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Guide Form Specification for Medium Voltage Automatic Metal-Enclosed Power Capacitor Bank

Design Criteria: General Industrial Applications. Typical for manufacturing and process plants serving motors, pumps, fans, compressors, conveyors, HVAC systems, process machinery, lighting, control equipment, computers, UPS systems, and variable frequency drives. Industrial facilities are commonly dominated by large motors, control equipment, process machinery, and VFDs, while harmonic-producing loads can also include lighting ballasts and UPS systems.

1 General

1.1 Scope of Work

This specification governs the design, manufacture, and testing of a medium-voltage, three-phase, metal-enclosed automatic capacitor bank intended for application on general industrial power systems. Typical applications include manufacturing plants, process facilities, utility service areas within industrial sites, and other installations where power factor correction, voltage support, reduced system current, and improved overall electrical efficiency are required. These systems commonly serve mixed plant loads such as motors, pumps, fans, compressors, conveyors, HVAC equipment, process machinery, lighting, control equipment, computers, UPS systems, and variable frequency drives.

The capacitor bank shall be provided as a fully integrated, compartmentalized assembly as specified, including all switching, protection, control, relaying, metering, and auxiliary components required for a complete and operable system. The capacitor bank shall be shipped completely assembled and factory-tested, requiring only field anchorage, removal of packaging and shipping supports, and electrical connections to the plant grounding, control, and power distribution system.

The design shall account for the actual plant load mix, operating conditions, system strength, switching duty, and the presence of non-linear loads where applicable. Because general industrial facilities often include variable frequency drives, UPS systems, electronic lighting, and other harmonic-producing loads, the capacitor bank application shall be suitable for the intended system and shall not create unacceptable resonance, harmonic amplification, or equipment overstress under normal or contingency operating conditions. IEEE 519 is specifically aimed at electrical systems that include both linear and non-linear loads, and industrial harmonic problems are often associated with drives and other electronic conversion equipment.

The capacitor bank shall be designed for reliable long-term operation in general industrial service. Reliability, maintainability, safety, and suitability for the intended application shall be primary design criteria.

1.2 Ratings and Capacity

The capacitor bank shall provide a total output of ______ kvar at ______ kV. The total capacity shall be divided into ______ switching steps of ______ kvar each. The capacitor bank shall have specific stages sized as follows:

Stage #	Reactive Power Rating (kvar 3-phase)
1	________________
2	________________
3	________________
4	________________
5	________________
6	________________
7	________________

- **Automation:** The capacitor bank shall be automatically switched based on [Power Factor / Current / Voltage / kVAR / Remote SCADA or similar communication].

1.3 Performance and Operational Requirements

1.3.1 Displacement Power Factor (DPF) Guarantee

- **Target Correction:** The capacitor bank shall be designed and guaranteed to maintain a target displacement power factor of [0.95 / 0.98 / 1.0] at the Point of Common Coupling (PCC) under maximum load conditions of [enter MVA] and [enter pf lagging].
- **Control Accuracy:** The automatic controller shall be programmed to maintain the target power factor [enter power lead/lag].

1.3.2 Reactive Power (kVAR) Output

- **Net Capacity:** The manufacturer shall guarantee the total net three-phase reactive power output (kVAR) at the nominal system voltage.
- **Tolerance:** The actual kvar output of the fully assembled bank shall be within +10% / -0% of the rated value at rated voltage in accordance with IEEE Std 18.

1.4 System Parameters

The equipment shall be designed for operation on a power system with the following characteristics:

Parameter	Value
Nominal System Voltage (kV)	____________
Maximum System Voltage (kV)	____________
Basic Insulation Level (kV)	____________
Three-Phase Short Circuit (RMS Sym. Amps)	____________
Line-to-Ground Short Circuit (RMS Sym. Amps)	____________

1.5 **Environmental Design Criteria**
The equipment shall be designed for continuous outdoor operation under the following ambient conditions:

Ambient Condition	Minimum	Maximum
Average Annual Temperature (°C)	___________	___________
Design Temperature (Extreme) (°C)	___________	___________
Average Daily Variation (°C)	___________	___________
Maximum Design Snow Loads (kg/m^2)	___________	___________

1.6 **Seismic Requirements**
Equipment, internal supports, and anchorage shall be designed for seismic forces in accordance with the International Building Code (IBC) and ASCE 7, Chapter 13 (Nonstructural Electrical Components). Design shall be based on the following project-specific criteria:

Risk Category: [_____]
Seismic Design Category: [_____]
Spectral Response (S_{DS}): [_____]
Spectral Response (S_{D1}): [_____]
Component Importance Factor (I_P): [1.0] [1.5]
Post-Earthquake Operability Required: [Yes] [No]

1.7 **Wind and Structural Loads**
Equipment, support structures, and anchorage shall be designed to resist wind loads in accordance with ASCE 7-22. The manufacturer shall provide structural calculations stamped by a Licensed Professional Engineer (PE) upon request.

- Ultimate Design Wind Speed (V_{ult}): ______ mph (3-second gust).
- Category: [B] [C] [D
    - Category C (open terrain) is the industry default for most substation and industrial environments.
- Risk Category: [I] [II] [III] [IV]
    - Standard industrial equipment is typically Category II, whereas "Essential Facilities" (critical utility infrastructure) require Category IV.
- Ground Elevation Factor (K_e): ______
- **Internal Pressure Coefficient (GC_{pi}):** The enclosure shall be designed as an "Enclosed" or "Partially Enclosed" structure per ASCE 7 definition, accounting for all ventilation louvers and openings.

2 Product Certification and Listing

2.1 The capacitor bank enclosure system shall be Listed and Labeled by a Nationally Recognized Testing Laboratory (NRTL) to the following standards:

- **United States:** IEEE C37.20.3 (Standard for Metal-Enclosed Interrupter Switchgear).
- **Canada:** CSA C22.2 No. 31 (Switchgear Assemblies) or CSA C22.2 No. 190 (Capacitors and Reactors).

