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Guide Form Specification

Medium Voltage Motor Starting Capacitor Bank

Design Criteria: Fast-switched capacitor bank or detuned capacitor bank for assisting the across-the-line starting of large induction and synchronous motors, providing a lower-cost alternative to adjustable speed drives and other motor-starting technologies where variable speed control is not required.

1 General

1.1 Scope of Work

This specification governs the design, manufacture, testing, and application engineering of a medium-voltage, three-phase, metal-enclosed motor starting capacitor bank for across-the-line starting of large induction and synchronous motors. The system shall be designed to provide fast-switched reactive power at or near the motor terminals during starting so as to reduce voltage sag on the plant electrical system and incoming supply at the PCC, while supporting successful motor acceleration without the use of variable frequency drives, reduced-voltage soft starters, and synchronous bypass switchgear.

The equipment shall be a fully integrated, compartmentalized assembly including all capacitor stages, switching devices, protection, control, monitoring, and auxiliary components required for a complete operating system. The motor-starting capacitor bank shall operate from a motor-start command and shall not require a motor-start confirmation signal or bidirectional start-confirmation handshake.

The system shall utilize commercially available, non-proprietary components and shall be shipped completely assembled and factory tested, requiring only field anchorage, removal of shipping materials and supports, and connection to the plant grounding, control, and power distribution systems.

The scope of work shall include the necessary application studies to determine the reactive power rating, staging, timing, and system configuration required to meet the specified motor-starting performance objectives, and the supply of the complete equipment ready for field interconnection.

1.2 Ratings and Capacity

The capacitor bank shall provide a total output of _____ kvar at _____ kV. The total capacity shall be divided into _____ stages. All stages must have the same ratings.

1.3 Performance and Operational Requirements

1.3.1 Motor Starting Voltage Performance

- **Point of Common Coupling (PCC) Voltage:** The Motor Starting Capacitor Bank shall be sized and guaranteed to limit the voltage drop at the Point of Common Coupling during motor starting to not more than [4% maximum], unless otherwise specified by the Owner or serving utility. This corresponds to maintaining not less than [96%] of nominal system voltage at the PCC during the starting event.

- **Motor Bus / Motor Terminal Voltage:** The system shall be designed and guaranteed to maintain not less than [90%] of nominal voltage at the motor bus and/or motor terminals during the starting event, unless more stringent project-specific requirements are specified.
- **Multiple Voltage Levels:** Where the application includes a captive transformer, multiple medium-voltage buses, or other intermediate system voltage levels, the manufacturer shall evaluate all relevant voltage levels and size the system to meet the specified voltage-performance objectives at each required location during motor starting

1.3.2 Starting Torque Performance

- **Torque Objective:** The Motor Starting Capacitor Bank shall be designed and guaranteed to provide sufficient voltage support during starting such that the connected motor develops adequate accelerating torque to successfully start and accelerate the driven load across the line without stall, unacceptable acceleration time, or inability to reach rated speed.
- **Analytical Basis:** The supplier shall evaluate available starting torque based on the resulting motor terminal voltage and the motor starting characteristics provided for the project. The final system rating shall be selected to satisfy the required starting torque margin for the connected load.

1.3.3 Reactive Power Rating and Stage Configuration

- **Sizing Basis:** The supplier shall determine the required total three-phase reactive power rating (MVAR), number of stages, and stage size needed to meet the specified motor-starting performance objectives. The sizing study shall consider, utility short-circuit strength, transformer impedance, system X/R ratio, motor horsepower, motor locked-rotor current, motor power factor, motor inertia, motor-load inertia, cable and feeder impedance, and any stated utility and plant voltage-drop limitations.
- **Stage Operation:** Capacitor stages shall be controlled with SEL 487V or equivalent relay so that only the reactive power required for the motor-starting event is applied. The number of stages and their ratings shall be selected to satisfy the starting-performance objectives while keeping stage-to-stage voltage change within acceptable project limits. The **start command initiates the sequence**, initial stage removal is based on measured bus voltage, and all subsequent stage removal is based on application-specific timing based on the results of the system and motor/load characteristics.

1.3.4 Upstream System Impact During Starting

- **Reduction of Starting Current:** The system shall be designed to reduce the starting current reflected into the upstream electrical system to the level required to satisfy the specified PCC voltage-drop objective and any stated utility inrush-current limitations.
- **Power Quality Objective:** The Motor Starting Capacitor Bank shall provide localized reactive power support during starting so as to reduce voltage sag on the plant electrical system and minimize disturbance to adjacent plant loads and the upstream utility system.

