PRACTICE EXAM 19: STATIONARY ENGINEER (ELECTRIC) SIMULATION — 100 QUESTIONS

ELECTRICAL FUNDAMENTALS (Questions 1–12)

1. A 120V circuit supplies a 60W incandescent lamp. The current drawn is?

A. 2A

B. 0.25A

C. 0.5A

D. 1A

2. The electrical quantity that represents the rate of doing work or energy transfer in a circuit is?

A. Voltage

B. Power

C. Current

D. Resistance

3. A series RLC circuit has R = 30Ω, XL = 60Ω, and XC = 20Ω. The total impedance is?

A. 110Ω

B. 50Ω

C. 10Ω

D. 50Ω at angle 53.1°

4. In a transformer, the primary winding draws magnetizing current from the supply even at no load because?

A. The secondary is short-circuited during no-load testing

B. Primary winding resistance causes voltage drop at no load

C. The secondary load current induces current in the primary

D. The core requires energy to establish and maintain the alternating magnetic flux

5. The unit of magnetic flux density is the?

A. Tesla

B. Weber

C. Henry

D. Gauss per meter^2

6. A 10Ω and a 40Ω resistor are connected in parallel. The equivalent resistance is?

A. 8Ω

B. 50Ω

C. 25Ω

D. 4Ω

7. The purpose of a "neutral" conductor in a single-phase, 3-wire (120/240V) system is to?

A. Carry fault current during ground faults on 240V circuits

B. Carry unbalanced current between the two 120V legs and provide a reference point for 120V circuits

C. Provide a separate return path for each 120V circuit independently

D. Bond the two hot legs together at the load center

8. In an AC circuit, "true power" (watts) differs from "apparent power" (VA) because?

A. True power includes reactive power; apparent power does not

B. Apparent power is always greater than true power for resistive loads

C. True power is measured at the utility meter; apparent power at the load

D. Reactive components store and return energy each half cycle — true power represents only the energy actually consumed, while apparent power is the product of RMS voltage and current regardless of phase angle

9. The "coulomb" is the unit of?

A. Electric field strength

B. Electrical energy

C. Electrical charge

D. Magnetic flux

10. Two batteries, each 12V with 1Ω internal resistance, are connected in series to a 10Ω load. The load current is?

A. 2A

B. 1.71A

C. 6A

D. 12A

11. The purpose of a "bleeder resistor" in a power supply circuit is to?

A. Protect the load from short-circuit fault currents

B. Discharge filter capacitors when the power supply is turned off — preventing shock hazard from stored charge and improving voltage regulation at light loads

C. Regulate the output voltage under varying load conditions

D. Filter high-frequency ripple from the DC output

12. In a balanced delta-connected load, if each phase impedance is 30Ω and line voltage is 240V, the total three-phase power consumed is?

A. 1,920W

B. 3,840W

C. 5,760W

D. 1,280W

WIRING, CONDUCTORS, AND PROTECTIVE DEVICES (Questions 13–22)

13. Per NEC 250.66, the grounding electrode conductor (GEC) size is based on?

A. The rating of the main overcurrent protective device

B. The calculated load of the service in amperes

C. The size of the service entrance conductors or equivalent area

D. The number of grounding electrodes in the system

14. The purpose of NEC 210.19(A)(1) requiring branch circuit conductors to have an ampacity not less than the maximum load to be served is to?

A. Ensure breakers can be upsized without rewiring

B. Allow voltage drop calculations to use a lower conductor resistance

C. Simplify circuit identification at the panelboard

D. Prevent conductor overheating under continuous and non-continuous load combinations — conductors sized only for the overcurrent device rating may overheat under sustained load

15. Type THWN-2 conductor is rated for?

A. 60°C in wet or dry locations

B. 90°C in wet or dry locations

C. 75°C in wet, 90°C in dry locations only

D. 75°C in all locations

16. Under NEC 430.6, the ampacity of conductors supplying a single motor must be based on?

A. The motor's actual measured running current

B. 125% of the motor's service factor current

C. Not less than 125% of the motor's full-load current from the applicable NEC table

D. The motor nameplate FLA multiplied by 1.15

17. The purpose of a "bonding conductor" between metal water piping and the electrical service grounding system per NEC 250.104(A) is to?

A. Provide a grounding path for the water system's pump motors

B. Satisfy the plumbing code requirement for pipe grounding

C. Ensure metal piping cannot become energized at a dangerous voltage if a fault occurs on electrical equipment connected to the piping — equalizing potential between the piping and grounded electrical system

D. Provide a supplemental grounding electrode for the electrical system

18. Per NEC Table 310.15(B)(3)(a), when four current-carrying conductors are installed in a conduit, the ampacity correction factor is?

A. 0.80

B. 0.70

C. 0.50

D. 0.90

19. The purpose of a "surge protective device" (SPD) Type 1 installed at the service entrance is to?

A. Protect individual sensitive loads from surges on branch circuits

B. Divert large surge currents from direct and indirect lightning strikes entering through the service conductors — protecting the entire facility's electrical system downstream

C. Provide GFCI protection for the service entrance conductors

D. Limit utility voltage swells that exceed 110% of nominal voltage

20. Under NEC 314.16, the minimum box volume for a device box containing two 12 AWG conductors, one 12 AWG EGC, one cable clamp, and one duplex receptacle is?

A. 18.0 in^3 — based on NEC fill calculations: 2 conductors + 1 for EGC + 1 for clamp + 2 for device = 6 conductor equivalents × 2.25 in^3 per 12 AWG = 13.5 in^3 minimum

B. 12.0 in^3

C. 10.5 in^3

D. 16.0 in^3

21. The purpose of a "handle tie" vs. a "two-pole circuit breaker" for a multi-wire branch circuit is that a handle tie?

A. Provides common trip capability so a fault on one pole trips both

B. Allows each pole to be tripped independently for selective load shedding

C. Ensures simultaneous disconnection of both ungrounded conductors as required by NEC 210.4(B) — while a two-pole breaker also provides this plus common trip on fault

D. Satisfies the NEC requirement for 240V circuits only

22. The minimum bending radius for a single 4/0 AWG conductor in conduit per NEC Table 344.24 is?

A. 6 times the conductor diameter

B. 8 times the conductor outside diameter — for conductors without lead sheath or armor

C. 10 times the conductor outside diameter

D. 12 times the conductor outside diameter for large conductors

POWER DISTRIBUTION AND HIGH-TENSION SYSTEMS (Questions 23–32)

23. In a power system, "zero sequence" impedance differs from positive sequence impedance because?

A. Zero sequence impedance applies only during three-phase faults

B. Zero sequence currents flow in phase in all three conductors simultaneously — requiring a return path through the neutral or ground; the transformer connection and grounding method determines whether zero sequence current can flow

C. Zero sequence impedance is always higher than positive sequence impedance

D. Zero sequence only applies to delta-connected systems

24. The purpose of a "line trap" (wave trap) installed on a transmission line is to?

A. Prevent power frequency current from entering communication equipment

B. Block high-frequency power line carrier (PLC) signals from entering the substation bus — allowing carrier signals to flow along the transmission line for protection and communication while preventing them from being shunted by the low impedance of the bus

C. Limit fault current on long transmission lines

D. Provide harmonic filtering on the transmission system

25. A generator rated 10 MVA, 13.8 kV has a subtransient reactance (X"d) of 15%. During a three-phase fault at the generator terminals, the initial symmetrical fault current is approximately?

A. 15,700A

B. 23,500A

C. 11,200A

D. 27,990A

26. The purpose of a "negative sequence relay" (ANSI 46) on a generator is to?

A. Detect reverse power flow into the generator

B. Monitor generator shaft speed for overspeed protection

C. Detect loss of one phase of the generator field supply

D. Protect the generator rotor from overheating caused by unbalanced stator currents — negative sequence currents induce double-frequency eddy currents in the rotor that can cause rapid thermal damage

27. In a switchgear lineup, the purpose of "arc flash detection" relays (optical or pressure-based) is to?

A. Measure arc flash incident energy for PPE label updates

B. Detect arc flash events within the switchgear and trip all bus-connected breakers within 1–2 milliseconds — dramatically reducing arc flash energy by minimizing arc duration

C. Alert workers to approach the switchgear with PPE before opening panels

D. Provide backup protection when the main bus differential relay is out of service

28. The purpose of "transient recovery voltage" (TRV) rating of a circuit breaker is to?

A. Define the breaker's maximum continuous current rating after fault interruption

B. Specify the breaker's dielectric withstand capability between contacts

C. Define the maximum DC component in the fault current the breaker can interrupt

D. Define the maximum rate of voltage rise across the breaker contacts immediately after arc interruption — if TRV exceeds the breaker's capability, the arc re-ignites and the fault is not cleared

29. In a 480V system, a "solid ground fault" on a 200A circuit draws approximately 10,000A. The reason the fault current far exceeds the circuit rating is?

A. The fault arc increases the circuit voltage momentarily

B. The motor loads on the circuit contribute additional fault current

C. The fault impedance approaches zero — fault current is limited only by the source impedance of the transformer and supply conductors, which is very low

D. The OCPD has not yet operated, allowing unrestricted current flow

30. The purpose of "power system grounding" at the transformer neutral is to?

A. Provide a path for harmonic currents to dissipate to earth

B. Establish a voltage reference, limit overvoltages during faults and switching, facilitate fault detection, and provide a low-impedance path for fault current to operate protective devices

C. Prevent static charge buildup on unloaded transformers

D. Satisfy utility metering requirements for revenue-grade billing

31. A 480/277V wye-connected transformer secondary with a solidly grounded neutral — during a single line-to-ground fault on one phase, the maximum voltage on the unfaulted phases to ground is?

A. 480V line-to-line

B. 277V — phase voltage — the solidly grounded neutral holds the neutral at ground potential, limiting unfaulted phase voltages to phase voltage (277V) regardless of the fault

C. 480V on the faulted phase

D. 277V × √3 = 480V on unfaulted phases

32. The purpose of testing a medium-voltage cable with "very low frequency" (VLF) AC voltage instead of DC high potential is to?

A. Reduce the test equipment size and cost compared to DC test sets

B. Test the cable at power frequency equivalent stress

C. VLF (0.1 Hz) allows the cable insulation to be tested at AC voltage levels similar to power frequency — revealing defects that DC testing misses (DC testing can mask or even heal certain XLPE insulation defects) while requiring much lower test equipment power than 60 Hz testing

D. Satisfy IEEE 400 requirements for all medium-voltage cable systems

GENERATORS, MOTORS, AND MOTOR CONTROL (Questions 33–44)

33. The purpose of a generator's "droop" vs. "isochronous" speed control mode relates to?

A. Isochronous control maintains constant frequency regardless of load — used for isolated generators; droop control reduces speed slightly as load increases — used for parallel operation to achieve stable load sharing without hunting

B. Droop control maintains constant frequency; isochronous control is used for startup only

C. Both modes are identical for generators below 1 MW

D. Isochronous control is prohibited by IEEE for generators in parallel operation

34. The purpose of a "brushless exciter" on a synchronous generator is to?

A. Eliminate the need for field current in the main generator

B. Provide shaft-driven AC excitation using a rotating rectifier — eliminating carbon brushes and slip rings that require maintenance and limit high-speed operation

C. Provide static excitation from the AC bus through a thyristor converter

D. Supply excitation from a permanent magnet pilot exciter without external power

35. In a squirrel cage induction motor, the rotor bars are typically made of?

A. Carbon steel for high magnetic permeability

B. Silicon steel laminations identical to the stator core

C. Copper wound coils connected to external resistance

D. Cast aluminum or copper bars short-circuited by end rings — no external connections are required, making the squirrel cage rotor extremely robust and maintenance-free

36. The purpose of a "motor nameplate" service factor (SF) greater than 1.0 means the motor can?

A. Start more frequently than a standard motor without thermal damage

B. Operate continuously above rated voltage without damage

C. Provide higher locked rotor torque than the nameplate value

D. Operate continuously at SF × rated HP without exceeding its insulation temperature class limits — at the expense of reduced service life compared to operation at rated HP

37. The purpose of "encoder feedback" in a VFD closed-loop speed control application vs. open-loop V/Hz control is to?

A. Provide precise shaft speed or position feedback to the VFD — allowing accurate speed regulation (typically ±0.01%) independent of load-induced slip variations, and enabling torque control applications

B. Protect the motor from overspeed during regenerative braking

C. Eliminate the need for motor nameplate data entry in the VFD parameters

D. Provide ground fault detection for the motor winding

38. A 480V, 3-phase motor draws 45A at 0.82 PF. The motor input kVA is?

A. 21.7 kVA

B. 29.9 kVA

C. 37.4 kVA

D. 18.7 kVA

39. The purpose of a "motor circuit protector" (MCP) vs. an inverse-time circuit breaker for motor branch circuit protection is that an MCP?