2.2 The capacitor bank control system shall be UL508A Certified for both Canadian and US products.

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3 Compliance with Standard & Codes

3.1 The metal enclosed shunt capacitor bank shall conform to or exceed the latest applicable requirements of the following standards and codes:

- UL-508A: Standard for Industrial Control Panels
- IEEE C37.20.3 - 2023: Standard for Metal-Enclosed Interrupter Switchgear
- IEEE C37.20.4 - 2013: Standard for Indoor AC Switches (1kV to 38kV) For Use In Metal-Enclosed Switchgear
- IEEE C37.011-2019: Guide for the Application of Transient Recover Voltage in High-Voltage Circuit Breakers
- IEEE C37.04-2018: Standard for Ratings and Requirements for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000V
- IEEE 18-2025: Standard for Shunt Power Capacitors
- IEEE 519-2022: Standard for Harmonic Control in Electric Power Systems
- IEEE 1036-2020: Guide for the Application of Shunt Power Capacitors
- IEEE C37.66-2021: IEEE Standard Requirements for Capacitor Switches
- IEEE C37.012-2022: Guide for the Application of Capacitive Current Switching for AC High-Voltage Circuit Breakers Above 1000V
- IEEE C37.99-2012: Guide for the Protection of Shunt Power Capacitor Banks
- IEEE PES-TR16: Transient Limiting Inductor Applications in Shunt Capacitor Banks
- IEEE-C62.22-2009: Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems
- IEEE C37.20.7-2024: Recommended Practice for Testing Switchgear Rated Up to 52kV for Internal Arcing Faults
- IEEE C37.48-2020: Guide and Tutorial for the Application of High-Voltage (> 1000 V) Fuses and Accessories
- UL-50 & UL 50E: Enclosures for Electrical Equipment, Environmental Considerations
- ANSI Z535.4 - R2023: Product Safety Signs and Labels
- NFPA 70 – 2023: Article 460 and Article 490 of the National Electrical Code
- ANSI C37.20.2: Guide for Enclosure Categories and Related Requirements
- NFPA 70-2023: Article 490: Equipment Over 1000 Volts, Nominal

4 Enclosure Construction

4.1 **Manufacturing and Responsibility**
The manufacturer of the enclosure shall also be the assembler of the capacitor bank. This integration is mandatory to ensure single-point accountability and total control over critical processes, including structural welding, surface preparation, and the application of the specified coating system.

4.2 **Structural Design**

- **Configuration:** The capacitor bank shall be a NEMA 3R, flush-door enclosure housing all necessary components, including controls, fuses, reactors, switches, and RC snubbers.
- **Accessibility:** All components shall be accessible and removable from the front or side of the enclosure.
- Materials: Enclosure walls and doors shall be fabricated from 11-gauge cold-rolled A60 galvannealed steel (or specify 12-guage stainless steel, type 304, 316, or 409).
- **Roof:** The roof shall be cross-kinked, half-gabled, or full-gabled to ensure positive watershed.

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- **Base:** The enclosure base shall be constructed of C4x5.4 structural steel channel. Formed sheet-metal bases are prohibited.
- **Lifting:** Removable 1/2-inch steel lifting plates shall be provided at each corner. Where equipment length could result in undue flexing during lifting, additional welded lifting points shall be provided along the C4x5.4 base channel.

4.3 Coating and Finish

The enclosure shall be finished with a high-performance, high-solids epoxy system. Interior and exterior surfaces shall be finished in ANSI 61 Gray.

- **Surface Preparation:** All surfaces shall be prepared per SSPC/AMPP (SP2, 3, 6, 7, 10, 11) or the paint manufacturer's specific recommendations. Documentation of preparation procedures must be included in the submittal.
- **Inaccessible Surfaces:** Any surface rendered inaccessible after fabrication must receive the full coating system prior to assembly. These areas are classified as Zone 2A per SSPC.
- **Performance Metrics:** The total Dry Film Thickness (DFT) shall be 3.5 to 8.0 mils. The coating must meet the following:
    - **Salt Spray (ASTM B117):** 5500 Hours (no face blistering).
    - **Humidity (ASTM D2247):** 5500 Hours (no face corrosion/blistering).
    - **Gloss Retention (ASTM G53):** >50% at 26 weeks (QUV-B).
    - **Elongation (ASTM D522):** 14%.
    - **Adhesion (ASTM D4541):** 2700 PSI.
    - **Fire Rating:** NFPA Class A.

4.4 Doors and Access

- **Design:** Doors shall be flush-mounted (no overhanging sills) with heavy-duty stainless steel hinges and 3-point latching, pad-lockable handles.
- **Safety Features:** Doors providing access to high-voltage compartments shall include door stays and drip shields. Doors shall be removable only when in the open position.
- **Internal Barriers:** The load-interrupter switch compartment (if provided) shall feature an internal hinged protective barrier to prevent inadvertent contact with live terminals while allowing access to main fuses (if provided).
- **Viewing Windows:** Impact-resistant, UV-resistant, wide-view windows shall be provided, as applicable, for the interrupter switch compartment to verify blade position, the fuse compartment to verify fuse status, and the capacitor compartment to verify blown-fuse indicator status and switching device position/status.

4.5 Ventilation and Thermal Management

- **Louvers and Filtration:** Ventilation louvers shall be equipped with 2-inch MERV 5 fiberglass capacitor bank stages. Capacitor bank stages must be replaceable while the bank is energized without exposure to live parts.
- **Hardware:** All fasteners and hardware, internal and external, shall be stainless steel. No externally accessible hardware shall support high-voltage components or operating mechanisms.
- **Environmental Control:** Thermostatically controlled strip heaters shall be provided in all non-ventilated compartments. Forced-air cooling fans shall be provided when required by thermal design.
- **Calculations:** Temperature rise calculations shall be provided by the manufacturer upon request.

4.6 Grounding and Labeling

- **Ground Bus:** A continuous 1/4" x 2" tin-plated copper ground bus shall span the full width of the enclosure.
- **Safety Labels:** Self-adhesive vinyl warning signs complying with ANSI Z535.4-R2023 shall be applied to each door.

