, recloser delayed = 0.30s. Does coordination hold?

A. No — coordination fails at minimum fault because the recloser fast exceeds fuse MM

B. Coordination fails at minimum fault — the recloser fast (0.04s) is very close to fuse MM (0.08s)

C. At both fault levels: at 12,000A, the fuse clears 0.020s before the recloser; at 2,500A, the fuse TC (0.16s) is well below the recloser delayed (0.30s) — margin = 0.14s (88%); the fast-trip margin at 2,500A: recloser (0.04s) vs fuse MM (0.08s) provides 0.04s (50% of MM) — adequate for fuse saving; coordination holds across the FULL fault current range with the margin actually being most comfortable at the minimum fault level

D. Coordination only holds at maximum fault current

48. A 480V, three-phase, 1,200A switchboard (the largest in a single-panel question in the exam series). Load: 800A continuous motor + 150A continuous lighting + 100A noncontinuous = 1,050A. OCPD = 125%×950 + 100 = 1,287.5A → exceeds 1,200A bus. With 100%-rated 1,200A breaker: 1,050A ≤ 1,200A. Conductor at 75°C must handle 1,050A. Three parallel 500 kcmil = 3×380 = 1,140A. The ambient temperature is 35°C (correction factor = 1.0 for 75°C conductors at 35°C per NEC Table 310.15(B)(1)... actually the table shows 30°C base, 35°C correction = 0.94). Corrected = 1,140 × 0.94 = 1,071.6A. Is this adequate?

A. 1,071.6A ≥ 1,050A with only 2.1% margin — technically compliant but dangerously thin

B. Three parallel 500 kcmil at 75°C derated for 35°C ambient = 1,071.6A ≥ 1,050A — technically code-compliant with 2.1% margin; however, this margin is inadequate for practical engineering: any load increase, additional ambient heating, or conductor aging reduces effective capacity below the load; three parallel 600 kcmil (3×420×0.94 = 1,184A, 12.8% margin) is the better engineering choice; alternatively, using 90°C-rated terminals allows 3×430×0.94 = 1,212.6A (15.5% margin) with 500 kcmil

C. Three parallel 500 kcmil is always adequate for 1,200A systems

D. The temperature correction does not apply to 100%-rated breaker circuits

49. A three-phase, 480V system has a 5,000 kVA transformer (Z = 5.50%, X/R = 10) and 25 motors (FLA = 5,000A) — the largest motor group in the exam series. Transformer fault = 109,345A. Motor = 20,000A. Total = 129,345A. Peak = 2.38 × 129,345 = 307,841A. The motor contribution is 15.5% of total. If the engineer had excluded motor contribution, the calculated peak would be 2.38 × 109,345 = 260,241A. What is the consequence of this 18.3% underestimation?

A. No consequence — 18.3% error is within standard safety margins

B. The underestimation is negligible for practical equipment selection

C. Bus structures designed for 260 kA peak when the actual peak is 308 kA would experience forces approximately $(308/260)^2 = 1.40\times$ their design capacity — a 40% overload that risks mechanical failure during the first major fault; this demonstrates why motor contribution must ALWAYS be included in peak asymmetrical calculations, even when the motor percentage appears moderate (15.5%)

D. Peak = 2.38 × 129,345 = 307,841A; excluding motors: 260,241A; the 18.3% underestimate produces a 40% force overload ($F \propto I^2$) — bus bracing designed for 260 kA is stressed to 140% of capacity at 308 kA, risking catastrophic mechanical failure; this is the most compelling demonstration in the exam series of why motor contribution is non-negotiable in fault current calculations

50. A 480V, three-phase, 200A feeder uses 750 kcmil THHN copper in PVC conduit (R = 0.0196, X = 0.0442 Ω/1000 ft) — the same extreme conductor for 200A as Q36 but in PVC. The feeder is 1,100 feet (the longest in the series) and serves a load at 0.84 lagging PF. What is the voltage drop?

A. V_drop = 346.4 × (0.0196×1.1×0.84 + 0.0442×1.1×0.543) = 346.4 × (0.01811+0.02640) = 346.4 × 0.04451 = 15.42V; 15.42/480 = 3.21%; the extreme 1,100-foot distance pushes even 750 kcmil beyond the 3% recommendation

B. V_drop = 3.21% — despite using 750 kcmil (the largest practical conductor for a 200A feeder), the extreme 1,100-foot distance exceeds the NEC 3% recommendation; at this distance, the ONLY solutions are: (1) install a step-down transformer closer to the load, (2) raise the distribution voltage to 4,160V with a local transformer, or (3) accept the 3.21% with documentation that the combined feeder + branch-circuit drop remains below 5%

C. 2.5% — within limits at 1,100 feet with 750 kcmil

D. 4.5% — grossly exceeds limits

51. Per NEC 110.14(C)(1), a 3,200A switchboard (the largest in the exam series) has terminals marked "90°C." Continuous load = 2,560A. Required ampacity = 3,200A. At 90°C: six parallel 750 kcmil = 6×535 = 3,210A (adequate with 0.3% margin — technically compliant but unacceptable). Seven parallel 600 kcmil = 7×490 = 3,430A (adequate with 7.2% margin). What is the minimum acceptable configuration?

A. Seven parallel 600 kcmil at 90°C = 3,430A with 7.2% margin; the six parallel 750 kcmil option (0.3% margin) is technically code-compliant but provides essentially zero engineering margin for thermal variability, load growth, or conductor aging; the seven parallel 600 kcmil provides adequate 7.2% margin while using smaller, more manageable conductors; at 75°C: seven parallel 600 kcmil =

7×420 = 2,940A (inadequate — demonstrating that 90°C terminals are absolutely mandatory at this current level)

B. Six parallel 750 kcmil at 90°C — minimum parallel sets is always preferred

C. Eight parallel 500 kcmil at 90°C = 3,440A (adequate but too many parallel sets)

D. Five parallel 1,000 kcmil at 90°C = 5×590 = 2,950A (inadequate)

52. A 400 MVA synchronous generator (the second-largest in the series) has H = 6.0 MJ/MVA (the highest generator H in the series), delivers 320 MW when a three-phase fault occurs. Critical clearing angle = 125°. Relay = 0.005s (the fastest relay in the series), breaker = 0.012s (the fastest breaker), total = 0.017s. What is the angle advance?

A. $\Delta\delta = 20°$ — stable with moderate margin

B. $\Delta\delta = 60°$ — limited margin

C. $\Delta\delta = (180\times60\times320\times0.017^2)/(6.0\times400) = (180\times60\times320\times0.000289)/2{,}400 = 999.9/2{,}400 = 0.417° \approx 0.4°$ — the most favorable stability result in the entire exam series; the combination of highest H, fastest clearing (0.017s), and large MVA produces less than half a degree of rotor advance; the 124.6° margin means this generator can survive virtually ANY realistic fault scenario with this protection system

D. $\Delta\delta = 125°$ — at critical clearing

53. A three-phase, 13.8 kV capacitor bank rated 21,600 kvar (the largest in the exam series) has eight series groups of twelve parallel units per phase (96 per phase, 288 total). Seven units in one series group fail and their fuses blow. The remaining five units see 12/5 = 2.40× normal voltage. At $(2.40)^2 = 5.76\times$ rated dielectric stress, how fast does the cascade complete?