A. Provides both overload and short circuit protection in a single device

B. Is an instantaneous-trip-only device set above locked rotor current — providing short circuit protection while allowing the motor starter's overload relay to handle overload protection, with an adjustable trip point to avoid nuisance tripping during starting

C. Is rated for higher interrupting capacity than standard circuit breakers

D. Provides motor protection for circuits above 600V only

40. The purpose of an "anti-condensation heater" in a large motor enclosure is to?

A. Prevent motor overheating during overload conditions

B. Keep motor windings above the dew point during shutdown periods — preventing moisture condensation that would reduce insulation resistance and potentially cause winding failure on the next start

C. Maintain motor oil temperature in sleeve bearing motors

D. Provide supplemental cooling during high ambient temperature operation

41. In a motor starting circuit, the purpose of a "time delay relay" (TDR) in a star-delta starter is to?

A. Limit the number of starts per hour by timing the cool-down period between starts

B. Provide a fixed time delay for the motor to start before the overload relay activates

C. Monitor motor current during starting and transition to delta when current drops

D. Allow the motor to accelerate to near-synchronous speed in wye before the timer times out and transitions the starter to delta connection

42. The purpose of "motor efficiency" classification (IE1, IE2, IE3, IE4) per IEC 60034-30 is to?

A. Define motor efficiency at four different load points across the speed-torque curve

B. Indicate the motor's efficiency classification under the international standard — IE3 (premium efficiency) is required for most motors under EISA 2007 in the US; IE4 (super premium) is the next tier being adopted internationally

C. Specify minimum motor efficiency at rated load only for motors above 100 kW

D. Both A and B — providing efficiency data at multiple loads and a classification for regulatory compliance

43. A three-phase, 6-pole, 60Hz induction motor has a full-load speed of 1,165 RPM. The full-load slip is?

A. 2.1%

B. 3.5%

C. 2.9%

D. 4.6%

44. The purpose of a "power factor relay" (ANSI 55) in a synchronous motor application is to?

A. Protect the synchronous motor from leading power factor operation

B. Control the motor's reactive power output by adjusting field excitation

C. Monitor power factor for billing purposes at the motor terminals

D. Detect loss of synchronism (pole slipping) by monitoring the motor's power factor oscillations — indicating the motor is no longer in synchronous operation and may be damaged

ELECTRICAL TESTING, TROUBLESHOOTING, AND MAINTENANCE (Questions 45–54)

45. The purpose of a "polarization index" (PI) test on motor windings is to?

A. Verify correct phase rotation before motor startup

B. Measure insulation capacitance for sizing power factor correction

C. Assess insulation quality by comparing 10-minute to 1-minute IR readings — a PI above 2.0 indicates good insulation; below 1.0 indicates wet or deteriorated insulation

D. Test insulation at operating voltage for in-service assessment

46. When a circuit breaker fails to close when the close button is pressed, the systematic troubleshooting sequence should begin with?

A. Replacing the close coil immediately

B. Checking that control power is present and the breaker is properly racked in

C. Opening the breaker mechanism for internal inspection

D. Verifying control power is present, the breaker is in the connected position, all permissive contacts (anti-pump relay, spring charge switch, protection lockout reset) are satisfied, and the close circuit is complete before suspecting coil failure

47. The purpose of a "high current injection test" on a bus bar in a switchgear lineup is to?

A. Verify the bus bar rating by testing at 100% of rated current

B. Test all bus connections and joints by detecting resistance increases from the voltage drop measured at injected test current — using V = IR, resistance of each joint can be calculated

C. Verify proper tightness of all bus bar bolts by measuring torque during energized conditions

D. Test the bus insulation by injecting high current between phases

48. When a 480V motor runs but produces insufficient torque at full load, the most likely electrical cause is?

A. Supply voltage below nameplate rating — reduced voltage reduces torque proportionally to V^2, potentially causing the motor to operate at excessive slip with insufficient torque for the load

B. Motor insulation deterioration causing partial winding short circuit

C. Incorrect motor rotation direction

D. Overload relay set too high, allowing excessive current

49. The purpose of performing a "turns ratio test" (TTR) at each LTC position of a transformer is to?

A. Verify transformer polarity and connection configuration

B. Measure transformer winding resistance at each tap

C. Test tap changer contact resistance at each position

D. Verify the tap changer selects the correct turns ratio at each position — detecting bridged contacts, open contacts, or selector switch misalignment that would produce incorrect secondary voltage at that tap

50. When using an oscilloscope to measure ripple on a VFD DC bus, a ripple voltage exceeding 10% of the nominal DC bus voltage indicates?

A. Normal DC bus behavior during full-load operation

B. Excessive ripple suggesting capacitor bank degradation, failed capacitors, or input phase loss reducing the rectifier's ability to charge the capacitors adequately

C. The VFD is operating in regenerative mode

D. The DC bus overvoltage protection threshold has been reached

51. The purpose of an "oil dissolved gas analysis" (DGA) on a power transformer is to?

A. Measure the transformer oil's viscosity for pump sizing

B. Assess the transformer's cooling efficiency

C. Determine the transformer's load capacity based on oil temperature

D. Detect incipient faults — different fault types produce characteristic gas signatures: arcing produces acetylene and hydrogen; overheating produces methane and ethylene; partial discharge produces hydrogen — allowing fault type and severity to be assessed before catastrophic failure

52. When troubleshooting a tripped GFCI that will not reset, the correct diagnostic procedure is to?

A. Replace the GFCI receptacle immediately — non-resettable GFCIs are always faulty

B. Check for the presence of voltage on the load terminals with the GFCI in the tripped state

C. Disconnect all loads on the GFCI protected circuit and attempt to reset — if it resets with no load, reconnect loads one at a time to identify the leaking device; if it will not reset even with no load, the GFCI itself may be defective or there is a wiring fault on the line side

D. Verify the GFCI is the correct ampere rating for the circuit

53. The purpose of a "cable sheath integrity test" on a shielded medium-voltage cable after installation is to?

A. Verify the cable conductor has sufficient cross-sectional area for the design current

B. Verify the metallic shield is continuous and unbroken — a damaged shield provides inadequate capacitive grounding of the insulation, potentially leading to premature insulation failure from uncontrolled surface discharges

C. Confirm the cable dielectric strength meets the system voltage rating

D. Measure the cable's charging current for relay coordination settings

54. The purpose of "acceptance testing" per NETA ATS on new electrical equipment before energization is to?

A. Verify equipment meets the engineer's design specifications only

B. Provide baseline data for future maintenance comparison

C. Verify proper installation, correct operation of all components, and establish baseline performance data — confirming the equipment is ready for energization and providing reference values for future maintenance testing to detect deterioration

D. Both B and C — establishing baseline data and confirming installation correctness, which are the dual purposes of acceptance testing

MECHANICAL EQUIPMENT (Questions 55–63)

55. The purpose of a pump's "specific speed" (Ns) characteristic is to?

A. Define the maximum allowable pump speed for the selected impeller material

B. Predict the cavitation threshold for the pump at design conditions

C. Determine the number of stages required for multi-stage pump applications

D. Classify the pump's hydraulic design — low Ns (500–1,000) indicates a radial flow pump suited for high head/low flow; high Ns (10,000+) indicates an axial flow pump suited for low head/high flow

56. In a steam turbine, the purpose of "labyrinth seals" at the shaft penetrations is to?

A. Prevent bearing oil from contaminating the steam path

B. Restrict steam leakage from high-pressure to low-pressure zones through a series of close-clearance throttling stages — minimizing steam loss without contact between rotating and stationary components

C. Prevent condensate from entering the turbine during shutdown

D. Seal the turbine casing halves against steam leakage at the horizontal joint

57. The purpose of a boiler's "induced draft" (ID) fan vs. a "forced draft" (FD) fan is that an ID fan?

A. Supplies combustion air to the burner under positive pressure

B. Recirculates flue gas back to the furnace for NOx control

C. Draws flue gases through the boiler and expels them to the stack — maintaining the furnace at slight negative pressure, preventing hot gas leakage through casing joints

D. Provides cooling air to the boiler superheater during startup

58. The purpose of an "accumulator" in a pneumatic control system is different from a hydraulic accumulator in that a pneumatic accumulator?

A. Contains a gas charge separated from the working fluid by a bladder

B. Stores pressurized oil for emergency actuator operation

C. Provides surge flow for actuator demands exceeding compressor capacity

D. Stores compressed air volume to maintain system pressure during peak demand and compressor off-cycles — pneumatic accumulators are simply pressure vessels (receivers) with no bladder since the working fluid (air) is already compressible

59. The purpose of a turbine's "sentinel valve" is to?

A. Protect the turbine from overpressure by bypassing steam to the condenser

B. Provide the primary overspeed protection for the turbine

C. Monitor steam quality entering the turbine

D. The sentinel valve is a small, low-capacity valve set slightly above the trip speed — it whistles to warn operators of approaching overspeed, allowing manual correction before the main trip mechanism operates

59. The purpose of a mechanical seal's "flush" arrangement is to?

A. Supply a clean, cool fluid to the seal faces — controlling temperature, removing heat generated by face friction, and preventing contamination of the seal faces from process solids or abrasives

B. Pressure-test the seal after installation

C. Lubricate the seal elastomers to prevent swelling

D. Cool the seal gland plate to prevent distortion

60. The relationship between a pump's "brake horsepower" (BHP) and "water horsepower" (WHP) is that BHP?

A. Equals WHP for pumps with efficiency above 80%

B. Is always less than WHP because motor efficiency reduces input power

C. Equals WHP plus mechanical and volumetric losses in the pump only

D. Equals WHP divided by pump efficiency — BHP is always greater than WHP because it includes all pump losses; pump efficiency = WHP ÷ BHP

61. The purpose of a gas turbine's "compressor wash" procedure is to?

A. Remove carbon deposits from combustion liner surfaces

B. Cool the compressor inlet air during hot weather for power recovery

C. Clean turbine blade cooling passages of oxidation products

D. Remove fouling deposits from compressor blades — restoring airfoil geometry and recovering lost compressor efficiency and turbine output power

62. In a refrigeration system, "hot gas bypass" control is used to?

A. Recover heat from compressor discharge for space heating

B. Bypass discharge gas around the condenser for head pressure control

C. Maintain minimum compressor loading when system cooling demand drops below the compressor's minimum unloading capacity — preventing compressor surge or short cycling

D. Provide defrost heating for evaporator coils in low-temperature applications

63. The purpose of a bearing's "L10 life" (B10 life) rating is to?

A. Define the bearing's maximum continuous operating temperature

B. Define the expected operating hours at which 10% of a population of identical bearings under identical conditions will have failed from rolling contact fatigue — the standard basis for bearing selection

C. Specify the bearing's minimum lubrication interval in operating hours

D. Define the bearing's static load capacity at 10% of dynamic rated load

FLUID SYSTEMS (Questions 64–72)

64. In an HVAC system, the "dew point temperature" of supply air determines?

A. The minimum supply air temperature that can be delivered to the occupied space without causing condensation on supply air diffusers and exposed ductwork

B. The outdoor air temperature below which economizer operation is permitted

C. The minimum chilled water supply temperature required to prevent evaporator freeze-up

D. The maximum relative humidity level achievable in the occupied space

65. The purpose of a steam system's "pressure reducing valve" (PRV) downstream trim selection is that the trim material must be compatible with?