- **Nameplate:** A riveted, anodized steel nameplate shall be provided, including:
  - Simplified one-line diagram of each branch
  - Nominal and Maximum System Voltage
  - Frequency
  - Withstand and BIL Rating
  - Total Reactive Power Rating of Capacitor bank
  - Individual Stage Ratings
    - ting, Current Rating)
    - Capacitor ratings (kvar, frequency, voltage)
    - Fuse ratings
    - Transient Inrush reactor ratings

5 LOAD INTERRUPTER / AIR DISCONNECT SWITCH

5.1 Switching Technology

The capacitor bank shall be equipped with an external, chain-operated load-interrupting switch. Current interruption shall be achieved through a dual arc-extinguishing system utilizing a combination of auto-pneumatic air-blast and hard-gas nozzle principles.

5.2 Electrical Ratings

- **Continuous Current:** The switch shall be rated for a minimum of 135% of the bank's nominal current rating.
- **Momentary Rating:** The switch shall have a 40-kA RMS asymmetrical momentary (withstand) rating.

5.3 Safety and Interlocking

- **Operational Interlock:** The air disconnect switch shall be mechanically or electrically interlocked with the vacuum switches/Breaker to prevent the disconnect from being operated while the reactor stage(s) are energized.
- **Security:** The operating mechanism shall be padlockable in both the fully open and fully closed positions.

5.4 Enclosure and Compartmentalization

- **Isolation:** The air disconnect switch shall be housed in a dedicated compartment, physically isolated from the shunt reactor and low-voltage control compartments by grounded steel barriers.
- **Secondary Protection:** In addition to the exterior enclosure door, an internal protective hinged barrier shall be provided. This barrier must be in place to prevent accidental contact with live parts when the exterior door is opened.

6 GROUND SWITCH

6.1 Functional Requirements

An externally operated ground switch shall be provided to effectively ground the load-side terminals of the air-interrupter switch. This ensures that the shunt reactor and associated internal components are discharged and maintained at ground potential during maintenance.

6.2 Security and Compliance

- **Locking:** The ground switch operating mechanism shall be padlockable in both the fully open and fully closed positions.
- **Standards:** The switch shall be designed and tested in accordance with applicable ANSI/IEEE standards. Certified test reports shall be furnished to the owner upon request.

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6.3 Safety Interlocking

The ground switch shall be mechanically interlocked with the main air-interrupter switch. This interlock must positively prevent the ground switch from being closed whenever the air-interrupter switch is in the closed position, and conversely, prevent the air-interrupter switch from closing while the ground switch is engaged.

7 MAIN INCOMING FUSES

7.1 Functional Configuration

The capacitor bank shall be equipped with SIBA medium-voltage current-limiting fuses for primary overcurrent and short-circuit protection.

- **Placement:** Fuses shall be electrically positioned on the load side of the air-disconnect switch.
- **Current Rating:** The fuse current rating shall be 1.35 times the total fundamental current rating of the bank.
- **Voltage Rating:** The rated voltage (U_n) of the fuse must be the next highest voltage range relative to the capacitor voltage and shall not be less than the maximum power-frequency voltage appearing across the fuse under all operating and fault-clearing conditions. Per IEEE 1036, phase-to-phase voltage shall be used for ungrounded-wye banks and phase-to-ground voltage for grounded-wye banks.
- **Sizing:** The main incoming fuses shall be one DIN size larger than the internal capacitor branch fuses where possible.

7.2 Remote Monitoring and Blown Fuse Sensing

The main incoming fuses shall utilize direct blown fuse sensing for remote monitoring of switching status.

- **Striker Pin:** Fuses shall be equipped with an integrated striker pin (force rating of 80N or 120N as appropriate) to provide visual indication of operation and to actuate remote signaling.
- **Microswitch Assembly:** A SIBA microswitch assembly unit shall be provided for remote monitoring. The assembly shall consist of a flexible Bowden drive that transfers the linear motion of the striker to change-over output contacts rated for 250 VAC, 6A.
- **Control System Integration:** The microswitch contacts (rated 250 VAC, 6A) shall be wired directly to the control and protection system.
- **Unbalance Protection:** Upon detection of a blown fuse, the protection system shall automatically take the capacitor bank offline to prevent damage from unbalance operation and to protect remaining system components.

7.3 Mounting and Mechanical Requirements

- **Fuse Clips:** Fuses shall be removable and mounted using silver or tin-plated high-conductivity copper spring contacts to ensure narrow time-current tolerances.
- **Standard Hardware:** Mounting shall utilize SIBA spring contacts.
- **Sealing:** The fuses shall feature a reliable sealing system against humidity, dust, and corrosion, utilizing a durable elastic sealing medium and glazed porcelain to ensure tightness against water vapor ingress.

7.4 Safety and Accessibility

- **Compartmentalization:** Fuses shall be housed in a dedicated compartment, physically separated from high-voltage line-side components by grounded metal barriers.
- **Interlocking:** The compartment shall be designed so that fuses are accessible only when the main air-disconnect switch is locked in the open (de-energized) position.
- **Visual Inspection:** Impact and UV-resistant wide-view windows shall be provided on the enclosure door to allow maintenance personnel to verify the status of the striker pin and blown fuse indicator without de-energizing the bank or opening the door.

8 MAIN CIRCUIT BREAKER (ALTERNATE)

8.1 General Requirements

For banks with higher reactive power ratings or elevated short-circuit requirements, a medium-voltage vacuum circuit breaker shall be provided as the primary disconnecting and protective device (replaces the air disconnect switch and main fuses). The breaker shall be an ABB VD4 or ABB ADVAC (spring-actuated), ABB AMVAC or ABB VD4-CS (magnetically actuated), or an approved equivalent.

- **Execution:** The breaker shall be provided in either a Fixed or Drawout (Roll-out) execution as specified in the project data sheets.
- **Compartmentalization:** The breaker shall be mounted in a dedicated, grounded steel compartment physically isolated from the capacitor and low-voltage control sections.