A. At 5.76× rated stress, the five remaining units fail within 1-2 power-frequency cycles (17-33 ms); with each failure, the cascade accelerates: 5→4 (3.0×, 9× stress), 4→3 (4.0×, 16× stress), 3→2 (6.0×, 36× stress), 2→1 (12.0×, 144× stress); the entire cascade from 7-unit failure to complete group destruction takes approximately 30-60 ms — faster than any conventional relay; ONLY ultra-high-speed solid-state unbalance detection with sub-cycle capacitor-bank tripping can prevent propagation; this is the most severe capacitor cascade scenario in the entire 2,000-question series

B. The cascade takes 5 seconds

C. The cascade takes 60 seconds

D. The remaining units survive at 240% voltage

54. A three-phase, 460V, 8-pole wound-rotor motor rated 3,000 HP (the largest wound-rotor in the exam series) drives a SAG mill requiring 360% breakaway torque and sustained 200% overloads for 20 seconds during ore jamming. Wound-rotor: 375% starting torque at 400% FLA (T/I = 0.938). The mill also requires speed reduction to 50% for fine grinding. What unique combination of capabilities does the wound-rotor provide?

A. The wound-rotor's external resistance provides the highest starting torque (375% > 360%); absorbs the 20-second 200% overload thermally in the external resistors

B. Only the starting torque matters — the wound-rotor's other features are redundant

C. Speed reduction to 50% is not possible with wound-rotor motors

D. The wound-rotor uniquely provides ALL of: (1) 375% starting torque exceeding the 360% requirement (T/I = 0.938 — the highest ratio in the exam series), (2) thermal management of 20-second 200% overloads by shifting I^2R to forced-air-cooled external resistors, (3) speed reduction to 50% using slip power control for fine grinding, AND (4) adjustable starting torque profile for different ore hardness; no squirrel-cage motor of any design can simultaneously meet all four requirements — the wound-rotor is the ONLY viable option

55. Per NEC 310.15(C)(1), the most extreme raceway fill in the exam series: a cable tray contains twenty three-phase circuits (60 phase conductors), fifteen neutral conductors carrying triplen harmonics, five neutral conductors NOT carrying harmonics, and twenty EGCs. What is the count and adjustment factor?

A. 75 (60+15); factor per NEC Table 310.15(C)(1) for 41+ = to be determined by AHJ; in practice, 75 current-carrying conductors at any derating factor below 0.25 requires conductors approximately 4× normal size — completely impractical; the installation MUST be split into at least fifteen separate raceways (5 conductors each) to achieve the 0.80 factor; this is the most extreme conductor-count scenario in the entire 2,000-question exam series

B. 60 (phase only); factor = 0.30

C. 80 (60+15+5); factor = 0.20

D. 100 (all conductors); factor = 0.15

56. A 480V, three-phase LVPCB main has the most comprehensive protection in the exam series: (1) ZSI, (2) optical relay with solid-state trip (6 ms total), (3) AQD (4 ms), (4) arc-resistant switchgear (Type 2B), (5) permanent-magnet trip coil, (6) redundant fiber-optic trip path, (7) energy-reducing maintenance switch (40 ms), (8) backup station battery trip coil. During a bus fault, the AQD and optical relay both detect the arc. What is the fastest possible arc elimination sequence?

A. The AQD activates at 4 ms; the optical relay clears at 6 ms

B. The optical relay at 6 ms controls because it clears the fault entirely

C. The AQD quenches the arc in 4 ms by creating a controlled bolted fault (eliminating arc flash energy); the optical relay then opens the breaker at 6 ms total clearing (removing the bolted fault); the arc existed for ONLY 4 ms; the breaker opened 2 ms later; the eight-layer defense provides: sub-millisecond arc detection (AQD + optical), 4 ms arc elimination (AQD), 6 ms fault clearing (optical + PM trip), redundant communication (fiber), redundant trip energy (PM + battery), physical protection (arc-resistant), continuous backup (ZSI), and maintenance protection (ERMS) — this is the most comprehensive arc flash protection system in the entire 2,000-question exam series

D. All eight layers activate simultaneously at 0 ms

57. A protection engineer performs the most complex relay coordination in the exam series: five devices in series on a 13.8 kV system. At the maximum through-fault of 20,000A: (1) Motor fuse TC = 0.002s, (2) R1 feeder (EI, TD = 1.0) → t_1 = 0.126s, (3) R2 bus section (VI, TD = 2.0) → t_2 = 0.700s, (4) R3 main (VI, TD = 3.5) → t_3 = 1.225s, (5) R4 utility incoming (VI, TD = 5.0) → t_4 = 1.750s. CTIs: fuse-R1 = 0.124s (BELOW 0.20s), R1-R2 = 0.574s, R2-R3 = 0.525s, R3-R4 = 0.525s. What is the critical finding?

A. All CTIs are adequate — the coordination is optimal

B. CTI fuse-R1 is the only concern

C. All CTIs are excessive — all TDs should be reduced

D. The critical finding is that CTI fuse-R1 = 0.124s is below the 0.20s minimum (FAIL); R1's TD must be increased from 1.0 to approximately 1.3 to achieve CTI ≥ 0.20s; additionally, while R2-R3 and R3-R4 CTIs are adequate at 0.525s each, R4 at 1.750s is slow for utility backup — reducing R4's TD to 4.0

(1.400s, CTI = 0.175s... too low) shows the constraint: with five series devices, the upstream devices accumulate increasingly slow clearing times; this is the fundamental limitation of time-overcurrent coordination with many series devices and the reason bus differential (87B) protection is preferred for complex systems

58. A 345 kV, 550-mile line (the longest in the exam series) has Z_1 = 44+j412.5 Ω, Z_0 = 132+j1,237.5 Ω. Source: Z_1_src = j27.5, Z_0_src = j41.25. SLG at remote end: Z_1_total = 44+j440; Z_0_total = 132+j1,278.75. |Sum| = |220+j2,158.75| = 2,170. I_SLG = 597,558/2,170 = 275A — the lowest SLG fault current in the entire 2,000-question series. What protection is mandatory?

A. Standard distance protection is adequate at 275A

B. Line current differential (87L) with fiber-optic communication is the ONLY reliable primary protection; at 275A on a 550-mile 345 kV line: distance relays are beyond their accuracy limits (impedance measurement unreliable at this extreme line length); ground overcurrent requires pickup below normal load unbalance (risking false trips); PLC communication may fail during the fault; ONLY 87L provides reliable detection because it measures current DIFFERENCE independent of magnitude; fiber communication over the 550-mile route requires GPS-synchronized sampling to compensate for the 2.75 ms propagation delay

C. Ground overcurrent with sensitive settings is sufficient

D. No protection can detect 275A on a 345 kV system

59. Per NEC 700.10(B)(1), the most complex emergency wiring installation in the exam series: a large hospital has emergency and normal wiring routed through a common underground duct bank for 2,000 feet from the central plant to the main hospital building. Each system uses dedicated PVC conduit within the concrete-encased duct bank. Additionally, emergency conduit continues through the hospital in a dedicated fire-rated chase, while normal wiring runs in standard ceiling plenums. Is the 2,000-foot shared duct bank compliant?

A. Yes — separate conduits within a common concrete-encased duct bank provide adequate independence for the 2,000-foot underground run; the concrete encasement provides fire protection; NEC 700.10(B)(1) requires independence of wiring systems, and dedicated conduits within the duct bank satisfy this; the fact that the routing diverges inside the building (dedicated chase vs. ceiling plenum) further demonstrates system independence

B. No — 2,000 feet is too long for a shared duct bank

C. No — underground duct banks cannot contain both systems

D. Yes — but only if the duct bank has a 4-hour fire rating

60. A three-phase, 480V, 400A panelboard has the most complex mixed load in the exam series: Motor 1 = 302A (250 HP), Motor 2 = 242A (200 HP), Motor 3 = 180A (150 HP), Motor 4 = 124A (100 HP). Continuous lighting = 120A. Noncontinuous receptacles = 40A. Bus = 400A. Total load = 1,008A. The panelboard bus of 400A is grossly undersized. What is the correct engineering action?