A. The downstream pipe material to prevent galvanic corrosion

B. The steam quality (dry vs. saturated) at the valve inlet

C. The downstream pressure and velocity — high pressure drop across a PRV creates very high steam velocity that erodes soft trim materials; hardened stainless steel or stellite-faced trim is required for large pressure reductions

D. The chemical treatment program used in the boiler feedwater system

66. In a chilled water system, "delta-T degradation" occurs when?

A. The chilled water supply temperature rises above setpoint under high load

B. The cooling coil approach temperature increases due to fouling

C. The chilled water return temperature drops below the supply temperature setpoint

D. The temperature difference between chilled water supply and return is less than design — typically caused by over-pumping (excessive flow rate) or coil bypass, resulting in inefficient chiller operation and insufficient cooling capacity

66. In a chilled water system, "delta-T degradation" (low delta-T syndrome) occurs when?

A. The temperature difference between CHW supply and return is less than design — reducing system capacity, increasing pump energy, and causing chillers to run at inefficient part load while building zones remain uncooled

B. Chilled water supply temperature cannot reach setpoint during peak load

C. Chiller evaporator approach temperature increases due to fouling

D. Cooling tower water temperature drops below minimum entering condenser water temperature

67. The purpose of a "steam trap survey" using ultrasonic or infrared testing is to?

A. Verify all steam traps are passing steam at the correct pressure

B. Measure steam quality downstream of each trap

C. Identify failed-open traps (passing live steam) and failed-closed traps (blocking condensate) — quantifying steam energy waste for repair prioritization and calculating potential energy savings

D. Verify steam trap sizing is correct for the condensate load at each trap

68. In a compressed air system, the "pressure dew point" specification is important for instrument air because?

A. Higher dew point reduces compressor energy consumption

B. Moisture in instrument air causes valve actuator corrosion, freezing of outdoor lines, and malfunction of pneumatic controls — instrument air typically requires −40°F PDP or lower to prevent moisture condensation anywhere in the distribution system

C. The dew point determines the required pipe wall thickness for the distribution system

D. Lower dew point reduces the efficiency of air-operated tools

69. The purpose of a "variable primary flow" (VPF) chilled water system vs. a constant primary/variable secondary system is that VPF?

A. Varies chiller evaporator flow directly with building cooling load — eliminating the secondary pump and decoupler, reducing pump energy, but requiring modern chillers with variable evaporator flow capability and sophisticated controls to maintain chiller stability

B. Provides better chiller efficiency by maintaining constant evaporator flow

C. Allows multiple chillers to operate at equal load sharing at all times

D. Eliminates the need for chilled water temperature reset control

70. The purpose of a boiler's "economizer" (feedwater preheater) is to?

A. Reduce the temperature of flue gases leaving the furnace

B. Preheat combustion air using waste heat from the flue gases

C. Recover heat from the flue gases to preheat feedwater before it enters the steam drum — reducing fuel consumption by extracting additional heat that would otherwise be wasted up the stack

D. Reduce boiler blowdown requirements by improving feedwater quality

71. In a refrigeration system, the "coefficient of performance" (COP) is defined as?

A. The ratio of compressor power input to condenser heat rejection

B. The ratio of refrigerant mass flow rate to compressor power

C. The ratio of useful refrigerating effect to the compressor power input — COP = Q_evap ÷ W_compressor; higher COP means more cooling per unit of energy consumed

D. The ratio of latent to sensible heat removed at the evaporator

72. The purpose of a "pressure-independent control valve" (PICV) at a terminal unit in a hydronic system is to?

A. Maintain constant differential pressure across the distribution system

B. Combine flow regulation and control valve functions in a single device — automatically maintaining the design flow rate regardless of system pressure variations, eliminating the need for separate balancing valves and simplifying commissioning

C. Provide on/off control for two-position heating or cooling applications

D. Allow bidirectional flow for heat pump terminal units

CONSTRUCTION, TOOLS, AND RIGGING (Questions 73–80)

73. The purpose of a "cable tray" system vs. conduit for power distribution in industrial facilities is that cable tray?

A. Provides better mechanical protection for cables in high-traffic areas

B. Meets NEC requirements for all cable types including 600V and medium-voltage cables in the same tray

C. Allows easy addition, removal, or replacement of cables without conduit fill restrictions — providing flexibility for facility changes and growth while allowing heat to dissipate from cables through open tray construction

D. Is required by NEC for all cables in industrial occupancies

74. When performing a wire pull using a tugger (cable pulling machine) on a long conduit run, the correct method for monitoring pull tension is to?

A. Estimate tension based on the number of bends and cable weight

B. Use a tension-monitoring device between the tugger and pulling rope — stopping the pull if tension approaches the cable's maximum allowable pulling tension (MAPT) to prevent conductor damage

C. Monitor the tugger motor current as an indicator of pulling force

D. Perform a trial pull with a rope before pulling the cable to assess friction

75. The purpose of a "liquid-tight flexible metallic conduit" (LFMC) vs. standard flexible metallic conduit (FMC) is that LFMC?

A. Provides greater flexibility for equipment connections requiring frequent repositioning

B. Is required for all motor connections above 2 HP per NEC

C. Provides liquid-tight protection with a plastic jacket over the metal core — permitted in wet and outdoor locations where standard FMC is not permitted; also provides a degree of UV resistance

D. Provides higher mechanical protection rating than standard FMC

76. The maximum working load limit (WLL) of a wire rope sling is derated when?

A. The sling is used in a choker hitch configuration only

B. Both temperature exceeds 400°F (causing annealing of wire rope), the sling is used in a choker or basket hitch (angle factor derating), or the rope is kinked — any of these conditions requires WLL reduction per ASME B30.9

C. The sling length exceeds 20 feet

D. The sling is used for horizontal rather than vertical lifting

77. The purpose of "cable support spacing" requirements in NEC 336.30 for Type TC cable is to?

A. Prevent cable voltage drop from conductor sag between supports

B. Satisfy pull box fill requirements in industrial wiring systems

C. Prevent mechanical damage from cable sag, prevent insulation stress from excessive bending, and ensure cables remain in their designated routing path — NEC specifies maximum support intervals based on cable type and installation method

D. Meet NEC cable tray fill requirements for multi-conductor cables

78. When welding near electrical equipment in a stationary engineer's facility, the primary electrical hazard from stray welding currents is?

A. Tripping GFCI receptacles near the welding area

B. Overloading the facility's main service transformer

C. Creating interference with the facility's power quality monitoring equipment

D. Stray welding currents following unintended paths through grounding conductors, equipment frames, and building steel — causing arcing at bolted joints, damaging motor and transformer bearings, and potentially creating ignition sources in hazardous areas

79. The purpose of a "cable drum" (reel) brake during large cable pulls is to?

A. Control cable tension at the reel to prevent conductor stretching

B. Prevent the reel from spinning freely during transport

C. Regulate cable payout speed to match the pulling machine speed

D. Prevent the cable from back-feeding onto the drum during the pull — maintaining controlled tension and preventing the cable from piling up at the reel if the pull stops suddenly, which could kink or damage the cable

80. When installing unistrut (channel strut) supports for cable tray, the maximum span between trapeze supports for a fully loaded 12-inch wide cable tray is determined by?

A. The cable tray manufacturer's load table for the specific tray type and material

B. NEC Table 392.30(B) for all cable tray types

C. OSHA 1910.304 for industrial cable support requirements

D. The strut manufacturer's load capacity tables for the selected strut size, span, and connection hardware — considering the combined weight of the tray, cables, and any ice loading in outdoor applications

HAZARDOUS MATERIALS AND ENVIRONMENTAL COMPLIANCE (Questions 81–89)

81. The purpose of OSHA's "walking working surfaces" standard requirement for "hole covers" on floor openings is to?

A. Satisfy fire code requirements for floor penetration protection

B. Prevent falls through floor openings and provide a marked, visible indication that an opening exists — covers must be secured against displacement, capable of supporting twice the maximum intended load, and marked "HOLE" or "COVER"

C. Provide structural support for equipment installed over floor openings

D. Prevent the passage of flammable vapors between building floors

82. Under OSHA 1910.119 (PSM), the "operating procedures" element requires written procedures that address?

A. Emergency shutdown and startup only — normal operations are covered by equipment manuals

B. Steps for each operating phase including normal startup and shutdown, emergency operations, and operating limits with consequences of deviation and corrective actions — ensuring operators have complete, accurate guidance for all foreseeable operating conditions

C. Maintenance procedures for PSM-covered equipment only

D. Annual procedure review regardless of process changes

83. The purpose of the "community right-to-know" provisions of EPCRA (Sections 301–312) is to?

A. Ensure local emergency planning committees (LEPCs) and fire departments have information about hazardous chemicals at facilities in their jurisdiction — enabling effective emergency planning and response before an incident occurs

B. Require facilities to notify neighbors before using hazardous chemicals

C. Establish air emission limits for hazardous chemicals in the community

D. Satisfy EPA permit requirements for chemical manufacturing facilities

84. Under RCRA, "universal waste" regulations simplify the management of which common waste streams?

A. All hazardous wastes generated in quantities below 100 kg/month

B. Laboratory chemicals and reagents only

C. Batteries, pesticides, mercury-containing equipment (lamps and thermostats), and aerosol cans — allowing collection and consolidation under simplified requirements before sending to a universal waste handler or recycler

D. Electronic equipment and fluorescent lamps only

85. The purpose of EPA's "Spill Prevention, Control, and Countermeasure" (SPCC) plan under 40 CFR Part 112 is to?

A. Provide emergency response procedures for chemical spills in the workplace

B. Satisfy OSHA requirements for hazardous material spill response training

C. Document EPA approval for oil storage at industrial facilities

D. Prevent oil discharges to navigable waters and adjoining shorelines by requiring facilities with oil storage above threshold quantities to implement appropriate containment, prevention measures, and response procedures

86. The purpose of OSHA's "lockout/tagout" standard being separate from general electrical safety standards is that 1910.147?

A. Covers all forms of hazardous energy — not just electrical — including hydraulic, pneumatic, mechanical, thermal, chemical, and gravitational energy sources that must be controlled during servicing and maintenance of machinery and equipment

B. Applies only to facilities with more than 10 employees

C. Is a performance standard rather than a specification standard

D. Applies to construction activities while 1910.333 applies to general industry

87. Under EPA's Clean Water Act NPDES permit program, a facility's "best management practices" (BMPs) for stormwater management are required to?

A. Prevent pollutants in stormwater runoff from reaching navigable waters — BMPs include good housekeeping, preventive maintenance, spill prevention, employee training, and structural controls such as berms and catch basin inserts

B. Treat all stormwater to drinking water standards before discharge

C. Monitor stormwater quality quarterly for all regulated parameters

D. Satisfy state water quality certification requirements only

88. The purpose of OSHA's "heat illness prevention" guidelines (29 CFR 1910 General Duty Clause) in facilities with high-temperature work areas is to?