1.3.5 Switching and Operational Duty

- **Transient-Free Switching:** The capacitor stages shall be switched on and off in a transient-free manner with an ABB DS1 switch (no substitutes) so that energization and de-energization do not create objectionable switching transients on the power system.
- **Sequential Starting Duty:** Unless otherwise specified, the system shall be suitable for one motor start at a time on the protected bus, with a minimum time between starts of **[5 minutes]**. Where specified, the system shall be provided with a fast-discharge arrangement

suitable for subsequent motor starts in approximately **[10 seconds]**. The operation sequence shall not depend upon receipt of motor-start confirmation (see section 15.3).

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 motor start solution enclosure system shall be Listed and Labeled by a Nationally Recognized Testing Laboratory (NRTL) to the following standards:
- **United States:** Where the equipment is not listed by a Nationally Recognized Testing Laboratory (NRTL), the complete equipment assembly shall be evaluated at the manufacturer's facility prior to shipment and shall bear a field-evaluation label applied by an accredited Field Evaluation Body (FEB) acceptable to the Authority Having Jurisdiction (AHJ).
 - **Canada:** Where the equipment is not certified by a certification organization acceptable to the applicable provincial or territorial Authority Having Jurisdiction (AHJ), the complete equipment assembly shall be subject to a Special Inspection / Field Evaluation in accordance with CSA SPE-1000, *Model Code for the Field Evaluation of Electrical Equipment*. The evaluation shall be performed by a Standards Council of Canada (SCC)-accredited inspection body recognized by the applicable AHJ, and the equipment shall bear the applicable Special Inspection / Field Evaluation label prior to shipment.
- 2.2 The capacitor bank control system shall be UL508A Certified for both Canadian and US products.

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 disconnect switches, ground switches, circuit breakers, capacitor switching device (ABB DS1), iron-core turning reactors (when necessary), capacitor fuses, capacitors, discharge devices (when applicable), and controls.
- **Accessibility:** All components shall be accessible and removable from the front, side, or rear of the enclosure.
- **Materials:** Enclosure walls and doors shall be fabricated from 11-gauge cold-rolled A60 galvanized steel (or specify 12-gauge stainless steel, type 304, 316, or 409).
- **Roof:** The roof shall be sloped front-to-back to ensure positive watershed.
- **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 disconnect switch compartment (if provided) shall feature an internal hinged protective barrier to prevent inadvertent contact with live terminals while allowing access to other compartments.
- **Viewing Windows:** Impact-resistant, UV-resistant, wide-view windows shall be provided, as applicable, for the interrupter switch compartment (if provided) to verify blade position, ground switch (if provided) 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 filters. Filters must be replaceable while the motor start system 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 (IF PROVIDED)

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 motor start solution 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.

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 motor start capacitor bank 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 Weather 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. Status contacts provided under this section shall be used for equipment monitoring, protection and interlocking and shall not constitute a motor-start confirmation.
- **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 filter bank's trapped-key interlock system to prevent out-of-sequence entry or operation of the capacitor bank.

9 Stage Switching Devices (ABB DS1)

9.1 General Requirements

Each capacitor stage shall be controlled by an **ABB DS1** capacitor switch, a specialized, servomotor-actuated device engineered for high-resolution, transient-free capacitive switching. No substitutions shall be allowed (unless approved), as this technology is field proven and qualified to switch large capacitor stages simultaneously while maintaining precise phase independence through its three-servomotor architecture. To meet the rigorous demands of motor starting duty, the switching system must be fully integrated with SEL-487V or ABB REX640 protection relay to provide switching commands, protection, interlocking and transient-free switching coordination. This integration utilizes custom logic and high-speed timing to ensure precise coordination, safety, and transient-free performance during rapid, sequential motor-starting operations.

9.2 Technology and Performance

- **Synchronous Actuation:** The switch shall utilize a brushless servomotor mechanism to independently control each phase. The embedded controller must synchronize the closing operation at the zero-voltage crossing and the opening operation at zero current to ensure transient-free and restrike-free performance.
- **Transient Elimination:** The switching operations must be repeatable with a precision level of approximately 300 μ S. This high-resolution control eliminates the need for traditional inrush mitigation devices such as transient inrush reactors.
- **Mechanical and Electrical Endurance:** The device shall be rated for at least 50,000 operations without the need for an overhaul. The servomotors must provide maintenance-free operation and remain reliable in extreme environmental conditions ranging from -15°C to +55°C. In cooler or warmer environments, a unitized air conditioner and/or heater shall be provided to keep the DS1 within its optimal temperature range.
- **On-Board Energy Storage:** The switch shall include an on-board capacitor to provide the necessary power for switching operations, ensuring emergency energy is available even in the event of a control supply failure.