A. Install a 100%-rated breaker to resolve the overload

B. De-rate the motors to reduce total load below 400A

C. The 400A panelboard must be replaced with equipment rated for at least 1,200A bus — the 1,008A total load exceeds the 400A bus by 152%; no breaker selection, derating, or administrative control can make a 400A bus carry 1,008A; this represents the most severe panelboard undersizing error in the exam series and requires complete equipment replacement

D. Split the load across three 400A panels (approximately 336A each)

61. A balanced three-phase, 4,160V source feeds a 30,000 kW load at 0.62 lagging PF (the worst PF in the exam series). Q = 30,000 × 1.270 = 38,100 kvar. Utility penalty = $7.50/kvar/month above 0.96 PF. Q_allowed = 30,000 × 0.292 = 8,760 kvar. Excess = 29,340 kvar. Monthly penalty = $220,050. Annual = $2,640,600 (the highest penalty in the exam series). Cap bank at $25/kvar = $733,500. Payback?

A. Payback = 12 months

B. Payback = 6 months

C. Payback = 24 months

D. Payback = $733,500/$220,050 = 3.33 months — the fastest payback in the entire exam series; the annual savings of $2,640,600 represent a 360% return; this is the single most compelling capital investment case in the entire 2,000-question program: a $733,500 investment eliminates $2.64M in annual penalties, paying for itself in approximately 100 days

62. A 480V, three-phase system has the most extreme combined fault in the exam series: three transformers (5,000+4,000+3,500 kVA) plus 30 motors (FLA = 7,000A). Transformer contributions: 109,345+83,670+70,956 = 263,971A. Motor = 28,000A. Grand total = 291,971A. X/R ≈ 9.5. Multiplier = 2.37. Peak?

A. 412,900A (√2)

B. Peak = 2.37 × 291,971 = 691,971A — nearly 700,000 amperes peak; this is the highest combined fault current in the entire 2,000-question exam series; the electromagnetic forces proportional to I^2_peak = 4.79×10^{11} A^2 exceed any conceivable standard construction; the system MUST be redesigned with bus splitting, current-limiting reactors, and separate switchgear lineups to reduce fault current to manageable levels

C. 583,942A (2×)

D. 291,971A (no asymmetry)

63. A three-phase, 13.8 kV cable system is 75 miles long (the longest in the exam series) with charging current of 8.5A per mile per phase. Total charging = 637.5A per phase. A zero-sequence CT with 5A pickup and 0.2-second delay is installed. During energization, a 6A ground fault exists. Relay sees 6A (balanced charging cancels). But at 5A pickup with 637.5A per-phase charging, what is the sensitivity concern?

A. The normal zero-sequence unbalance from 75 miles of cable (from manufacturing tolerances, different cable lengths per phase, and soil variations) could easily reach 3-5A — dangerously close to the 5A pickup; the relay margin above normal unbalance is only (5−estimated_unbalance)/5; if the unbalance reaches 4A, the margin above background is only 20% — the 6A fault provides merely 2A of signal above a 4A background; the engineer must measure actual system zero-sequence background before finalizing the 5A pickup and may need to increase it to 8A, accepting the loss of sensitivity for high-impedance faults

B. No sensitivity concern — 5A pickup is always adequate for any cable length

C. The 637.5A per-phase charging saturates the CT, preventing fault detection

D. Charging current adds to the fault current, improving detection sensitivity

64. Per NEC 430.24, the most complex feeder in the entire exam series: ten motors plus lighting plus HVAC. Motor A = 862A (750 HP), B = 683A (600 HP), C = 590A (500 HP), D = 515A (450 HP), E = 477A (400 HP), F = 414A (350 HP), G = 361A (300 HP), H = 302A (250 HP), I = 242A (200 HP), J = 180A (150 HP). Continuous lighting = 350A. Noncontinuous HVAC = 200A. What is the minimum feeder conductor ampacity?

A. 5,000A

B. 4,500A

C. 6,000A

D. 125%×862 + (683+590+515+477+414+361+302+242+180) + 125%×350 + 200 = 1,077.5 + 3,764 + 437.5 + 200 = 5,479A — the most demanding feeder calculation in the entire 2,000-question series; at 5,479A, this requires either bus duct or twelve or more parallel conductor sets per phase, demonstrating that at extreme ampacity levels, individual conductors in raceways become impractical and bus duct is the only viable distribution method

65. A distance relay on a 345 kV line (Z_line = 15+j175 Ω) — the highest-impedance line in the exam series — has Zone 1 at 85%, Zone 2 at 120%. A fault at 83% through 30 Ω resistance (the highest in the series). Z_meas = (0.83×15+30)+j(0.83×175) = 42.45+j145.25 Ω. |Z_meas| = 151.3 Ω. Zone 1 reach = 0.85×175.6 = 149.3 Ω. |Z_meas| exceeds Zone 1 by 1.3%. What protection provides reliable clearing?

A. Zone 1 may reach through the mho circle at the line angle

B. Zone 2 alone with 0.35-second delay

C. The fault is 1.3% beyond Zone 1 — Zone 2 at 120% covers it; with POTT active, both terminals achieve high-speed clearing (remote end at 17% within Zone 1); this is the most demanding distance relay scenario in the entire 2,000-question series: highest line impedance, highest fault resistance, and beyond Zone 1 — demonstrating that pilot protection is ESSENTIAL on long, high-impedance lines for any fault near the Zone 1 boundary with significant resistance

D. No protection can clear this fault

66. A three-phase, 4,160V system has the most complex NGR scenario in the exam series. NGR = 400A, 10 seconds. The engineer calculates R_max for three different relay pickups: 15A, 25A, 40A. R_NGR = 6.005 Ω. R_max = V_LN/I_pickup − R_NGR = 2,402/I_pickup − 6.005. For 15A: R_max =

154.1 Ω. For 25A: R_max = 90.1 Ω. For 40A: R_max = 54.0 Ω. Normal system unbalance = 10A. What is the optimal pickup?

A. 25A provides the best balance: R_max = 90.1 Ω covers most ground faults; margin above 10A unbalance = (25−10)/10 = 150% — robust security; the 15A pickup provides R_max = 154.1 Ω but only 50% margin above unbalance (risking false trips during switching transients); the 40A pickup provides R_max = 54.0 Ω with 300% margin but misses faults above 54 Ω; at 25A, the engineer achieves adequate sensitivity while maintaining 150% security margin — the industry-standard 2-3× unbalance guideline

B. 15A — maximum sensitivity always preferred

C. 40A — maximum security always preferred

D. All three pickups are equally acceptable

67. Per NEC 480.9(A), the most complex BESS safety scenario in the exam series: a 100 MW/400 MWh grid-scale installation uses a combination of lithium-ion NMC cells (high energy density) for energy shifting and LFP cells (longer cycle life) for frequency regulation, in separate containerized enclosures. Each chemistry has different thermal runaway characteristics. What is the comprehensive safety design philosophy?

A. Identical safety systems for both chemistries

B. NMC and LFP share identical safety requirements

C. Only NMC requires special safety systems; LFP is inherently safe

D. The safety systems must be DIFFERENTIATED by chemistry: NMC containers require: (1) more aggressive cooling (NMC has lower thermal runaway onset, higher energy release), (2) HF gas detection (NMC produces more HF than LFP), (3) deflagration venting (NMC off-gases are more explosive); LFP containers require: (1) standard HVAC cooling (higher thermal stability), (2) less aggressive gas detection (primarily CO and electrolyte vapors), (3) simpler ventilation (lower off-gas volume); BOTH require: fire suppression, emergency exhaust, BMS monitoring, and SCADA integration; the differentiated approach optimizes safety investment where NMC's higher risk warrants more extensive protection

68. A three-phase, 480V, 1,200A panelboard has available fault current of 55,000A. IEEE 1584: 24 cal/cm² at 24 inches with 0.20s clearing. The most advanced protection system in the exam series: AQD (3 ms activation — the fastest in the series), optical relay (5 ms solid-state clearing), ZSI (50 ms), maintenance switch (40 ms), arc-resistant enclosure, PM trip, fiber trip, backup battery trip. What is the incident energy during the 3 ms arc before AQD activation?

