Engineering Support Services for:

Plains and Eastern HVdc

Clean Line Energy Partners

Report R1308.00.00

Specification Development

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Glossary of Terms and Definitions

AMRS	Central Alarm Monitoring and Reporting System
Availability	A measure of the amount of energy which could have been transmitted except for capacity limitations due to outages, arising from any cause, either forced or scheduled.
Award of Contract	Formal notice to recognize the successful equipment supplier's bid of project
BTU	British Thermal Units
Commencement Date	Official start time of the HVdc project
Commissioning Engineer	The technical person who will coordinate all of the testing work under this contract with the specific requirements of the Owner based on the Specification
Commissioning Instructions	
Company or Owner	Plains & Eastern Clean Line
Continuously Transposed Cable	Used in power transformers to provide several advantages in design and construction compared to conventional
Contract	Formal and legal agreement between the Contractor and Owner
Contract Documents	Pertains to all manuals, drawings and correspondence.
Contract Period	To be negotiated
Contract Price	Cost of the project.
Contracting Officer	Individual involved with the contract negotiations.
Contracting Officer's Technical Representative	The contractor's main technical contact person involved with the project.
Contractor	Single supplier of responsible for the design, equipment manufacturer and builder of the HVdc project
Contractor Site Manager	Formal representative in the field for the project.
CT	Current Transformer
DCCT	Direct Current measuring devices
Defect Liability Period	A time period during which any equipment failures are corrected at the Contractor's expense
Defect Liability Period	To be negotiated
DGA	Dissolved Gas Analysis
DMR	Dedicated Metallic Return
DNP3i	SCADA serial protocol
Engineer	Technical consultant to the Owner

EPC	Engineering, Procurement and Construction
Factory System Tests	A series of performance test done in the factory before delivery to site
Fire Emergency Plan	To be supplied by Clean Line?
Fire Risk Program	To be supplied by Clean Line?
Guarantee Period	A period of time stated in the contract where performance criteria are to be met by the Contractor
Guaranteed Reliability and Availability	Performance assertion based upon a predetermined index established by industry standards or contract negotiations
Guarantees	As per specification
Heat Run Test	A pre-defined length of time when all systems are stable
Inspection and Test Plans	Policies and procedures to assure that purchased equipment and materials conform to the quality requirements of the contract and to ISO9001
Instrument Calibration Certificate	Certifies that the instrument has been tested by accredited company.
ITP	Inspection and Test Plan
LIWL	Lightning Impulse Withstand Level
Master Controlling station	
MCBs/ MCCBs	Magnetic Circuit Breakers.
Multiple valve unit	An assembly of a number of valves mounted in a single structure.
NERC-CIP	North American Electrical Reliability Corporation - Critical Infrastructure Protection (
OFAF/ODAF	Oil Forced Air Forced/ Oil Direct Air Forced
Offer	The formal tender /bid from the equipment vendor based on the Specification for the HVdc project
Offer or Bid	The vendor's formal proposal for the supply of equipment for the HVdc scheme based on the Specification
Offeror	A vendor who submits a proposal for the supply of equipment for the HVdc project
OLTC	On Load Tap Changer
Operational Acceptance	
Operator	The person(s) in charge of the normal station operation
Operator Control and Display	
Operator Control and Display computer	The video display that is used by station staff to operate the HVdc station under normal conditions
OTI	Oil Temperature Indicator
Owner	Plains & Eastern Clean Line ("Company", "Owner") plans to develop this project based on a complete Engineering, Procurement, and Construction (EPC) contract
Owner's Representative	The Owner's technical adviser

Owner's Requirements	The Owner's specific requirements for the project including the Specification
P & E	Plains & Eastern HVdc system
PD	Partial Discharge
Performance Guarantees	Pertaining to Availability and Reliability established criteria.
Plant(Owners or Contractors)	
PMR	Pole Metallic Return
PRM	Progress Review Meeting
Project	
Purchaser	The Owner or the Company
QA	Quality Assurance
QP	Quality Plans
Quality Control Manager	Person in charge of the program
RAS	Remedial Action Scheme
Reliability	A measure of the capability of the HVDC link to transmit power above some minimum defined value at any point in time under normal operating conditions
RIV	Radio Interference Voltage
RTO/ISO	Regional Transmission Operator / Independent System Operator
SCADA	Supervisory Control and Data Acquisition
Scope of Supply	Broad description of the contractor's responsibilities
Senior Construction Manager	
SER	Sequence of Events Recorder
Specification	Comprehensive technical requirements for the design and manufacture of the HVdc equipment and overall HVdc project development
Supplier	The Contractor's equipment provider
Technical Requirements	Referring to specific & detailed technical sections within the Specification pertaining to the Contractor's design of equipment
TFR/DFR	Transient Fault Recorder/ Digital Fault Recorder
Thyristor level	Comprising a single thyristor, control and protection and associated components which make up a single voltage level within the valve
TP	Test Plan
Trial Operation Period	The trial operation period shall take place after completion of the various commissioning tests and correction of punch-list items discovered during commissioning. The purpose is to satisfy the Owner and the Contractor that equipment is fit for its purpose and is working satisfactorily under normal operating conditions. The trial operation period is 45 consecutive days.
TRM	Technical Review Meeting

Valve	A valve is all the components , external to the main assembly which forms one of the 6 arms of a 6 pulse Gratz converter bridge
Valve Module	The smallest assembly, comprising a number of thyristor levels, voltage grading and damping components, valve reactors, etc. from which the valve is built up and which exhibits the same electrical properties as the complete valve, but only a portion of the full voltage capabilities of the valve.
Works	A term related to the entire project.
WTI	Winding Temperature Indicator

1. Plains & Eastern Clean Line Project

This part of the specification covers the technical requirements for the converter stations of the Plains & Eastern HVdc (P&E) system based on line commutated converters (LCC). Plains & Eastern Clean Line ("Owner") plans to develop this project based on a complete Engineering, Procurement, and Construction (EPC) contract which it intends to award to a single entity ("Contractor"). The proposed HVdc transmission line would traverse from the Oklahoma panhandle region, across Arkansas and terminate at the Tennessee Valley Authority system a distance of approximately 711 miles. The western portion of this project will interconnect to the transmission system operated by the Southwest Power Pool in Texas County, Oklahoma. The eastern portion of the project will interconnect to the transmission system operated by the Tennessee Valley Authority in Shelby County, Tennessee. A third converter terminal located in Pope County, Arkansas and rated to deliver 500 MW will require that this scheme function as a multi terminal project. P&E will be configured as a bipolar LCC, ±600kV HVdc overhead transmission system rated at delivering a total of 3500 megawatts (MW) to the AC point-of-interconnection associated with the inverter station(s) in the eastern portion of the scheme, with a dedicated metallic return (DMR).

The Contractor's broad scope of work is defined in the subsequent sections of this Specification. All equipment, materials and services, whether explicitly stated or otherwise, that are necessary for the satisfactory operation of the converter stations, as described in the Specification, shall be deemed to be included in the scope of work of the Contractor unless specifically noted otherwise in this Specification.

The equipment and systems shall be capable of continuous operation for an anticipated minimum life of 40 years. The Owner shall have the right to reject or accept any work or material which, in its assessment, does not meet the requirements of this Specification and/or applicable National and International standards, codes, and rules.

In the event of a conflict between requirements of any two sections of the Specification/documents or requirements of different codes/standards specified, the more stringent requirement, as per the interpretation of the Owner, shall apply unless confirmed otherwise by the Owner in writing based on a written request from the Contractor.

1.1. Schedule

The project will proceed in 2 phases:

Phase 1 – A two converter terminal system rated at delivering a total of 3500 MW at the AC point-of-interconnection associated with the eastern portion of the scheme by an approximate 711 mile overhead HVdc transmission line with a DMR.

Phase 2 – Addition of a third converter station in Arkansas which is rated at delivering up to 500 MW at the AC point-of-interconnection associated with this converter station (multi-terminal operation). The net power transfer at the original inverter will still remain at 3500 MW, as measured at the ac point-of-interconnection. Provision must be made for operating the third terminal in rectifier or inverter mode. Delivery of the third converter station may follow delivery of the end points by up to XX weeks.

The Phase 1 rectifier must accommodate for the phase 2 rating in phase 1, with some non-essential equipment deferred (i.e. phase 2 ac filters)

1.2. Scope of Work

The scope of work is as follows:

1. A completely operational ±600 kV bipolar system consisting of three converter stations in two phases, including the necessary communication interface equipment and associated 345 kV HVac sub-station at the Hitchland Station, and 500 kV HVac sub-stations at Shelby Station and the Entergy terminal, where Hitchland is the converter station located in the western portion of the scheme, Shelby is the converter station in the eastern most portion of the scheme, and Entergy is the intermediate converter station. The scope shall include the overall project management, studies, design, engineering, training of P&E's personnel, manufacture, factory testing, supply of all items, delivery to the sites, loading and unloading, storing, handling, and moving into final position, installation, site testing, commissioning and placing the HVdc system and associated substations into successful operation.
2. The complete detailed engineering of the converter stations including the design of all civil works and all other required facilities and systems for Phase 1, detailed consideration shall also be given by the Contractor in pricing the implementation of the Phase 2 civil works as part of this Contract.
3. The supply of all spare parts, equipment handling, testing, maintenance and commissioning equipment as required for satisfactory operation of the HVdc converter stations and ac systems.
4. Complete civil works including, but not limited to, transformer, tower and equipment foundations, yard grading, roads, and walkways.
5. Supply of all labor and construction equipment, management and supervisory staff required to construct and commission the HVdc converter station.
6. Removal of all temporary site construction buildings and facilities.
7. The facility and necessary switchgear to transfer from monopolar DMR operation to monopolar permanent metallic operation (PMR) on other pole conductor and vice versa.
8. The facility and switchgear to operate monopolar with DMR and permanent metallic return (PMR) in parallel.
9. Any necessary dynamic reactive power devices and ac voltage control required to meet the requirements specified.
10. The termination equipment of the HVdc lines in the applicable stations.
11. In multi-terminal operation, the facility and necessary switch gear to reverse the power direction of any terminal.

1.2.1. System Engineering and Studies

The Contractor shall be responsible for overall system engineering studies and detailed design for all elements, systems, facilities and equipment. This shall include the proper definition and execution of all the interfaces with the systems of the existing AC networks at each converter station.

1. All required ac-dc simulator, digital or other studies as defined in Section 10.
2. Studies for insulation coordination for ac and dc equipment within the Contractor's scope of supply, studies for integration of the new HVdc system in the existing system, studies to ensure the proper coordination of the metal oxide surge arresters supplied with those located in the ac system where other surge arresters are used.
3. Studies for deciding the operational strategy and limits of the complete HVdc system.
4. Studies to ensure and demonstrate that the sending and receiving end networks shall not be adversely affected by the operation of the HVdc system, particularly with regard to sub-

synchronous oscillations and sub-synchronous resonances and harmonic injection and self-excitation.

5. Studies to determine the need for any voltage control dynamic devices (e.g. synchronous condensers, static var compensators (SVC), STATCOMs, or any other dynamic compensation equipment).
6. Stability studies.
7. Seismic studies for supplied equipment including the final valve and valve hall configuration.
8. Studies to ensure proper integration with the installed generation.
9. All other studies as defined in Section 10.
10. Multi-terminal operation system studies for Phase implementation.

1.2.2. Engineering and Detailed Design

The Contractor shall be responsible for the engineering and detailed design of the converter station. The design shall include, but not be limited to, the following main items in accordance with requirements of the Specification:

1. Design and specification of all equipment, systems, subsystems, facilities and auxiliary station services.
2. Station design including all electrical, mechanical and civil engineering, construction and installation specifications.
3. Detailed design of all interfaces with the equipment, services and facilities provided by P&E.

The Owner will carry out design review during the detailed design. The design review will include all the major equipment and systems, including at least the following:

1. Main circuit design
2. Insulation coordination
3. Harmonic performance
4. Availability and reliability
5. Audible noise
6. Station losses
7. Converter transformers including oil and transformer processing
8. Valve cooling
9. Thyristor valves
10. Control and protection
11. Telecommunication interface system
12. Sequences
13. Filters and Var compensation
14. DC switchgear
15. DC smoothing reactor
16. AC and dc bus work and their grounding systems
17. LV ac and dc auxiliary supply and UPS
18. Valve hall fire detection system

19. System studies
20. Multi-terminal operation

The Contractor shall provide all necessary information as shall be sought by the Owner during the design review.

1.2.3. Manufacturing and/or Supply of Equipment

1.2.3.1. HVDC Converter Equipment and HVAC Equipment

The HVdc converter equipment and HVac equipment to be designed, manufactured, tested, supplied, installed and commissioned by the Contractor in accordance with the Specification shall include, but not be limited to, the following major items:

1. Converters and associated auxiliaries, including monitoring, reporting and display systems.
2. Fully redundant converter station controls and protection and all associated measuring devices including interfaces with supervisory control and recording of transient disturbances on the system including inclusion of controllability of a third converter terminal (multi-terminal operation).
3. Facilities to remove and exchange a failed converter transformer with the spare unit in a maximum time of 72 hours.
4. Valve cooling systems and associated piping, including control, monitoring and display systems.
5. Valve hall ventilation systems including control, monitoring and display of systems.
6. Valve hall fire detection and protection systems
7. Fire protection systems in all buildings supplied by the Contractor as well as a deluge system for the converter transformers.
8. HV & LV pole equipment and all associated bus work, insulators, switchgear, controls, protection and measuring devices; dc line disconnects.
9. Converter transformers, with insulating oil and associated control and protection.
10. DC smoothing reactors.
11. AC & dc harmonic filters, PLC filters and associated controls, protection and measuring devices.
12. AC & dc surge arresters and dc surge capacitors.
13. Lightning protection
14. HVdc line fault location equipment
15. DMR monitoring and protection equipment including:
16. All the necessary switch gear for switching and operation monopolar with DMR alone, PMR alone and DMR in parallel with PMR.
17. The necessary switchgear in order to perform a power reversal of the tap online.
18. Connections to the HVdc line and DMR.
19. High Voltage ac and dc current and voltage measuring equipment.
20. Firewalls between transformers.
21. HV circuit breakers, isolators and grounding switches.
22. Switchyard control and protection system.
23. Bus work, bus post insulators, string insulators and hardware.

24. All interlocking logic/equipment for the HVdc and HVac yards.

1.2.3.2. Reactive Compensation

The reactive compensation equipment to be designed, manufactured, tested, supplied, installed and commissioned by the Contractor, in accordance with the Specification, shall include all the ac harmonic filters, shunt capacitors and reactors and other types of compensation as determined by the studies. This can include dynamic devices such as SVCs, STATCOMs and/or synchronous condensers. The facilities shall include all control, protection, monitoring and switching equipment. Phase 2 reactive power may be deferred.

1.2.3.3. Station Service and Mechanical Systems and Other Services

The Contractor shall design, manufacture, test, supply, install and commission all the station auxiliary systems and services at each converter station in accordance with the Specification, including but not limited to the following:

1. Station service transformers
2. Station service switchgear, ac and dc distribution boards, and motor control centers.
3. Batteries, battery chargers, and associated controls and protection.
4. Operator control and display for converter station, dc and ac switchyards and HVdc system.
5. Alarm, monitoring, annunciating & reporting systems.
6. Station operation, operator status display, metering and recording facilities.
7. Lighting systems, including indoor, outdoor and emergency lighting.
8. Complete grounding grid (as required including connection to equipment, cubicles, structures, cable trays, perimeter fence, etc. and lightning protection system).
9. All cabling systems, associated cable trenches and cable trays.
10. Water treatment and storage systems for equipment cooling and fire protection.
11. Air conditioning and ventilation systems.
12. Fire detection fighting systems.
13. Control, protection, monitoring, metering for all auxiliary services, as required.