9.3 Fast Consecutive Motor Starts (If specified)

A standard motor starting solution typically permits only one operation every 5 minutes to allow for passive resistor-based capacitor discharge. When consecutive starts are required in less than 5 minutes, the fast switching motor start capacitor bank shall be equipped with a specialized fast-discharge circuit to ensure safe, rapid re-energization.

- **Rapid Cycle Capability:** When specified, a fast-discharge circuit shall be provided to reduce the residual capacitor voltage to near-zero within 5 seconds. This allows a subsequent motor start to occur within 10 seconds of the previous de-energization without risk of transient-induced damage.

9.4 Monitoring and Diagnostics

- **Advanced Monitoring:** The DS1 switch shall include embedded diagnostics to evaluate its own health and to alarm when necessary and lockout when necessary.

9.5 Safety and Interlocking

- **Mechanical Interlocking:** The DS1 shall be electrically and mechanically interlocked with the bank's main air-disconnect switch (or main incoming breaker) and ground switch to prevent unauthorized access or operation while the bank is energized.
- **Self-Protection:** The DS1 shall feature an internal "Self-Open" function that operates in the event of an alarm, insufficient operating energy, or an unsuccessful close operation. This function shall be internal to the switching device and shall constitute device self-protection only; it shall not be used by the MotorVAR controller as motor-start confirmation or to determine successful completion of the motor-start sequence.

10 Detuning

10.1 General Design and Construction

A fast switching motor start capacitor bank, like any other capacitor bank application can excite a resonance when placed in a harmonic environment. For motor start applications in a harmonic environment, detuning reactors shall be provided to tune the motor start solution to either the 4.8th or the 4.2nd harmonic as determined by a harmonic study.

- **Materials:** Windings shall be copper or aluminum based on the supplier's recommendation. The magnetic core shall be constructed of high-grade, grain-oriented magnetic steel laminations.
- **Insulation System:** The reactors shall utilize a 220°C insulation system. The design shall limit temperature rise to 115°C over a 60°C ambient (or 80°C rise over a 60°C ambient).
- **Processing:** The complete reactor assembly shall undergo Vacuum Pressure Impregnation (VPI) using a high-performance resin to ensure mechanical and environmental integrity.
- **Magnetic Design:** To minimize gap magnetic losses and extraneous magnetic fields, a distributed gap design shall be utilized. All core gaps shall be cemented to minimize audible noise levels.

10.2 Electrical Ratings and Saturation

The reactor current ratings and magnetic design shall be based on the following criteria:

- **Saturation Margin:** The reactor core shall not saturate for currents less than 250% of the fundamental current rating of the filter bank or stage.
- **Flux Density:** Peak flux density of the core shall be limited to 1.2 – 1.4 Tesla, assuming all harmonic current peaks are 100% coincident. Core design must be based on peak flux, not solely on the RMS current rating.
- **Harmonic Spectrum:** Reactor ratings shall be verified by computer simulations. If project-specific harmonic data is unavailable at the time of the bid, the following minimum current spectrum (in Amperes) shall be utilized for design:
 - **I₁** (Fundamental Current Rating of the Reactor): 1.5 times fundamental current rating of the stage or bank at nominal system voltage.
 - **ITuned** (Tuning Frequency Current Rating of the Reactor): 0.5 times fundamental current rating of the branch (stage) at nominal system voltage.
- **Thermal Duty and Starting Profile:** The reactor shall not be designed or applied on a short-time or intermittent-duty basis. The reactor shall be 100% continuously rated for operation at its specified voltage, current, and reactive power duty without exceeding the temperature limits of its insulation

system. The continuous-duty rating shall apply regardless of the frequency or duration of motor-starting sequences.

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 (if provided) or incoming main breaker (if provided) 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 stages) offline.

11.5 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 covers to protect against debris and moisture.
- **Design Restrictions:** The system shall allow all doors to be opened simultaneously once the sequence is initiated.

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 filter 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/CUL-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

