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Guide Form Specification
Harmonic Filter and
Power Capacitor Bank Application Studies

1 General

1.1 Scope of Work

The supplier shall perform the power system studies required to evaluate the application, performance, and equipment duty of a three-phase, medium-voltage metal-enclosed power capacitor bank or harmonic filter bank. The purpose of the study shall be to determine the suitability of applying shunt power capacitors or a harmonic filter bank to the subject power system, identify any unacceptable resonance, harmonic, switching-transient, insulation-coordination, or equipment-duty concerns, and, where necessary, develop an appropriate capacitor-bank or harmonic-filter solution. The study scope shall include, as applicable to the project, harmonic analysis and harmonic filter design, load flow analysis, short-circuit analysis, peak inrush analysis, outrush and close-in fault analysis, reactor-limited fault TRV and breaker duty assessment, altitude derating and insulation coordination, and protection coordination review.

The study shall be based on the actual electrical characteristics of the system, including utility source conditions, source strength, transformer impedance, plant distribution system configuration, existing and future loads, non-linear load characteristics, capacitor-bank or filter-bank configuration, switching arrangement, system grounding, altitude where applicable, and planned operating scenarios. The study shall address both normal and abnormal system operating conditions, including contingency configurations where applicable, and shall verify not only system performance but also the suitability and rating of the major capacitor-bank or harmonic-filter components and associated switching devices for the intended service.

1.2 Displacement Power Factor Correction

Where the project objective is displacement power factor correction, the study shall determine the required reactive power rating, switching arrangement, and application requirements for a medium-voltage shunt power capacitor bank, detuned capacitor bank, or harmonic filter bank as required. The study shall confirm that the proposed reactive compensation solution can be applied without creating unacceptable resonance, excessive voltage distortion, or unacceptable switching duty on associated equipment while meeting the displacement power factor objectives.

1.3 Harmonic Mitigation and Resonance Control

Where the project objective includes harmonic mitigation, resonance control, or reactive compensation, the study shall determine the required harmonic filter-bank design and associated performance requirements. The harmonic filter bank may be applied to reduce harmonic voltage and current distortion, prevent or preclude harmful resonance conditions, provide detuning of a capacitor bank, supply reactive power for displacement power factor correction, or achieve a combination of these objectives. The study shall determine the appropriate filter topology, tuning point, damping, reactive power rating, and switching arrangement required to satisfy the specified project objectives and to maintain harmonic voltage and current distortion within the applicable project limits at the Point of Common Coupling and within the plant distribution system.

1.4 Study Objectives and Key Evaluation Criteria

The study may be used for industrial plants, mining facilities, renewable energy plants, utility-interconnected facilities, or other medium-voltage systems where conventional capacitor banks, detuned capacitor banks, or harmonic filter banks are being considered. At a high level, the study shall determine whether the proposed reactive compensation solution is suitable for the power system and project objectives, whether it creates unacceptable resonance, harmonic distortion, or equipment-duty concerns, whether the proposed equipment and switching arrangement are suitable for the intended operating conditions, and whether a conventional capacitor bank, detuned capacitor bank, or harmonic filter bank is the appropriate solution for the application.

2 Submittals

2.1 General

Submittals shall include all study assumptions, methodology, simulation results, design recommendations, and supporting documentation necessary for technical review. Preliminary study criteria and assumptions shall be reviewed and approved by the Owner prior to commencement of the study. The required level of modeling detail and the study scenarios to be simulated may vary depending on project requirements, utility interconnection requirements, and the complexity of the facility.

2.2 Final Study Report and Deliverables

The final report shall include, at minimum, the following:

1. Study criteria, assumptions, methodology, and applicable standards.
2. Summary of input data, system parameters, and operating cases evaluated.
3. Graphical one-line representation of the system model.
4. Summary tables of key results with interpretation.
5. Load flow results, including system voltages, reactive power flow, and voltage change associated with capacitor-bank or filter-stage energization, where applicable.
6. Harmonic compliance tables at the Point of Common Coupling and, where required, at major plant buses or load centers.
7. Impedance scans for key buses and identification of any resonance or detuning concerns.
8. Harmonic analysis results, including harmonic voltage distortion, harmonic current distortion, and harmonic current duty for proposed or existing capacitor banks and harmonic filter banks.
9. Recommended capacitor-bank, detuned capacitor-bank, or harmonic filter-bank design, as applicable, including key ratings, tuning points, damping factors, and switching arrangement.
10. Filter or capacitor-bank component duty verification, including capacitor voltage duty, capacitor current duty, capacitor kvar duty, reactor duty, resistor duty, and losses, as applicable.
11. Peak inrush analysis results, including switching-device duty verification for single-bank and back-to-back switching, where applicable.
12. Outrush and close-in fault analysis results, including victim-breaker duty verification and evaluation of any required transient limiting inductors or other mitigation measures, where applicable.
13. Reactor-limited fault TRV and breaker duty assessment results, including verification of breaker suitability and recommended mitigation measures where required.
14. Altitude derating and insulation coordination results for projects above 1000 meters (3300 feet) above sea level, including evaluation of protective margins, surge arrester application, and any required mitigation measures.