8.2 Drawout (Roll-out) Construction

If a draw out/roll-out breaker is specified, the following requirements shall apply:

- **Substation Integration:** The breaker shall be a horizontal drawout type capable of being rolled directly onto a substation floor, including surfaces with stone cover.
- **Racking:** Provisions shall be provided for manual or motorized racking of the breaker with the compartment door closed to enhance operator safety.

8.3 Environmental Control and Protection

- **Condensation and Cold Protection:** The breaker compartment shall be equipped with thermostatically controlled strip heaters to prevent condensation and ensure reliable operation in cold ambient conditions.
- **Maintenance-Free Design:** The vacuum interrupters shall be embedded and sealed for life, requiring no adjustment of the breaker mechanism or contact wear measurements during the service life of the unit.

8.4 Control and Monitoring Interface

The breaker shall be fully integrated into the control and protection system. All of the following signals shall be wired out to the low-voltage control panel:

- **Status Signaling:** Mechanical and electrical indicators for Open/Closed (Green/Red) and Spring Charged/Discharged status.
- **Monitored Contacts:** All "A" and "B" auxiliary contacts, loss of voltage, and trip coil monitors shall be wired to terminal blocks for use by the protection system.
- **Operations:** An operation counter shall be provided as standard.

8.5 Protection and Instrumentation

- **Relay Protection:** The breaker shall be wired to a protection panel equipped with an SEL-751, SEL-487V or ABB REX640 protection and control relay providing instantaneous and time-overcurrent (phase and ground) protection for the capacitor bank amongst other relay and control functions.
- **Interlocking:** The breaker shall form an integral part of the capacitor bank's trapped-key interlock system to prevent out-of-sequence entry or operation of the capacitor bank.

9 Stage/Branch Switching Devices

9.1 General Requirements

Each capacitor stage shall be controlled by a switching device specifically rated for capacitive and inductive switching duties. The device type shall be selected based on system voltage, fault current, and reactive power (MVAR) requirements as specified in the project data sheets.

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9.2 **Medium-Voltage Vacuum Contactors (4.16 kV – 7.2 kV)**
For applications within the 4.16 kV to 7.2 kV range, stages may be controlled by vacuum contactors such as the **ABB ConVac** series or equivalent.

- **Ratings:** Contactors shall be suitable for high-frequency switching and rated for the maximum continuous current of the capacitor stage, including harmonic content.
- **Mechanical Life:** The contactor shall offer a high mechanical endurance (up to 1,000,000 operations) to suit automatic power factor correction applications.

9.3 **Vacuum Switches (4.16 kV – 27 kV)** For system voltages up to 27 kV, stages shall be controlled by vacuum switches specifically tested for capacitor switching, such as the Hitachi PS Series or equivalent.

- **Compliance:** The switches shall be tested in accordance with IEEE C37.66. Certified test results demonstrating restrike-free performance shall be provided upon request.
- **Design:** The switches shall utilize a solenoid-operated mechanism and vacuum interrupters to ensure fast, reliable switching of capacitive loads.

9.4 **Vacuum Circuit Breakers (4.16kV – 38kV)**
When stage MVAR ratings exceed the capability of standard switches, a vacuum circuit breaker shall be utilized.

- **Technology:** Breakers shall be ABB VD4, ABB ADVAC (spring-operated), ABB AMVAC, ABB ADVAC or ABB VD4-CS (magnetically actuated), or an approved equivalent.
- **Maintenance-Free Interrupters:** The vacuum interrupters shall be embedded in resin (sealed-for-life) to protect against dust, humidity, and condensation.
- **Execution:** Breakers may be provided in Fixed or Drawout (Roll-on-the-floor) configurations. Drawout units shall be capable of racking with the compartment door closed.

9.5 **SF6 Switching Technology (38 kV Applications)**
Stages shall be controlled by an SF6 insulated switching device, such as the Southern States CapSwitcher® or equivalent.

- **Transient Mitigation:** The switch shall utilize closing resistors or specialized interrupter technology to minimize voltage transients and inrush currents during switching.
- **Monitoring:** The device shall include a gas density switch or pressure gauge for continuous monitoring of the SF6 insulation levels.

9.6 **Control and Safety Interlocking**

- **Selector Interface:** Each switching device shall be equipped with a local ON/OFF/AUTO selector switch. In "AUTO," the device accepts signals from the digital controller; "ON/OFF" serves as a manual override.
- **Reclose Protection:** The control system shall enforce a mandatory discharge timer, preventing the switching device from re-closing within a 5-minute period after de-energization.
- **Safety Interlocks:** All stage switching devices shall be electrically and/or mechanically interlocked with the bank's main air-disconnect switch (or main breaker) and ground switch. They must be in the "OPEN" position before the main disconnect (or main breaker) can be operated or the enclosure doors are accessed.

10 Transient Inrush Reactors

10.1 **General Design and Construction**
Each capacitor bank stage shall be equipped with single-phase, air-core, dry-type transient limiting inductors (inrush reactors). These reactors are specifically designed to increase the life expectancy of switching devices by limiting the magnitude and frequency of transient inrush currents associated with back-to-back switching.

- **Materials:** Windings shall consist of low-loss copper or aluminum magnet wire or foil.
- **Insulation System:** The reactors shall utilize a 220°C insulation system.
- **Processing:** The complete assembly shall undergo an epoxy resin impregnation system to reduce audible noise, promote heat dissipation, and provide environmental protection in harsh conditions.
- **Mechanical Construction:** The design shall utilize a GPO-3 high-strength, open-profile bobbin to ensure rigidity and maximize heat dissipation. Terminals shall feature NEMA two-hole bolt patterns on 1/4" x 2" bus bar to facilitate in-line bus connections.

10.2 Performance and Standards Compliance

The reactors shall be sized to ensure the switching equipment operates within the high-frequency capacitive switching limits defined by the current IEEE standards, specifically IEEE Std C37.012-2022 and IEEE Std C37.66-2021.