1.2.3.4. Type Testing

The Contractor shall offer type tested equipment for the project. The Owner may accept the results and the reports of previous type tests based on the following:

1. Type test in accordance with the Specification and relevant specified standards.
2. The type tested equipment shall be of the same design, insulation class and rating as per the equipment offered under this contract.
3. The tests have been performed within 5 years from the date of contract award.
4. The stresses of the equivalent type tests shall be equal or greater than those determined for the equipment to be supplied.

The converter transformers and HVdc valves must be type tested. Previous test data will not be accepted.

In the event that equipment furnished includes important modifications of, or significant departure from, the designs of equipment on which type test report has been furnished or if there is evidence that the equipment does not comply with the requirements of the Specifications, the Contractor shall conduct the type test without any cost implication to the Owner. In case equipment of same design and rating are supplied under this contract from different supplier, they shall be type tested. Type tests performed on similar equipment that was performed 5 years or longer from the date of bid opening shall not be accepted.

Acceptance of the type test reports shall be at the discretion of the Owner. All type tests performed shall be witnessed by the Owner unless authority to proceed with the tests in absence is received from the Owner in writing.

The Contractor shall give notice of type tests to be witnessed by the Owner at least 30 days in advance of the scheduled tests.

1.2.4. Civil Works

The civil works, including structural works, to be provided by the Contractor, in accordance with the Specification, shall include the design & construction of all the items required for Phase 1 as listed below.

a. Detailed survey and soil investigation
b. Overall civil layout drawings
c. Final site grading and leveling, foundations, roadways within the designated areas, temporary fencing for the Contractor's designated areas and the eventual permanent fencing of the station complex.
d. Underground civil works: cable trenches, cable duct banks, cable pits, oil retention, fast drain systems, fire water, deluge, drainage, ground grid, etc.
e. Foundations for buildings and all equipment supplied by the Contractor
f. Architectural and structural design of converter building
g. Support structures for all equipment supplied by the Contractor
h. Building electrical power distribution and lighting
i. Water supply connections
j. Sewage connections

The Contractor shall also consider during the pricing of Phase 1 the civil works required for the implementation of Phase 2.

1.2.4.1. Building and Civil works

The Contractor shall be responsible to design and furnish any buildings needed for HVDC converter station at each site. The Contractor shall design and supply the required materials and construct all facilities required for the ac equipment area associated with the converter transformers and ac filters, dc switchyard and other work specified within its designated areas in this Specification for Phase 1including, but not limited to, the following:

1. All civil works, foundations, structures, equipment supports, trenches and duct banks for the ac equipment area associated with the converter transformers and ac filters, ac filter area and dc switchyard.
2. Converter buildings
3. Oil containment
4. Clean water connections
5. Waste water connections
6. Roadways within the switchyard for the present and for future expansions.

7. Provide all temporary fencing for the Contractor's designated area including internal fencing needed within the Contractor's designated area.

1.2.4.2. Foundations and Structures

1. Foundations for all equipment including spare converter transformers and spare parts that will be stored outdoors.
2. All switchyard structures including gantries/bus structures, equipment structures.
3. Other foundations and structures found necessary as a result of detailed design performed by the Contractor after the Award of the Contract

1.2.4.3. Noise, Fire and Blast Walls

All walls or other structures required to contain and reduce noise and/or to protect equipment, building and other structures from fire or explosion in nearby equipment or areas.

1.2.5. Spare Parts

Spare parts and maintenance accessories required by the Contractor to meet the Guaranteed Availability and Reliability over the Guarantee Period as specified further in Section 11.

The Contractor may use the spares that are being provided during installation, testing & commissioning of the system however they must be replenished prior to acceptance.

Spares used during the warranty period are to be replaced by the Contractor at the end of the warranty period thereby restoring the stock of spare parts to the quantities provided at the beginning of the warranty.

All spares shall be of the same materials and workmanship as the corresponding parts of the equipment furnished, and shall be fully interchangeable with those in service.

The contractor shall support their supplied equipment with a supply of spare parts and engineering services for not less than 15 years after final acceptance. The contractor shall provide estimates of the cost differential and delivery time for spare parts that are purchased after the original manufacturing run.

A spare part intended for use as a replacement for any one of several similar parts, for example a capacitor unit, shall be a replacement to any one of those parts without resulting in deterioration in the performance of the equipment or system.

All spares meant for outdoor use, such as bushings, transformers, reactors, resistors, capacitors, arrestors, etc. shall be suitable for prolonged outdoor storage without being energized. The spare converter transformers shall be supplied complete with bushings, coolers, OLTC, conservator tanks, oil, protective and monitoring devices etc. as applicable.

The spares shall be available at site prior to the beginning of trial operation.

1.2.5.1. Mandatory Spares

Table 1 lists the mandatory spares shall be supplied as a minimum by the Contractor per converter station.

Table 1 Mandatory Spares

1	Converter Transformers	1 of each type and rating complete with all accessories
2	Thyristors	One complete bridge arm worth of thyristors

3	Thyristor level components	One half of the number of all the components used at the thyristor level in one bridge arm including the electronics
4	Valve reactors	One half of the numbers of the valve reactors used in one bridge arm
5	Wall bushings and transformer bushings	1 of each type and rating
6	Smoothing Reactors	1 of each type and rating or the number provided in one pole whichever is greater
7	Complete dc current measuring unit	1 of each type and rating
8	Complete dc Voltage Divider	1 of each type and rating
9	dc yard disconnects & switches	1 of each type and rating and two extra set of contacts
10	HVac Circuit Breakers along with operating mechanism	1 complete breaker of each type and rating
11	HVac Isolators with one grounding switch	1 pole of each type and rating along with operating mechanism and three extra set of contacts
12	Connectors for dc yard and valve halls	2 of each type and rating
13	AC & dc Surge arresters	1 of each type and rating
14	AC Current Transformers	1 of each type and rating
15	Capacitive and Inductive voltage transformers	1 of each type and rating
16	Cards, relays for C&P, Communication interface cards	10% of each type, minimum of 2
17	Capacitor units	5% of each type and ratings with a minimum of 2
18	Filter reactors and resistors	1 of each type and rating
19	Valve hall ground disconnects	1 of each type and rating
20	Control system	10% of each type of circuit card and power supplies with a minimum of 2
21	Optical fiber cables	VBE fiber one complete pole pre-terminated all others 10% of installed length with termination equipment provided of each type
22	Fault locator blocking reactors	One of each type and rating

23	Fault locator blocking capacitors	One of each type and rating
24	Fault locator coupling capacitor	One

1.2.5.2. **Availability of Spares**

The Contractor shall supply the spare parts required to meet the specified Guaranteed Availability, and shall include such spare parts in the Scope of Supply. If such spares are already included in the list of mandatory spares, it shall be indicated and identified. The detailed lists of spare parts to meet the Guaranteed Reliability & Availability requirements shall be part of the Contract documents. However, if it is found during detailed engineering and / or Reliability & Availability prediction calculation that additional spares are required to meet target values, the same shall be made available by the Contractor without any additional cost to the Owner.

1.2.5.3. **Site Spares**

The Contractor shall supply any additional spares which may be consumed during installation, testing and commissioning of the systems. The quantity of these spares shall be decided based on the Contractor's previous experience, such that site work shall not be hampered due to non-availability of these spares.

1.2.5.4. **Tools**

Any special tools and materials shall be furnished by the Contractor at no increase in price. The Contractor shall also furnish all special tools prescribed to perform functions for required maintenance or initial adjustments. All tools furnished shall be plainly marked for identification, new, and unused, except for valve module lifting devices which shall be those used to install the valves.

1.3. **Services Provided by the Contractor**

The services to be provided by the Contractor shall include, but not be limited to, the major items listed below as they are related to the converter stations.

- Overall Project Management
- Training of Personnel
- Site Supervision
- Coordination Activities

1.3.1. **Project Management**

The Contractor shall be responsible for the overall management and supervision associated with the construction, installation, testing, and commissioning of the HVdc converter station. The Contractor shall establish a site project office at each converter station.

For performing the project management functions, the Contractor shall provide experienced and knowledgeable personnel, in all areas during the execution of the project. The Contractor shall nominate a Project Manager who shall be responsible for the complete work for this project and to whom all correspondence shall be addressed.

1.3.2. Training of Personnel

As part of the contract, the Contractor shall organize and conduct programs for the training of the operating and maintenance personnel. The training shall be conducted at the terminal and completed at least 90 days prior to the testing and commissioning of the equipment. The Contractor shall submit an outline of the proposed training programs to the Owner for approval 30 days prior to their commencement. The training programs shall be continued as long as may be necessary to enable all trainees to thoroughly familiarize themselves with the operation and maintenance of the equipment and achieve the system availability requirements which may require multiple sessions. The trainees shall be given instruction and training on the actual equipment prior to and after testing and commissioning so that they may familiarize themselves with the equipment prior to the date specified for commercial operation.

The Owner will have the right to make sound and video recordings of all training classes or presentations and have access to all training materials to enable the training of employees for a period of at least 5 years.

1.3.2.1. Scope of Training

The Contractor shall organize and conduct a complete and thorough training program in the English language providing all training material and equipment. These training programs shall be on equipment, systems and operating instructions under which shall be provided to both professional and technical personnel of P&E or authorized representatives prior to the start of testing and commissioning in the areas broadly set forth hereunder.

- System engineering and design including application
- HVdc equipment training to include the following:

  Training manuals

  Descriptive material for the digital control system software design

  Control system hardware design

  Operation manuals

  Maintenance manuals

  Classroom instruction

  Staffing requirements

  Troubleshooting techniques
- Long term operation and maintenance training requirements for the entire P&E complex.

1.3.2.2. Training Program

The training program shall include but not be limited to:

1. Transformers and filters
2. Thyristor Valves and associated components
3. Valve Cooling System
4. Control and protection equipment
5. Computer systems
6. Start/Stop and de-block/block of converters of the HVdc System
7. Power order setting and remote operation

8. Alarm, Monitoring and Reporting System
9. Locating Faults and troubleshooting the same.
10. Replacement of consumables
11. Auxiliary power system
12. HVdc Control development environment and control modification process
13. Equipment nomenclature and documentation system

The aforementioned training materials shall be submitted to the Owner in electronic format. If any dynamic reactive power devices are supplied, the same level of training as detailed above shall be provided for the applicable devices.

1.3.2.3. Computer Programs

The Offeror shall identify the computer programs used for carrying out studies and detailed design of the project. The Contractor shall also provide a non-“black box” software model of the complete control and protection systems as supplied for the project and used in the system studies.

1.3.2.4. Site Personnel

The Contractor shall provide highly skilled and experienced site supervisory personnel to supervise all aspects of each HVdc converter station considered within the Specification to ensure that all the site operations are carried out in such a manner as to provide the Owner with a high quality system and that the operating and maintenance personnel at each site are adequately trained to operate the system properly, safely and efficiently.

The supervisory personnel provided by the Contractor shall be responsible for proper construction, transportation, installation, erection, testing and commissioning of the system and training of personnel with regard to the HVdc converter station. They shall also provide operating and maintenance assistance during the Guarantee Period.

During the period of trial operation of HVdc link, the Contractor shall provide one engineer at each converter station.

1.3.3. Interface Coordination

The interface points for the HVdc terminals with the external points and auxiliary systems are described in the relevant portions of this Specification. Further, the Contractor shall provide any other equipment / services to complete the interface points given below:

1.3.3.1. Interface with Services

1. Electrical Interface to include point of coupling in the dc and ac yard, communication equipment, and construction power
2. Station service interface
3. Grounding connections
4. Water Supply interface

1.3.3.2. Construction Power Supply and Other Services

Construction power will be generally available throughout from existing ac switchyard. The Owner will provide a suitable location for a construction trailer, and a room for offices in a suitable on site location. All other services such as rest rooms, phones, internet, etc. are the responsibility of the Contractor.

1.3.3.3. Connections with Lines

Connection to the HVdc line will be made to the existing dead end tower as indicated on the switchyard layout drawing XXXX. The Contractor shall be responsible for further connections to HVdc switchyard including supply and erection of all accessories required.

1.3.3.4. Energy Metering

Interchange metering will be supplied and installed by the Owner. The Contractor shall provide suitable rack space, connection to the communication system, auxiliary power and connections to metering current and voltage circuits.

1.3.4. Performance/Functional Guarantees

The Contractor shall design each station in such a way that the performance parameters are met for all specified operating conditions and all necessary measurements shall be made to prove conformance to the Specification. If any deficiency is found, the Contractor shall carry out all modifications/ rectifications/ replacements required to meet the required performance, at no extra cost to the Owner. All specified requirements must be fulfilled by the Contractor prior to acceptance of the HVdc system or any part thereof.

In addition, the following Performance Guarantees shall be provided by the Contractor, as detailed in the Specification.

1. Energy Availability
2. Reliability
3. Station Efficiency
4. Station Power Rating
5. Thyristor Failure Rate
6. Capacitor Failure Rate

The detailed requirements for these guarantees are given in Section 11 of this Specification.

1.3.5. Installation, Testing and Commissioning

The Contractor shall construct and install all equipment, systems and services to be provided for the HVdc converter stations and shall be responsible for the provision of all construction labor, material and supervisory staff in accordance with the specification.

The Contractor shall furnish all tools and construction equipment including lifting jacks, pulling equipment, cranes, etc. necessary for the proper construction, installation and erection of the equipment.

The testing, commissioning and putting into operation of the identified material, equipment and other systems shall be carried out in accordance with the requirements of the Specification.

The Owner shall reserve the right to assign their personnel and/or their consultants to the Contractor's testing and commissioning team to participate in and/or witness the testing and commissioning operations at the converter stations. The Owner's personnel may participate in the testing and commissioning of the complete HVdc system at their discretion.

1.3.6. Sequencing of Commissioning Activities

The sequence of commissioning will be determined by the Owner in cooperation with the utilities to which the P&E project will interconnect.

1.3.7. Future Developments and Expected Equipment Lifetimes

The Contractor is required to document the items of equipment which are not expected to operate for 40 years without replacement and to indicate expected lifetimes accordingly. In the case of control and protection equipment, the expected life to replacement is also to be indicated.

In order to facilitate the potential future upgrade for multi-terminal operation and/or replacement of the control and protection systems included in this Specification, the following general practices and conditions will apply:

1. Space shall be made available for multi-terminal operation and the maintenance and future replacement of newly installed and existing equipment. The space shall be sufficient such that the maintenance, installation and removal activities will not impact in-service equipment.
2. Switchyard layouts shall be such that the use of space is kept to a minimum and shall not inhibit future extensions of the switchyards.
3. All connection cubicles, outdoor junction boxes (ODJBs) and communication and data interfaces shall have 50 % spare capacity to allow for future replacement of the installed equipment.
4. All connection cubicles shall be laid out with field cables from one side and the cables to new equipment on the other side to facilitate simple replacement
5. Drawings shall be arranged with clear demarcation points identified to minimize the number of drawings which would be required to be produced during an upgrade in the future.
6. A clear description of the interfaces for control systems, specifically the valve control and VBE must be provided.
7. The Contractor shall provide a data dictionary of all system interfaces and communication protocols to a level which will enable the Owner to design systems that are compatible with the system supplied. All documentation supplied shall be editable by the Owner to facilitate modification.
8. The Contractor shall allow the Owner the right to freely disclose system interface and communication protocol details to third parties (including competitors) to allow the Owner to maintain, upgrade, and improve the system.
9. Object oriented programming practices shall be used for all software and the software is to be adequately commented to allow for its support for the lifetime of the equipment.
10. The running of software should be immune to changes in processor clock speeds and calendar date rollovers.
11. All protocols used shall comply with a currently accepted industry standard and shall not be proprietary.

Space shall be made available in buildings for locating the Owner’s equipment and or other facilities (e.g. cubicles for communication and revenue metering equipment in the control rooms).