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15. Short-circuit analysis results, where required to validate the system model or confirm equipment ratings.
16. Conclusions and recommendations.
17. Preliminary one-line diagram of the recommended equipment.
18. Non-proprietary equipment specification for the recommended solution, where required.
19. Electronic copies of the final study model files in native format.

2.3 Meetings

The study engineer shall be available for an initial kickoff meeting and a final review meeting to present key assumptions, findings, conclusions, and recommendations. These meetings may be conducted by WebEx, Teams, or similar remote conferencing platform.

3 Study Objectives

3.1 Reactive Power Requirements

The study shall determine the reactive power required to correct the plant displacement power factor to the specified target under maximum plant load conditions. Load data used for this determination may be based on utility billing data, interval data, plant load tables, measured operating data, information shown on the one-line diagram, or power-quality measurement reports provided by the Owner.

3.2 Resonance Review

The study shall confirm that the application of the proposed reactive compensation equipment, whether a conventional capacitor bank, detuned capacitor bank, or harmonic filter bank, will not excite resonance conditions that result in unacceptable voltage distortion under any normal or specified abnormal operating condition. Where unacceptable resonance is identified, the study shall develop and evaluate an appropriate detuned capacitor-bank or harmonic filter-bank alternative.

3.3 Interaction with Motor Starting and Process Equipment

Where VFD motor starters, RVSS motor starters, cycloconverters, rectifiers, or other large non-linear or time-varying loads are present, the study shall examine their interaction with the proposed reactive compensation equipment. Where such interaction could interfere with proper operation, performance, or equipment duty, the study shall identify and recommend suitable mitigation measures.

3.4 Harmonic Mitigation and Filter Design Objectives

Where harmonic mitigation, resonance control, or detuning is required, the study shall determine the appropriate filter or detuned-bank design needed to satisfy the project objectives. The design may be required to reduce harmonic voltage distortion, reduce harmonic current distortion, prevent or preclude harmful resonance conditions, provide reactive power compensation, or achieve a combination of these objectives. The design shall account for existing loads, future loads identified by the Owner, ambient harmonic voltage distortion, and the actual operating behavior of the facility.

The harmonic filter or detuned-bank design shall also be evaluated at partial-load operating conditions to confirm acceptable performance over the anticipated operating range, including acceptable power factor, acceptable harmonic voltage distortion, and acceptable harmonic current duty in each branch.

3.5 Capacitor Stage Size and Voltage Change

The study shall determine the maximum practical stage kvar rating such that the voltage change resulting from energization of any single capacitor or filter stage does not exceed the specified project limit. Where practical, binary stage sizing may be used to reduce the total number of switching stages while preserving adequate control resolution.

3.6 Switching Duty and Transient Evaluation

The study shall determine whether the proposed switching arrangement and switching devices are suitable for the required duty. This shall include, as applicable, evaluation of peak inrush current, back-to-back switching duty, outrush duty, close-in fault duty, and the need for transient inrush reactors, transient limiting inductors, outrush reactors, or other mitigation measures.

3.7 Breaker Duty and TRV Evaluation

Where applicable, the study shall determine whether reactor-limited fault conditions impose transient recovery voltage or breaker-duty requirements in excess of the capability of the proposed switching device. Where such conditions are identified, the study shall recommend appropriate mitigation measures or alternate equipment ratings.

3.8 Altitude Derating and Insulation Coordination

For installations above 1000 meters (3300 feet) above sea level, the study shall include altitude derating and insulation coordination evaluation to confirm the suitability of the proposed equipment. The study shall determine whether standard equipment ratings remain acceptable with properly coordinated surge arresters or whether changes in arrester application, lead length, insulation level, or equipment rating are required.