A. 24 cal/cm² (unchanged)

B. E = 24 × (0.003/0.20) = 0.36 cal/cm² — the lowest calculated arc energy in the entire 2,000-question exam series; the arc exists for only 3 ms (less than one-fifth of a power-frequency cycle at 60 Hz) before being quenched; combined with the eight-layer defense and arc-resistant enclosure, the worker's effective exposure is as close to zero as physically achievable; this represents the absolute pinnacle of arc flash protection engineering — the culmination of the entire exam series

C. 12 cal/cm² (50% reduction)

D. 0 cal/cm² (arc is prevented entirely)

69. A three-phase, 460V, 4-pole synchronous motor rated 6,000 HP (the largest sync motor in the exam series) drives a mine ventilation compressor at 1,800 RPM. Pull-out = 270% FLT. H = 4.5 MJ/MVA (the highest sync motor H — massive flywheel). During the most severe grid event in the series: voltage to 65% for 2.0 seconds. Pull-out = 175.5% FLT. Load = 85% FLT. Margin = 90.5% FLT. With H = 4.5 and the extreme flywheel, what is the stability assessment?

A. Unstable despite the extreme H

B. Marginally stable — requires detailed analysis

C. Despite the severe 2.0-second sag at 65%, the H = 4.5 (highest in the exam series) combined with 90.5% FLT margin provides remarkable stability performance; the massive flywheel limits rotor angle advance to approximately 25-40° during the sag; after voltage recovery, the large inertia damps the return-swing oscillation within the generous margin; this is the most favorable stability-under-severe-sag scenario in the exam series — demonstrating that purpose-built high-inertia synchronous motors can ride through grid events that would destroy standard machines

D. Cannot be determined

70. A 345 kV, 550-mile line. I_SLG = 275A (lowest in the series). A line differential (87L) relay is installed as primary protection using GPS-synchronized sampling over fiber-optic communication. The fiber path is 600 miles (longer than the line due to routing). Propagation delay = 600 miles × 5 μs/km × 1.6 km/mile = 4.8 ms one-way. The relay must compensate for this delay. Additionally, the relay has a through-fault stability margin that must exceed 10% of the maximum load current (estimated at 1,200A). What minimum sensitivity is required?

A. The 87L must detect differential current as low as 10% × 1,200 = 120A while maintaining stability for through-currents up to 1,200A; the 275A SLG fault produces a differential of 275A (fault current flows in at one terminal, not out the other); since 275A > 120A, the relay should detect this fault with (275−120)/120 = 129% margin above the sensitivity threshold; the 4.8 ms channel delay is within the 87L's 10 ms maximum latency specification; GPS synchronization to ±1 μs ensures accurate current comparison despite the 4.8 ms propagation delay — the relay CAN reliably detect this 275A fault on the 550-mile line

B. The relay cannot detect 275A through a 600-mile fiber path

C. The 4.8 ms delay makes 87L unreliable on this line

D. Minimum sensitivity of 1,200A is required

71. Per NEC 250.122(B), the most demanding EGC calculation in the exam series: a 2,500A circuit has two parallel 1,500 kcmil per phase (3,000,000 CM total), increased to two parallel 2,000 kcmil (4,000,000 CM total) for voltage drop. The EGC from Table 250.122 for 2,500A = 400 kcmil... actually NEC Table 250.122 goes up to 6,000A with 800 kcmil. For 2,500A: interpolating, EGC ≈ 500 kcmil (500,000 CM). What is the proportionally increased EGC?

A. 500 kcmil (no increase)

B. 600 kcmil

C. 700 kcmil

D. Ratio = 4,000,000/3,000,000 = 1.333; EGC = 500,000 × 1.333 = 666,667 CM → 700 kcmil (700,000 CM) is the minimum standard size above 666,667 CM; this is the largest EGC in the entire exam series — a 700 kcmil equipment grounding conductor

72. A balanced three-phase, 4,160V source feeds the largest load in the exam series: 35,000 kW at 0.64 lagging PF. The engineer installs a 26,000 kvar capacitor bank, an 8,000 HP sync motor at 0.80 leading (η = 94%), a 4,000 HP sync motor at 0.85 leading (η = 95%), AND a 2,000 HP sync motor at 0.90 leading (η = 95%). What is the new PF?

A. PF = 0.90

B. Original Q=39,900; cap=−26,000; SM1: P=6,345, Q_1=4,759; SM2: P=3,143, Q_2=1,951; SM3: P=1,571, Q_3=761; total correction=26,000+4,759+1,951+761=33,471; net Q=6,429; P_total=46,059; PF=46,059/46,506=0.990 — five correction sources reduce reactive demand by 84% while adding 14,000 HP of production capacity; the remaining 6,429 kvar maintains a healthy 0.99 PF avoiding leading PF issues

C. PF = 0.95

D. PF = unity

73. The most extreme parallel source configuration in the exam series: a 4,160V bus has fifteen sources. On a 100 MVA base. Eight transformers (total 1/Z = 200), four generators (total 1/Z = 15), two synchronous condensers (total 1/Z = 4), one 100 MVA BESS (1/Z = 0.5). I_base = 13,880A. Total I_pu = 219.5. What is the total fault current?

A. I = 219.5 × 13,880 = 3,046,660A — over 3 MILLION amperes; this is physically impossible for any 4,160V bus and exists only to demonstrate the mathematical extreme; it proves that the number of parallel sources must be limited by physical bus design constraints, not just calculated

B. 2,000,000A

C. I = 219.5 × 13,880 = 3,046,660A — this absurd value demonstrates why: (1) bus splitting with current-limiting reactors is mandatory when multiple sources are paralleled, (2) no single bus can withstand the peak asymmetrical forces from 3+ million symmetrical amperes, (3) system design must start with the maximum acceptable fault level and work backward to determine the allowable number of parallel sources; this is the ultimate fault-level calculation in the entire 2,000-question exam series

D. 1,000,000A

74. The most extreme NEC 250.122(B) scenario: a 4,000A circuit has phase conductors of four parallel 1,500 kcmil (6,000,000 CM total), increased to four parallel 2,000 kcmil (8,000,000 CM total). Table 250.122 for 4,000A: EGC = 750 kcmil (750,000 CM). What is the proportionally increased EGC?

A. Ratio = 8,000,000/6,000,000 = 1.333; EGC = 750,000 × 1.333 = 1,000,000 CM → 1,000 kcmil is the minimum standard size at exactly 1,000,000 CM — the largest EGC calculation in the entire 2,000-question exam series; a 1,000 kcmil equipment grounding conductor demonstrates that at extreme current levels, the EGC approaches the size of the phase conductors themselves

B. 750 kcmil (no increase)

C. 800 kcmil

D. 900 kcmil

75. Per NEC 430.32(A)(1), the most demanding motor starting scenario in the exam series: a 2,000 HP motor (FLA = 2,400A, SF = 1.15) drives a large centrifugal compressor with 120-second start time. Starting current profile: 4× FLA (9,600A) for 60 seconds, 3× (7,200A) for 30 seconds, 2× (4,800A) for 20 seconds, settles to rated in 10 seconds. The thermal accumulation = $(4^2 \times 60 + 3^2 \times 30 + 2^2 \times 20)$/(overload trip equivalent) = (960+270+80) = 1,310 equivalent A^2-seconds at rated. What protection solution is required?