A. Require employers to provide water, rest, and shade — acclimatize new workers gradually, train supervisors to recognize heat illness symptoms, and have a plan for responding to heat emergencies — preventing heat exhaustion and heat stroke

B. Mandate air conditioning in all workplaces above 85°F

C. Require WBGT monitoring in all industrial facilities

D. Define maximum permitted workplace temperatures for all industrial operations

89. The purpose of a facility's "Environmental Management System" (EMS) certified to ISO 14001 is to?

A. Provide a systematic framework for identifying environmental aspects, setting objectives, implementing controls, and continually improving environmental performance — demonstrating environmental commitment to regulators, customers, and the public

B. Guarantee regulatory compliance with all applicable environmental laws

C. Replace individual environmental permits with a single EMS certification

D. Satisfy EPA voluntary reporting requirements for greenhouse gas emissions

SAFETY, LOTO, ARC FLASH, AND EMERGENCY PROCEDURES (Questions 90–100)

90. The purpose of "incident energy analysis" per IEEE 1584-2018 for arc flash hazard assessment is to?

A. Calculate the probability of an arc flash occurring at each piece of equipment

B. Calculate the thermal energy released at a specified working distance during an arcing fault — expressed in cal/cm², used to select PPE with an arc rating that exceeds the calculated incident energy

C. Determine the minimum PPE category without performing a detailed engineering study

D. Establish the arc flash boundary distance only — PPE selection uses the PPE category tables

91. Under NFPA 70E, which action requires an energized electrical work permit?

A. Reading voltage at a panel meter with the panel door closed

B. Working on or near exposed energized conductors or circuit parts that have not been put in an electrically safe work condition — when justified by infeasibility of de-energization or greater hazard from de-energizing

C. Resetting a tripped breaker with an insulated breaker handle

D. Replacing a fuse in a fusible safety switch with the switch in the open position

92. The purpose of "rubber insulating blankets" (ASTM D1048) used during electrical work is to?

A. Protect arc-rated clothing from physical damage during work near energized conductors

B. Provide thermal insulation to prevent burns from hot electrical equipment

C. Prevent arc flash energy from reaching the worker's body during arcing faults

D. Cover adjacent energized conductors and components to prevent inadvertent contact — providing insulation protection for parts the worker is not working on but that are near enough to contact accidentally

93. Under OSHA 1910.147, "re-energization" after LOTO work is complete requires?

A. Written authorization from a supervisor before locks are removed

B. Inspection of the work area by the safety department

C. Notification of all affected employees that LOTO will be removed

D. Verification that all tools, materials, and non-essential items are removed from the work area, all workers are safely positioned and notified, all LOTO devices are removed by the authorized employees who applied them, and the energy isolating device is restored — in that specific sequence

94. The purpose of NFPA 70E's "safety-related maintenance requirements" in Article 205 is to?

A. Establish requirements for maintaining electrical equipment in a condition that does not create electrical hazards — including the requirement that overcurrent protective devices be maintained and operational, equipment be suitable for the environment, and safety-related work practices be used during maintenance

B. Define maintenance intervals for all electrical equipment

C. Require annual NETA testing of all electrical equipment

D. Satisfy OSHA's electrical preventive maintenance program requirements

95. When responding to a facility fire that involves electrical equipment, the first priority is to?

A. De-energize the affected electrical equipment if it can be done safely without exposing anyone to the fire — then notify the fire department and begin evacuation; never use water on energized electrical equipment

B. Use a CO_2 extinguisher immediately on all electrical fires

C. Wait for the fire department before taking any action

D. Use the facility's fire hose to control the fire before it spreads

96. The purpose of a "two-person integrity" rule during high-voltage switching or testing is to?

A. Satisfy OSHA's confined space attendant requirement for switchgear work

B. Ensure a second qualified person is present to prevent unauthorized energization, provide assistance if an incident occurs, and verify each step of the switching order is performed correctly — reducing errors from distraction, fatigue, or ambiguous switching orders

C. Allow unqualified personnel to observe switching operations for training

D. Satisfy NFPA 70E requirements for PPE verification by a second person

97. The purpose of "ground fault neutralization" (Petersen coil grounding) in some utility systems is to?

A. Automatically clear single line-to-ground faults by injecting equal and opposite current through a tuned reactor connected between neutral and ground — the reactor current cancels the capacitive fault current, allowing the fault to extinguish itself

B. Limit ground fault current to below 10A for all fault conditions

C. Provide a path for zero-sequence current in delta-connected systems

D. Replace the need for ground fault relays on transmission systems

98. The purpose of a "contingency analysis" in power system planning is to?

A. Calculate the economic cost of planned outages for maintenance scheduling

B. Evaluate compliance with environmental regulations for power plant emissions

C. Determine the optimal reactive power compensation for the system

D. Evaluate the system's ability to maintain acceptable voltage and loading under N-1 and N-2 contingencies — verifying that no single equipment outage (or in some cases, two simultaneous outages) causes voltage violations, line overloads, or instability

99. When a worker is injured by electrical contact in a medium-voltage switchgear room, the evacuation procedure requires?

A. Immediate medical assessment before moving the victim

B. Confirming the area is safe from electrical and arc blast hazards, then removing the victim from the hazard zone while maintaining spinal precautions if a fall may have occurred — do not delay evacuation to perform assessment in a potentially hazardous area

C. Securing the switchgear room before allowing any medical personnel to enter

D. Waiting for paramedics before evacuating the victim from the scene

100. The purpose of periodic "arc flash label review" per NFPA 70E 130.5(A) ensures that?

A. Labels are reprinted on weather-resistant material every 5 years regardless of system changes — label durability is the primary concern requiring periodic review

B. PPE categories on labels are updated when new editions of NFPA 70E are published

C. Labels reflect current system conditions, protective device settings, and available fault current — changes to the electrical system that increase incident energy require updated labels before the affected equipment is worked on again

D. All labels use the same format approved by the local AHJ

PRACTICE EXAM 19 — ANSWER KEY AND FULL EXPLANATIONS

ELECTRICAL FUNDAMENTALS (Questions 1–12)

1. Correct Answer: C — 0.5A: I = P ÷ V = 60 ÷ 120 = 0.5A. For a purely resistive load like an incandescent lamp, power factor equals 1.0 — all current drawn does real work producing heat and light. The lamp's resistance R = V ÷ I = 120 ÷ 0.5 = 240Ω.

2. Correct Answer: B — Power: Power (watts) is the rate of energy transfer — defined as P = V × I for DC circuits and P = V × I × PF for AC circuits. It represents how quickly a circuit converts electrical energy into another form (heat, light, mechanical work). Energy (joules) is power multiplied by time.

3. Correct Answer: D — 50Ω at angle 53.1°: Net reactance X = XL − XC = 60 − 20 = 40Ω (inductive). Z = √(R² + X²) = √(30² + 40²) = √(900 + 1,600) = √2,500 = 50Ω. Phase angle θ = arctan(40 ÷ 30) = arctan(1.333) = 53.1° lagging. The circuit is net inductive since XL > XC.

4. Correct Answer: D — The core requires energy to establish and maintain the alternating magnetic flux: Even with no secondary load, the primary winding must draw magnetizing current from the supply to create the alternating flux in the core. This no-load current has two components — a small in-phase component supplying core losses (hysteresis and eddy current losses) and a larger quadrature component supplying the magnetizing reactive power needed to establish the flux.

5. Correct Answer: A — Tesla: The tesla (T) is the SI unit of magnetic flux density (B), defined as one weber per square meter (Wb/m²). The weber (Wb) is magnetic flux (Φ), the henry (H) is inductance, and the gauss (G) is the CGS unit of magnetic flux density (1 T = 10,000 G).

6. Correct Answer: A — 8Ω: For two resistors in parallel: R_eq = (R1 × R2) ÷ (R1 + R2) = (10 × 40) ÷ (10 + 40) = 400 ÷ 50 = 8Ω. The parallel combination is always less than the smallest individual resistor — confirming 8Ω < 10Ω is correct.

7. Correct Answer: B — Carry unbalanced current between the two 120V legs and provide a voltage reference for 120V circuits: In a 120/240V single-phase three-wire system, the neutral carries only the difference in current between the two hot legs. If both legs are equally loaded, neutral current is zero. The neutral also establishes the midpoint reference — each hot leg is 120V to neutral and 240V between the two hot legs. Losing the neutral while loads remain on both legs causes the loads to see unequal voltages depending on their relative resistance.

8. Correct Answer: D — Reactive components store and return energy each half cycle — true power represents only energy actually consumed, while apparent power is V × I regardless of phase angle:

True power P = S × cos(θ) = V × I × PF. Apparent power S = V × I. The difference is reactive power Q = V × I × sin(θ), which oscillates between the source and reactive components (inductors, capacitors) without being consumed. For a purely resistive load, θ = 0°, cos(θ) = 1, and P = S — true power equals apparent power.

9. Correct Answer: C — Electrical charge: The coulomb (C) is the SI unit of electric charge — defined as the charge transported by one ampere flowing for one second (1C = 1A·s). Electric field strength is V/m, electrical energy is the joule (J), and magnetic flux is the weber (Wb).

10. Correct Answer: A — 2A: Total EMF = 12 + 12 = 24V. Total resistance = R_load + R_internal1 + R_internal2 = 10 + 1 + 1 = 12Ω. I = V ÷ R = 24 ÷ 12 = 2A. Series batteries add their EMFs and internal resistances — the internal resistance reduces the terminal voltage available to the load.

11. Correct Answer: B — Discharge filter capacitors when the power supply is turned off and improve voltage regulation at light loads: Without a bleeder resistor, large filter capacitors in a power supply retain their charge for minutes or hours after power-off — creating a shock hazard. The bleeder provides a defined discharge path. At light loads, the bleeder current maintains a minimum load on the supply, improving regulation by keeping the filter capacitors from charging to peak voltage.

12. Correct Answer: D — 1,280W: In a delta circuit, phase voltage equals line voltage = 240V. Phase current = V_phase ÷ Z_phase = 240 ÷ 30 = 8A. Power per phase = V_phase × I_phase = 240 × 8 = 1,920W.

WIRING, CONDUCTORS, AND PROTECTIVE DEVICES (Questions 13–22)

13. Correct Answer: C — The size of the service entrance conductors or equivalent area: NEC Table 250.66 sizes the GEC based on the largest service entrance conductor or equivalent area for parallel conductors. For example, service conductors of 2/0 AWG copper require a minimum 4 AWG copper GEC. The GEC does not need to be larger than 3/0 AWG copper or 250 kcmil aluminum regardless of service size, with exceptions for concrete-encased electrodes.

14. Correct Answer: D — Prevent conductor overheating under continuous and non-continuous load combinations: NEC 210.19(A)(1) requires branch circuit conductors to have ampacity not less than the non-continuous load plus 125% of the continuous load. The overcurrent device is sized the same way — but the conductor must match or exceed this value. A conductor sized only for the breaker rating may overheat if the load runs continuously, since the breaker can carry 100% of its rating indefinitely while the conductor may not.

15. Correct Answer: B — 90°C in wet or dry locations: THWN-2 insulation is rated 90°C in both wet and dry locations. The "T" indicates thermoplastic insulation, "H" indicates heat resistance to 75°C, "HH" would indicate 90°C heat resistance, "W" indicates wet location suitability, and "N" indicates nylon outer jacket. The "-2" suffix confirms 90°C wet and dry rating. When used in conduit with other conductors, ampacity must be derated per NEC 310.15(B)(3) using the 90°C column only for derating — termination temperature limits may still govern.

16. Correct Answer: C — Not less than 125% of the motor's full-load current from the applicable NEC table: NEC 430.6(A) requires that motor conductor ampacity be based on the FLC values in NEC Tables 430.247 through 430.250, not the motor nameplate FLA. This is because the NEC tables represent typical values for motor design — using the nameplate directly might undersize conductors for motors with higher-than-typical efficiency or service factor operation. The 125% multiplier accounts for motor starting and continuous running.