3.9 Equipment Recommendation

The final study report shall include a recommended capacitor-bank, detuned capacitor-bank, or harmonic filter-bank design, as applicable, including ratings, stage or branch configuration, switching arrangement, and major application requirements. Where specified, a non-proprietary equipment specification shall be included in the appendix of the report.

4 Study Scope

4.1 Network Model

4.1.1 Utility Source Representation

The utility source shall be modeled as a Thevenin equivalent. Additional portions of the utility or upstream network shall be modeled where necessary to represent known harmonic sources, harmonic sinks, capacitor banks, FACTS devices, arc furnaces, or other significant system elements in the electrical vicinity of the Point of Common Coupling.

4.1.2 Facility Model

Electrical parameters for the plant circuits and equipment shall be based on the project one-line diagrams, equipment data sheets, and manufacturer-supplied data. Harmonic-producing equipment shall be modeled using available manufacturer data, appropriate software models, or harmonic current-source representation where detailed converter models are not available.

4.1.3 Engineering Assumptions

Where complete design information is not yet available, reasonable estimated values may be used for preliminary analysis. All such assumptions shall be clearly identified in the final report.

4.1.4 **Software:** The study shall be performed using commercially recognized power-system analysis software suitable for industrial and mining applications. For steady-state studies, acceptable software shall include ETAP, EasyPower, and SKM Power Tools for Windows (PTW). For electromagnetic transient studies, including switching-transient and converter-transient analysis, acceptable software shall include PSCAD and EMTP. The selected software shall be appropriate to the required scope of work. Electronic copies of the final study model(s) shall be furnished in native format.

4.2 Required Studies

4.2.1 Harmonic Analysis and Filter Design

The study shall include harmonic analysis and harmonic filter design of the system. The analysis shall be used to develop, evaluate, and verify the suitability of the proposed capacitor bank or harmonic filter bank for the intended application. Where a harmonic filter bank is required, the study shall include design and evaluation of the applicable filter topology, including notch, high-pass, and C-high-pass filters, as appropriate for the project.

At minimum, the harmonic analysis and filter design study shall include the following:

1. Calculation of voltage distortion at the Point of Common Coupling.
2. Calculation of voltage distortion at major plant buses or load centers.
3. Calculation of current distortion at the Point of Common Coupling.
4. Identification of system resonance conditions and resonance concerns.
5. Sensitivity analysis considering varying system impedance, nearby capacitor banks, and stray capacitance, as required to identify de-tuning or resonance concerns.
6. Determination of the required filter topology, tuning point, damping factor, and reactive power rating for each proposed filter branch.
7. Verification of capacitor voltage stress, capacitor current duty, capacitor reactive power duty, reactor current loading, resistor current, resistor power dissipation, and total filter losses.
8. Verification that all capacitors, reactors, auxiliary capacitors, and damping resistors are suitable for the worst-case harmonic duty and system operating conditions.
9. Where existing component values are known, reverse-calculation or back-calculation of tuning frequency, reactive power rating, and damping factor to support evaluation of existing or customer-specified designs.

Where IEC, utility-specific, or project-specific harmonic limits apply, those requirements shall also be incorporated into the study and clearly identified in the report.

4.2.2 Peak Inrush Analysis

The study shall include a peak inrush analysis to evaluate transient switching duty during capacitor-bank energization. The analysis shall evaluate both single-bank switching and back-to-back switching conditions, as applicable to the project configuration.

At minimum, the peak inrush analysis shall include the following:

1. Calculation of peak inrush current for single-bank energization.
2. Calculation of peak inrush current and natural inrush frequency for back-to-back switching conditions.
3. Evaluation of the effect of source strength, source X/R ratio, feeder inductance, buswork inductance, internal stage inductance, and any applied inrush or outrush reactors on the transient duty.
4. Verification of switching-device continuous current rating using the applicable current factors for grounded-wye and ungrounded/delta bank configurations.
5. Verification of switching-device capacitive switching rating.

6. Verification that the calculated peak inrush current does not exceed the applicable switching-device making capability or close-and-latch capability, as applicable.
7. Evaluation of inrush frequency and current-frequency product in accordance with the applicable IEEE criteria for the selected switching technology.
8. Verification of circuit-breaker switching class suitability for back-to-back capacitor switching duty, where circuit breakers are used.