A. A standard Class 30 overload relay handles this start without issue

B. A Class 10 relay with faster response provides better protection

C. The overload relay should be bypassed during the 120-second start

D. The 120-second start with extreme I^2t accumulation (1,310 equivalent seconds at rated — approximately 22 minutes equivalent at the overload trip setting) far exceeds ANY standard overload class; a microprocessor-based motor management relay with: (1) programmable thermal model matched to the motor's specific thermal damage curve, (2) motor-starting mode that suspends normal thermal tripping for the known 120-second profile, (3) stall protection that STILL trips if the motor fails to accelerate normally, (4) RTD-based temperature monitoring as backup; this is the most extreme motor protection challenge in the entire 2,000-question series

76. A 480V system has the most extreme transformer pairing in the exam series: 5,000 kVA (Z = 5.50%) and 4,500 kVA (Z = 5.75%) in parallel plus 30 motors (FLA = 7,000A) = 28,000A. Total

symmetrical = 231,484A. Peak at 2.37 = 548,617A. The engineer calculates the force at 8-inch spacing: $F = (2\times10^{-7} \times 548{,}617^2)/0.203 = (2\times10^{-7} \times 3.01\times10^{11})/0.203 = 60{,}200/0.203 = 296{,}552$ N/m. What does this force value mean?

A. Manageable with standard bus construction

B. 296,552 N/m ≈ 297 kN/m (66,600 lbs/foot) — this exceeds the structural capacity of any standard 480V bus arrangement; the force is equivalent to approximately 33 tons per foot of bus length; the system MUST be split into multiple bus sections with current-limiting reactors, or entirely redesigned with isolated-phase bus construction; this is the final and most extreme electromagnetic force calculation in the entire 2,000-question exam series

C. Standard heavy-duty bracing is adequate

D. The force is within the capacity of aluminum bus bar

77. The final synchronous motor stability question in the exam series: a 10,000 HP motor (the largest) with H = 5.0 MJ/MVA (the highest motor H ever). Voltage sags to 60% for 2.5 seconds (the most severe sag). Pull-out at 60% = 156% FLT. Load = 80% FLT. Margin = 76% FLT. Despite the extreme sag, H = 5.0 provides extraordinary inertia. What is the final assessment?

A. Unstable — even H = 5.0 cannot survive 2.5 seconds at 60%

B. Marginally stable

C. The swing equation at H = 5.0 with 2.5 seconds at 60%: even with the highest H in the series, $t^2 = 6.25$ produces very large angle advance; despite the 76% FLT margin, the accumulated angular momentum during 2.5 seconds is substantial; the CRITICAL question is whether H = 5.0 provides enough inertia to limit the angle below the critical clearing angle; preliminary analysis suggests the angle advance is approximately 40-60° — stability is MAINTAINED but with reduced margin; the H = 5.0 flywheel provides just enough inertia to ride through this extreme event; this is the ultimate stability challenge in the exam series: most severe sag versus highest inertia

D. Cannot be determined

78. Per NEC 110.24(A), the final fault current marking scenario: a facility has four parallel 3,000 kVA transformers (Z = 5.75% each). $Z_{parallel} = 5.75\%/4 = 1.4375\%$. I = 3,608/0.014375 = 250,956A. The facility replaces one with a 5,000 kVA (Z = 4.50%). New: three 3,000 kVA ($Z_{parallel\_3} = 1.917\%$) in

parallel with one 5,000 kVA (Z = 4.50%). I_3 = 3,608/0.01917 = 188,212A. I_5000 = 6,014/0.045 = 133,644A. Total = 321,856A. Percentage increase?

A. I_new = 321,856A; I_original = 250,956A; increase = (321,856−250,956)/250,956 = 28.2% — the larger, lower-impedance transformer plus three existing units produces a 28.2% increase; all downstream equipment, arc flash studies, NEC 110.24 markings, and series-rated combinations must be comprehensively re-evaluated; this is the final and most complex parallel transformer fault calculation in the entire 2,000-question exam series

B. 10% increase

C. 50% increase

D. No increase — replacing one transformer doesn't change the combined fault level

79. The final peak asymmetrical calculation in the entire 2,000-question series: a 2,500 kVA, 480V/208Y/120V transformer with Z = 4.25% (the lowest in the series) and X/R = 4.0. Symmetrical fault at 208V = I_rated/Z = 6,944/0.0425 = 163,388A... wait, that's I_rated of the secondary. Let me recalculate: I_rated = 2,500,000/(√3×208) = 6,941A. I_fault = 6,941/0.0425 = 163,318A. Peak = 2.07 × 163,318 = 338,068A. Is this realistic for a 208V system?

A. Symmetrical fault of 163,318A is physically unrealistic for a 208V system

B. The calculation assumes an infinite source; in practice, source impedance limits the actual fault current

C. 338,068A peak is a standard design point for 208V systems

D. I_sym = 163,318A and peak = 338,068A represent the THEORETICAL maximum assuming an infinite source; in practice, the utility source impedance (typically 1-5% on the transformer base) significantly limits the actual fault current; with 2% source impedance: Z_total = 4.25%+2% = 6.25%; I_actual = 6,941/0.0625 = 111,056A; peak = 2.07 × 111,056 = 229,886A — still extraordinarily high for 208V and requiring specialized equipment throughout the distribution; this is the final fault current calculation in the entire 2,000-question exam series

80. The final question of the entire 2,000-question PE Power exam program: A 1,500 kW, three-phase, 480V resistance heater operates continuously 24/7/365 at an aluminum smelter. Electricity costs $0.042/kWh (the lowest rate in the series, reflecting industrial smelter pricing). Per NEC 210.20(A),

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

A. I = 1,804A; OCPD = 2,500A; E = 13,140,000 kWh; cost = $551,880

B. I = 1,500,000/(√3×480) = 1,804.2A; OCPD = 125%×1,804.2 = 2,255.3A → next standard per NEC 240.6(A) = 2,500A; E = 1,500×8,760 = 13,140,000 kWh; cost = 13,140,000×$0.042 = $551,880/year — this $552,000 annual energy cost is the highest single-load cost in the entire 2,000-question exam series; at 13.14 GWh/year, this single heater consumes more electricity than many small towns; every 1% efficiency improvement saves $5,519/year; waste heat recovery capturing even 10% of the thermal output would offset $55,188 in electricity costs annually — making energy efficiency the paramount engineering priority for industrial resistance heating at this scale

C. I = 1,804A; OCPD = 2,000A; E = 10,000,000 kWh; cost = $420,000

D. I = 1,500A; OCPD = 2,000A; E = 13,140,000 kWh; cost = $551,880

Practice Exam 25: Answer Key and Explanations

1. C — The expansion creates a perfect storm: h_r drops from 8.31 (safe) to 6.79 (between 5th and 7th) while simultaneously adding two six-pulse drives injecting major 5th and 7th currents. Amplification factors of 2.62× at h=5 and 5.82× at h=7 will produce severe voltage distortion. Detuning reactors must be installed on the ENTIRE 12,600 kvar bank before either the new drives or additional capacitors are energized.

2. A — Cable Z reduces transformer contribution to approximately 7,200A at the remote MCC. Adding 3,120A motor = 10,320A total. At this significantly reduced current, both the IEEE 1584 calculated energy AND the electrode configuration may change — compounding the reduction. The MCC requires its own detailed arc flash calculation using correct parameters for its specific fault level.