The Contractor shall keep a register of “Lessons Learned”, documenting problems/issues encountered during the implementation of the Contract and the actions taken to resolve/mitigate them. The register shall cover the period starting with the commencement of the factory tests and finishing at the successful completion of the Defect Liability Period, at which time it shall be handed over to the Owner.

1.3.8. P&E-Supplied Equipment, Facilities and Services

The supply of all equipment, materials, and services required for the execution of the Contract shall be the responsibility of the Contractor with the specific exception of the items listed herein.

1.3.8.1. Buildings

XXXXX

1.3.8.2. **Auxiliary facilities**

XXXX

2. Site and Technical Information

2.1. Description of the AC Systems

For a brief overview of the surrounding ac system, refer to Figure XXXXX

2.2. Location and Site Conditions

The following sections describe the site conditions for the three converter stations at Hitchland and Shelby as well as the tap at location at Entergy. However it is the Contractor's sole responsibility to familiarize themselves with the sites, and in particular with any space limitations at any site, in order to ensure the proposed solutions can be accommodated within the sites.

2.3. Location(s)

Clean Line identified the proposed location for the western converter station based on the presence of both an excellent wind resource (as classified by the DOE National Renewable Energy Laboratory) and adequate electrical interconnection facilities, including planned upgrades to existing facilities. Clean Line identified the proposed location for the eastern converter station based on the presence of high-voltage transmission facilities capable of interconnection and delivery of up to 3,500MW of energy to portions of the mid-south and southeastern U.S. The midpoint station was, likewise, situated in a robust portion of the 500 kV network in the mid-south.

2.3.1. Oklahoma

Hitchland Station is the western terminal of P&E. The station is located in the vicinity of the City of Guymon in Texas County, Oklahoma.

The address for delivery of equipment, materials, and packages is:
XXX

2.3.2. Tennessee

Shelby Station is the eastern terminal of P&E. The station is located within 20 miles of the City of Memphis in Shelby County, Tennessee and adjacent to the TVA 500 kV Shelby substation

The address for delivery of equipment, materials, and packages is:
XXX

2.3.3. Arkansas

Entergy Station is a 500MW intermediate tap of the project. The station is located in southwestern Arkansas.

The address for delivery of equipment, materials, and packages is:
XXX

2.4. Location Map

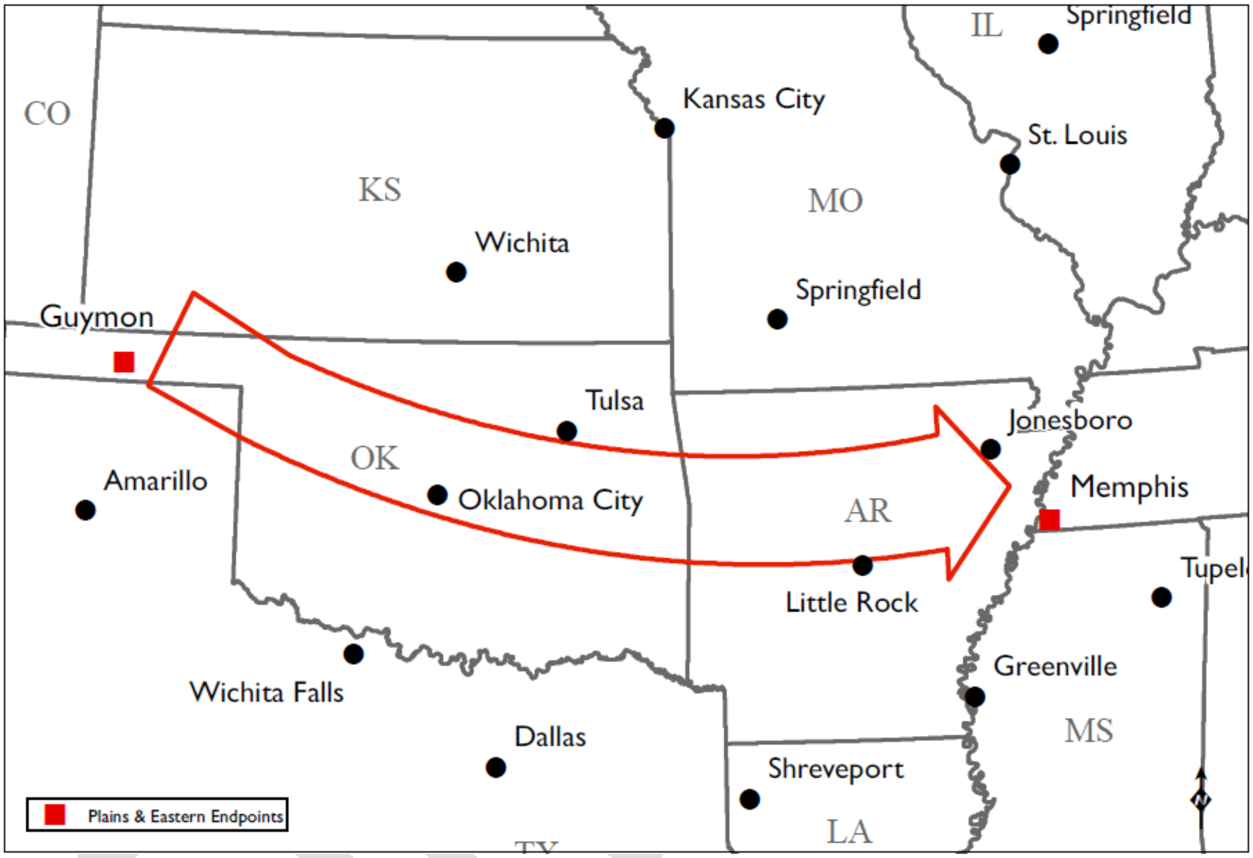

Figure 1 Plains and Eastern HVdc Endpoints

2.5. Aerial Overview

2.6. Site Access

Access

2.7. Soil information

The Contractor shall be responsible for performing an independent geotechnical study to verify soil conditions and other design criteria. This work will need to be coordinated with the Owner after award. Past geotechnical information located in Appendix XX – Geotechnical Information is included for reference only. All soil that is not re-used on site shall be disposed of at the XXX Landfill.

2.8. Service Water

Water will be from a municipal source or wells will be dug if necessary. The water will be used for local firefighting requirements on site and for use within the converter buildings area.

The water supply and distribution system shall include the supply, distribution and storage of water to the converter stations for at least the following purposes.

a) Water supply to the converter station from shall be provided by the Contractor within HVdc terminal fencing area. The Contractor shall make necessary arrangements of pumps, valves, piping etc., as required, to supply the water to the main storage system & regulate its filling/makeup automatically.

b) Treatment facilities shall be provided for water suitable for the station cooling system and to meet other station requirements including that of drinking water. The water treatment shall inhibit scaling, minimize biological growth and corrosion in the piping and equipment.

c) Distribution from source to points of consumption.

d) Storage of water for the firefighting system.

e) Storage of water sufficient for 24 hours of continuous operation of HVdc converter in the event of interruption of water supply to the tanks.

f) Equipment for analysis of water which shall be adequate for monitoring the quality of the water supply and to check the effectiveness of the water treatment system.

g) The equipment for water analysis shall be installed on the water treatment plant. The equipment shall monitor flow, hardness and pH value and generate alarm for values beyond design limits. The measured value & alarm shall be wired to the station alarm system.

h) Water supply for the valve cooling system.

i) Water supply for sanitary services. The daily water consumption for sanitary services at each converter station is estimated to be about 2000 litres?

Two 100% capacity water storage tanks shall be provided. Each tank shall be constructed in such a way that there shall be segregation between requirement for fire water storage and water for other purposes. Both the tanks shall have interconnection piping with isolation valves for both tanks. Separate piping for firefighting, valve cooling and other purposes shall be provided from the tanks.

2.9. Design Parameters

The Contractor shall use the parameters and data given in this section for the design of the HVdc converter stations.

2.9.1. Site and Environmental Data

Table 2 outlines the site and environmental data for the three areas involved with this HVdc system.

Table 2 Site and Environmental Data

	Hitchland Station	Shelby Station	Entergy Terminal	Unit
Site elevation above sea level	3084/940	308/94	581/177	ft/m

Minimum ambient air temperature	-19 / -28	-13 / -25		◦F/◦C
Maximum ambient air temperature (20 year record)	108 / 42	108 / 42		◦F/◦C
Maximum daily average ambient air temperature	71/21.6	72/22.2	73/22.7	◦F/◦C
Minimum daily average ambient air temperature	42/5.6	50/10	50/10	◦F/◦C
Precipitation – Normal for Year	19.3/490.22	54.89/1394.21	48.91/1242.3	in/mm
Precipitation – Maximum Monthly				in/mm
Precipitation – Max in 24 hr		10.32/262.13		in/mm
Ice loading conditions (50 year record)				in/mm
Maximum ground snow depth				in/mm
Maximum frost depth				in/mm
Maximum steady wind velocity				mile/hr
Wind gust factor or maximum wind gust (3s)				mile/hr
Solar Radiation				W/m^2
Seismic zone and withstand data				
Lightning Ground Stroke Density				stroke/mile^2/yr
Dust concentration (or pollution level) per IEC Publication 60815				
Earth resistivity (see Unit 4, Appendix 37)				Ohm-ft
Available Station Service Power Source:				Kvac

2.10. **Shielding and Lightning Protection**

The Contractor shall design, supply and install an overhead shielding system, using overhead shield wires or lightning masts, to protect all equipment in its supply (including all spare transformers) from direct lightning strokes. The design shall follow the requirements of IEEE 998.

The design of the lightning shielding system shall:

a. Be based on the local keraunic level as specified in Section XXX.

b. Use the Electro-geometric model (EGM) as outlined in IEEE 998.

c. Take into consideration separate calculations for each voltage level in the station using the appropriate BIL levels

d. Take into consideration the EGM model for various buses for each voltage level.

e. Provide 100% effective shielding from direct lightning strikes.

f. Provide shielding for all structures, equipment, and buildings within the dc switchyard and the ac switchyard for equipment supplied by the Contractor.

g. Take into consideration the design of the station ground grid, and the grounding and bonding system

h. Allow for station structures to accommodate shield wires, if such wires are required by the lightning shielding system

i. All structures and masts shall be designed to adhere to the environmental conditions specified in Section 2.9.

The Contractor shall produce a report for review by the Owner that demonstrates that the probability of buses and equipment being hit by a direct lightning stroke that could damage equipment is negligible

2.11. Seismic data

XXX

2.12. Electrical Data and Design Criteria

Clean Line's criteria for the design are based on:

- Short Circuit Levels - The fundamental frequency impedance of the ac system to which the HVdc converter station is connected is dependent on the system configuration and load dispatch.
- The maximum fundamental frequency short circuit current shall be taken as 63 kA for switchyard equipment rating purposes. For transformer design parameters, please refer to XX
- The short circuit levels at the converter bus at nominal voltage and fundamental frequency are given in Table 3 and Table 4.

Table 3 Short Circuit Levels

		Hitchland Station	Shelby Station	Entergy Terminal
Maximum Short Circuit Level At in-service date	Three-phase	6014	25,762	15,284
	X/R	11.34	15.96	18.78
	Single-phase	6223	24,174	17,136
	X/R	11.34	15.96	18.78
Maximum Short Circuit Level Future values	Three-phase			
	X/R			
	Single-phase			
	X/R			

Table 4 summarizes the minimum short circuit levels. The rectifier ac bus is specified without any contribution from the wind turbines, it is the ac system contributions only that are listed in this table.

Table 4 Minimum Short Circuit Levels

Terminal	Outages	Short Circuit Levels		
		MVA	kA	X/R
Rectifier				
Normal	none	5,030	8.42	12.31
N-1	345kV Hitchland-Finney	3,984	6.67	12.30
N-2	345kV Hitchland-Wwrdehv 1 & 2	3,108	5.20	10.80
Mid-point Tap				
Normal	none	11,212	12.95	16.59
N-1	500kV Tap - ANO	5,888	6.80	14.14
N-2	500kV Tap – ANO & 500kV 8P Hill – 8Mayfl	1,720	1.99	13.11
Inverter				
Normal	none	21,697	25.05	16.81
N-1	500kV Shelby-Sansouci	15,879	18.34	15.69
N-2	500kV Shelby-Sansouci & 500kV Shelby-Lagoon Creek	13,086	15.11	15.30

2.12.1. Normal Steady State Voltages

The ac bus voltage is normally within a certain range. Bus voltages outside this range may occur during transient events such as switching and faults, during swings following the loss of other transmission assets, during reactive switching, following the contingencies such as changes to generation and loads, and during system emergencies.

Table 5 shows the typical steady state operating voltages for the different ac system voltage levels.

Table 5 Normal Steady State Voltages

Nominal kV	SPS	EAI	TVA
161 kV	0.95-1.05	0.95-1.05	0.97-1.06
345 kV	0.95-1.05	0.95-1.05	-
500 kV	-	0.95-1.05	0.98-1.08

Table 6 shows the post contingency steady state voltage limits for the different ac system voltage levels.

Table 6 Post Contingency Steady State Voltages

Nominal kV	SPS	EAI	TVA
161 kV	0.90-1.05	0.92-1.05	0.95-1.06 (N-1), .93-1.06 (N-2)
345 kV	0.90-1.05	0.92-1.05	-
500 kV	-	0.92-1.05	0.98-1.08

2.12.2. Dynamic Criteria

The dynamic stability analysis will demonstrate whether the P&E HVdc project meets the dynamic stability requirements of the interconnecting Transmission Owners (TOs).

A few of the criteria most pertinent to the stability analysis are highlighted below.

2.12.3. Transient Voltage Dip

The criteria for transient voltage dips at each terminal are defined in Table 7 Transient Voltage Dip Criteria.

Table 7 Transient Voltage Dip Criteria

Interconnecting Transmission Owner	Criteria for transient voltage dip
SPS (Rectifier)	For N-1 disturbances: - not > 25% at a load bus For N-2 disturbances: - not > 30% at any bus - not > 20% for more than 40 cycles at a load bus
EAI (Tap)	Normal clearing disturbances: - not > 20% for more than 20 cycles at any bus - not > 25% at any load bus - not > 30% at any non-load bus Breaker fail disturbances: - not > 20% for more than 40 cycles at any bus - not > 30% at any bus
TVA (Inverter)	Not > 20% for more than 40 cycles

2.12.4. Transient Overvoltage

The criteria for transient overvoltage (TOV) at each terminal are defined in Table 8.

Table 8 TOV Criteria

Interconnecting Transmission Owner	Criteria for TOV
SPS (Rectifier)	missing
EAI (Tap)	missing
TVA (Inverter)	missing

2.12.5. Frequency Criteria

AC system frequency is normally within 59.5 to 60.5 Hz and in this range the HVdc converter station shall operate without any restrictions on power transfer. On some occasions operation with frequencies as low as 57 Hz can also occur and therefore the equipment shall be designed to operate between 57 Hz and 63 Hz such that the HVdc station shall not trip for these wider frequency excursions although power reduction shall be allowed. The specific frequency criteria at each terminal are defined in Table 9.

Table 9 Frequency Criteria

Interconnecting Transmission Owner	Criteria for Frequency
SPS (Rectifier)	For N-1 disturbances: - not < 59.6 Hz for more than 6 cycles For N-2 disturbances: - not > 59.0 Hz for more than 6 cycles
EAI (Tap)	missing
TVA (Inverter)	missing

2.12.6. Negative Sequence Criteria

For the purpose of determining all performance requirements, the continuous negative sequence voltage may be as high as 1%.

For the purpose of determining all equipment ratings, the continuous negative sequence voltage may be as high as 2%.