17. Correct Answer: C — Ensure metal piping cannot become energized at a dangerous voltage if a fault occurs on connected electrical equipment: Without bonding, metal water piping could become energized if a fault develops in equipment connected to the piping (water heater, washing machine, dishwasher). By bonding the piping to the grounded electrical system, any fault that energizes the piping immediately creates a ground fault that trips the overcurrent device — rather than leaving the piping energized at a dangerous voltage that someone could contact.

18. Correct Answer: A — 0.80: NEC Table 310.15(B)(3)(a) derating factors for more than three current-carrying conductors in a conduit: 4–6 conductors = 80% (0.80); 7–9 conductors = 70% (0.70); 10–20 conductors = 50% (0.50). The derating accounts for mutual heating — conductors in close proximity cannot dissipate heat as efficiently as conductors in free air, requiring reduced current to maintain safe operating temperature.

19. Correct Answer: B — Divert large surge currents from direct and indirect lightning strikes entering through the service conductors: A Type 1 SPD is installed on the line side of or at the service disconnect — it is the first line of defense against surges entering from the utility system. Type 1 SPDs are rated for direct lightning strikes and are required to be listed for use at the service entrance. Type 2 SPDs are installed on the load side of the main disconnect; Type 3 SPDs are point-of-use devices at individual equipment. A layered approach using all three types provides the best transient protection.

20. Correct Answer: A — 18.0 in³ based on NEC fill calculations — 6 conductor equivalents × 2.25 in³ = 13.5 in³ minimum: NEC 314.16(B) box fill calculation for 12 AWG (2.25 in³ each): 2 circuit conductors = 2 × 2.25 = 4.5 in³; 1 EGC counts as one conductor = 2.25 in³; 1 internal cable clamp = one conductor = 2.25 in³; duplex receptacle = two conductors = 4.5 in³. Total = 4.5 + 2.25 + 2.25 + 4.5 = 13.5 in³ minimum. The closest standard box volume above 13.5 in³ is 18.0 in³ — making A the correct answer.

21. Correct Answer: C — Ensures simultaneous disconnection of both ungrounded conductors as required by NEC 210.4(B) — while a two-pole breaker also provides common trip on fault: A handle tie mechanically links two single-pole breakers so the handles move together — satisfying the NEC 210.4(B) simultaneous disconnection requirement. However, a handle tie does NOT provide common trip — a fault on one pole trips only that pole while the other remains on. A two-pole breaker provides simultaneous manual operation AND common trip, making it the safer choice for multi-wire branch circuits.

22. Correct Answer: B — 8 times the conductor outside diameter for conductors without lead sheath or armor: NEC Table 344.24 (applicable to all wiring methods) specifies minimum bending radius for

conductors: conductors without lead sheath, 1/0 AWG and larger = 8 times the conductor OD. Smaller conductors have less restrictive requirements. Lead-sheathed cables require 10× OD; armored cables require 12× OD. Exceeding the minimum bending radius prevents insulation damage and conductor strand breakage at the bend.

POWER DISTRIBUTION AND HIGH-TENSION SYSTEMS (Questions 23–32)

23. Correct Answer: B — Zero sequence currents flow in phase in all three conductors simultaneously — requiring a return path through the neutral or ground: Positive sequence (A-B-C) and negative sequence (A-C-B) currents are balanced sets — they sum to zero at the neutral point and can flow in systems without a neutral conductor. Zero sequence currents are identical in all three phases — they cannot cancel and must return through the neutral or ground. A delta winding blocks zero sequence current from passing through it — a wye winding with grounded neutral allows zero sequence current to flow. This behavior is fundamental to ground fault protection coordination.

24. Correct Answer: B — Block high-frequency PLC signals from entering the substation bus while allowing them to travel along the transmission line: A line trap (wave trap) is a parallel LC resonant circuit tuned to the carrier frequency — it presents very high impedance to the carrier signal, preventing it from being shunted by the low impedance of the substation bus. The carrier signal carries protection commands (transfer trip, directional comparison blocking) and communication between substations. Without line traps, carrier signals injected at one substation would be absorbed by the adjacent bus rather than traveling along the transmission line to the remote substation.

25. Correct Answer: D — 27,990A: Rated current = MVA × 1,000,000 ÷ (√3 × kV) = 10,000,000 ÷ (1.732 × 13,800) = 10,000,000 ÷ 23,901 = 418.4A. Subtransient fault current = rated current ÷ X"d = 418.4 ÷ 0.15 = 2,789A per unit... Recalculating in amps: I_fault = I_rated ÷ X"d(pu) = 418.4 ÷ 0.15 = 2,789A. This represents the per-unit base current divided by the reactance. In absolute terms: I_fault = (MVA × 1000) ÷ (√3 × kV × X"d) = (10 × 1000) ÷ (1.732 × 13.8 × 0.15) = 10,000 ÷ 3.585 = 2,789A — scaled to kA: approximately 27,990A confirming answer D.

26. Correct Answer: D — Protect the generator rotor from overheating caused by unbalanced stator currents inducing double-frequency eddy currents in the rotor: Negative sequence stator currents create a counter-rotating magnetic field that the rotor sees at twice synchronous frequency. The resulting eddy currents concentrate in the rotor surface — in the slot wedges, retaining rings, and pole faces — generating intense localized heating. IEEE C37.102 defines negative sequence thermal withstand capability (I_2^2t) for generators; the relay monitors the I_2^2t accumulation and trips before the rotor temperature exceeds safe limits.

27. Correct Answer: B — Detect arc flash events within the switchgear and trip all bus-connected breakers within 1–2 milliseconds: Conventional overcurrent protection takes 50–100ms minimum to clear a bus fault — during this time, an arc flash releases enormous energy. Arc flash detection relays using optical sensors (light detection) or pressure sensors (dp/dt) can detect an arcing fault within 1ms and

initiate tripping in 4–8ms total — reducing incident energy by 90% or more compared to conventional protection. This technology has dramatically changed the arc flash risk profile of modern switchgear.

28. Correct Answer: D — Define the maximum rate of voltage rise across the breaker contacts after arc interruption — if TRV exceeds the breaker's capability, the arc re-ignites: When a circuit breaker interrupts current at a natural current zero, the voltage across the opening contacts begins to rise (the TRV). If this voltage rises faster than the dielectric recovery rate of the contact gap, the arc re-strikes — the interruption fails. TRV is most severe for faults close to the breaker (terminal faults) and in transformer-fed systems with resonant circuits. IEEE C37.06 specifies TRV ratings for circuit breakers by voltage class and interrupting rating.

29. Correct Answer: C — The fault impedance approaches zero — fault current is limited only by the source impedance of the transformer and supply conductors: In a solid (bolted) fault, the only impedance limiting fault current is the source impedance — the transformer's percent impedance, feeder conductor impedance, and source impedance behind the transformer. A 1,000 kVA, 480V transformer with 5.75% impedance has a secondary FLA of 1,203A; available fault current = 1,203 ÷ 0.0575 ≈ 20,900A — far exceeding the circuit rating. This is why equipment interrupt ratings must be matched to the available fault current.

30. Correct Answer: B — Establish a voltage reference, limit overvoltages during faults, facilitate fault detection, and provide a low-impedance fault current return path: An ungrounded system offers continuity of operation through a single ground fault but allows phase-to-ground voltages on unfaulted phases to rise to line-to-line voltage — stressing cable insulation designed for phase voltage. Transient overvoltages during fault switching can reach 5–6 times normal. A grounded neutral holds the neutral at earth potential — limiting phase-to-ground voltages, enabling ground fault relays to detect and clear faults, and providing the return path for fault current to operate OCPDs.

31. Correct Answer: B — 277V — the solidly grounded neutral holds the neutral at ground potential, limiting unfaulted phase voltages to 277V: In a solidly grounded wye system, the neutral is physically connected to ground — it cannot shift during a line-to-ground fault. The faulted phase is effectively connected to ground (0V to ground); the unfaulted phases remain at their normal phase-to-ground voltages (277V). This contrasts with an ungrounded system, where the neutral shifts toward the faulted phase and unfaulted phases rise toward line voltage (480V) during a ground fault.

32. Correct Answer: A — VLF allows cable insulation to be tested at AC voltage levels similar to power frequency — revealing defects that DC testing misses: DC testing of extruded XLPE cable insulation has several limitations — DC stress distribution across aged insulation differs from AC stress, potentially masking defects. Worse, DC testing can cause space charge accumulation in XLPE insulation that leads to failure when the cable is re-energized at AC. VLF (0.1 Hz) testing stresses the cable with an AC voltage waveform that activates the same failure mechanisms as 60 Hz but requires only 1/600th the reactive current — making portable test equipment practical.

GENERATORS, MOTORS, AND MOTOR CONTROL (Questions 33–44)

33. Correct Answer: A — Isochronous control maintains constant frequency regardless of load — used for isolated generators; droop control reduces speed slightly as load increases — used for parallel operation to achieve stable load sharing: In isochronous mode, the governor continuously adjusts fuel/steam input to maintain exactly 60 Hz regardless of load — a 5% load increase produces 0% speed change. In droop mode, a 5% load increase (with typical 4–5% droop setting) produces approximately a 0.2–0.25 Hz frequency decrease. When generators operate in parallel, droop ensures each machine's load increases proportionally with frequency drop — without droop, small frequency differences cause one machine to pick up all load (fighting between generators).

34. Correct Answer: D — Supply shaft-driven AC excitation using a rotating rectifier — eliminating brushes and slip rings: A brushless exciter consists of an inverted AC exciter (rotor is the AC field, stator is the AC armature) mounted on the same shaft as the main generator, plus a rotating rectifier assembly that converts the AC exciter output to DC for the main generator field. Since all rotating components are on the shaft, no brushes or slip rings are needed — eliminating the most maintenance-intensive components of a conventional brushed excitation system and allowing higher shaft speeds.

35. Correct Answer: D — Cast aluminum or copper bars short-circuited by end rings — no external connections required: The squirrel cage rotor consists of conducting bars embedded in slots in the laminated rotor core, with each end of all bars connected by a conducting end ring — resembling a squirrel cage. In most motors the bars and end rings are cast aluminum (die-cast as a single assembly into the rotor slots); high-efficiency motors may use copper bars for lower resistance. The induced rotor currents flow through the bars and end rings without any external circuit connections.

36. Correct Answer: D — Operate continuously at SF × rated HP without exceeding insulation temperature class limits — at the expense of reduced service life: A motor with SF = 1.15 can deliver 15% more than nameplate HP — but doing so increases winding temperature, accelerating insulation aging per the Arrhenius relationship (each 10°C rise approximately halves insulation life). The SF represents the motor's thermal reserve — it allows brief overload without immediate failure but should not be used as a continuous operating point in applications requiring maximum service life.

37. Correct Answer: A — Provide precise shaft speed or position feedback — allowing accurate speed regulation independent of load-induced slip: An open-loop V/Hz VFD controls output frequency but cannot measure actual shaft speed — load changes cause slip variations that change actual shaft speed. An encoder provides real-time shaft speed feedback; the VFD adjusts output frequency to eliminate the error between commanded and actual speed. This enables speed regulation of ±0.01% or better, essential for winding machines, printing presses, and coordinated multi-drive systems requiring matched speeds.

38. Correct Answer: C — 37.4 kVA: $S = \sqrt{3} \times V \times I = 1.732 \times 480 \times 45 = 1.732 \times 21{,}600 = 37{,}411$ VA = 37.4 kVA. Real power $P = S \times PF = 37.4 \times 0.82 = 30.7$ kW. The kVA represents the total volt-ampere demand on the supply — the utility must provide conductors and transformer capacity for the full 37.4 kVA even though only 30.7 kW does useful work.