- **SEL-487V Relay / ABB REX640:** The motor-starting capacitor bank shall utilize an SEL-487V, ABB REX640, or approved equivalent protection and control relay programmed specifically for the motor-starting application. The relay shall coordinate capacitor-stage switching, system protection, interlocking, and application-specific timing.
- **Motor-Start Command:** The MotorVAR control sequence shall be initiated by a motor-start command received from the associated motor starter. Where multiple motors are connected to the same bus, the initiating command shall identify the motor to be started so that the programmed capacitor stages and switching sequence appropriate to that motor are selected.
- **Control Philosophy:** No motor-start confirmation signal or bidirectional motor-start confirmation handshake shall be required for operation of the MotorVAR system. The MotorVAR controller shall not determine whether the motor has successfully started based upon receipt or absence of a motor-start confirmation signal.
- **Capacitor-Stage Sequencing:** Upon receipt of the motor-start command, the programmed capacitor stages shall be energized. Initial stage removal shall be initiated based upon measured system voltage. Subsequent capacitor stages shall be removed using application-specific time delays established from the motor characteristics, motor/load inertia, electrical-system characteristics, and motor-starting study.
- **Protection Independence:** Protective functions, including overvoltage protection, shall operate independently of motor-start confirmation. A protective trip shall be initiated when the applicable electrical protection threshold is exceeded regardless of motor-start status.
- **Monitoring and Diagnostics:** Equipment status, alarms, diagnostic information, auxiliary contacts, and communications may be used for equipment monitoring, protection, maintenance, annunciation, and interlocking. Such functions shall not be required to determine successful completion of the motor-start sequence.

15.4 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).

15.5 Advanced Metering and Protection

- **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 50th harmonic.
- **System Overvoltage Protection:** The bank shall be equipped with independent three-phase overvoltage protection with separate alarm and trip setpoints for protection of the capacitors, motor, and connected electrical system. The protection shall operate solely in response to measured system voltage and shall operate independently of motor-start status. The overvoltage function shall not be used to determine or confirm whether the motor has started.

15.6 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 motor start solution enclosure system shall be Listed and Labeled by a Nationally Recognized Testing Laboratory (NRTL) to the following standards:

United States: Where the equipment is not listed by a Nationally Recognized Testing Laboratory (NRTL), the complete equipment assembly shall be evaluated at the manufacturer's facility prior to shipment and shall bear a field-evaluation label applied by an accredited Field Evaluation Body (FEB) acceptable to the Authority Having Jurisdiction (AHJ).

Canada: Where the equipment is not certified by a certification organization acceptable to the applicable provincial or territorial Authority Having Jurisdiction (AHJ), the complete equipment assembly shall be subject to a Special Inspection / Field Evaluation in accordance with CSA SPE-1000, Model Code for the Field Evaluation of Electrical Equipment. The evaluation shall be performed by a Standards Council of Canada (SCC)-accredited inspection body recognized by the applicable AHJ, and the equipment shall bear the applicable Special Inspection / Field Evaluation label prior to shipment.

16.3 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.

16.4 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.

16.5 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 Motor Starting Performance

The following motor starting calculations and possible starting methods shall be performed to ensure reliable starting performance.

- **Motor Only (Across-the-Line) Case:** This calculation evaluates the baseline impact of starting the motor without compensation, determining the maximum voltage sag at the bus and the motor terminals, as well as the available starting torque under weak grid conditions.
- **Capacitor Start Case:** This analysis calculates the specific reactive power requirements needed to support the bus voltage during the start, modeling the local reactive power injection to minimize system inrush current and maintain motor terminal voltage.
- **Capacitor Start + Line Reactor Case:** For specialized applications, the combined effect of a series line reactor and capacitor start system shall be evaluated calculating the required line reactor inductance to optimize voltage sag mitigation, inrush current limitation, and torque preservation.
- **Engineering Letter Report:** A formal letter report shall be provided for each study, documenting the expected results and performance levels for the specified equipment, including calculated voltage sags, starting torque percentages, and system inrush magnitudes.
- **Data Requirements:** All technical data required for the completion of the motor starting study shall be provided by the customer upon the issuance of a purchase order.

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 motor start 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.

17.1.4 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, protection schemes, motor-start command inputs, protection functions, and monitoring/status outputs.
- **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 with all switches in the closed position.

- **Power-Frequency Withstand:** Power-Frequency Withstand: The complete equipment assembly shall be subjected to power-frequency dielectric withstand testing in accordance with IEEE C37.20.3 and IEEE Std 4.
- **Lightning-Impulse Withstand (BIL):** The equipment insulation system shall be designed and tested to the applicable lightning-impulse withstand (BIL) requirements of IEEE C37.20.3, with impulse testing performed in accordance with IEEE Std 4.

20.3 Component-Specific Testing

- **Air Disconnect Switch:** Each air disconnect switch shall be subjected to contact-resistance testing using a micro-ohmmeter, a 1-minute power-frequency dielectric withstand test at the applicable test voltage, and mechanical operation verification. Testing shall be performed in accordance with the applicable requirements of IEEE C37.30.1 and IEEE Std 4.
- **Transient Inrush Reactors (when applicable):** 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

- **ABB DS1:** Testing shall include Hi-Pot, Timing, Contact Resistance, Heater Wattage, and all other field tests recommended by ABB.

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 20.1 (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 shunt reactor 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:

VarStec Power Solutions
MotorVar
Info@VarStec.com
VarStec.com