2.13. Reactive Power Capability of the AC System

The converter stations shall be fully compensated in terms of reactive power for the complete range of dc power from the minimum to the maximum power rating as defined in the Performance Requirements Section 4. The specified limits of reactive power exchange shall be used by the Offeror for calculating the reactive power equipment requirement for the converter station. The Contractor shall provide reactive power supply and reactive power absorption equipment which shall be suitably rated to meet the specified reactive exchange limits between minimum and maximum continuous dc power.

The reactive power exchange with the connected ac system shall be calculated by summation of the measured values of the reactive power consumed by the converter equipment and the reactive power by the filters/capacitor supplied for under this contract.

The maximum reactive power exchange values at the converter station as shown in Table 10 shall not exceed at any level of dc power transfer.

Table 10 Reactive Power Exchange Values

Hitchland Station	+/- XX MVAr
Shelby Station	+/- XX MVAr
Entergy Junction	+/- XX MVAr

The ac filter or shunt capacitor banks shall not exceed XX Mvar of reactive output at 60 hz.

Switching of individual ac filters or shunt capacitor banks shall not cause step voltage changes that exceed 2% of nominal system voltage at minimum short circuit capacity for power transfer in both directions.

2.14. Generation Near the Converter Stations

While Clean Line is only developing the HVdc system for P&E (i.e. not developing the wind farms that will be utilizing P&E system), it will be placing an interconnection requirement that only Type 3 or Type 4 wind turbine generators (WTGs) be permitted to interconnect to the P&E HVac collector system. Since the actual breakdown of Type 3 and Type 4 generators that will actually interconnect is not yet known, it is recommended that 50% of Type 3 and 50% of Type 4 WTGs breakdown be assumed for each interconnecting wind farm. The total amount of WTGs interconnected to P&E HVac should be sufficient to deliver 3,500 MW to large inverter and 500MW to the tap (i.e. account for HVdc line and converter losses) plus a 10% overbuild above this level.

2.15. Existing HVdc

2.16. Background Harmonics

Background harmonic measurements were performed at the Shelby and Hitchland Stations at the end of April 2014. Due to a very severe storm that occurred around this time period, harmonics measurements could not be performed due to the damage to the electrical network in the area of the proposed mid tap location.

All measurements shown are based on the average harmonic values calculated over a 15 minute time period. For background harmonic measurements for filter design, WG B4.47 "Aspects of AC Filter Design" was used as a reference for the measurement criteria.

Table 11 displays the average, minimum and maximum harmonics values for all three phases from the 2nd to the 50th harmonic at the Hitchland Station. These quantities were calculated over the four week monitoring period and were based on the 15 minute average measurements with the minimum and maximum values being the extremes from the trending curves for each phase at the Hitchland Station. Values highlighted shows that the average trended value of the 5th harmonic of 1.0% was exceeded on each phase. Maximum values reached as high as 1.89%. The 5th harmonic reached these high points mainly during the weekend or throughout the night and early morning during light load periods.

Due to the high 5th harmonic, IEC 61000-3-6 limits will be adopted, with the 5th harmonic limit being now at 2.0%, the 5th harmonic data is in compliance.

Table 11 Individual Harmonic Values at Hitchland Station

	A Phase			B Phase			C Phase		
Harmonic	Average	Min	Max	Average	Min	Max	Average	Min	Max
2	0.01	0.00	0.03	0.03	0.00	0.05	0.02	0.01	0.03
3	0.15	0.02	0.28	0.15	0.05	0.33	0.29	0.16	0.49
4	0.02	0.01	0.06	0.03	0.01	0.07	0.02	0.01	0.06
5	1.18	0.46	1.78	1.11	0.53	1.71	1.23	0.53	1.89
6	0.02	0.00	0.03	0.01	0.00	0.03	0.02	0.00	0.05
7	0.39	0.03	0.94	0.43	0.02	0.96	0.32	0.02	0.76
8	0.01	0.01	0.03	0.02	0.01	0.05	0.01	0.00	0.03
9	0.04	0.01	0.09	0.04	0.01	0.12	0.03	0.01	0.09
10	0.01	0.00	0.02	0.01	0.00	0.03	0.01	0.00	0.02
11	0.09	0.01	0.53	0.09	0.01	0.36	0.08	0.01	0.44
12	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.02
13	0.05	0.01	0.14	0.04	0.01	0.13	0.05	0.01	0.17
14	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01
15	0.01	0.00	0.03	0.01	0.00	0.02	0.01	0.00	0.03
16	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01
17	0.02	0.00	0.14	0.02	0.00	0.12	0.02	0.00	0.13
18	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
19	0.03	0.00	0.10	0.03	0.00	0.08	0.03	0.00	0.09
20	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
21	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.02
22	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.02
23	0.07	0.01	0.19	0.05	0.01	0.14	0.07	0.01	0.19
24	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
25	0.02	0.00	0.07	0.02	0.00	0.04	0.02	0.00	0.06
26	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
27	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
28	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
29	0.04	0.00	0.13	0.03	0.00	0.08	0.04	0.00	0.14
30	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
31	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.02
32	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
33	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.02
36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 12 displays the average, minimum and maximum harmonics values for all three phases from the 2^{nd} to the 50^{th} harmonic at the Selby Station. These quantities were calculated over the one week monitoring period and were based on the 15 minute average measurements with the minimum and maximum values being the extremes from the trending curves for each phase at the Shelby Station. Values highlighted show that the average trended value of the 5th was around the 1% level and reached a value between 1.24% and 1.38%. The high 5^{th} harmonic mainly occurred during the weekend and throughout the night and early morning during light load periods.

Table 12 Individual Harmonic Values at Shelby Station

	A Phase			B Phase			C Phase		
Harmonic	Average	Min	Max	Average	Min	Max	Average	Min	Max
2	0.03	0.01	0.05	0.03	0.01	0.05	0.03	0.01	0.05
3	0.13	0.09	0.18	0.10	0.07	0.15	0.04	0.01	0.10
4	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.02
5	0.99	0.77	1.24	1.06	0.82	1.32	1.06	0.83	1.38
6	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.02
7	0.17	0.02	0.51	0.18	0.02	0.45	0.18	0.02	0.45
8	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01
9	0.02	0.00	0.03	0.01	0.00	0.03	0.02	0.01	0.04
10	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
11	0.09	0.01	0.18	0.07	0.01	0.14	0.07	0.02	0.15
12	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
13	0.06	0.02	0.15	0.05	0.01	0.13	0.06	0.02	0.15
14	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
15	0.02	0.01	0.02	0.01	0.00	0.01	0.01	0.00	0.01
16	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
17	0.05	0.02	0.09	0.04	0.00	0.06	0.03	0.01	0.07
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.03	0.01	0.05	0.01	0.00	0.03	0.01	0.00	0.03
20	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
21	0.01	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01
22	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
23	0.03	0.01	0.06	0.03	0.01	0.06	0.03	0.01	0.06
24	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
25	0.02	0.01	0.05	0.02	0.01	0.04	0.01	0.01	0.03
26	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
27	0.01	0.01	0.02	0.01	0.00	0.01	0.01	0.00	0.01
28	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
29	0.03	0.01	0.06	0.04	0.01	0.10	0.02	0.01	0.04
30	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
31	0.01	0.01	0.03	0.01	0.00	0.03	0.02	0.00	0.04
32	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01
33	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	0.01	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.02
36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	0.01	0.00	0.03	0.01	0.01	0.03	0.01	0.00	0.02
38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	0.01	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

For the background harmonic voltage data at the Entergy Terminal, the maximum harmonic limits as specified in IEC 61000-3-6 will be applied.

2.17. Harmonic Impedances

The ac system harmonic impedance for ac filter performance and rating calculations shall be any impedance within the harmonic impedance diagram as shown in Figure 2 and Table 13 unless otherwise specified.

These harmonic impedances are suitable to be used for equivalents for ac filter performance and rating studies. The harmonic impedances of the ac system in the figure and table are at the converter ac buses.

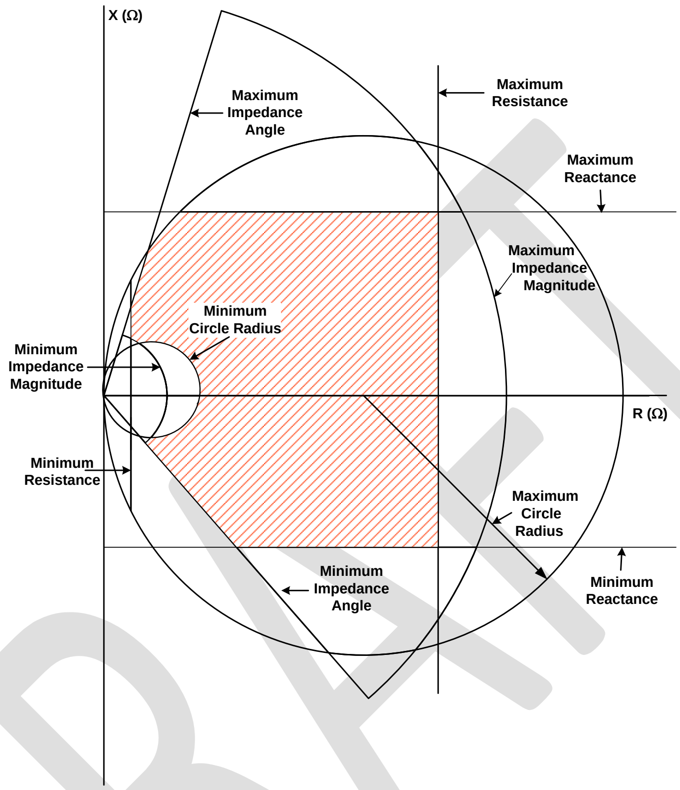

Figure 2 AC Harmonic Impedance Diagram

Table 13 Harmonic Impedance

Harmonic Number	Maximum Resistance (Ohms)	Minimum Resistance (Ohms)	Maximum Reactance (Ohms)	Minimum Reactance (Ohms)	Maximum Impedance Magnitude (Ohms)	Minimum Impedance Magnitude (Ohms)	Maximum Impedance Angle (Degrees)	Minimum Impedance Angle (Degrees)	Maximum Circle Radius (Ohms)	Minimum Circle Radius (Ohms)
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
to										
50										

2.18. Communication System

The Contractor shall interface the Control and Protection system between the various converter stations via the XXX communication system. The electrical interface shall be DS1 at a nominal rate of 1.544Mbps. BPA will supply DS1 channels for the contractors use.

There shall be redundant data channels per pole and bipole plus additional channel(s) for Sequential Event Messages (SEM), Digital Fault Record data and dc line fault locator data.

The telecomm system shall be NERC-CIP compliant.

2.19. HVDC Transmission Line:

The bipolar line will have an interim capacity of XX MW. The line route length is XX miles.

2.19.1. Conductor:

The conductor and ground wire data are as follows:

(a) Conductor Data:
Two (2) conductor bundle with 18 inch spacing. Each conductor of 2,312 kcmil - ACSR "Thrasher".
Stranding (Al/Steel) 76/19
Diameter XX inches
Min. clearance to ground XX feet at 100ºC Maximum Operating Temperature, 30ºC Ambient
DC resistance @ 25C XX ohms/mi./line pole
AC resistance @ 25C XX ohms/mi./line pole

(b) Ground Wire Data:
Type
Number
Stranding
Diameter, strand
Outside, diameter

(**c) DC Circuit Resistance**:

	Maximum (ohms)	Minimum (ohms)
Bipole	XX	XX
Monopole – DMR Return	XX	XX
Monopole – Pole Metallic Return PMR	XX	XX

2.19.2. Mutual and Self Impedances

Mutual and self impedances may be calculated from the following data:

1. Geometric configuration of the towers provided in XX
2. Average ground resistivity is 100 ohm-meters.
3. Any ac lines that are parallel??

Self Supporting Tower

2.19.3. **Insulation:**

The insulation data are as follows:

	Suspension String	Dead End String
Critical impulse flashover 1.2 x 50 usec, positive	XX kV	XX kV
DC, critical flashover, wet, negative	XX kV	XX kV
Tower Grounding Details:		
Type Double Shield Wire		
Shield Angle	XX degrees	
Footing resistance, maximum	XX ohms	

2.20. **Dedicated Metallic Return Line (DMR)**

3. General Requirements

The equipment furnished by the Contractor shall conform to the following general requirements, which form an integral part of the Specification, in addition to meeting the specific requirements called for elsewhere in the Specification.

The Contractor shall note that the standards mentioned herein are not mutually exclusive or complete in themselves, but are intended to complement each other, with minimum repetition, to define the requirements of the Specification.

ISO	International Organization for Standardization.
IEC	International Electro technical Commission.
ANSI	American National Standards Institute.
NEMA	National Electrical Manufacturers Association.
CIGRE	International Conference on Large High Voltage Electric Systems.
ASME	American Society for Mechanical Engineers.
IEEE	Institute of Electrical and Electronics Engineers.
ASTM	American Society for Testing and Materials.
NFPA	National Fire Protection Association.
NBFU	National Board of Fire Underwriters.
NESC	National Electric Safety Code

3.1. Standards

All work undertaken by the Contractor shall be designed, and constructed, to meet the functional requirements of these Technical Requirements and all applicable standards, guidelines, codes and regulations governing such installations including, but not limited to, those listed below.

The work covered by these Technical Requirements shall be designed and manufactured in accordance with applicable federal, state, and local laws, codes, and regulations. When specific requirements stipulated in these Technical Requirements exceed or change those required by the applicable standards, the stipulations of these Technical Requirements shall take precedence.

The order of precedence with respect to standards that the Contractor shall follow in its design is as follows:

j. Local Utility Standards XXXX
k. Standards as specifically noted in the Specification
l. ANSI/IEEE Standards
m. IEC standards
n. RTO/ISO standards
o. CIGRE recommendations and guidelines

Where a standard is quoted in the text of these Technical Requirements, the Contractor shall make use of the version of the quoted standard current at the Commencement Date and shall not substitute another standard unless approval is obtained from the Owner.

If an inappropriate standard has been quoted or a suitable standard has not been quoted or is not available from the standards listed above, the Contractor shall select an appropriate standard, and seek the Owner's approval prior to proceeding with the manufacture of the item.

If there is disagreement between the Owner and the Contractor as to the interpretation of a standard the Owner’s interpretation shall be final.

3.1.1. General Standards

IEC-60060	High Voltage Test Techniques
IEC-60071Part 1 to 5	Insulation Co-ordination
IEC-60156	Method for the Determination of the Electric Strength of Insulating Oils
IEC-60270	High Voltage Test Techniques
IEC-60296	Specification for Unused Mineral Insulating Oils for Transformers and Switchgear
IEC-60376	Specification and Acceptance of New Sulphur Hexafluoride
IEC-60437	Radio Interference Test on High Voltage Insulators
IEC-60506	Switching Impulse Tests on High Voltage Insulators
IEC-60507	Artificial Pollution Tests on High Voltage Insulators to be used on AC Systems
IEC-60694	Common Clauses for High Voltage Switchgear & Control gear Standards.
IEC-60815	Guide of the Selection of Insulators in respect of Polluted Conditions.
IEC-60865	Short Circuit Currents
IEC-61803	Determination of losses in HVdc converter stations
IEEE-80	IEEE Guide for Safety in AC Substation Grounding
IEEE 100	The Authoritative Dictionary of IEEE Standards Terms (7th Edition)
IEEE-516	IEEE Guide for Maintenance Methods on Energized Power Lines
IEEE 693	Recommended Practice for Seismic Design of Substations
IEEE 1313.1	IEEE Standard for Insulation Coordination – Definitions, Principles, and Rules
IEEE 1313.2	IEEE Guide for the Application of Insulation Coordination

ASTM D1275	Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils
DIN 51353	Testing of Insulating Oils, Detection of Corrosive Sulphur, Silver Strip Method
IEC-60060	High Voltage Test Techniques
IEC-60071Part 1 to 5	Insulation Co-ordination
IEC-60156	Method for the Determination of the Electric Strength of Insulating Oils
IEC-60270	High Voltage Test Techniques
IEC-60296	Specification for Unused Mineral Insulating Oils for Transformers and Switchgear
IEC-60376	Specification and Acceptance of New Sulphur Hexafluoride
IEC-60437	Radio Interference Test on High Voltage Insulators
IEC-60506	Switching Impulse Tests on High Voltage Insulators
IEC-60507	Artificial Pollution Tests on High Voltage Insulators to be used on AC Systems
IEC-60694	Common Clauses for High Voltage Switchgear & Control gear Standards.
IEC-60815	Guide of the Selection of Insulators in respect of Polluted Conditions.
IEC-60865	Short Circuit Currents
IEC-61803	Determination of losses in HVdc converter stations
IEEE-80	IEEE Guide for Safety in AC Substation Grounding
IEEE 100	The Authoritative Dictionary of IEEE Standards Terms (7th Edition)
IEEE-516	IEEE Guide for Maintenance Methods on Energized Power Lines
IEEE 693	Recommended Practice for Seismic Design of Substations
IEEE 1313.1	IEEE Standard for Insulation Coordination – Definitions, Principles, and Rules
IEEE 1313.2	IEEE Guide for the Application of Insulation Coordination
ASTM D1275	Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils
DIN 51353	Testing of Insulating Oils, Detection of Corrosive Sulphur, Silver Strip Method

Unless specifically agreed to by the Owner prior to Award of Contract, this project shall be designed and operate in accordance with the standards indicated and the requirements of the Specification. The Contractor shall be held responsible for any deviation.