- **Transient Limitation**: The reactors shall limit the peak transient inrush current to a value less than or equal to the rated peak inrush making current of the switching device, minus a specified engineering margin.
- **Device-Specific Frequency Limits**: For modern vacuum and SF6 capacitor switches evaluated under IEEE Std C37.66-2021, there is no upper limit to the natural inrush frequency provided the peak current is within rating. For vacuum and SF6 circuit breakers evaluated under IEEE Std C37.012-2022, the reactors must ensure that the current-frequency product (I x f) does not exceed four times the rated product (4 x I x f) unless the inrush peak is less than 10% of its rating.
- **Back-to-Back Switching**: For multi-stage banks, the reactor inductance must limit the high-frequency discharge from energized stages into the unenergized stage being switched. Calculations must confirm that the calculated peak inrush current (including engineering margin) does not exceed the rated transient peak inrush current for capacitor switches, or the rated back-to-back capacitor bank inrush making current for circuit breakers.

10.3 Electrical Ratings

- **Continuous Current**: The reactor ampacity shall be rated for at least 135% of the nominal stage current.
- **System Factors**: All calculations shall account for maximum system overvoltage of 10%, maximum positive capacitor tolerance (typically +10%), and harmonic current effects as required by IEEE Std 1036-2020.
- **Expansion Capability**: Where future expansion is specified, the reactor rating shall be based on 135% (for grounded banks) or 125% (for ungrounded banks) of the maximum future capacity of the stage.
- **Verification**: The manufacturer shall provide peak inrush analysis calculations verifying that the peak current magnitudes and, where applicable for circuit breakers, the (I x f) product limits, incorporate a defined engineering margin and are within the specific switching device's nameplate capabilities per the latest IEEE standards.

11 CAPACITORS AND PROTECTION

11.1 General Design and Construction

The capacitor bank shall be equipped with all-film, low-loss, double-bushing capacitors.

- **Acceptable Manufacturers:** Capacitors shall be manufactured by Hitachi, Eaton, or GE only. All other manufacturers will not be accepted.
- **Standards:** Capacitor units shall be designed, manufactured, and tested to meet or exceed IEEE 18-2025, Standard for Shunt Power Capacitors. For projects shipping to Canada, CSA C22.2 No. 190 shall apply.
- **Discharge Requirements:** Each capacitor unit shall contain internal discharge resistors to reduce the stored residual voltage to 50 volts or less within 5 minutes of disconnection.

11.2 Voltage Rating and Harmonic Duty

- **System Over-voltage:** The capacitors shall be rated for a continuous nominal system over-voltage of 110%.

11.3 Mechanical Installation

- **Compartmentalization:** Capacitors shall be located in a dedicated compartment, physically separated from the main incoming fuse, control, and incoming air-disconnect switch or incoming main breaker compartments. They may be mounted near and in the same compartment as the tuning reactors and the branch switching device.
- **Mounting:** Units shall be mounted horizontally or vertically on C4x5.4 structural steel channels. The design shall allow for easy removal of units from the front of the enclosure.

11.4 Capacitor Branch Protection

Each capacitor unit shall be protected by a high-voltage, current-limiting SIBA fuse equipped with a striker-pin blown fuse indicator.

- **Fuse Sizing:** The current rating shall be approximately 2.0 times the nominal phase current of the capacitor.
- **Fuse Voltage:** For grounded-wye banks, the rating shall be at least 1.0x phase-to-ground voltage. For ungrounded banks, the rating shall be at least 1.1x phase-to-ground voltage.
- **Direct Fuse Sensing:** The protection system shall utilize a SIBA direct fuse sensing system (utilizing microswitches and a Bowden cable) to detect both blown fuse and overloaded fuse conditions.
- **Operational Logic:** Any detected fuse operation shall result in the control system taking the affected capacitor stage (and any other appropriate stage due) offline.

11.5 Unbalance Detection Relay

- **Split-Wye Neutral Current Detection** (Optional): When neutral unbalance protection is specified, it shall utilize a split-wye neutral current detection system. Neutral voltage detection systems are prohibited due to TRV and false-tripping concerns.
- **Relay Calibration:** All unbalance relays shall be set and ready for operation. Factory test reports and setting sheets shall be provided.

11.6 Visual Indication:

A rooftop-mounted NEMA 4X strobe light shall provide external indication of a blown fuse. The strobe shall flash at 80 pulses per minute with a peak candlepower of 175,000.

12 LIGHTNING / SURGE ARRESTERS

12.1 Protective Classification

The capacitor bank shall be equipped with distribution class or station class surge arresters to provide primary overvoltage protection against atmospheric lightning strikes and system switching transients.

12.2 Sizing and Coordination

- **Responsibility:** The specific voltage and energy discharge ratings of the arresters shall be determined and recommended by the capacitor bank manufacturer.
- **Selection Criteria:** The selection shall ensure proper insulation coordination with the equipment BIL and the specific grounding configuration (solidly grounded, ungrounded, or resistance grounded) of the host utility or facility power system.

13 PHASE AND GROUND BUS

13.1 Material and Plating

All primary phase and ground busbars shall be fabricated from high-conductivity copper and **tin-plated** at all contact surfaces and throughout their length to ensure maximum conductivity and long-term corrosion resistance.

13.2 Bolted Connections and Hardware

All bus-to-bus bolted joints shall be secured using 3/8” – 16 stainless steel hardware to ensure consistent contact pressure. Each bolted connection shall include:

- One (1) stainless steel bolt.
- Two (2) stainless steel flat washers (one under the bolt head, one under the nut).
- One (1) stainless steel split lockwasher (positioned between the flat washer and the nut).
- One (1) stainless steel nut.

13.3 Electrical and Thermal Ratings

- **Current Density:** The bus system shall be sized such that the current density does not exceed 1200 Amps per square inch at the maximum continuous rating of the bank.
- **Expansion Capability:** Where future expansion is specified or required, the buswork shall be rated for the maximum ultimate capacity of the capacitor bank.

13.4 Mechanical Strength and Short-Circuit Withstand

The busbars, primary interconnections, and their associated supports (insulators) shall be mechanically engineered to withstand the electromagnetic stresses associated with the specified peak available short-circuit current at the terminals of the capacitor bank.