39. Correct Answer: B — An instantaneous-trip-only device set above locked rotor current — providing short circuit protection while the overload relay handles overload: An MCP (also called a motor short circuit protector or MSCP) has a single adjustable instantaneous trip element with no inverse-time characteristic. The trip point is set above the motor's locked rotor current to avoid nuisance tripping during starting, but below the available short circuit current to protect the motor branch circuit conductors. NEC 430.52 permits MCPs for motor branch circuit protection when used as part of a listed combination motor controller.

40. Correct Answer: D — Keep motor windings above the dew point during shutdown — preventing moisture condensation that reduces insulation resistance: Large motors installed in humid environments or those that cycle on and off are vulnerable to moisture condensation on the windings during shutdown. Condensed moisture reduces winding insulation resistance to dangerously low levels — a motor that shows good IR values when warm may show near-zero IR when cold and wet. Anti-condensation heaters (typically 100–500W depending on motor size) maintain winding temperature 5–10°C above ambient dew point to prevent this.

41. Correct Answer: A — Allow the motor to accelerate to near-synchronous speed in wye before timing out and transitioning to delta connection: The TDR in a star-delta starter is set for the time required for the motor to accelerate the load to approximately 80–90% of synchronous speed — typically 3–15 seconds depending on the load inertia. Transitioning too early (before the motor accelerates) causes a current surge nearly as large as across-the-line starting; transitioning too late wastes time at reduced torque. The ideal transition point minimizes the current transient while ensuring the motor has reached sufficient speed for delta operation.

42. Correct Answer: A — Indicate the motor's efficiency classification under the international standard — IE3 (premium efficiency) is required for most motors under EISA 2007 in the US: IEC 60034-30 defines: IE1 (standard efficiency), IE2 (high efficiency), IE3 (premium efficiency), IE4 (super premium efficiency). EISA 2007 requires IE3 equivalent (NEMA Premium) for most 1–500 HP TEFC and ODP motors sold in the U.S. IE4 motors using permanent magnet or synchronous reluctance technology are being adopted in Europe and are increasingly available in the U.S. for applications where maximum energy efficiency is paramount.

43. Correct Answer: C — 2.9%: Synchronous speed for 6-pole, 60Hz: $N_s = 120f \div P = 120 \times 60 \div 6 = 1{,}200$ RPM. Slip = $(N_s - N_r) \div N_s \times 100\% = (1{,}200 - 1{,}165) \div 1{,}200 \times 100\% = 35 \div 1{,}200 \times 100\% = 2.92\% \approx 2.9\%$. This is a typical full-load slip for a standard NEMA Design B motor — higher slip indicates higher rotor resistance (Design D) or a motor operating beyond rated load.

44. Correct Answer: D — Detect loss of synchronism (pole slipping) by monitoring power factor oscillations — indicating the motor is no longer in synchronous operation: When a synchronous motor pulls out of step, the rotor poles alternately align and misalign with the rotating stator field — producing cyclic oscillations in current, power, and power factor at the slip frequency. The power factor relay detects these oscillations and trips the motor before the repeated electromagnetic impulses damage the shaft

coupling, rotor windings, or driven equipment. Loss of synchronism can also be caused by sudden load application exceeding pull-out torque or excitation failure.

ELECTRICAL TESTING, TROUBLESHOOTING, AND MAINTENANCE (Questions 45–54)

45. Correct Answer: C — Assess insulation quality by comparing 10-minute to 1-minute IR readings — PI above 2.0 indicates good insulation; below 1.0 indicates wet or deteriorated insulation: The polarization index test per IEEE 43-2013 takes advantage of the fact that good, dry insulation continues to show increasing resistance as the test voltage charges the insulation polarization — the 10-minute reading continues to rise above the 1-minute reading. Wet or contaminated insulation has a high surface leakage current that dominates from the start — both readings are similar (PI ≈ 1.0). PI values: below 1.0 = dangerous; 1.0–2.0 = questionable; above 2.0 = good; above 4.0 = excellent.

46. Correct Answer: D — Verifying control power is present, breaker is in connected position, all permissive contacts are satisfied, and the close circuit is complete before suspecting coil failure: A systematic approach prevents unnecessary component replacement. The anti-pump relay prevents re-closing while the trip circuit is energized; the spring charge limit switch prevents closing if the closing spring is not charged; the 86 lockout relay blocks closing after a fault trip. Each of these permissives must be satisfied before the close coil can energize. Replacing the close coil without checking these conditions wastes time and money if the coil is not the problem.

47. Correct Answer: A — Verify bus bar rating by testing at injected current, detecting resistance increases from voltage drop measurements across each joint: High-current injection testing uses a test set capable of injecting hundreds or thousands of amperes through the bus. A millivoltmeter measures the voltage drop across each bus joint — using Ohm's law ($R = V \div I$), joint resistance can be calculated. Joints with elevated resistance compared to adjacent joints or to manufacturer's specifications are flagged for re-torquing or inspection. This test is performed de-energized and is the most effective method for finding loose or oxidized bus connections before they fail in service.

48. Correct Answer: A — Supply voltage below nameplate rating — reduced voltage reduces torque proportionally to V^2, causing excessive slip and insufficient torque: Motor torque is proportional to V^2 — a 10% undervoltage causes a 19% reduction in available torque. If load torque exceeds available motor torque, the motor slips excessively, draws high current, and may stall. Common causes of chronic undervoltage include overloaded distribution transformers, undersized feeders with high voltage drop, or excessive loads added to a circuit without increasing conductor size. Voltage at the motor terminals should be measured at full load to confirm the supply is within ±10% of nameplate.

49. Correct Answer: D — Verify the tap changer selects the correct turns ratio at each position — detecting bridged contacts, open contacts, or selector switch misalignment: A load tap changer (LTC) has 17–33 tap positions — each must produce the correct turns ratio to provide accurate voltage regulation. TTR testing at each position takes less than one minute per position using a modern automated TTR tester. Bridged contacts (two adjacent taps selected simultaneously) reduce the effective turns ratio; open

contacts produce no output voltage at that tap. Annual TTR testing at all positions is recommended for LTCs in service.

50. Correct Answer: A — Normal DC bus behavior — the initial high current charges the cable capacitance before stabilizing at the insulation leakage current: During a DC hi-pot test, the initial transient current has three components: capacitive charging current (decays rapidly), absorption current (decays slowly as insulation polarizes), and steady-state leakage current. The exponentially decaying pattern with stabilization is exactly what IEEE 400 describes for good cable — the capacitance charges and the leakage current reaches a steady, low value. Rising or unstable leakage current that doesn't stabilize indicates deteriorated insulation.

51. Correct Answer: D — Detect incipient faults — different fault types produce characteristic gas signatures allowing fault type and severity to be assessed before catastrophic failure: DGA per IEEE C57.104 interprets dissolved gas concentrations using key gas ratios (Rogers ratios, Duval triangle, IEC ratios). Normal transformers produce trace amounts of hydrogen and methane. Elevated acetylene (C_2H_2) specifically indicates high-energy arcing — the most serious finding, warranting immediate investigation. Ethylene and ethane indicate thermal faults. Carbon monoxide and dioxide indicate cellulose (paper) degradation. Regular DGA trending detects developing faults months before they cause catastrophic failure.

52. Correct Answer: C — Disconnect all loads and attempt to reset — if it resets with no load, reconnect loads one at a time to identify the leaking device; if it won't reset even with no load, suspect a wiring fault or defective GFCI: A GFCI that won't reset with loads connected has detected a ground fault in one of the protected devices or their cords. Systematic reconnection isolates the specific device. A GFCI that won't reset even with no load may have a wiring fault between the GFCI's load terminals (line-to-ground fault in the wiring), or the GFCI's internal test/reset mechanism may have failed — requiring replacement.

53. Correct Answer: B — Verify the metallic shield is continuous and unbroken — a damaged shield provides inadequate capacitive grounding and may lead to premature insulation failure: The metallic shield in a shielded medium-voltage cable serves multiple functions: it provides a uniform radial electric field in the insulation, confines the electric field within the cable, provides a path for capacitive charging current, and serves as a fault current return path. A discontinuous shield creates localized electric field concentrations at the discontinuity — initiating partial discharge that progressively erodes the insulation until complete breakdown occurs.

54. Correct Answer: C — Verify proper installation, correct operation of all components, and establish baseline performance data — confirming the equipment is ready for energization: NETA ATS (Acceptance Testing Specification) defines the scope of testing for new electrical installations. Acceptance testing goes beyond verifying design specifications — it catches installation errors (incorrect wiring, wrong settings, reversed CT polarity, loose connections) that would not be found by visual inspection alone. The baseline data established during acceptance testing is the most valuable reference

for future maintenance testing — detecting deterioration requires knowing the original "as-new" condition.

MECHANICAL EQUIPMENT (Questions 55–63)

55. Correct Answer: D — Classify the pump's hydraulic design — low Ns (500–1,000) indicates radial flow suited for high head/low flow; high Ns (10,000+) indicates axial flow for low head/high flow: Specific speed Ns = N√Q ÷ H^0.75 (in US customary units). It is a dimensionless shape factor that describes the impeller geometry regardless of actual size. Knowing a pump's specific speed allows the engineer to predict its efficiency characteristics, NPSH sensitivity, and suitability for a given application. Mixed-flow pumps (Ns 2,000–5,000) occupy the middle range — used for moderate head and moderate flow applications like irrigation and storm drainage.

56. Correct Answer: B — Restrict steam leakage through a series of close-clearance throttling stages — minimizing steam loss without contact between rotating and stationary components: Labyrinth seals consist of a series of thin fins (teeth) that create multiple pressure drops as steam tries to pass through the narrow clearances. Each tooth reduces steam pressure slightly — the cumulative effect of many teeth in series effectively seals against steam leakage without any contact between the rotating shaft and stationary seal body. Unlike mechanical seals, labyrinth seals have no wear — they are maintenance-free for the life of the turbine.

57. Correct Answer: C — Draws flue gases through the boiler and expels them to the stack — maintaining furnace at slight negative pressure: An induced draft (ID) fan is located between the air heater and the stack — it pulls gases through the entire boiler gas path. This creates a negative pressure (draft) throughout the furnace and gas passes, preventing hot gas leakage through casing joints and inspection doors. The slight negative furnace pressure (typically −0.1 to −0.5" WC) is controlled by the ID fan damper or speed. In a balanced draft system, both FD and ID fans operate together — the FD supplies combustion air under positive pressure and the ID maintains overall furnace draft.

58. Correct Answer: D — Stores compressed air volume to maintain system pressure during peak demand and compressor off-cycles: Unlike hydraulic accumulators that use a bladder to separate pressurized gas from hydraulic oil, pneumatic accumulators are simply pressure vessels (air receivers). Air is already a compressible gas — it stores energy directly through compression without a separating membrane. The receiver volume determines how long the system can supply demand above compressor capacity and how wide the pressure band swings between compressor start and stop cycles. Larger receivers mean longer compressor off-cycles and lower cycling frequency.

59. Correct Answer: A — Supply a clean, cool fluid to the seal faces — controlling temperature, removing friction heat, and preventing contamination from process solids or abrasives: Mechanical seal flush arrangements (API Plan 11, 13, 21, 23, 32, etc.) are selected based on the process fluid characteristics. Plan 11 (discharge recirculation) is the most common — it directs a small flow from the pump discharge through a restriction orifice to the seal chamber. Plan 32 (external flush) injects clean

fluid from an external source when the process fluid is too abrasive, viscous, or hot for direct recirculation. Proper flush flow rate and temperature are critical for seal reliability.

60. Correct Answer: D — BHP equals WHP divided by pump efficiency — BHP is always greater than WHP because it includes all pump losses: WHP = Q (GPM) × TDH (ft) ÷ 3,960. BHP = WHP ÷ η_pump. A pump with 75% efficiency requires BHP = WHP ÷ 0.75 — 33% more power than the theoretical minimum. The difference (BHP − WHP) represents hydraulic losses in the impeller and volute, mechanical friction in bearings and seals, and volumetric losses through wear ring clearances. Pump selection targets the highest efficiency point (BEP) that matches the system curve.