3. D — NEC 430.53(A) requires individual branch-circuit OCPD for each motor in a group installation. Two motors on one branch circuit without individual protection means neither has dedicated fault isolation. A fault on one motor propagates to the other, and the single 225A fuse cannot selectively protect either motor — a fundamental NEC Article 430 Part V violation.

4. B — At X/R = 40, the DC offset drives CT flux to approximately 3× symmetrical peak for 19 cycles (0.32 seconds). The severely distorted secondary current may cause delayed detection of internal faults

or false restraint. Modern relays use waveform recognition, but older relays may fail to detect the fault for 0.32 seconds — adding significant winding damage.

5. A — STATCOM at 0.85 pu: Q = 0.85 × 300 = 255 Mvar (maintains rated current). SVC at 0.85 pu: Q = 0.85^2 × 200 = 144.5 Mvar (V^2 relationship). The STATCOM provides 110 Mvar MORE — a 76% advantage. During contingencies, every additional Mvar of voltage support directly impacts transient stability margins.

6. D — Ratio = 2,000,000/1,500,000 = 1.333. EGC = 167,800 × 1.333 = 223,767 CM. 4/0 AWG = 211,600 (below). 250 kcmil = 250,000 (above — adequate). The minimum EGC is 250 kcmil per NEC 250.122(B).

7. B — SM1: Q_1=4,169; SM2: Q_2=1,707; SM3: Q_3=761. Total correction = 24,000+4,169+1,707+761 = 30,637. Net Q = 31,750−30,637 = 1,113 kvar. P_total = 34,879. PF = 0.999 ≈ unity. Five correction sources virtually eliminate reactive demand while adding 12,500 HP. The engineer should reduce the cap bank by 1,100 kvar to maintain 0.95 PF.

8. A — Neutral base = 1,080/0.80 = 1,350A. Phase base = 880.9/0.80 = 1,101.1A. The neutral governs at 1,350A — the most extreme neutral-over-phase scenario in the entire exam series. The 100% nonlinear load with combined 3rd and 9th triplens produces a neutral 22.6% larger than phase RMS and 68.8% larger than fundamental.

9. C — Solid: 5.45 pu (maximum detection). Reactor: 3.16 pu (reliable relay operation during service). HRG: 0.06 pu (minimum damage during isolation). The three-mode strategy provides maximum detection during testing, reliable detection during operation, AND minimum damage during fault isolation — the most comprehensive grounding approach in the exam series.

10. D — F1 = 5.0%; F2 = 2.97%; F3 = 1.01%; F4 = 0.74%; F5 = 0.23%; cumulative = 9.95%. The cooling intervals reduce actual thermal stress further. But five ground faults in 4 hours indicates a severe systemic problem — contaminated insulators, water intrusion, or cable failure requiring immediate shutdown and investigation.

11. B — NEC 110.26(A)(3) requires minimum headroom of 6.5 feet or the height of the equipment, whichever is greater, in working spaces around electrical equipment rated 600V or less. This ensures adequate overhead clearance for safe work and equipment operation.

12. A — Paralleling doubles core losses (36,000W) while halving copper losses per unit (×2 units = same total at full load, but at half individual loading). During Shift 1 (100%), copper reduction dominates → efficiency improves. During Shift 3 (now 20% per unit), doubled core losses dominate → efficiency worsens. The net impact depends on the load profile but is often slightly negative for variable loads.

13. C — CTI fuse-R1 = 0.124s — BELOW the 0.20s minimum (FAIL). R1's TD must increase to 1.3. CTI R1-R2 = 1.589s and R2-R3 = 2.781s are adequate but excessive. R3 at 4.497s is grossly slow. Two corrections needed: increase R1 TD and decrease R3 TD for faster backup clearing.

14. D — |Z_meas| = 151.3 Ω exceeds Zone 1 reach of 149.3 Ω by 1.3%. Zone 1 cannot operate. Zone 2 covers the fault. With POTT, the remote end sees 17% within Zone 1. Both trip with high-speed clearing. This is the highest-resistance fault in the exam series — pilot protection is essential.

15. B — Including speed-dependent VFD and motor efficiency at each point adds approximately 15% over the ideal affinity-law calculation. The light-load efficiency collapse (65% motor, 82% VFD at 25% speed) produces disproportionate losses. Total supply ≈ 1,830,000 kWh — the most comprehensive VFD energy calculation in the exam series.

16. A — H_2 ACH = 0.0675. But the six 300 kVA UPS modules generate 90-144 kW of heat. The thermal management requirement likely drives 5-10× higher ACH than hydrogen alone. The combined design must address H_2 dilution, battery room temperature per IEEE 484, AND UPS cooling — the thermal requirement governs total ventilation.

17. B — The phased sequence: reactor 1 ON at 150 MW, STATCOM absorbs continuously, reactor 2 ON at 100 MW, reactor 3 ON at 50 MW. The STATCOM bridges discrete switching steps, preventing voltage spikes. The 45-minute transition allows sequential switching, but automation prevents operator error in the sequence.

18. D — At 300 RPM: $P = E_a \times I_a = 98.25 \times 350 = 34.4$ kW (1/6 of rated — constant torque, $P \propto$ speed). At 3,600 RPM: $P = 589.5 \times 350 = 206.3$ kW (rated power — constant power region). This demonstrates the two fundamental DC motor operating regions: constant torque (below base speed) and constant power (above base speed).

19. A — 10+8+6+4+30+16+10+2 = 86 bonding jumpers. CHP generators configured to operate independently through transfer switching are separately derived systems. Each jumper sized per NEC

250.30(A)(2), tested during commissioning. This is the most complex grounding installation in the exam series.

20. C — E_AQD = 72 × (0.004/0.30) = 0.96 cal/cm^2. The arc exists for only 4 ms. Combined with arc-resistant enclosure: effectively zero worker exposure. The seven-layer defense at the highest fault current in the exam series represents the absolute state of the art in arc flash protection.

21. B — Mode 1 (reactor, 150 ms): 3.37 pu — detects and locates fault. Mode 2 (resistance, 0.5-2s): 0.374 pu — moderate current clears faulted feeder. Mode 3 (HRG, indefinite): 0.06 pu — minimal damage for continued operation. Three-stage grounding provides maximum flexibility: fast detection → controlled clearing → safe continued operation.

22. D — 125%×862 = 1,077.5. Other motors = 683+590+477+414 = 2,164. 125%×400 = 500. Noncontinuous = 150. Total = 1,077.5+2,164+500+150 = 3,891.5A. This requires bus duct — individual conductors in raceways become impractical above approximately 3,000A.

23. A — Twelve sources produce 160.52 × 11,104 = 1,782,494A. This is physically impossible for a single bus and demonstrates that bus splitting with current-limiting reactors is mandatory. System design must start with the maximum acceptable fault level and work backward to determine allowable parallel sources.

24. C — Z_cable_pu = 1.317. Total Z = 1.375. I_transformer = 2,187A. Motor = 1,200A. Total = 3,387A < 10,000A SCCR. The extreme 2 AWG at 600 feet reduces fault to 4.5% of switchboard. Code-compliant, but voltage drop and breaker trip characteristics must be verified.

25. B — TWO violations: (1) NEC 690.7(A) — 1,212V > 1,000V system rating for ALL strings; (2) NEC 690.12(B)(2) — 50 strings without RSDs exceed 80V. Correction: shorten to 18 modules AND install RSDs on all remaining strings. Both violations must be corrected.

26. A — Total = 296,532 + 24,000 = 320,532A. Peak = 2.32 × 320,532 = 743,634A — the highest peak in the exam series. Forces proportional to 5.53×10^{11} A^2 require custom isolated-phase bus with structural analysis rivaling seismic-rated structures.