14 KEYED INTERLOCK SYSTEM

14.1 General Requirements

The capacitor bank shall be equipped with a comprehensive trapped-key interlock system. This system is mandatory to enforce a strict safety sequence, preventing unauthorized entry and ensuring that all high-voltage components are de-energized and grounded before enclosure doors can be opened.

14.2 System Configuration and Hardware

- **Mounting:** Keyed interlocks shall be mounted behind the enclosure doors, with only the key cylinders protruding through the door face.
- **Environmental Protection:** All lock cylinders shall be equipped with stainless steel spring-loaded covers to protect against debris and moisture.
- **Design Restrictions:** The system shall allow all doors to be opened simultaneously once the sequence is initiated. Master key interchanges and externally mounted (surface-mounted) interlocks are prohibited.

14.3 **Sequential Interlock Logic** The interlock scheme shall encompass the upstream protective device (where applicable), the main air-disconnect switch (or main breaker if used), the ground switch, and all enclosure doors. The mandatory operating sequence shall be as follows:

1. **De-energization of Stages:** Manually switch all capacitor stages to the **OFF** position using the local ON/OFF/AUTO control switches.
2. **Isolation and Grounding:** Use the primary "A1" key to unlock the air-disconnect switch. Open the air-disconnect switch and subsequently close the mechanically interlocked ground switch.

3. **Key Release (Grounding):** Remove the "A2" key from the ground switch. The removal of this key shall mechanically lock the ground switch in the **CLOSED** (grounded) position.
4. **Primary Access:** Use the "A2" key to unlock the Air-Disconnect Switch External Compartment Door. Upon opening, the "A3" key shall be released from the door lock.
   - *Note: Access to the switch terminals (or breaker terminals) remains blocked by the internal hinged barrier. If specified, this internal barrier can be further interlocked with the upstream feeder breaker.*
5. **Sequential Door Release:** Use the "A3" key to open the first capacitor bank stage branch compartment door, which releases the "A4" key.
   - Use the "A4" key to open the subsequent door, releasing the next key in the sequence (if applicable).
6. **Final Access:** This "daisy-chain" procedure shall be repeated until all enclosure doors are unlocked and open.

15 CONTROLS AND PROTECTION

15.1 Control Compartment and Isolation

- **Integration:** The control compartment shall be an integral part of the enclosure; externally mounted control cabinets are prohibited.
- **Isolation:** All low-voltage controls shall be physically isolated from high-voltage compartments via grounded steel barriers and shall remain safely accessible while the bank is energized.
- **Entry and Wiring:** The compartment shall facilitate top or bottom entry for customer control wiring without requiring access to medium-voltage sections. All control wiring traversing high-voltage areas must be enclosed in metal conduit or integrated wire troughs.
- **Ergonomics:** The compartment shall feature a swing-out dead-front panel to provide rear access to panel-mounted components and wiring.

15.2 Control Power and Protection

- **Source:** A dry-type Control Power Transformer (CPT) shall be provided, connected between phases B and C. The CPT shall include both primary and secondary overcurrent protection. As an alternative, the capacitor bank shall be designed to accept AC or DC control power from the customer.
- **Circuit Protection:** The complete control circuit shall be protected by a main circuit breaker. UL-rated control power circuit breakers shall be utilized for protection and switching of key control components.
- **Compliance:** The control system assembly shall be listed under UL 508A for Industrial Control Panels.

15.3 Automation and Switching Logic

- **Power Factor Controller:** The bank shall include a digital power factor controller capable of automatically switching equal or unequal stages to regulate facility power factor to a preset value.
- **Intelligent Monitoring:** The controller shall monitor individual stages for loss in kvar and continue to regulate if a defective stage is detected.
- **Data Display:** The interface shall display power factor, switching counters, duty cycles, network data (I, U, S, P, Q), alarm logs, step status, and harmonic spectrums (Voltage/Current THD up to the 50th harmonic).
- **Alarming:** System alarms shall include low power factor, hunting, abnormal PF, low voltage, overcompensation, wrong frequency, overcurrent, overvoltage, over-temperature, and capacitor overload.

15.4 Stage Interface and Arc Flash Safety

- **Standard Interface:** Each stage shall be equipped with an ON/OFF/AUTO selector switch and visual indicators for Stage ON (Green) and Stage OFF (Red).

- **Switching Delays:** An interposing on-delay relay shall prevent the energization of any stage in less than 5 minutes to allow for capacitor discharge. This delay must be enforced when switching from "Manual" to "Auto" modes.
    - **Safety Delay:** For Arc Flash Hazard Mitigation, a 10-second delay shall be implemented before any manual switching operation to allow personnel to move outside the arc flash boundary.

15.5 Arc Flash Hazard Mitigation (Optional)

- **Remote Mounting:** The control and protection system may be remotely mounted in a NEMA 1 indoor enclosure. Interconnections shall be facilitated through a marshalling cabinet within the main equipment enclosure.
- **Active Protection (ABB UFES):** The capacitor bank may be equipped with an ABB Ultra-Fast Earthing Switch (UFES) for active arc fault protection. The system shall include electronic detection, primary switching elements, and arc sensors, with a transfer trip wired to the upstream breaker.
- **Optical Detection:** An arc flash detection relay (SEL751A) with high-speed optical sensors shall be installed to provide high-speed tripping of the feeder or main breaker (if provided).

15.6 Advanced Metering and Protection (Optional)

- **Power Quality Metering:** When specified, a three-phase digital power meter shall be provided. If the meter is utilized for protection functions, an SEL-735 Power Quality Meter shall be used.
- **Monitoring Parameters:** The meter shall monitor voltage, current, real/apparent/reactive power, power factor, unbalance, frequency, and energy accumulation and all harmonic voltage and currents to the 50^{th} harmonic.
- **System Protection:** The bank shall be equipped with a three-phase over-voltage relay (protecting both capacitors and system equipment) with dual setpoints for alarm and trip functions.

15.7 Enclosure Amenities

- **Lighting:** Integrated lighting shall be provided for all compartments, operated by a master switch in the control compartment.
- **Convenience:** A 20-amp GFI duplex outlet shall be installed within the control compartment.