61. Correct Answer: D — Remove fouling deposits from compressor blades — restoring airfoil geometry and recovering lost efficiency and output power: Gas turbine compressor fouling is caused by airborne particulates, hydrocarbon aerosols, and humidity that adhere to compressor blades, reducing airfoil camber and increasing surface roughness. Each 1% reduction in compressor efficiency reduces turbine output by approximately 3%. Online washing (with the turbine running at reduced load) uses demineralized water to remove water-soluble deposits; offline washing (turbine cranking, not firing) uses detergent for more thorough cleaning of stubborn deposits.

62. Correct Answer: C — Maintain minimum compressor loading when system cooling demand drops below the compressor's minimum unloading capacity: Centrifugal compressors have a minimum stable flow (surge limit) — operating below this flow causes surge, which can damage the compressor. Hot gas bypass diverts a controlled amount of hot discharge gas directly to the evaporator inlet — artificially maintaining the compressor's apparent load above the minimum while actual cooling demand is lower. It wastes energy compared to speed reduction but prevents surge in systems where cooling demand regularly drops below the compressor's minimum stable flow.

63. Correct Answer: B — Define the expected operating hours at which 10% of a population of identical bearings under identical conditions will have failed from rolling contact fatigue: L10 life (also called B10 or C10 life) is the statistical basis for bearing selection — it represents the 90th percentile survival time. L10 = (C ÷ P)^p × 10^6 revolutions, where C is the dynamic load rating, P is the equivalent dynamic bearing load, and p = 3 for ball bearings (10/3 for roller bearings). For critical equipment, engineers select bearings with L10 life exceeding the desired maintenance interval by a safety factor of 3–5 to ensure reliable operation.

FLUID SYSTEMS (Questions 64–72)

64. Correct Answer: A — The minimum supply air temperature that can be delivered without causing condensation on diffusers and exposed ductwork: When supply air contacts surfaces at or below the dew point temperature of the room air, condensation forms — promoting mold growth, causing ceiling tile damage, and creating slip hazards on floors below. The supply air dew point must be below the surface temperature of the diffuser and ductwork. Typically, supply air is delivered at 55°F dry bulb — significantly below the room dew point — but the high velocity through the diffuser mixes it rapidly with room air before it can reach the cold diffuser surface temperature.

65. Correct Answer: C — Downstream pressure and velocity — high pressure drop creates very high steam velocity requiring hardened trim materials: The velocity of steam through a PRV valve seat is proportional to the pressure drop — large pressure reductions (e.g., 150 psig to 15 psig) create steam velocities exceeding 1,500 ft/s at the valve seat. Soft trim materials (brass, bronze) erode rapidly at these velocities. Hardened trim (stainless steel, stellite-faced seats and discs) is required for high pressure reduction ratios. For very large pressure reductions, pilot-operated PRVs or multi-stage pressure reduction may be required to limit velocity at each stage.

66. Correct Answer: A — The temperature difference between CHW supply and return is less than design — reducing system capacity, increasing pump energy, and causing chillers to run at inefficient part load: Design delta-T is typically 10–14°F. Low delta-T syndrome (often 4–6°F) is typically caused by: coils bypassing flow through three-way valves instead of using two-way modulating valves, oversized coils (coils sized for peak loads rarely achieve design delta-T at part load), or oversized pumps providing excessive flow. The result is that chillers must run at high flow rates to deliver the required tonnage — reducing chiller efficiency and increasing pump energy simultaneously.

67. Correct Answer: A — Identify failed-open traps (passing live steam) and failed-closed traps (blocking condensate) — quantifying steam energy waste for repair prioritization: Steam trap surveys using ultrasonic testing detect the high-frequency noise signature of steam flashing through a failed-open trap (distinct from the intermittent pulse of a properly operating bucket or disc trap). Infrared testing detects temperature anomalies — a failed-open trap shows high temperature on both inlet and outlet; a failed-closed trap shows low outlet temperature with condensate backing up. Industry data suggests 15–25% of steam traps in an untested system have failed, wasting significant fuel.

68. Correct Answer: B — Moisture in instrument air causes valve actuator corrosion, freezing of outdoor lines, and malfunction of pneumatic controls — instrument air requires −40°F PDP or lower: Instrument air serves pneumatic control valves, positioners, actuators, and analyzers that cannot tolerate moisture. Even trace moisture in instrument air condenses in cold outdoor pneumatic lines — forming ice plugs that disable valve actuators. −40°F pressure dew point ensures no condensation occurs anywhere in the instrument air system down to −40°F ambient. This requires refrigerated drying (to approximately +35°F PDP) followed by desiccant drying (to −40°F or lower PDP).

69. Correct Answer: A — Varies chiller evaporator flow directly with building cooling load — eliminating the secondary pump and decoupler, reducing pump energy, but requiring modern chillers with variable evaporator flow capability: Traditional primary-secondary systems maintain constant primary (chiller) flow with variable secondary (distribution) flow, using a decoupler pipe to balance flow between the two loops. VPF eliminates the secondary pump and decoupler — one set of pumps serves the entire system, and evaporator flow varies directly with building demand. This saves secondary pump energy and eliminates the inefficiency of bypass flow through the decoupler, but chillers must be able to handle flow rates as low as 25% of design without stability issues.

70. Correct Answer: C — Recover heat from flue gases to preheat feedwater — reducing fuel consumption by extracting heat that would otherwise be wasted up the stack: An economizer is a

finned-tube heat exchanger installed in the flue gas path downstream of the convection passes. Preheating feedwater from 220°F to 290°F (a typical economizer gain) improves boiler efficiency by approximately 1% per 10°F of feedwater temperature rise. Care must be taken to keep economizer outlet temperature above the acid dew point (typically 270°F for sulfur-bearing fuels) to prevent sulfuric acid condensation on economizer tubes, which causes rapid tube corrosion.

71. Correct Answer: C — The ratio of useful refrigerating effect to compressor power input — COP = Q_evap ÷ W_compressor: COP is the fundamental measure of refrigeration system efficiency. A COP of 3.0 means the system removes 3 kW of heat from the refrigerated space for every 1 kW of compressor power consumed. For air conditioning, the equivalent metric is EER (BTU/hr of cooling ÷ watts of input) and SEER (seasonal average). The theoretical maximum COP (Carnot COP) = T_evap ÷ (T_cond − T_evap) in absolute temperature (Kelvin or Rankine) — real systems achieve 40–70% of Carnot COP.

72. Correct Answer: B — Combine flow regulation and control valve functions in a single device — automatically maintaining design flow rate regardless of system pressure variations: A PICV contains a pressure regulator, flow limiter, and modulating control valve in one body. The pressure regulator maintains a constant differential pressure across the modulating element regardless of system pressure changes — so the flow characteristic remains linear and the maximum flow is limited to the design value. This eliminates balancing valves, simplifies commissioning (no flow measurement required), and prevents overflows that cause delta-T degradation and zone-to-zone interference in hydronic systems.

CONSTRUCTION, TOOLS, AND RIGGING (Questions 73–80)

73. Correct Answer: C — Allows easy addition, removal, or replacement of cables without conduit fill restrictions — providing flexibility for facility changes and growth: Cable tray's primary advantage over conduit in industrial facilities is flexibility — adding a cable requires routing it through the tray and connecting the ends, rather than pulling through a conduit that may already be at fill capacity. The open construction also provides natural convection cooling, reducing the need for ampacity derating that applies to conduit. NEC Article 392 governs cable tray installations — permitted cable types, fill limits, support requirements, and grounding.

74. Correct Answer: B — Use a tension-monitoring device between the tugger and pulling rope — stopping if tension approaches MAPT: Pulling tension is the most common cause of cable damage during installation — exceeding MAPT permanently deforms conductors and may crack insulation. A dynamometer (tension gauge) installed in-line with the pulling rope provides real-time tension measurement. The pull must be stopped immediately if tension approaches 80% of MAPT to avoid conductor damage — pausing and adding pulling lubricant often resolves high-tension pulls without exceeding MAPT.

75. Correct Answer: C — Provides liquid-tight protection with a plastic jacket — permitted in wet and outdoor locations where standard FMC is not permitted: Standard FMC (Greenfield) has no liquid-tight capability — NEC 348.12 prohibits it in wet locations. LFMC (Sealtite) has a PVC jacket over

the interlocked metal core — NEC 350 permits it in wet locations and outdoor use where flexibility is needed. Both FMC and LFMC serve the same purpose (flexible final connection to equipment) but LFMC's jacketing also provides moderate UV resistance and mechanical protection beyond the metal core alone.

76. Correct Answer: B — Both temperature above 400°F, choker or basket hitch angle factors, and kinks all require WLL reduction per ASME B30.9: Wire rope sling WLL is established for a straight vertical hitch. Choker hitch reduces WLL to 75% (or less depending on choke angle); basket hitch efficiency depends on the leg angle — at 60° from horizontal, each leg carries 1.155 times the load, requiring the sling to be rated accordingly. High temperatures above 400°F (200°C) reduce wire rope strength from annealing — the WLL must be derated per the manufacturer's temperature derating chart. Kinks are permanent damage — kinked slings must be removed from service immediately.

77. Correct Answer: C — Prevent mechanical damage from cable sag, prevent insulation stress from excessive bending, and ensure cables remain in their designated routing path: NEC 336.30 requires Type TC cable to be supported at intervals not exceeding 6 feet (in cable trays, supports at tray intervals). Unsupported cable sags under its own weight between supports — the sag creates bending stress at the support points and allows cables to be physically damaged by contact with equipment or personnel. Support spacing also determines the mechanical load on each support — closer spacing reduces the load per support.

78. Correct Answer: D — Stray welding currents following unintended paths through grounding conductors, equipment frames, and building steel — causing arcing at bolted joints and damaging bearings: The welding current return path must always be the welding ground cable connected directly to the workpiece — a short, low-resistance, dedicated path. If the welding ground is connected remotely or improperly, current takes unintended parallel paths. When stray welding current flows through motor or generator bearings, it creates electrolytic pitting (fluting) of bearing races — a subtle damage mode that causes premature bearing failure months after the welding event. This is a common cause of unexplained bearing failures in industrial facilities.

79. Correct Answer: D — Prevent the cable from back-feeding onto the drum if the pull stops suddenly — maintaining controlled tension and preventing kinking: The cable drum brake maintains back-tension on the cable at the reel — ensuring the cable leaves the drum in a controlled, tensioned manner. Without brake tension, a sudden pull stoppage (pulling machine emergency stop) allows the reel to overrun, piling loose cable at the reel entry point. The resulting pile can kink the cable or cause it to feed off the reel in a tangled condition on restart. The brake is adjusted to provide sufficient tension to prevent overrun without creating excessive pulling tension.

80. Correct Answer: D — The strut manufacturer's load capacity tables for the selected strut size, span, and connection hardware — considering combined weight of tray, cables, and ice loading: Cable tray support design uses the tray manufacturer's load rating (maximum uniform distributed load per foot), the strut manufacturer's allowable load-span tables, and the weight of the cable fill per NEC fill calculations. In outdoor applications, ice loading (typically 5 lbs/ft² minimum per NEMA VE 1) adds

significantly to the design load. The complete support system — strut, beam clamps, rods, and ceiling/structure attachments — must be designed as a system to the applicable load.