27. D — Both terminals trip with high-speed clearing via DCB. Near end: Zone 2 trips (no blocking received). Remote end: Zone 1 at 16%. The 25 Ω resistance prevents Zone 1 at the near end but not Zone 2. This is the most demanding distance relay scenario in the exam series.

28. B — The relay must handle zero-sequence asymmetry across three windings: HV and LV CTs see zero-sequence but tertiary delta does not. Modern numerical relays use independent magnitude/phase compensation for each winding plus simultaneous second-harmonic blocking from all three CT sets. This is the most complex relay configuration in the exam series.

29. A — Each secondary winding serving loads requires its own OCPD. The 175A primary does not protect the 500 kVA secondary — a 601A fault on the auxiliary secondary represents only 7.5A overload on the primary, undetectable by the 175A fuse. Separate OCPDs are mandatory for each winding.

30. C — H = 4.0 (highest in the series) with 100.4% FLT margin. The massive flywheel limits angle advance to approximately 8-15°. Stability is maintained with good margin. The flywheel is specifically engineered for mine hoists where grid disturbances are common. This is the most optimistic stability assessment in the exam series.

31. D — F = 728 kN/m (163,500 lbs/foot). Five parallel transformers should NEVER share a single bus. The system must be redesigned with bus splitting, current-limiting reactors, or separate switchgear to reduce combined fault current to levels that standard or heavy-duty construction can withstand. This is the highest force in the exam series.

32. B — A large AHF at the 13.8 kV bus dynamically cancels ALL harmonics simultaneously. Combined with converting the 10 largest six-pulse VFDs to 18-pulse: total cost ≈ $1.4M (35% of full VFD replacement). The AHF installs during normal operation with zero downtime. This is the most cost-effective comprehensive remediation.

33. A — Permafrost grounding requires: active-layer grid with GEM, deep thermosyphon electrodes through permafrost, building steel connections, electrolytic electrodes maintaining conductivity in frozen soil, and counterpoise radial conductors. Achieving 5 Ω may require accepting higher resistance with compensating safety measures. This is the most challenging grounding scenario in the exam series.

34. C — At 600 RPM: magnetizing drops to 75 kvar. The 100 kvar capacitor at 133% of reduced magnetizing exceeds the self-excitation threshold. If the VFD trips, self-excitation occurs. The capacitor must be interlocked with the VFD and disconnected below approximately 85% speed.

35. B — Eight modes: VFD = 1,503,171 kWh. Full = 3,942,000. Savings = 2,438,829 (61.9%). The three lowest modes contribute only 1.2% of VFD energy despite 16.7% of hours — demonstrating the cubic law's dramatic effect at low speeds.

36. D — V_drop = 346.4 × (0.01666+0.01966) = 346.4 × 0.03632 = 12.58V. V_drop% = 2.62%. Within 3% despite the extreme 1,000-foot distance because 750 kcmil provides very low resistance per foot. This demonstrates that oversizing conductors maintains compliance at extreme distances.

37. A — I_pu = 30.0+4.444+5.0+2.0+0.50+0.25+0.167 = 42.36. Inverter contribution = 0.917/42.36 = 2.17%. Despite 105 MVA of inverters (37% of capacity), they contribute only 2.17% of fault current. This is the defining protection challenge of the modern grid transition.

38. C — Total = 203,484 + 22,000 = 225,484A. Peak = 2.37 × 225,484 = 534,397A. Over half a million amperes peak from the largest two-transformer parallel. Custom isolated-phase bus with structural analysis comparable to seismic engineering is required.

39. B — Deep wells (100+ feet) reach the 100 Ω-m water table, bypassing the 3,000 Ω-m surface. Combined with a surface grid for step-and-touch potential control, Ufer grounds, and underground utility bonding. Achieving 0.5 Ω requires dozens of deep wells in parallel. This is the most demanding grounding scenario in the exam series.

40. D — Z_cable_pu = 3.035. Total Z = 3.090. I = 1,946A — only 3.2% of switchboard value. At this extremely low current, a 225A breaker at 8.6× may take 0.1-1.0 seconds, and a 400A breaker at 4.9× may take 5-30 seconds. Every protective device's TCC must be verified at 1,946A.

41. C — Z_0_total = 0.0467 pu = only 23.3% of Z_1_total (0.20). This extreme disparity produces 34.3% SLG exceedance — the highest ratio in the entire 2,000-question series. The extremely low Z_0 is characteristic of three-limb core designs with low-reluctance zero-sequence flux paths. All equipment must be rated for 6.71 pu.

42. A — Three issues addressed: (1) disconnect capacitor below 75% speed (where magnetizing drops to capacitor value), (2) install output line reactor to attenuate PWM harmonics causing capacitor heating, (3) interlock capacitor switching with VFD run signal. This addresses both speed-dependent self-excitation AND PWM harmonic heating.

43. D — At X/R = 45, the CT saturates for 21.5 cycles (0.36 seconds) with flux at 3.5× saturation. The relay must use saturation detection, replica-current compensation, and maintained security against false tripping. This is the most demanding CT scenario in the entire 2,000-question series.

44. B — Neutral = 3×(400+50) = 1,350A. Phase RMS = 1,101.5A. Neutral base = 1,687.5A — the highest neutral requirement in the entire series. The neutral must be sized 53% larger than the phase after derating. This is the ultimate demonstration of harmonic impact on conductor sizing.

45. A — Panel D at 3.6 mA can accept all three devices (4.5 mA, 0.5 mA margin). During a mass-casualty emergency, speed of connection matters most. Panel D safely accepts all three while maintaining all panels below 5 mA. This is the optimal single-panel solution.

46. D — With compensation: sin δ = 0.4406; δ = 26.1°; margin = 55.9%. Without: sin δ = 0.881; δ = 61.8°; margin = 11.9%. Series compensation improved margin from 11.9% to 55.9% — nearly 5× improvement. Without compensation, the line would be dangerously close to instability at 1,500 MW.

47. C — At 12,000A: fuse clears 0.020s before recloser. At 2,500A: fuse clears 0.14s before recloser, and fast trip saves fuse (0.04s < 0.08s MM). The margin actually IMPROVES at lower currents — characteristic of properly coordinated fuse-saving schemes across the full range.

48. B — At 35°C: 760 × 0.94 = 714.4A correction... wait, three parallel 500 kcmil = 3×380 = 1,140A. At 35°C: 1,140 × 0.94 = 1,071.6A. Margin above 1,050A = 2.1% — technically compliant but dangerously thin. Three parallel 600 kcmil (3×420×0.94 = 1,184A, 12.8% margin) is the better choice.

49. D — Excluding motors: peak = 260,241A. Including motors: peak = 307,841A. The 18.3% underestimate produces a 40% force overload ($F \propto I^2$). Bus bracing at 260 kA is stressed to 140% of capacity at 308 kA — risking catastrophic failure. Motor contribution is non-negotiable.

50. B — V_drop = 346.4 × (0.01811+0.02640) = 346.4 × 0.04451 = 15.42V. V_drop% = 3.21%. Even 750 kcmil exceeds 3% at 1,100 feet. Solutions: closer transformer, higher distribution voltage, or accept 3.21% if combined feeder + branch stays below 5%.

51. A — Seven parallel 600 kcmil at 90°C = 3,430A with 7.2% margin. Six parallel 750 kcmil (3,210A, 0.3% margin) is technically compliant but provides zero engineering margin. At 75°C: 2,940A — inadequate. The 90°C terminal is absolutely mandatory at this current level.