16 SUPPLIER QUALITY AND QUALIFICATIONS

16.1 Quality Management System

The supplier shall maintain a formal quality management system with third-party certification by an internationally recognized accreditation body to ISO 9001:2015 (or the latest revision). A valid copy of the ISO certification shall be submitted with the quotation.

16.2 Product Certification and Listing

The supplier shall be authorized by a Nationally Recognized Testing Laboratory (NRTL) to apply certification labels to the equipment.

- **Enclosure and Assembly:** The capacitor bank shall be compliant with IEEE C37.20.3 (Standard for Metal-Enclosed Interrupter Switchgear).
- **Components:** The assembly shall meet the requirements of CSA C22.2 No. 190 (Capacitors) and CSA C22.2 No. 31 (Switchgear Assemblies).

16.3 Control Panel Compliance

The supplier shall maintain factory certification through periodic inspections by an NRTL (such as UL or TÜV) to apply UL 508A and C-UL labels to their industrial control panels. A copy of the current certification shall be provided with the quotation.

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16.4 Engineering Proficiency

To ensure technical competence in medium-voltage reactive compensation, the supplier shall maintain a staff of experienced, Licensed Professional Engineers (PE). These individuals shall hold degrees in Electrical Power Engineering, preferably with advanced degrees, as evidence of their proficiency in power system design and analysis.

16.5 References and Experience

The supplier shall provide a reference list of customers for whom they have provided similar medium-voltage metal-enclosed equipment. This list shall include contact information to facilitate reference checks and shall be provided at the time of quotation.

16.6 Factory Audits

The supplier shall allow the customer to perform factory audits at the manufacturing facility. Such audits shall occur at a mutually agreed-upon date and time between the customer and the supplier to verify manufacturing processes and quality control measures.

17 SYSTEM STUDIES AND ENGINEERING ANALYSIS

17.1 Required Application Studies

The following studies shall be performed by the supplier and submitted with the project drawing submittals.

17.1.1 Transient Analysis

The capacitor bank supplier shall perform the following transient analyses to verify safe equipment application:

- **Peak Inrush Analysis:** Evaluate single-bank and back-to-back switching duty to confirm that the switching devices are adequately rated. Analysis shall be based on IEEE C37.04, IEEE C37.09, IEEE C37.012, IEEE C37.66, and IEEE 1036.
- **Outrush and Close-In Fault Analysis:** Evaluate high-frequency discharge current and peak outrush duty on the designated victim breaker to confirm that breaker close-and-latch capabilities are not exceeded. Analysis shall be based on IEEE C37.012, IEEE PES-TR16, and IEEE C37.04.
- **Reactor-Limited Fault TRV Assessment:** Evaluate breaker TRV duty for reactor-limited short-circuit faults to confirm that RRRV and TRV peak remain within breaker capability. Analysis shall be based on IEEE C37.011, IEEE C37.04, and IEEE C37.06.1.

17.1.2 Altitude Derating and Insulation Coordination Study

For installations above 1000 meters, the supplier shall also perform an Altitude Derating and Insulation Coordination Study to verify that equipment dielectric performance remains acceptable at altitude through proper insulation coordination and surge arrester application. Analysis shall be based on IEEE C62.22, IEC 60071-1, IEC 60071-2, IEEE C37.010, IEEE C37.20.2, IEEE C37.20.3, IEC TR 62271-306, and IEC 60694 / IEC 60871-1.

17.1.3 Harmonic Resonance and System Interaction

- **Resonance Analysis:** The vendor shall perform a resonance analysis to identify any resonant conditions that may occur with the application of the capacitor bank under all operating conditions. Data required for this analysis will be provided after issuance of the purchase order. The results of the analysis shall be submitted in a letter report, together with recommendations for any required equipment modifications.
- **Modeling Scope:** Analysis must account for varying system short-circuit levels and the presence of any existing harmonic-producing loads or nearby reactive compensation.

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17.1.4 **Voltage Rise and Regulation**

- **Steady-State Voltage:** The manufacturer shall provide calculations demonstrating the expected steady-state voltage rise at the bank terminals upon energization of each stage.
- **Compliance:** The design shall ensure that the voltage rise does not exceed [2% / 3%] or the specific limits of the host utility to prevent over-voltages.

17.1.5 **Engineering Proficiency**

- **Single-Point Responsibility:** All system modeling, resonance checks, and power factor calculations shall be performed by the manufacturer's internal engineering staff.
- **Third-Party Restriction:** Sub-contracting of the system engineering or performance validation to third-party consultants is strictly prohibited to ensure single-point accountability.

17.2 **Protection Coordination Study**

A formal Time-Current Coordination (TCC) study shall be provided to ensure selective coordination between internal and external protective devices.

- **Fuse-to-Fuse Coordination:** The study shall demonstrate proper coordination between capacitor branch fuses and main incoming fuses.
- **Case Rupture Coordination:** The study shall demonstrate proper fuse selection to prevent case rupture.
- **Upstream Integration:** All internal protection (including unbalance, overcurrent, and harmonic overload) shall be coordinated with the upstream feeder breaker settings and the capacitor case rupture curves.

18 SUBMITTALS AND DOCUMENTATION

18.1 **Approval Drawing Package**

Following the issuance of a purchase order, the supplier shall submit a complete set of approval drawings for review. Fabrication shall not commence until the customer has provided written approval of the submittal package.

18.2 **Submittal Content**

The submittal package shall be comprehensive and include, at a minimum, the following technical documentation:

- **Installation Instructions:** Detailed procedures for site handling, leveling, and assembly.
- **Schematic Diagrams:** Complete Single-Line and Three-Line diagrams illustrating the primary power circuit, switching logic, and protection schemes.
- **Plan View and Section Drawings:** Detailed drawings showing the enclosure footprint, anchoring requirements (pad details), and specific locations for top or bottom cable entry.
- **Component Layout:** Internal elevation drawings identifying the physical arrangement and clearances for all major components, including transient inrush reactors, switches, fuses, capacitors, breakers, and all controls.
- **Technical Data Sheets:** Manufacturer-published specifications and data sheets for all internal primary components (reactors, switches, breakers, arresters, fuses, capacitors, and controllers and all other significant devices).
- **Bill of Materials (BOM):** A complete material listing identifying part numbers, ratings, and quantities for all system components.