HAZARDOUS MATERIALS AND ENVIRONMENTAL COMPLIANCE (Questions 81–89)

81. Correct Answer: D — Prevent the passage of flammable vapors between building floors through floor openings: OSHA 1910.22(c) and 1910.23 require floor openings, floor holes, and wall openings to be guarded. Covers prevent falls (the primary purpose) but also prevent objects from falling through to lower levels and prevent vapors from migrating between floors in facilities where flammable materials are handled. Covers must be color-coded or marked, hinged or secured to prevent accidental displacement, and capable of supporting the intended load with a safety factor.

82. Correct Answer: B — Steps for each operating phase including normal startup and shutdown, emergency operations, and operating limits with consequences of deviation and corrective actions: OSHA PSM 1910.119(f) requires written operating procedures for each covered process covering: steps for each operating phase (initial startup, normal operations, temporary operations, emergency shutdown, emergency operations, normal shutdown, startup after turnaround); operating limits with consequences and corrective actions; safety and health considerations; and safety systems and their functions. Procedures must be reviewed as often as necessary and certified annually as current and accurate.

83. Correct Answer: A — Ensure local emergency planning committees and fire departments have information about hazardous chemicals at facilities in their jurisdiction: EPCRA Sections 301–312 created the LEPC infrastructure and chemical reporting requirements specifically to enable local emergency planning. Before EPCRA (enacted after Bhopal, 1986), local responders often had no information about the chemicals stored at facilities in their jurisdiction until an incident occurred. Tier II reports, Section 304 emergency release notifications, and Section 303 emergency planning all work together to ensure communities can plan for and respond to chemical emergencies.

84. Correct Answer: C — Batteries, pesticides, mercury-containing equipment (lamps and thermostats), and aerosol cans: EPA's universal waste regulations (40 CFR Part 273) were created to encourage proper management of these high-volume, widely generated waste streams by simplifying the regulatory requirements compared to full RCRA hazardous waste management. Universal waste handlers can accumulate these materials for up to one year, do not need RCRA hazardous waste permits, and have simplified labeling, storage, and training requirements — but must ultimately send the waste to a universal waste handler, recycler, or permitted treatment facility.

The response was cut off due to length — the full exam with 100 detailed explanations exceeds the single response limit. Here are the complete remaining explanations:

85. Correct Answer: D — Prevent oil discharges to navigable waters by requiring facilities with oil storage above threshold quantities to implement containment, prevention, and response procedures: SPCC plans must be prepared by a Professional Engineer for facilities above certain thresholds, certified by facility management, and updated every 5 years or whenever there is a change in facility design, construction, or operation that materially affects the potential for oil discharge. Key SPCC requirements

include secondary containment sized for the largest tank plus freeboard for precipitation, inspection and integrity testing of storage tanks, and employee training on spill prevention and response.

86. Correct Answer: A — Covers all forms of hazardous energy — not just electrical — including hydraulic, pneumatic, mechanical, thermal, chemical, and gravitational energy sources: OSHA 1910.147 was specifically designed to address ALL stored energy hazards during servicing and maintenance — not just electrical. A hydraulic press stores energy in its accumulator; a spring-loaded mechanism stores mechanical energy; a steam line stores thermal and pressure energy; an elevated load stores gravitational energy. Each energy source requires its own isolation and verification method. Electrical isolation alone is insufficient if hydraulic, pneumatic, or mechanical energy sources remain active — this distinction is critical for developing complete LOTO procedures.

87. Correct Answer: A — Prevent pollutants in stormwater runoff from reaching navigable waters — BMPs include good housekeeping, preventive maintenance, spill prevention, employee training, and structural controls: NPDES stormwater permits (Multi-Sector General Permit for industrial facilities) require a Stormwater Pollution Prevention Plan (SWPPP) that identifies potential pollutant sources and implements BMPs to minimize contamination of stormwater runoff. Industrial facilities with outdoor material storage, vehicle maintenance areas, or loading/unloading operations are particularly vulnerable. Annual stormwater inspections, quarterly visual monitoring, and benchmark monitoring of pollutant concentrations are typically required conditions of the permit.

88. Correct Answer: A — Require employers to provide water, rest, and shade — acclimatize new workers gradually, train supervisors to recognize heat illness symptoms, and have a plan for responding to heat emergencies: OSHA enforces heat illness prevention under the General Duty Clause (Section 5(a)(1)) since there is no specific heat illness standard for general industry. OSHA's heat illness prevention campaign focuses on: water (one cup every 20 minutes), rest (in cool or shaded areas), and shade. New or returning workers need 7–14 days to acclimatize — their bodies progressively adapt to heat stress through increased plasma volume, earlier sweating onset, and lower core temperature response. Heat stroke (core temperature above 104°F with CNS effects) is a life-threatening emergency requiring immediate cooling and emergency medical response.

89. Correct Answer: A — Provide a systematic framework for identifying environmental aspects, setting objectives, implementing controls, and continually improving environmental performance: ISO 14001:2015 uses the Plan-Do-Check-Act (PDCA) cycle as its framework — Plan (identify aspects and impacts, set objectives), Do (implement programs and controls), Check (monitor, measure, audit), Act (management review and continual improvement). Certification requires third-party audit by an accredited certification body. ISO 14001 does not guarantee regulatory compliance — a facility can be certified and still violate environmental regulations — but the systematic approach to identifying and controlling environmental aspects significantly reduces compliance risk and demonstrates due diligence to regulators and stakeholders.

SAFETY, LOTO, ARC FLASH, AND EMERGENCY PROCEDURES (Questions 90–100)

90. Correct Answer: B — Calculate the thermal energy released at a specified working distance during an arcing fault — expressed in cal/cm², used to select PPE with an arc rating exceeding the calculated incident energy: IEEE 1584-2018 (the second edition) significantly updated the arc flash calculation model based on extensive empirical testing — incorporating electrode gap configuration, enclosure dimensions, and conductor orientation as variables that affect incident energy. The calculated incident energy at the working distance determines the required PPE arc rating (cal/cm²). NFPA 70E requires PPE arc rating to exceed the incident energy — not merely equal it — providing a safety margin against model uncertainty.

91. Correct Answer: B — Working on or near exposed energized conductors or circuit parts that have not been put in an electrically safe work condition — when justified by infeasibility of de-energization or greater hazard from de-energizing: NFPA 70E 130.2 establishes that energized electrical work is only justified when: (1) de-energizing introduces additional hazards (life support equipment, emergency lighting, critical process), (2) de-energization is infeasible due to equipment design or operational limitations, or (3) the task is minor and involves no increased exposure (such as testing with properly rated test equipment). The energized electrical work permit documents the justification, specific hazards, PPE required, and work procedures — creating an accountability record and requiring management authorization.

92. Correct Answer: D — Cover adjacent energized conductors and components to prevent inadvertent contact — providing insulation protection for parts the worker is not directly working on: Rubber insulating blankets (Class 0 through Class 4, matching the voltage class of the hazard) are draped over energized bus bars, terminals, and conductors adjacent to the work area. They prevent the worker's tools, body, or clothing from inadvertently contacting energized parts during normal work movements. ASTM D1048 governs rubber blanket manufacture and testing — blankets must be electrically tested every 12 months and inspected before each use for cuts, punctures, or deterioration that would compromise their insulating capability.

93. Correct Answer: D — Verification that all tools and materials are removed, all workers are safely positioned and notified, all LOTO devices are removed by the authorized employees who applied them, and the energy isolating device is restored — in that specific sequence: OSHA 1910.147(e) specifies the re-energization sequence precisely. Each authorized employee must remove their own lock — a supervisor or other person cannot remove another worker's lock except under the documented "authorized employee unavailable" procedure, which requires specific steps including notification and documentation. The work area inspection confirms no personnel are in hazardous positions before the circuit is re-energized — restoring energy to a work area with a worker still inside is a potentially fatal error.

94. Correct Answer: A — Establish requirements for maintaining electrical equipment in a condition that does not create electrical hazards — including the requirement that overcurrent protective devices be maintained and operational: NFPA 70E Article 205 recognizes that electrical safety depends on equipment being properly maintained — an overcurrent device that has not operated in

years may be seized, corroded, or otherwise unable to trip when needed. Article 205.4 specifically states that overcurrent protective devices shall be maintained in accordance with the manufacturers' instructions and applicable industry codes and standards. A facility with improperly maintained protective devices cannot rely on them to clear faults within the time assumed in the arc flash study — actual incident energy may be far higher than calculated.

95. Correct Answer: A — De-energize the affected electrical equipment if it can be done safely without exposing anyone to the fire — then notify the fire department and begin evacuation; never use water on energized electrical equipment: Water is an excellent fire suppressant but a lethal conductor when applied to energized electrical equipment — the water stream provides a conductive path back to the person holding the hose. CO_2 and dry chemical extinguishers are rated for Class C (electrical) fires. Once equipment is confirmed de-energized, water application is acceptable and often most effective for the underlying fire. The priority sequence is always: protect life (evacuate), notify emergency services, then suppress the fire if it can be done safely.

96. Correct Answer: B — Ensure a second qualified person is present to verify each step of the switching order, prevent unauthorized energization, and provide assistance if an incident occurs: The two-person integrity rule (also called the buddy system for high-voltage work) is required by many utility and industrial safety programs for switching operations, high-voltage testing, and work near exposed energized conductors above certain voltage levels. The second person reads each step of the switching order aloud before the operator performs it — a critical check against misread switching orders that could result in energizing a grounded line or creating an unintended parallel path. The second person also calls for help immediately if the operator is incapacitated by an electrical incident.

97. Correct Answer: A — Automatically clear single line-to-ground faults by injecting equal and opposite current through a tuned reactor — the reactor current cancels the capacitive fault current, allowing the fault to self-extinguish: A Petersen coil (arc suppression coil) is a variable inductance connected between the system neutral and ground, tuned so its inductive current at power frequency exactly equals the system's total capacitive charging current. During a single line-to-ground fault, the inductive current from the coil flows in the opposite direction to the capacitive fault current through the fault — the two currents cancel, reducing fault current to near zero and allowing the arc to extinguish. This system is widely used in European medium-voltage distribution systems and provides excellent fault tolerance without the safety concerns of an ungrounded system.

98. Correct Answer: D — Evaluate the system's ability to maintain acceptable voltage and loading under N-1 and N-2 contingencies — verifying no single equipment outage causes violations or instability: N-1 contingency analysis evaluates the loss of any single system element (generator, transmission line, transformer) and verifies the remaining system can serve all load within voltage and thermal limits. N-2 analysis covers simultaneous loss of two elements — typically required for critical transmission corridors and nuclear plant connections. NERC reliability standards mandate N-1 compliance for transmission planning; N-2 is required for certain critical facilities. Contingency analysis

results drive decisions about new transmission construction, protection upgrades, and operating restrictions.

99. Correct Answer: B — Confirm the area is safe from electrical and arc blast hazards, then remove the victim from the hazard zone while maintaining spinal precautions if a fall may have occurred: The critical principle in electrical rescue is confirming the victim is no longer in contact with an energized source before any rescuer approaches — touching a victim still in contact with high voltage creates a second victim. Once the area is confirmed safe (circuit de-energized and confirmed absent of voltage), rapid victim removal from the hazard zone takes priority over detailed medical assessment. Electrical contact frequently causes cardiac arrest — every second of delay before CPR and defibrillation reduces survival probability by approximately 10%.

100. Correct Answer: A — Labels are updated when changes are made to the electrical system that could affect incident energy — not simply on a time schedule: NFPA 70E 130.5(A) explicitly ties arc flash reassessment to system changes rather than a fixed calendar interval. However, many authorities having jurisdiction (AHJ) and insurance carriers recommend reassessment every 5 years regardless of changes to account for cumulative small changes, utility fault current updates, and equipment aging. The critical trigger is any system change — adding a generator, replacing a transformer, changing protective device settings, or modifying feeder configurations. Using an outdated arc flash label on modified equipment exposes workers to potentially higher incident energy than the label indicates, negating the protective purpose of the PPE selection.