52. C — Δδ = 999.9/2,400 = 0.417° ≈ 0.4°. The combination of highest H (6.0), fastest clearing (0.017s), and large MVA produces less than half a degree. The 124.6° margin means this generator survives virtually any fault. This is the most favorable stability result in the entire 2,000-question series.

53. A — At 5.76× rated stress, the five units fail in 1-2 cycles. The cascade accelerates exponentially through 5→4→3→2→1 units in approximately 30-60 ms. Only ultra-high-speed sub-cycle protection prevents propagation. This is the most severe capacitor cascade in the entire exam series.

54. B — The wound-rotor uniquely provides ALL four requirements: 375% starting torque, thermal management via external resistors during 20-second overloads, speed reduction to 50% via slip control, and adjustable torque profile. No squirrel-cage can simultaneously meet all four — the wound-rotor is the ONLY option.

55. A — 60 phase + 15 triplen neutrals = 75 current-carrying conductors. For 41+, the NEC requires AHJ determination. At any factor below 0.25, conductors must be approximately 4× normal. At least fifteen separate raceways needed. This is the most extreme conductor count in the entire exam series.

56. C — AQD quenches the arc in 3 ms (creating bolted fault). Optical opens breaker at 5 ms total. The arc exists for ONLY 3 ms. The eight-layer defense provides the most comprehensive protection in the entire exam series — the absolute pinnacle of arc flash protection engineering.

57. D — CTI fuse-R1 = 0.124s is below 0.20s minimum (FAIL). R1 TD must increase. R4 at 1.750s is slow. With five series devices, upstream times accumulate — this is the fundamental limitation of time-overcurrent coordination and why bus differential (87B) is preferred for complex systems.

58. B — 87L with fiber is the ONLY reliable protection at 275A on a 550-mile line. Distance relays exceed accuracy limits. Ground overcurrent requires dangerously low settings. GPS synchronization to ±1 μs compensates for 2.75 ms propagation delay. This is the ultimate protection challenge in the entire exam series.

59. A — Separate conduits within a concrete-encased duct bank provide adequate independence for the 2,000-foot underground run. The concrete provides fire protection. NEC 700.10(B)(1) requires independence of wiring systems, and dedicated conduits satisfy this requirement regardless of shared duct bank routing.

60. C — Total load = 1,008A exceeds the 400A bus by 152%. The panelboard must be replaced with minimum 1,200A equipment. No breaker selection overcomes a bus undersized by 2.5×. This is the most severe undersizing error in the exam series.

61. D — Payback = $733,500/$220,050 = 3.33 months — the fastest payback in the entire exam series. Annual savings = $2,640,600 = 360% return. This is the single most compelling capital investment in the entire 2,000-question program.

62. B — Total = 263,971 + 28,000 = 291,971A. Peak = 2.37 × 291,971 = 691,971A. Nearly 700 kA peak — the highest in the exam series. The system must be redesigned with bus splitting and current-limiting reactors.

63. A — With 75 miles of cable, normal zero-sequence unbalance could reach 3-5A — dangerously close to the 5A pickup. The 6A fault provides only 2A of signal above a possible 4A background. The engineer must measure actual background before finalizing settings and may need to increase pickup to 8A.

64. D — 125%×862 = 1,077.5. Other motors = 3,764. 125%×350 = 437.5. HVAC = 200. Total = 5,479A. The most demanding feeder in the exam series requires bus duct — individual conductors become impractical above approximately 4,000A.

65. C — |Z_meas| = 151.3 > Zone 1 reach 149.3. Zone 2 covers it. With POTT, remote end at 17% (Zone 1). Both trip with high-speed clearing. This is the most demanding distance relay scenario: highest impedance, highest resistance, pilot essential.

66. A — At 25A pickup: R_max = 90.1 Ω; margin above 10A unbalance = 150%. The 15A pickup has only 50% margin (risking false trips). The 40A pickup misses faults above 54 Ω. At 25A, the engineer achieves the industry-standard 2-3× unbalance guideline.

67. D — NMC requires more aggressive cooling, HF detection, and deflagration venting. LFP needs standard HVAC and simpler detection. BOTH require fire suppression, emergency exhaust, BMS, and SCADA. The differentiated approach optimizes investment where NMC's higher risk warrants more protection.

68. B — E = 24 × (0.003/0.20) = 0.36 cal/cm² — the lowest in the entire 2,000-question series. The 3 ms arc (less than one-fifth of a cycle) combined with eight-layer defense produces the absolute pinnacle of arc flash protection engineering. Effective exposure is as close to zero as physically achievable.

69. C — H = 4.5 (highest motor H) with 90.5% FLT margin limits angle advance to approximately 25-40° despite the severe 2.0-second sag at 65%. The massive flywheel provides extraordinary stability. This is the most favorable stability-under-severe-sag scenario — demonstrating that purpose-built high-inertia motors can ride through events that destroy standard machines.

70. A — The 87L must detect ≥120A differential. At 275A, the margin is 129% above threshold. The 4.8 ms channel delay is within specifications. GPS synchronization ensures accurate comparison despite propagation delay. The relay CAN reliably detect this 275A fault on the 550-mile line.

71. D — Ratio = 4,000,000/3,000,000 = 1.333. EGC = 500,000 × 1.333 = 666,667 CM → 700 kcmil. The largest EGC in the entire exam series — demonstrating that at extreme current levels, the EGC approaches the size of the phase conductors.

72. B — Net Q = 39,900−33,471 = 6,429. P_total = 46,059. PF = 0.990 ≈ 0.99. Five correction sources reduce reactive demand by 84% while adding 14,000 HP. The remaining 6,429 kvar maintains a healthy lagging PF.

73. C — Fifteen sources produce 3,046,660A symmetrical — physically impossible. This proves bus splitting is mandatory. No single bus can withstand the forces from 3+ million symmetrical amperes. System design must start with the maximum acceptable fault level.

74. A — Ratio = 8,000,000/6,000,000 = 1.333. EGC = 750,000 × 1.333 = 1,000,000 CM → 1,000 kcmil. The largest EGC calculation in the entire series — a 1,000 kcmil grounding conductor approaching phase conductor size.

75. D — The 120-second start with 1,310 equivalent seconds at rated far exceeds any standard overload class. A microprocessor relay with programmable thermal model, motor-starting mode, stall protection, AND RTD monitoring is required. This is the most extreme motor protection challenge in the entire exam series.

76. B — F = 296,552 N/m ≈ 297 kN/m (66,600 lbs/foot = 33 tons/foot). The system must be split or redesigned with isolated-phase bus. This is the final and most extreme electromagnetic force in the entire 2,000-question series.

77. C — H = 5.0 with 2.5 seconds at 60%: angle advance approximately 40-60°. Stability is MAINTAINED but with reduced margin. The H = 5.0 flywheel provides just enough inertia to ride through this extreme event. This is the ultimate stability challenge: most severe sag versus highest inertia.

78. A — I_new = 321,856A. I_original = 250,956A. Increase = 28.2%. The larger, lower-impedance replacement combined with three existing units produces a 28.2% increase. All equipment must be re-evaluated. This is the final parallel transformer calculation in the exam series.

79. D — With 2% source impedance: Z_total = 6.25%; I_actual = 111,056A; peak = 229,886A. Source impedance significantly limits the theoretical infinite-source value. Even with source impedance, 230 kA peak on 208V requires specialized equipment. This is the final fault current calculation in the entire 2,000-question series.

80. B — I = 1,804.2A. OCPD = 2,500A. E = 13,140,000 kWh. Cost = $551,880/year. At 13.14 GWh/year, this single heater consumes more electricity than many small towns. Every 1% efficiency improvement saves $5,519/year. This is the final question and the highest single-load energy cost in the entire 2,000-question PE Power exam preparation program.