1. Transformers

ANSI B16.5	Steel Pipe Flanges and Flanged Fittings
IEEE C57.12.00	General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers
IEEE C57.12.10	Transformers, 230,000 Volts and below, 833/958 through 8,333/10,417 kVA, Single-Phase, and 750/862 through 60,000/80,000/100,000 kVA, without LTC; And 3750/4687 through 60,000/80,000/100,000 kVA, with LTC; including Supplement C57.12.10a-1978
IEEE C57.12.70	Terminal Markings and Connections for Distribution and Power Transformers
IEEE C57.12.80	Terminology for Power and Distribution Transformers
IEEE C57.12.90	Test Code for Liquid-Immersed Distribution, Power and Regulating Transformers, and Guide for Short-Circuit Testing of Distribution and Power Transformers
IEEE C57.13	Requirements for Instrument Transformers
IEEE C57.91	Guide for Loading Liquid-Immersed Power Transformers and ERRATA AND COR-1
IEEE C57.93	Guide for Installation of Liquid-Immersed Power Transformers
IEEE C57.129	IEEE Trial-Use Standard General Requirements and Test Code for Oil-Immersed HVDC Converter Transformers
IEEE C57.131	Standard Requirements for Load Tap changers
ASTM B432	Standard for Copper and Copper Alloy to Steel Plate
ASTM D3487	Mineral Insulating Oil used in Electrical Apparatus
ASTM D4059	Analysis of Polychlorinated Biphenyls in Insulating Liquids by Gas Chromatography
NEMA CC 1	Electric Power Connectors for Substations
NEMA MG 1	Motors and Generators
ASME Y14.5	
ANSI- C57.12.00	IEEE Standard for Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers
ANSI-Z55.1	Grey Finishes for Industrial Apparatus & Equipment
IEC-60076	Power Transformers
IEC- 60289	Reactors
IEC- 60296	Specification for Unused Mineral Oil for Transformers and Switchgear
IEC- 60354	Loading Guide for Oil-Immersed Transformers

IEC- 60422	Supervision and Maintenance guide for Mineral Insulating Oil in Electrical Equipment
IEC 60475	Method of Sampling Liquid dielectrics
IEC 60542	Application Guide for On-Load Tap-Changers
IEC-60551	Measurement of Transformer and Reactor Sound Levels.
IEC 60567	Guide for the Sampling of Gases and of Oil from Oil-filled Electrical Equipment for the Analysis of Free and Dissolved Gases
IEC 60722	Guide to the lightning impulse and switching impulse testing of power transformers and reactor (compare IEC 60076 part 3)
IEC-60214	On-Load Tap-Changers
NEMA- TR-1	Transformers, Regulators and Reactors

3.1.2. Circuit Breakers

IEEE C37.04	Rating Structure for AC High-Voltage Circuit Breakers
IEEE C37.04	Rating Structure for AC High-Voltage Circuit Breakers Corrigendum 1 Cor 1-2009
IEEE C37.04a	Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis Amendment 1: Capacitance Current Switching
IEEE C37.04b	Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis Amendment 2: To Change the Description of Transient Recovery Voltage for Harmonization with IEC 62271-100
IEEE C37.09	Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
IEEE C37.09	Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical -Current Basis Corrigendum 1
IEEE C37.09a	Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis--Amendment 1: Capacitance Current Switching
IEEE C37.011	Application Guide for Transient Recovery Voltage for AC High Voltage Circuit Breakers
IEEE C37.11	Requirements for Electrical Control for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
IEEE C37.90.1	Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus
IEEE C37.100	Standard Definitions for Power Switchgear
IEEE 315	Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters)
NEMA CC1	Electric Power Connectors
NEMA SG 4	High-Voltage Circuit Breakers

IEEE C37.06	AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis- Preferred Ratings and Related Required Capabilities for Voltages Above 1000V
IEEE C37.06.1	High –Voltage Circuit Breakers Rated on Symmetrical Current Basis Designated – Definite Purpose for Fast Transient Recovery Voltage Rise Times
IEEE C37.010	Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
IEEE C37.12	Guide for Specifications of High-Voltage Circuit Breakers (over 100 Volts)
IEEE C37.12.1	Guide for High-Voltage(>1000 V) Circuit Breaker Instruction Manual Content
IEEE C57.13	Requirements for Instrument Transformers
ASTM D2472	Sulfur Hexafluoride
IEC 62271-100	High-voltage switchgear and control gear-Part 100: Alternating current circuit-breakers (Annex N)
IEC-62271-100	High Voltage Alternating Current Circuit Breakers
IEC-61264	Pressurized Hollow Column Insulators
IEC-60427	Synthetic Testing of High Voltage Alternating Current Circuit Breakers

3.1.3. Current Transformers, Voltage Transformers, and Capacitive Voltage Transformers

IEEE C57.13	Requirements for Instrument Transformers
ANSI/AISC 360-05	Specification for Structural Steel Building
IEEE C57.13.5	IEEE Standard of Performance and Test Requirements for Instrument Transformers of a Nominal System Voltage of 115kV and Above
IEEE C57.13.6	IEEE Standard for High – Accuracy Instrument Transformers
IEEE C57.19	IEEE Standard of General Requirements and Test Procedures For Power Apparatus Bushings
IEEE No. 4	Standard Techniques for High Voltage Testing
IEEE No. 100	Standard Dictionary of Electrical Terms
NEMA CC 1	Electrical Power Connectors for Substations
ASTM D3487	Mineral Insulating Oil Used in Electrical Apparatus
ASTM D4059E1	Method for Analysis of Polychlorinated Biphenyls in Mineral Insulating Liquid by Gas Chromatography
AS IEEE MSE Y14.5M	Dimensioning and Tolerancing
IEC 60270	High –Voltage Techniques- Partial Discharge Measurements
IEC-60186	Voltage Transformers
IEC-60358	Coupling Capacitors and Capacitor Dividers
IEC-60044-4	Instrument Transformers Partial Discharge Measurements

IEC-60481	Coupling Devices for Power Line Carrier Systems

3.1.4. Bushings

ANSI B1.1	Unified Inch Screw Threads
ANSI Z400.1	Hazardous Industrial Chemicals - Material Safety Data Sheets - Preparation
IEEE 4-1995	Standard Techniques for High Voltage Testing
IEEE C57.19.00	General Requirements and Test Procedure for Outdoor Power Apparatus Bushings
IEEE C57.19.01	Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings
NEMA 107	Methods of Measurement of Radio Influence Voltage (RIV) of High Voltage Apparatus
ASTM D3487	Mineral Insulating Oil Used in Electrical Apparatus
ASTM D4059	Analysis of Polychlorinated Biphenyl in Mineral Insulated Oils by gas Chromatography
ASTM D1275-06	Standard Test Method for Corrosive Sulfur in Electrical Insulating Oils
IEC-60137	Bushings for Alternating Voltages above 1000V
IEC-61462	Composite Insulators
IEC-62199	Bushings for DC Applications
IEEE-21 ANSI C76.1	IEEE Standard General Requirements and Test Procedure for Outdoor Apparatus Bushings

3.1.5. Insulators

ANSI Y14.5M	Dimensioning and Tolerancing
ANSI Z55.1	Gray Finishes for Industrial Apparatus and Equipment
Fed SpecA-A-208	Ink, Marking, Stencil, Opaque (Porous and Nonporous Surfaces).
Fed Spec TT-I	
IEEE Std 4	Standard Techniques for High Voltage Testing
ASME B1.1	Unified Inch Screw Threads
ASME B18.2.1	Square and Hex Bolts & Screws
ASME B18.2.2	Square and Hex Nuts (RI987)
ASME B18.21.1	Lock washers
IEC-60120	Dimensions of Ball and Socket Couplings of String Insulator Units
IEC-60137	Bushing For Alternating Voltage above 1000V
IEC-60168	Tests on Indoor and Outdoor Post Insulators for Systems with Nominal Voltage Greater than 1000 V

IEC-60233	Tests on Hollow Insulators for use in Electrical Equipment
IEC-60273	Characteristics of Indoor and Outdoor Post Insulators and Post Insulator Units for Systems with Nominal Voltage Greater than 1000 V
IEC-60305	Characteristics of String Insulator Units of the Cap and Pin Type
IEC-60372	Locking Devices for Ball and Socket Couplings of String Insulator Units.
IEC-60383	Tests on Insulators of Ceramic Material or Glass for Overhead Lines With a Nominal Voltage greater than 1000 V
IEC-60433	Characteristics of String Insulator Units of the Long Rod Type
IEC-60471	Dimensions of Clevis and Tongue Coupling of String Insulator Units
ANSI-C29	Wet Process Porcelain Insulators
ANSI- C29.1	Test methods for Electrical Power Insulators
ANSI- C29.2	For insulators, Wet-Process Porcelain and Toughened Glass Suspension Type
ANSI C29.8	For Wet-Process Porcelain Insulators Apparatus, Cap and Pin Type
ANSI- C29.9	For Wet Process Porcelain Insulators Apparatus, Post-Type
ASTM A-153	Zinc Coating (Hot-Dip) On Iron and Steel Hardware
IEC 61109	Composite Insulator for AC Overhead Lines with Nominal Voltage greater than 1000 V
IEC-601325	Insulators for OH Lines with a nominal voltage above 1000V. Ceramic or Glass units for dc systems
IEC-60587	Electrical Insulating Materials used under Severe Ambient Conditions – Test Methods for Evaluating Resistance to Tracking and Erosion

3.1.6. Surge Arrestors

IEEE C62.11	Metal Oxide Surge Arresters for Alternating-Current Power Circuits
IEC 60099-4	Metal Oxide Surge Arresters without Gaps for AC Systems
ANSI B1.1	Unified Inch Screw Threads
NEMA 107	Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus

NEMA CC1	Electric Power Connections for Substations
ASTM A36/A36M	Structural Steel
ASTM A123/A123M	Zinc, (Hot-Galvanized) Coatings on iron and steel products, standards specification for zinc (Hot Dip Galvanized) coatings on iron and steel products.
ASTM A153/A153M	Standard Specification for Zinc Coating, (Hot-Dip) on Iron and Steel Hardware
Fed Spec PPP-P-1660	Pallet, Expandable
IEC-60099-4	Metal oxide surge arresters without gaps
ANSI- C62.1	IEEE Standard for Surge Arresters for AC Power Circuits

3.1.7. Cubicles and Panels

IEC-68.2.2	Basic environmental testing procedures Part 2: Tests: B : Dry heat
IEC-60529	Degrees of Protection provided by enclosures
IEC-60158	Low Voltage Control Gear Contractor
ANSI- C37.20	Switchgear Assemblies, including Metal enclosed Bus
ANSI- C37.50	Test Procedures for Low Voltage Alternating Current Power Circuit Breakers
ANSI-C 39	Electrical Measuring Instruments
ANSI-C 83	Components for Electric Equipment
NEMA- AB	Molded Case Circuit Breakers
NEMA- CS	Industrial Controls and Systems
NEMA- PB-1	Panel Boards
NEMA- SG-3	Low Voltage Power Circuit Breakers
NEMA- SG-5	Power Switchgear Assemblies
NEMA- SG-6	Power Switching Equipment
NEMA-5E-3	Motor Control Centers

3.1.8. Disconnect Switches

IEEE C37.30	Standard Requirements for High Voltage Switches
IEEE C37.32	High-Voltage Switches, Bus Supports, and Accessories Schedules of Preferred Ratings, Construction Guidelines and Specifications

IEEE C37.34	Test Code for High Voltage Air Switches
IEEE C37.35	High Voltage Air Disconnecting and Interrupter Switches
IEEE C37.36b	Current Interruptions with Horn Gap Air Switches
IEEE C37.37	Loading Guide for AC High Voltage Air Switches
IEEE Std. 4	Standard Techniques for High Voltage Testing
IEEE Std. 4A	Amendment to IEEE Standard Techniques for High-Voltage Testing
NEMA CCI	Electric Power Connections for Substations
NEMA ICS 1	Industrial Controls and Systems, General Requirements
NEMA ICS 2	Industrial Controls and Systems, Contactor and Overload Relays
NEMA ICS 3	Industrial Controls and Systems, Medium Voltage Controllers
NEMA ICS 4	Industrial Controls and Systems, Terminal Blocks
NEMA ICS 5	Industrial Controls and Systems, Control Circuits and Pilot Devices
NEMA ICS 6	Industrial Controls and Systems, Enclosures
NEMA MG1	Motors and Generators
NEMA MG2	Motors and Generators Safety Standards
NEMA 250	Enclosures for Electrical Equipment (1000 Volts Maximum)
ASTM A36/A36M	Carbon Structural Steel
ASTM A123/A123M	Zinc (Hot-Dip Galvanized) Coatings for Iron and Steel Products
ASTM A153/A153M	Zinc Coating (Hot-Dip) on Iron and Steel Hardware
ASTM B98/B98M	Copper-Silicon Alloy Rod, Bar and Shapes
ASTM B221	Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles and Tubes
ASME Y14.5	Dimensioning and Tolerancing
IEC 62271-102	High –Voltage Switchgear and Control gear
IEC 62271-1	High-Voltage Switchgear and Control gear Part1: Common Specifications
ANSI-C37.30	IEEE Standard Requirements for High Voltage Switches
ANSI- C37.32	Schedule of Preferred Ratings, Manufacturing Specifications and Application Guide for High voltage Air Switches, Bus Supports and Switch Accessories
IEC-60129	Alternating Current Isolators (Disconnectors) & Earthing Switches
IEC-60265	High Voltage Switches
IEC-62271-102	High Voltage Alternating Current Disconnectors and Earthing Switches

3.1.9. **Capacitors**

IEEE Std. 18	IEEE Standard for Shunt Power Capacitors
IEEE Std. 1036	Application of Shunt Power Capacitors
IEEE C29.9-1983	Wet-Process Porcelain Insulators (Apparatus, Post-Type)
IEEE C57.13	Requirements for Instrument Transformers
IEEE C37.04	Standard Rating Structure for AC High-Voltage Circuit Breaker
ANSI C84.1	Electric Power Systems and Equipment – Voltage Ratings (60 Hertz
ANSI/AISC 360	Specification for Structural Steel Buildings
NEMA CC 1	Electrical Power Connectors for Substations
NWMA CP 1	Shunt Capacitors
ASTM A123/A123M	Zinc (Hot Galvanized) Coatings on Iron and Steel Products
ASTM A153/A153M	Zinc Coating (Hot Dip) on Iron and Steel Hardware
ASTM B98	Copper-Silicon Alloy Rod, Bar and Shapes
ASTM D4059-1996	Analysis of Polychlorinated Biphenyls in Mineral Insulating Oils by Gas Chromatography
ASME Y14.5M	Dimensioning and Tolerancing
IEC 60871-1	Shunt Capacitors for AC Power Systems Having a Rated Voltage above 660 V, Part 1 - General Performance, Testing and Rating
IEC 60871-2	Shunt Capacitors for AC Power Systems Having a Rated Voltage above 660 V, Part 2 - Endurance Testing
Aluminum Design Manual	