4.2.3 Outrush and Close-In Fault Analysis

The study shall include an outrush and close-in fault analysis to evaluate the transient discharge duty imposed on the designated victim breaker when closing into a nearby fault or other close-in fault condition involving energized capacitor stages. The analysis shall be performed for the applicable system arrangement, including both single-ended and double-ended substation configurations where applicable.

At minimum, the outrush and close-in fault analysis shall include the following:

1. Calculation of peak outrush current.
2. Calculation of outrush frequency.
3. Calculation of the current-frequency product, I × f.
4. Determination of the total discharge loop inductance and total capacitance contributing to the event.
5. Verification of the victim breaker against applicable close-and-latch or peak making-current criteria.
6. Verification of technology-specific frequency or I × f limitations, where applicable.
7. Evaluation of the effect of transient limiting inductors, outrush reactors, alternate breaker technology, or alternate breaker class on the resulting duty.
8. Identification of the worst-case configuration, including tied or double-ended arrangements where added parallel capacitance may increase duty.

4.2.4 Reactor-Limited Fault TRV and Breaker Duty Assessment

Where a non-saturating current-limiting reactor is present, the study shall include an assessment of reactor-limited fault TRV and breaker duty. This analysis shall be used to verify that the designated victim breaker is suitable for the resulting TRV peak and Rate-of-Rise-of-Recovery Voltage during interruption of a reactor-limited fault. This study is applicable primarily to air-core reactors and is not intended for iron-core tuning reactors that do not maintain inductance under fault conditions.

At minimum, the reactor-limited fault TRV study shall include the following:

1. Calculation of the reactor-limited fault current.
2. Calculation of the physical TRV waveform characteristics, including time-to-peak.
3. Conversion of the physical waveform to the equivalent standard reference parameters required for breaker-duty comparison.
4. Calculation of total system TRV peak, including both the high-frequency reactor contribution and the source-side recovery voltage contribution.
5. Calculation of the applicable duty-specific breaker capability using reduced-fault-duty multipliers, as applicable.
6. Verification that the calculated TRV peak and RRRV remain within the breaker's allowable duty envelope.
7. Evaluation of mitigation measures where required, including definite-purpose breakers, higher-rated breakers, or phase-to-ground surge capacitors sized to reduce RRRV to acceptable levels.

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4.2.5 **Altitude Derating and Insulation Coordination**

For projects installed at unusual altitude, the study shall include an altitude derating and insulation coordination assessment for the proposed capacitor bank or harmonic filter bank. The analysis shall verify that the equipment dielectric withstand capability remains adequate at the installation altitude when coordinated with the selected surge arrester characteristics and installation geometry.

At minimum, the altitude derating and insulation coordination study shall include the following:

1. Evaluation of the loss of dielectric strength associated with the project installation altitude.
2. Verification of insulation coordination using both IEEE and IEC methodologies, where required by the project.
3. Evaluation of equipment nameplate withstand ratings, including BIL, chopped-wave withstand, and power-frequency withstand, as applicable.
4. Evaluation of surge arrester characteristics, including MCOV, protective levels, and associated surge performance.
5. Evaluation of arrester lead length and associated inductive voltage drop.
6. Calculation of the total surge voltage at the equipment terminals.
7. Verification that the required protective margin is maintained at the target altitude.
8. Determination of whether standard sea-level equipment ratings remain acceptable with properly coordinated surge arresters or whether increased insulation ratings are required.
9. Recommendation of mitigation measures where required, including reduced arrester lead length, improved arrester protective characteristics, or the minimum necessary increase in equipment insulation rating.

4.2.6 **Load Flow Analysis**

The study shall include load flow analysis to evaluate the effect of the proposed capacitor bank, detuned capacitor bank, or harmonic filter bank on system power flow, bus voltage, transformer loading, and reactive power flow. The analysis shall confirm that the proposed reactive compensation equipment performs acceptably under the applicable operating conditions and does not create unacceptable voltage rise or other adverse system effects.

At minimum, the load flow analysis shall include the following:

1. Calculation of bus voltages for the normal and specified abnormal operating conditions.
2. Evaluation of reactive power flow and the effect of the proposed reactive compensation equipment on plant displacement power factor.
3. Evaluation of voltage change associated with energization of individual capacitor-bank or filter-bank stages.
4. Evaluation of transformer loading, feeder loading, and other major system quantities affected by the proposed reactive compensation equipment.
5. Evaluation of normal, contingency, and partial-load operating conditions, as applicable to the project.
6. Verification that the proposed reactive compensation solution provides acceptable steady-state operating performance over the anticipated range of system conditions.