18.3 **Operation and Maintenance (O&M) Manuals**

Final "As-Built" documentation, including certified test reports and localized O&M manuals, shall be provided with the equipment shipment.

19 BID REQUIREMENTS

19.1 **Inspection and Test Plan (ITP)**
The supplier shall submit a comprehensive Inspection and Test Plan (ITP) with the bid. This document must detail all proposed factory production tests, specialized type tests, and final certifications. The ITP shall include a definitive schedule for the submission of all test reports, indexed from the date of award.

19.2 **Supplier Document List (SDL)**
A Supplier Document List (SDL) shall be provided, identifying all submittal and close-out documentation to be furnished (e.g., approval drawings, O&M manuals, certified test reports). The SDL must include a submittal schedule expressed in weeks after the date of award.

19.3 **Statement of Exceptions**
The supplier shall explicitly state all technical or commercial exceptions to this specification within the bid proposal. If no exceptions are taken, the supplier must provide an affirmative statement that the proposal is in full compliance with the specification as written.

19.4 **Supplier Qualification**
The supplier must complete and include the attached **Supplier Qualification Form** with their formal quotation. Failure to provide this completed form at the time of bid submission shall be grounds for immediate rejection of the proposal.

19.5 **Warranty and Field Service**
The supplier shall provide written details regarding available extended warranty options and field service agreements. These policy documents must be included in the bid package to allow for evaluation of long-term support capabilities.

19.6 **Quality Policy** The supplier's formal, written Quality Policy shall be submitted with the bid as evidence of the manufacturer's commitment to quality assurance and continuous improvement.

19.7 **Shipping Terms** All quotations shall be provided on an **F.O.B. Factory, Freight Allowed** basis, unless otherwise specified in the project-specific RFP.

20 TESTING AND TEST REPORTS

20.1 **General Requirements**
The manufacturer shall perform comprehensive testing on all components and the completed assembly in accordance with applicable IEEE, ANSI, and NEMA standards. A detailed **Inspection and Test Plan (ITP)** shall be provided with the bid. Fabrication and assembly shall be governed by this ITP, and all results shall be documented in a certified test report.

20.2 **Dielectric and Insulation Testing**
The fully assembled unit shall undergo dielectric testing to verify insulation integrity under various operational configurations (e.g., main switch open/closed, stage switches open/closed).

- **Power-Frequency Withstand:** Conducted per IEEE C37.20.3 and IEEE Std 4.
- **Lightning-Impulse Withstand (BIL):** Conducted in accordance with IEEE C37.57 and IEEE C37.20.3, Table 1.

20.3 Component-Specific Testing

- **Air Disconnect Switch:** Shall include Contact Resistance (Ductor) testing, a 1-minute Hi-Pot test at standard voltage, and mechanical operation verification.
- **Transient Reactors:** Shall be tested for inductance and insulation integrity.
- **Instrument Transformers (CTs/PTs):** Shall undergo Turns Ratio, Polarity, Insulation (Megger), and Excitation testing per IEEE C57.13.
- **Surge Arresters:** Verification of Reference Voltage, Residual/Discharge Voltage, Partial Discharge, and Power Frequency withstand.
- **Capacitors (if applicable):** Shall include leak testing, capacitance and loss (tan delta) measurement, discharge resistor verification, and high-voltage ground testing.

20.4 Advanced Switching Device Testing

- **Southern States CapSwitcher®:** Testing shall include Hi-Pot, Timing, Contact Resistance, Heater Wattage, SF6 Leak Check, Gas Density Switch verification, and Slow-Close operational checks.
- **SF6 Circuit Breakers:** Shall undergo mechanical operation cycles, Power-Frequency Withstand, Contact Resistance, and Operating Time (Opening/Closing) benchmarks.

20.5 Control and Protection Verification

All relays, meters, and control devices shall be programmed, calibrated, and functionally tested prior to shipment.

- **Documentation:** Final relay settings and calibration constants shall be documented and included in the O&M manuals.
- **Wiring:** A point-to-point continuity check of all control wiring shall be performed.

20.6 Final Inspection and Witnessing

- **Assembly:** The equipment shall be fully assembled and undergo a final mechanical and electrical integration test prior to shipment.
- **Certified Reports:** All test reports must be signed by a Professional Engineer or Quality Manager and approved by the customer before the equipment leaves the factory.
- **Witness Testing:** The customer reserves the right to witness any or all tests at the manufacturer's facility at no additional contract cost. The manufacturer shall provide a minimum of **15 working days** notice prior to the commencement of witnessed testing.

21 ACCEPTABLE PRODUCT AND SUPPLIERS

21.1 Warranty Requirements

The supplier shall provide a standard warranty for all equipment and components for a period of 18 months from the date of shipment or 12 months from the date of energization, whichever occurs first. In addition to the standard warranty, the supplier must have extended warranty programs available for purchase at the time of the bid.

21.2 Testing Capabilities

The supplier must demonstrate the facility infrastructure and technical expertise required to meet all primary, dielectric, and functional testing requirements specified in Section 4.10 (Testing and Test Reports).

21.3 **Quality System Certification**

The manufacturer shall maintain a current ISO 9001 certification. This certification must be issued by an independent, ISO-accredited auditing firm. A valid copy of the ISO 9001 certificate shall be included as a mandatory component of the bid package.

21.4 **Manufacturer Experience and References**

The supplier shall demonstrate that they are a regular, established manufacturer of medium-voltage automatic metal-enclosed capacitor banks. To verify technical proficiency and product reliability, the following shall be provided upon request:

- **Product Literature:** Formal technical specifications and brochures detailing the manufacturer's capacitor bank product line.
- **Reference List:** A list of customers and projects involving the successful installation and operation of similar metal-enclosed reactive compensation systems.

21.5 **Acceptable Manufacturer and Product:**

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