IEC-60070	Power Capacitors
ANSI/ IEEE-18	Shunt Power Capacitors
IEC 60871-1thru5	Shunt Capacitors for AC Power Systems having a Rated Voltage above 1000 V
IEC 60931-1	Shunt Power Capacitors
IEC 61642	Industrial AC Network Affected by Harmonic Application of Filter and Shunt Capacitor

3.1.10. Communication Equipment and Line Traps

ANSI C93.1	Power line Carrier Coupling Capacitor and Voltage Transformer (CCVT) requirements
ANSI C57.13	Requirements for Instrument Transformers
ANSI/AISC 360	Specification for Structural Steel Building
IEEE 4	Standard Techniques for High Voltage Testing
IEEE C57.19	IEEE Standard of General Requirements and Test Procedures For Power Apparatus Bushings

NEMA CC1	Electrical Power Connectors
ASTM A153/A153M	Zinc Coating (Hot-Dip) on Iron and Steel
ASTM D3487	Mineral Insulating Oil Used in Electrical Apparatus
ASTM D4059EI	Methods for analysis of Polychlorinated Biphenyls in Mineral Insulating Liquid by Gas Chromatography
IEC 60270	High –Voltage Techniques- Partial Discharge Measurements.
ASME Y14.5M	Dimensioning and Tolerancing
CCIR	International Radio Consultative Committee
CCITT	International Telegraph & Telephone Consultative Committee
EIA	Electronic Industries Association
IEC 60870-5-103	Gateway Protocol Communication
IEC-60353	Line Traps
IEC-60481	Coupling Devices for Power Line Carrier Systems
IEC-60495	Single sideboard power line carrier terminals
IEC-60663	Planning of (single Side-Band) Power Line Carrier Systems

3.1.11. **Converter Valves**

IEC-60700-1	Testing of Semiconductor Valves for High Voltage dc Power Transmission
IEC 60919-1	Performance of High Voltage DC System
IEEE 857-1996	<u>Recommended Practice for Test Procedures for High-Voltage Direct-Current Thyristor Valves</u>

3.1.12. **Protection and Control Equipment**

IEC-60051	Recommendations for Direct Acting Indicating Electrical Measuring Instruments and their Accessories.
IEC-60255	Electric Relays
IEC-60297	Dimensions of mechanical structures of the 482.6 mm (19inches) series
IEC-60337	Control Switches (low voltage switching devices for control and auxiliary circuits, including contactor relays)
IEC-60359	Expression of the Functional Performance of Electronic

	Measuring Equipment
IEC-60387	Symbols for Alternating- Current and Electricity Meters
IEC-60447	Standard Directions of Movement for Actuators which control the Operation of Electrical Apparatus
IEC-60521	Class 0.5, 1 and 2 Alternating Current Watt-hour Meters
IEC-60547	Modular Plug-in Unit and Standard 19-Inch rack Mounting Unit Based on NIM Standard (for electronic nuclear instruments)
IEC -61850	Communication networks and Systems in Substations.
ANSI-81	Screw Threads
ANSI-B18	Bolts and Nuts
ANSI- C37.1	Relays, Station Controls etc.
ANSI- C37.2	Manual and Automatic Station Control, Supervisory and Associated Telemeter Equipment
ANSI- C37.90	Relays and Relay Systems Associated with Electric Power Apparatus
ANSI C39.1	Requirements for Electrical Analog Indicating Instruments

3.1.13. Reactors

ANSI/IEEE C57.16	Terminology and Test Code for Dry-Type Air-Core Series-Connected Reactors
IEEE C57.21	IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors over 500 kVa
IEEE-1277	IEEE Trial-Use General Requirements and Test Code for Dry-Type and Oil-Immersed Smoothing Reactors for DC Power Transmission

3.1.14. Motors

IEC-60034	Rotating Electrical Machines

3.1.15. Material Standards

ASTM	Specification and Tests for Materials

3.1.16. Clamps and Connectors

NEMA- CC-1	Electric Power Connectors for substation.
NEMA- CC-3	Connectors for Use between Aluminium or Aluminium-Copper Overhead Conductors

3.1.17. Bus Work and Insulators

IEC-60120	Dimensions of Ball and Socket Couplings of String Insulator Units
IEC-60137	Bushing For Alternating Voltage above 1000V
IEC-60168	Tests on Indoor and Outdoor Post Insulators for Systems with Nominal Voltage Greater than 1000 V
IEC-60233	Tests on Hollow Insulators for use in Electrical Equipment
IEC-60273	Characteristics of Indoor and Outdoor Post Insulators and Post Insulator Units for Systems with Nominal Voltage Greater than 1000 V
IEC-60305	Characteristics of String Insulator Units of the Cap and Pin Type
IEC-60372	Locking Devices for Ball and Socket Couplings of String Insulator Units.
IEC-60383	Tests on Insulators of Ceramic Material or Glass for Overhead Lines With a Nominal Voltage greater than 1000 V
IEC-60433	Characteristics of String Insulator Units of the Long Rod Type
IEC-60471	Dimensions of Clevis and Tongue Coupling of String Insulator Units
ANSI-C29	Wet Process Porcelain Insulators
ANSI- C29.1	Test methods for Electrical Power Insulators
ANSI- C29.2	For insulators, Wet-Process Porcelain and Toughened Glass Suspension Type
ANSI C29.8	For Wet-Process Porcelain Insulators Apparatus, Cap and Pin Type
ANSI- C29.9	For Wet Process Porcelain Insulators Apparatus, Post-Type
ASTM A-153	Zinc Coating (Hot-Dip) On Iron and Steel Hardware
IEC 61109	Composite Insulator for AC Overhead Lines with Nominal Voltage greater than 1000 V

3.1.18. Batteries and Battery Chargers

IEC-60086	Primary Batteries
IEC-60086-2	Primary Batteries, Specification sheets
NEMA-1B1	Definitions and precautionary labels for Lead-acid Industrial Storage Batteries
NEMA-1B4	Determination of ampere hour and watt-hour capacity of lead-acid industrial storage batteries for stationary service.
NEMA-1B5	Life testing of lead-acid Industrial storage batteries for stationary service
IEEE-484	Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations
IEEE-485	Sizing Large Lead Storage Batteries for Generating Stations and Substations
NEMA-PV3	Safety Code for Semiconductor Power Converters
NEMA-PV5	Constant potential type electric Utility (Semi-Conductor Static Converter) Battery Chargers
NEMA-RI2	General Purpose and Communication Battery Chargers

3.1.19. Wires and Cables

IEC-60434	Rubber insulated cables with copper(part 1) conductors
IEC-60096	Radio Frequency Cables
IEC-60183	Guide to the Selection of High Voltage Cables
IEC-60189	Low Frequency cables and wires with PVC Insulation and PVC Sheath
IEC-60227	Polyvinyl Chloride Insulated Cables of Rated Voltages up to and Including 450/750 V
IEC-60228	Conductors of Insulated Cables
IEC-60230	Impulse Test on Cables and their Accessories
IEC-60287	Calculation of the Continuous Current rating of Cables (100% Load Factor)

IEC-60304	Standard Colours for Insulation for Low-Frequency Cables and Wires
IEC-60330	Methods of Test for PVC Insulation and Sheath of Electrical Cables
IEC-60331	Fire - Resisting Characteristics of Electric Cables
IEC-60332	Tests on Electric Cables under Fire conditions
IEC-60502	Extruded solid dielectric insulated power cables for rated voltages from 1 kV up to 30 kV
IEC-60540	Tests methods for insulators & sheaths of electric cables & cords (electrometric & thermoplastic)
IEC-7541	Tests on gases evolved during combustion of electrical cables
NEMA-WC1	Asbestos and Asbestos-Varnished Cloth and Asbestos-Thermoplastic Insulated Wire and Cable
NEMA-WC2	Steel Armour and Associated Covering for Impregnated Paper - Insulated Cables
NEMA-WC3	Rubber Insulated Wire and Cable for transmission and Distribution of Electrical Energy
NEMA-WC5	Thermoplastic Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
NEMA-WC7	Cross-Limited Thermo setting Polyethylene Insulated Wire & Cable for the Transmission and Distribution of Electric Energy
NEMA-WC8	Ethylene-Propylene-Rubber-Insulated Wire & Cable for the Transmission and Distribution of Electrical Energy
NEMA-W67	Cross - Linked - Thermo Setting Poly (IPCEA,S-66- 524) ethylene Insulated Wire and Cable for the transmission and Distribution of Electrical Energy
IPCEA S-61-402	Thermoplastic Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
ASTMD- 2843	Standard test methods for density of smoke from burning or decomposition of plastics
IEEE-48	Pot Heads

3.1.20. Air Conditioning

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers

AMCA	Air Moving and Conditioning Association

3.1.21. Fire Protection

NFPA 850	National Fire Protection Association – Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations.

3.1.22. Seismic Performance

All support structures and foundations shall be designed for moderate level spectral acceleration in accordance with IEEE 693-2005, IEEE Recommended Practice for Seismic Design of Substations and each respective utility's requirements.

AC circuit breakers, ac instrument transformers, ac surge arresters and ac disconnect switches are considered "transferrable equipment" and shall be qualified at the IEEE 693 high seismic level. All other supplied equipment, including converter transformers and valves shall be qualified at the moderate seismic level.

3.1.23. Safety Requirements

The Contractor shall comply with each converter site's Accident Prevention and Safety Procedure Manual.

4. Performance Requirements

4.1. Transmission System Rating

The Plains and Eastern (P&E) project is an HVdc transmission system that will deliver power from wind plants in Oklahoma and Texas to connections in Tennessee and Arkansas and their surrounding ac systems. The proposed HVdc transmission line would traverse from the Oklahoma panhandle region, across Arkansas and terminate at the Tennessee Valley Authority system a distance of approximately 711 miles. The western portion of this project will interconnect to the transmission system operated by the Southwest Power Pool in Texas County, Oklahoma. The eastern portion of the project will interconnect to the transmission system operated by the Tennessee Valley Authority in Shelby County, Tennessee.

A third converter terminal located in Pope County, Arkansas, rated to deliver 500 MW will require that the HVdc system operate in multi terminal. P&E will be configured as a bipolar LCC, ±600kV HVdc overhead transmission system delivering 3500 megawatts (MW) and 500 MW to the two inverter stations. These power values shall be measured at the line side of the converter transformer.

The converter station shall be configured as one 12-pulse valve group per pole.

The system shall be designed to utilize a dedicated metallic return (DMR) conductor during normal bipole operation.

The Contractor in designing the pole dc terminal equipment on the HV side shall avoid resonance with the dc line, in particular at fundamental and second harmonic. This means that, the smoothing reactor sizing and dc filter design should consider such resonance conditions. Similarly the design of the neutral equipment shall avoid resonance with the DMR.

All components of the transmission system supplied as part of the Contractor's scope of supply shall be rated to meet the requirements given in this section and other requirements specified elsewhere in the Owner's technical specification.

The ac system data given in Section 2.12 and site environmental data given in Section 2.9 shall be used in the determination of performance and rating unless a more limiting value is otherwise stated in another Sub-Clause. Discrepancies shall be referred to the Owner for clarification.

Performance and ratings shall be determined taking into account simultaneous occurrence of extreme values of environmental and ac and dc system parameters and extreme values of manufacturing and measuring tolerances. There shall be no limitation on the rating or any de-rating of equipment supplied under the Contract due to failure to take into account the worst combination of system conditions including environmental conditions, voltage, frequency variation, voltage unbalance, or any tolerances and measuring uncertainties which shall be assumed to occur simultaneously. The ratings and all performance criteria shall be achieved for the normal continuous range of converter ac bus voltage and continuous frequency variation for all operating conditions and shall be available under all specified fault level conditions and all specified ambient temperature conditions with all redundant cooling equipment out of service

Performance should be optimized to ensure that following ac system faults and dc line faults the power recovery at the 3500MW inverter is as quick as possible while taking into account the restrictions that may occur due to the variable wind generation at the rectifier terminal.

It is understood that the 500MW tap may impose some challenges and the Owner is open to the vendor determining the optimal technology, rating, layout, firing angles or combination of these items to ensure a robust, reliable, economical design.

When determining ratings that are impacted by environmental variables such as temperature it should be noted that extreme variation above the quoted values may occasionally occur. In such event, the equipment shall not trip but shall continue to operate within its inherent rating but possibly at reduced capacity. The required capacity reduction shall be automatically determined and applied to ensure that the rated temperature rise of supplied equipment will not be exceeded. The application of capacity reduction limits in such case shall be by a ramp and based on actual temperature or thermal image models so that the reduction in capacity is limited to the smallest possible degree.

Operation shall be possible and there shall be no restriction on connecting, starting and remaining in operation within the extreme maximum continuous and extreme minimum continuous ac bus voltages defined in Table 5. The Contractor shall advise of any limitations on performance or power transfer when operating outside the normal continuous ac bus voltage range but within the extreme continuous bus voltage range. There shall be no reduction in the power transfer capability of the dc transmission system due to frequency disturbances as specified in Section 2.12. The converter valves and cooling, converter transformers and all associated auxiliary equipment shall continue to operate without tripping during the frequency disturbances.

The Contractor will guarantee the nominal continuous ratings, the continuous overload ratings, the inherent short time overload ratings, the reduced voltage operation ratings and the minimum continuous power transfer ratings.

The power rating levels and power transmission capabilities due to but not limited to extreme ambient conditions or reduced voltage operation, under the specified conditions quoted by the Bidder shall not be less than the specified levels for all phases of the development. Specifically, the Bidder/Contractor will guarantee the nominal continuous ratings, the continuous overload ratings, the inherent short time overload ratings, the reduced voltage operation ratings and the minimum continuous power transfer ratings.

The power transmission capability may also be determined by calculation based on test values including tolerances of all components
.
In the calculation of power transmission capability, the most unfavourable combination of control and measurement tolerances, particularly as those that affect tap changer position, shall be considered.
All performance requirements shall be demonstrated for all phases.

In the event of an ac system contingency that reduces the system strength below the specified minimum level as defined in Section2.12, the Contractor shall determine the maximum power that may be transferred which will ensure the stable operation of the HVdc system and all ac system voltage requirements are met.

4.2. DC Power Circuit Requirements

The dc power circuit shall allow for the following:

- Isolating and grounding any pole, or converter in any converter station for with no disturbance to the other pole in operation.
- Isolating and grounding the station for transmission line for maintenance.
- Connecting, isolating and grounding dc filter branches for maintenance without affecting the transmission in the pole associated with this DC filter.

4.3. Transmission System Rating

4.3.1. Nominal Continuous Ratings

The converters shall have guaranteed nominal continuous ratings as measured by the ac and dc switchyard measuring transducers as given in Table 14 Converter Ratings.

Table 14 Converter Ratings

	Guaranteed Nominal Continuous Converter Ratings		
	Hitchland Converter (rectifier)	Shelby Inverter	Tap Inverter
Rated Voltage	+/-600kV	Voltage to be determined by the rated voltage minus the line drop	Voltage to be determined by the rated voltage minus the line drop
Rated Current	As required to meet Inverter/tap requirements	TBD	TBD
Rated Power	As required to meet Inverter/tap requirements	3500MW	500 MW

The above ratings shall be achieved at maximum ambient temperature with all redundant ac filters out of service and with all redundant thyristors short circuited, for all system conditions as specified in Section 2.9.1.