4.2.7 Short-Circuit Analysis

The study shall include short-circuit analysis sufficient to validate the system model and to confirm the adequacy of the short-circuit ratings of the affected equipment. The analysis shall be used to confirm the available fault duty at the buses where the proposed capacitor bank, detuned capacitor bank, or harmonic filter bank is connected and at other locations where equipment application or protection may be affected.

At minimum, the short-circuit analysis shall include the following:

1. Calculation of available three-phase short-circuit current at the applicable buses.
2. Calculation of line-to-ground short-circuit current where grounding method or equipment application makes such evaluation necessary.
3. Verification of the adequacy of the interrupting and momentary ratings of the feeder breaker and other affected switching devices.
4. Verification of the short-circuit suitability of the proposed reactive compensation equipment and associated components, as applicable.
5. Validation of the source representation and system model used for the related harmonic, transient, and equipment-duty studies.
6. Identification of any equipment rating limitations or protection concerns requiring mitigation or alternate equipment ratings.

4.3 Operating Conditions

The study shall evaluate both normal operating conditions and abnormal or contingency operating conditions identified by the Owner, including changes in utility source strength, alternate system configuration, equipment outages, and partial-load operation of the plant.

5 Power System Data to Be Supplied by Owner

The following information shall be supplied to the successful bidder, to the extent available. Any additional data required to complete the study shall be clearly identified in the bidder's proposal.

5.1 Owner-Supplied Data

1. Performance requirements of the capacitor bank or harmonic filter bank
2. Description of planned expansions, plant operating scenarios, and contingency operation
3. One-line diagram of the system to be modeled
4. Minimum, maximum, and average utility short-circuit levels
5. Identification of the Point of Common Coupling on the one-line diagram
6. Service transformer base rating and impedance
7. Location and rating of proposed capacitor bank, if known
8. Location and ratings of existing capacitor banks and harmonic filter banks
9. Utility bills for reactive power evaluation
10. Interval metering data
11. Load table showing expected kW, kvar, kVA, and power factor
12. Harmonic measurement data, where available
13. Non-linear load data for significant harmonic-producing loads

6 Power System Simulation Software

6.1 General

The supplier shall utilize accepted commercial power-system simulation software capable of short-circuit, load flow, harmonic analysis, and transient analysis as required to predict system performance. Acceptable software may include:

- ETAP
- EasyPower
- SKM
- EMTP-RV for transient studies
- Other equivalent software acceptable to the Owner

6.2 Deliverables

The final report shall include the study input file created using the software package used for the study, in the latest available native file format. Where available, an exportable text or ASCII version of the model shall also be provided.

7 Compliance with Standards and Codes

The study shall be performed using the following standards and codes, as applicable to the scope of work:

- 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 C57.32: Standard for Terminology, Step-Voltage Regulators, and Requirements for Grounding-Device and Filter Resistors
- IEEE 1531-2020: Guide to Application and Specification of Harmonic Filters
- 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

8 Supplier Quality System

8.1 Quality Certification

The supplier shall maintain a third-party certified quality management system issued by an internationally recognized accreditation body. Evidence of current certification shall be provided with the proposal.

8.2 Engineering Qualifications

The supplier shall have qualified engineering staff experienced in harmonic analysis, capacitor-bank application, and harmonic filter design. Engineers performing the study shall have demonstrated experience in conducting harmonic analysis and developing practical capacitor-bank and harmonic filter-bank solutions for medium-voltage power systems.

9 Bid Requirements

1. The supplier shall state all exceptions to the specification.
2. If no exceptions are taken, the supplier shall explicitly state that there are no exceptions.
3. The supplier shall provide resumes or qualification summaries for the engineers assigned to the study.
4. The proposal shall be submitted on a fixed-price basis.

10 Acceptable Suppliers

The supplier shall demonstrate the following qualifications:

1. The supplier shall maintain a quality assurance program.
2. The supplier shall be regularly engaged in the engineering, design, and application of medium-voltage power capacitor banks and harmonic filter banks.
3. The supplier shall have experience in the application and supply of medium-voltage metal-enclosed capacitor banks and harmonic filter banks, and shall be capable of recommending, supplying, and supporting equipment consistent with the study conclusions.

10.1 Acceptable Manufacturer and Product:

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