The Bidder shall state the allowable power transfer for each converter for the following modes listed in Table 15 below:

Table 15 Power Transfer Modes

Case	Hitchland Converter	Shelby Converter	Tap Converter
1 (design case)	Rectifier	Inverter	Inverter
2	Rectifier	Rectifier	Inverter
3	Rectifier	Inverter	Rectifier
4	Inverter	Rectifier	Inverter
6	Blocked	Rectifier	Inverter
7	Blocked	Inverter	Rectifier
8	Rectifier	Blocked	Inverter
9	Inverter	Blocked	Rectifier
10	Rectifier	Inverter	Blocked
11	Inverter	Rectifier	Blocked

In addition, the power transmission requirements shall be met without the redundant cooling and within the limits of reactive power interchange specified, ac harmonic filter performance specified, dc harmonic filter performance specified, and all other relevant performance parameters as specified.

The basis for calculation of the converter station equipment ratings to meet this nominal continuous rating shall be as follows:

- Maximum daily average air temperature and maximum ambient air temperature in accordance with Table 2.
- Redundant cooling not available for service.
- Converter transformer hot spot temperatures shall be limited to the maximum values given in Table 2.

4.3.2. Direct Voltage

The nominal direct voltage at the Hitchland converter dc line terminal shall be ±600 kV relative to neutral when the station is operating in the rectifier mode. The dc voltage at the remaining converters shall be determined by the contractor taking into account the dc line drop and ensuring that all power requirements are met. The dc voltage of 600 kV shall be maintained within ±15kV by tap changer and firing angle control for all power flows up to rated value or for all ac bus bar voltages and ac system frequencies ranges specified in Section Frequency Criteria. The dc pole voltage in all phases shall be achievable in bipolar, monopolar with DMR, DMR in parallel with PMR and PMR operating modes of operation

4.3.3. Direction of Power Flow

The converter stations shall be capable of transmitting power in both power directions. During the transmission of power from Hitchland to the Shelby and mid tap converters, the bipolar power shall be 3500 MW at the Shelby inverter and 500MW at the mid tap as measured at the ac side of the converter transformers. During the transmission of power in other directions, the Bidders shall state the power available. It shall be possible to reverse the power direction of the tap while maintaining the same power direction at the other two stations.

4.3.4. Operating Modes

The converter station shall be designed and rated to operate in balanced bipolar mode in which the unbalance current between the two poles shall not exceed 20 amperes.

The converter station shall be designed to operate in mono-polar operation utilizing the DMR or utilizing the other pole conductor as a metallic pole return mode PMR, or both the DMR and PMR in parallel. The switching between the metallic return mode and metallic pole return mode shall be performed without power interruption.

4.3.5. Power Transmission Requirements

The power transmission requirements given below shall be achieved with all redundant equipment out of service and redundant thyristors short circuited. The power transmission requirements specified shall be met for the frequency range specified in Table 9 Frequency Criteria throughout the entire range of ambient temperatures as specified in Section 2.9.1 and at all ac bus voltages as specified in Table 5 . In addition the power transmission requirements shall be met within the limits of reactive power exchange specified in Table 10 Reactive Power Exchange Values, ac harmonic filter performance specified, dc harmonic filter performance specified, and all other relevant performance parameters as specified.

Any limitation on steady state or short time power flow which may be necessary due to abnormal ac system conditions identified by either the Owner or by the Contractor shall be implemented by the Contractor within the control system.

4.3.5.1. Minimum Power Requirements

The converter station shall be designed for a minimum power of 5%.

4.3.5.2. Short Time Overload Requirements

The Bidder shall state in its proposal, the short time overload capability with and without redundant cooling and for how long and how often it can be applied in a 24 hour period. A curve giving the overload vs. ambient temperature with and without redundant cooling shall be provided.

4.3.5.3. Reduced Voltage Operation

The Hitchland converter station shall be capable of operating continuously at a nominal pole voltage to neutral of 420 kV as a rectifier in bipolar and in monopole modes. The system shall be capable of transmitting not less than 70% rated bipolar power in all modes.

The reduced dc voltage operation can be initiated by the dc line restart sequence or by the operator.

When the other converters are running as rectifiers, the voltage shall be 70% of the voltage of the rectifier with the highest dc voltage.

It shall also be possible to set the dc voltage reference between 420 kV to 600 kV in either pole in steps of 10 kV by the operator. Power levels in this voltage range shall be as permitted by the main circuit rating of the equipment. The reduced voltage may be achieved by a combination of tap changer and firing angle control.

The transmitted power rating with reduced dc line voltage shall be achieved for all ambient temperatures specified in Table 2.

Forac bus voltages in excess of the values stated in Table 5, the permissible transmitted power levels may be reduced and/or the pole to neutral dc voltage increased; however the percentage increase in voltage shall not be greater than the percentage by which the ac bus voltage exceeds the values in Table 5.

The Contractor shall furnish a power versus ac voltage curve for the converter station.

It should be noted that ac harmonic filter performance and reactive power balance requirements as specified are to be met during reduced voltage operation; but it may be assumed that all filters are available for service if required.

It shall be possible to start the transmission in reduced voltage mode by the operator.

4.3.5.4. **Increased Reactive Power Absorption**

The use of higher than normal firing and extinction angles temporarily to assist in reactive power management/ voltage control of the ac system may be utilized by the Contractor provided that all equipment is adequately rated and that all the requirements of this Specification are met.

4.3.5.5. **Unbalanced Operation**

The HVdc equipment shall be designed and rated to operate with different dc current orders. Necessary facilities shall be provided to permit these modes of operation and to allow the individual pole power and/ or current orders and/or voltage to be set independently.

Each pole shall be capable of transmitting its full rated power including overloads specified for the relevant conditions.

4.4. <u>Dynamic Performance</u>

The converter station shall conform to the performance requirements specified herein. It shall be designed to optimally co-ordinate all aspects of its controls to ensure safe and reliable operation without adversely affecting the connected ac system and shall assist the latter, following disturbances. The performance requirements shall be met under all specified ambient conditions, modes of operation, ac system conditions, project phases and other parameters as given in this Specification.

The principal objectives of the design shall include:

- Optimal response of HVdc controls following step change in ordered parameters like current, power, dc voltage and firing angles etc.
- Stable operation of the dc system following major disturbances.
- Stabilization of the ac system following major disturbances.
- Control of power levels depending on the system configuration. Such a control may require Run Back control features.

The Contractor shall determine the necessary control modes to be implemented at each converter station including but not limited to dc power control, dc current control, dc voltage control and extinction angle control. The Contractor shall also include converter transformer tap changer control as required.

The operation of control and protection functions such as voltage dependent current limits, commutation failure protection, and circuits provided to enhance commutation during disturbed ac voltage conditions shall be optimized to assist in meeting the specified responses.

4.4.1. **Control System Stability**

The Contractor shall demonstrate, to the Owner that the HVdc control system, is stable under all operating conditions and cannot excite oscillations, such as sub-synchronous oscillations, between the

HVdc and ac system. The control system shall be tuned for optimal overall performance for all conditions and configurations of the ac system.

The Contractor shall also demonstrate that the as-built control system does not excite low order harmonic resonance(s) in the ac system and/or between HVdc and ac systems for any system configuration.

Performance of the control system in this respect shall be demonstrated by the Contractor, during the dynamic performance testing study.

4.4.2. Response Times

The controls of the HVdc system shall be capable of stable operation, while meeting all the response requirements, for various system (ac/dc) parameter step changes and changes in the system conditions as specified herein.

The Contractor shall optimize the recovery of the dc system following faults with the objective of obtaining the fastest practical power transfer recovery with the minimum energy loss to the receiving ac system while at the same time maintaining the stability of the ac systems.

4.4.2.1. System Conditions

The Contractor shall demonstrate the response and stability of the as built controls using an HVdc simulator using an equivalent (test) system to be agreed to by the Owner. The response shall be later verified to the extent possible during system commissioning at site.

The response times specified herein shall be achieved at all ac system short circuit levels between the minimum and maximum values given in Table 3 and Table 4.

The reactive compensation connected prior to the reference change or disturbance shall be established by the required reactive power switching controls. Conditions shall be determined and mutually agreed between the Contractor and the Owner for the various defined test cases.

The Contractor shall design the HVdc system control such that the specified responses are met for the maximum communication system delays and the dynamic voltage ranges.

4.4.2.2. Response Definitions

Figure 3 shows the response definition described below as interpreted for a step increase. Figure 4 shows the response definition as interpreted for a step decrease.

The response time (tr1) is defined as the time from the initiation of the order change to the time when 90% of the ordered change has been accomplished, subject to the condition that the measured value remains at the new order within a tolerance of +10% of the ordered change at rectifier dc terminal after the first overshoot.

If the measured value exceeds the tolerance of +10% of the ordered change after the first overshoot, then the response time (tr2) shall be defined to be the interval from the initiation of the order change to the time when the measured value returns to and thereafter remains at the new order within a tolerance of +10% of the ordered change.

The first overshoot shall not exceed 30% of the ordered change and the measured value shall settle at the new order within a tolerance of +2% by the second overshoot.

For an over damped system, the response times (tr3) is defined as the time from initiation of the order change to the time when 90% of the ordered change has been accomplished. The measured value shall settle at the new order within a tolerance of +2% by four times tr3.

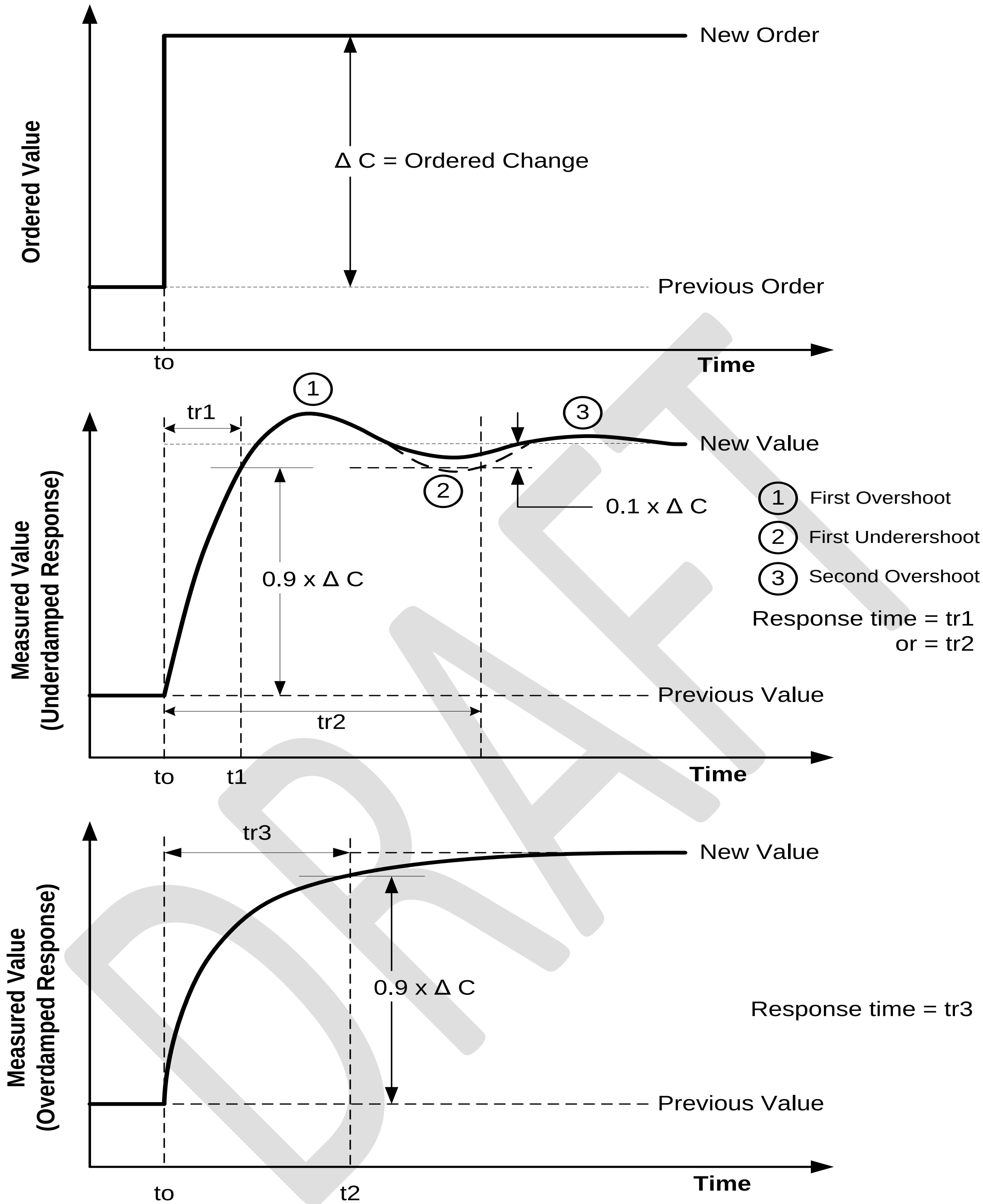

Figure 3 Response Times for a Step Increase

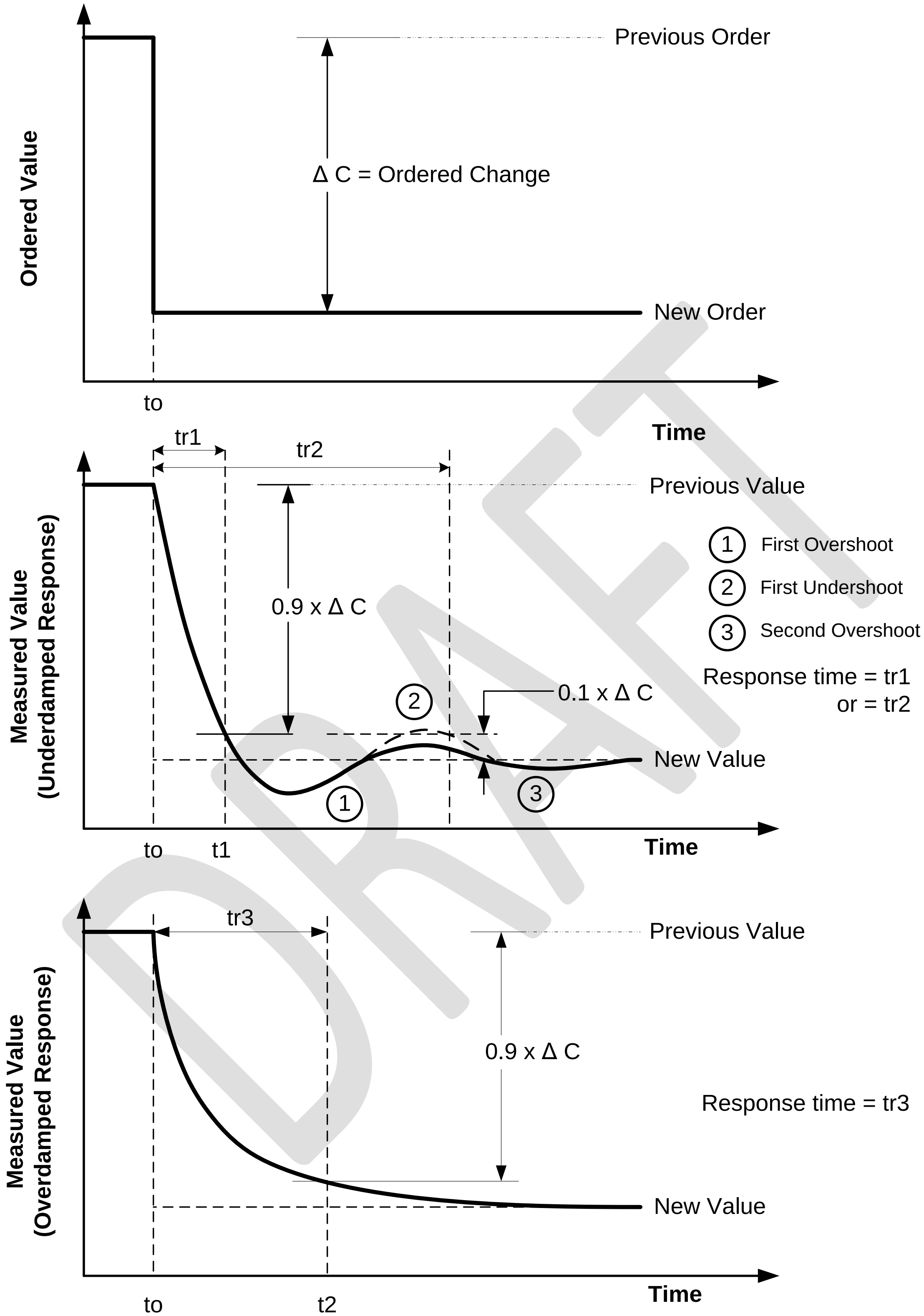

Figure 4 Response for a Step Decrease

4.4.2.3. **Response Requirements**

Power Order Step Response

The HVdc controls, when in power control mode or any other mode where the dc power transfer is controlled, respond to maintain the power transfer of the poles at the ordered or desired level at any power level between minimum and the overload rating

When operating at any power order between the minimum and rated power transfer, the dc power controller shall respond to either a step increase or a step decrease in dc power order such that 90% of the ordered change is achieved within 150 milliseconds of the power order change at the rectifier end. The Contractor shall verify that such response time does not give rise for any risk of ac system voltage instability. This time includes the dc current order check back time.

The specified dc power order step response shall be demonstrated for a step change in bipolar and in monopolar operation for the following cases. In the case of monopolar operation the specified response shall be demonstrated for operation of the pole in both metallic return and metallic modes.

1. Power transfer order step from 1.0 pu to 0.5 pu
2. Power transfer order step from 0.5 pu to 1.0 pu applied immediately after the system has settled from step (1).
3. Power transfer order step from 0.5 pu to 1.0 pu
4. Power transfer order step from 1.0 pu to 0.5 pu applied 100 ms after step (3).
5. Response to ac bus voltage change

The Contractor shall demonstrate the response of the power controls to sudden changes in ac bus voltages of plus and minus 5 % from nominal at power transfer levels of:

1. Minimum transmitted power in bipolar mode
2. Rated continuous maximum power in bipolar mode

The HVdc system shall be running in its normal control mode with all control parameters (alpha, gamma and dc voltage) at their nominal values prior to the application of the power order step.

DC Current Response

When operating at any dc power transfer level between the minimum and maximum rated power levels, the pole dc current shall respond to either a step increase or a step decrease in current order as follows:

- Within 30 milliseconds for current order changes not exceeding the margin.

  The specified dc current order step response shall be demonstrated by the Contractor for a step change on one pole, with and without the other pole operating at a dc power level of 1.0 pu, for the following cases:

  a) Current order step from (1.0 - x) pu to 1.0 pu
  b) Current order step from 1.0 pu to (1.0 - x) pu, applied immediately after the step of (a) has settled.
  c) Current order step from 1.0 pu to (1.0 - x) pu
  d) Current order step from (1.0 - x) pu to 1.0 pu applied immediately after the step of (c) has settled.

  Where 'x' is a value equal to the current margin less the tolerance of the measuring and control circuits, to be specified by the Contractor and approved by the Owner.

- Within 70 milliseconds for current order changes exceeding the margin.

The specified dc current order step response in this case shall be demonstrated by the Contractor for a step change on one pole, with and without the other pole operating at a dc power level of 1.0 pu, for the cases (a),(b),(c) and (d) defined in the previous paragraph with 'x' replaced by 0.5.

DC Voltage Response

The converter station shall be designed to ensure that at any transmitted power level and in any operating mode, the pole dc voltage shall not exceed 615 kV for a period in excess of 100 ms. If required, the Contractor shall incorporate additional measures in the control system to achieve the reduction in dc voltage within the limits specified above.

The Contractor shall demonstrate that while Hitchland is operating as a rectifier at nominal dc voltage of 600 kV that a step decrease in the dc voltage reference to 420 kV on one pole lasting 100 ms and back to 600 kV dc voltage reference shall be stable and shall have no impact on the transmitted power through current order coordination between the two poles.

Power voltage instability

Constant power control can lead to power voltage instability under certain disturbances. To prevent such power voltage instability, the Contractor shall provide control measures to prevent ac system collapse during ac system disturbance due to the action of the HVdc control. The contractor may adopt a power reduction function in the control system to avoid such instability if the short circuit MVA changes during a particular power transmission level.

4.4.2.4. **Pole Blocking**

The dc system shall be designed such that the power transfer loss of a faulted pole due to pole blocking and line fault clearing is transferred to the remaining pole. The power transfer on the remaining pole shall be increased up to its rated short-time power transfer capability to compensate for the power transfer loss on the faulted pole and to minimize ac network disturbance.

When an increase in power transfer of the healthy pole is required due to blocking of the other pole, 90 % of the increase in dc power transfer required shall be achieved within 100 milliseconds of the faulted pole blocking.

For the case where a pole blocks while communications are not in-service, 90 % of the required dc power transfer to the other pole shall be achieved within 100 milliseconds of the rectifier blocking.

The specified response for a pole blocking shall be demonstrated by the Contractor for the following cases:

1. Bipolar operation in eastward and westward power transfer with 0.5 pu continuous rated bipolar power transfer, and one of the poles permanently blocking
2. Bipolar operation in eastward and westward power transfer with 0.5 pu continuous rated bipolar power transfer, and one of the poles has a line fault with successful recovery.
3. Bipolar operation in eastward and westward power transfer at 1.0 pu continuous rated bipolar power transfer, and one of the poles permanently blocking
4. Bipolar operation in eastward and westward power transfer at 1.0 pu continuous rated bipolar power transfer and one of the poles has a line fault with successful recovery.
5. Bipolar operation in eastward and westward power transfer with 0.5 pu continuous rated bipolar power transfer, and one of the poles at the tap permanently blocking
6. Bipolar operation in eastward and westward power transfer at 1.0 pu continuous rated bipolar power transfer, and one of the poles at the tap permanently blocking

4.4.2.5. **AC Faults**

The Contractor shall demonstrate the response of the HVdc system to ac voltage changes or faults at all converter stations for all modes listed in Section 4.3. The response shall be demonstrated for the following:

1. Single phase-to-ground fault, for 4 cycles and 15 cycles followed by fault clearing and with fault levels resulting in voltage reduction to 90%, 70%, 50%, 30%, 20%, and 0% of nominal converter ac bus voltage.
2. Phase-to-phase fault, for 4 cycles and 15 cycles followed by fault clearing and with fault levels resulting in voltage reduction to 90%, 70%, 50%, 30%, 20%, and 0%, of nominal converter ac bus voltage.
3. Phase-to-phase-to-ground fault, for 4 cycles and 15 cycles followed by fault clearing and with fault levels resulting in voltage reduction to 90%, 70%, 50%, 30%, 20%, and 0% of nominal converter ac bus voltage.
4. Three phase-to-ground faults, for 4 cycles and 15 cycles fault followed by fault clearing , with fault levels resulting in voltage reduction to 90%, 70%, 50%, 30%, 20%, and 0% of nominal converter ac bus voltage.
5. Zero impedance three phase fault on the 500 kV ac busbar followed by fault clearing and results in the loss of one dc pole.
6. Solid single phase-to-ground at the converter bus
7. Solid three phase-to-ground at the converter bus

For faults on the 345 KV system, fault times of 5 and 16 cycles shall be used. For faults on the 500 kV system, fault times of 5 and 13 cycles shall be used.

AC fault response for the above mentioned faults shall be demonstrated for the following operating conditions prior to the fault application:

1. Bipolar operation at 25 %, 50 %, 75 % and 100 % at maximum power in the normal power transfer mode.
2. DMR operation at 25 %, 50 %, 75 % and 100 % at maximum power in the normal power transfer mode.
3. PMR operation at 25 %, 50 %, 75 % and 100 % of rated power transfer in the normal power transfer mode.

The HVdc system shall recover to 90% of the pre-fault dc power transfer level consistently within 150 ms from the instant of fault clearing, without subsequent commutation failure or sustained oscillation for all inverter ac system fault conditions. For all rectifier ac system fault conditions, the recovery time, to 90% pre-fault power level, shall be within 150 ms from the instant of fault clearing. This recovery time shall be achieved for all fault levels as defined in Section 2.12.

The recovery shall be in a controlled and stable manner without commutation failures following ac system faults. The post fault power order shall be equal to the pre-fault power order unless ac/ dc systems dictate otherwise. Any such conditions shall be discussed mutually and agreed to during detailed engineering.

The converter equipment shall be designed such that no delay is required between the clearance of the fault and the start of transmission.

The control equipment shall however be provided with the facility to adjust the delay between fault clearance and the start of recovery and the rate of recovery. The selectable range of settings will be discussed during the engineering studies and agreed upon.

The capability for recovery, in a stable manner, specified above shall be demonstrated by the Contractor. The list of faults shall be agreed to. However, in demonstrating the capability of the HVdc system to recover, blocking of a pole shall not be adopted as a strategy.

4.4.2.6. **DC Line Faults**

The dc line fault protection sequence shall detect the fault, de-energize the faulted line pole by control action, allow a time period for fault deionization, and then automatically attempt restoration of the dc power transfer on the pole.

The total time to restore the dc power to 90% of the pre-fault dc power from the end of the deionization period shall not exceed 100 milliseconds. The clearing and recovery of dc line pole fault shall be demonstrated in bipolar, DMR, PMR and DMR with PMR in parallel modes at 1 pu power transfer prior to the fault for the particular mode. Faults shall be applied at the line ends and at the line midpoint of the line for each line segment between the converter stations. The demonstration shall include the influence of the function provided to transfer power from the faulted pole to the other pole.

Suitable modeling of dc line, which takes into account the electro-magnetic coupling between the poles, shall be considered in the above studies.

The restart of one pole at reduced dc voltage of 420 kV following a dc line fault while the other pole is at 1 pu dc voltage shall be demonstrated.

The system shall be capable of performing 3 at full voltage and 1 restart at reduced voltage.

4.4.2.7. **Operation during Reduced AC Voltage Conditions**

To assist in the recovery of the network, the converter station shall be able to continue operation with reduced ac bus bar voltages.

The converter equipment shall be able to continue operating without blocking of converters with ac bus voltage reduced to 30% of nominal during three phase faults, and to zero on one phase during single line to ground faults, for a period of 1 second followed by voltage recovery to 85%. The converters shall continue to transmit power to the extent possible under the above reduced voltage conditions. This shall be demonstrated by the Contractor on the simulator. The valve firing system as well as all the cooling equipment shall be rated for these conditions.

4.4.2.8. **Operation during Temporary Over-Voltages**

The Contractor shall demonstrate that the converter valves are capable of continuing to operate under the highest temporary overvoltage conditions which could occur with the valves deblocked and also that the valves are capable of deblocking under the highest temporary over voltage conditions within 5 (five) cycles of the initiation of a fault or disturbance.

4.4.2.9. **Controlled Shutdown**

Each pole shall be able to be shut down in a controlled manner by the automatic reduction in the power order accompanied by appropriate ac harmonic filter bank switching. The Contractor shall coordinate the shutdown sequence and timing to ensure no adverse impact on the ac systems.

4.4.3. Commutation Failure Performance

There shall be no commutation failures for the disturbances described below:

- Disturbances resulting in voltage drops of 5 % or less compared to the voltage prior to the disturbance.
- Dynamic ac voltage swings of less than ±10 % with an oscillation period of one second or longer switching of any reactive element in the converter stations.
- Energization of the converter transformer on the other pole.
- Filter switching

4.5. Dynamic Performance Demonstration

The Contractor shall carry out a detailed dynamic performance study of the dc system and all its control and protection functions using digital computer models in the design stage but before the design is finalized.

Design stage demonstrations using digital computer programs shall use full system or reduced equivalent system representations depending on the particular study goals and software used. The Contractor shall demonstrate to the satisfaction of the Owner that the design of the control and protection equipment will meet the operational, performance and equipment requirements of the Owner's Specification.

Acceptable performance of the actual control hardware and software shall be demonstrated during factory system testing of the complete control and protection systems using an RTDS.

The Contractor shall provide, for approval by the Owner, detailed description of the overall dc simulator representation prior to the start of the dynamic performance study.

The Contractor shall carry out studies for both power transfer directions, for all phases of development.

For the purposes of this demonstration, the Contractor shall use the ac system equivalents and the dc transmission line/DMR parameters defined in Section 2.19.

The Contractor shall design the HVdc system control such that the specified performance is met with the communication system in service and for a maximum communication system delay. The studies shall also address performance when the communications are out of service.

The reactive compensation represented shall be in accordance with the general performance and operating philosophies specified in Section 2.13 and Section 4.7 and shall be determined for specific demonstration cases and configurations by the Contractor and approved by the Owner.

The Contractor shall provide, for approval by the Owner, a list of all types of studies that will be carried out by the Contractor as part of the dynamic performance study. The list shall indicate the scope of each study type, study objectives, the impact of study results on equipment design, the study tools to be used, and the impact of power transfer direction, and study program schedule.

This performance study shall include but not be limited to the following types of studies:

1. Performance of dc system controllers in response to power and current order changes.
2. Performance of the dc system for various rectifier and inverter ac system faults. The performance of the dc system shall be demonstrated both during the fault and subsequent to fault clearing.
3. Performance of the dc system for each protection operation, including dc line protection and in-station protections. The fault cases shall be selected to demonstrate clearly coordination of protections, transient current and voltage characteristics, fault clearing control action, and protection-initiated fault isolation sequences.
4. Performance of dc system during steady-state conditions for all specified dc operating modes and configurations, including operation of the dc converter transformer tap changer controls and control mode switchover.
5. Performance during pole start-up and shut-down sequences during two and multi-terminal operation
6. Performance of the supplementary dc controls.
7. Performance of the dc controls in the presence of a low order harmonic resonance between the ac filters and the ac systems with the system negative sequence at the maximum value for rating as specified in Section 2.12.6.
8. Performance of the dc controls for reduced short circuit levels down to equivalent short circuit ratios of 2.5 when operating as an inverter station.
9. Performance of the dc controls for ac filter and shunt capacitor switching.
10. Demonstrate successful limitation of overvoltages.

The ac system equivalents given in Section XXX shall be used in the performance demonstrations except where a low order resonance between the ac filters and the ac system is being simulated. Should the Contractor propose a design that optimizes the overall performance and reliability, but with some compromise in the specified response times, the Contractor is encouraged to submit such a design as an alternative for the evaluation and approval of the Owner.

4.6. Performance of HVdc with Wind

The source of generation to be connected to the rectifier is wind generation. The HVdc link shall be designed to continuously control the exchange of real and reactive power with the ac system at the rectifier during steady-state operation (pre and post contingency) to be within +/- XX MW and +/- XX MVAr.

There is an interconnection requirement that only Type 3 and Type 4 wind turbines be connected to the rectifier, however the specific breakdown of Type 3 and Type 4 turbines and the specific manufacturers of the wind turbines are not known at this time. The layout of the wind collector system is also not known. At this stage of the project, there are four scenarios mapped out for the wind collector system, which are all educated estimates of what the collector system may look like. In addition, an assumption of a 50% Type 3 – 50% Type 4 turbine type breakdown is reasonable, however it will be prudent for the HVdc system to be designed to be flexible to operate with a different wind turbine type breakdown. Therefore an 80% Type 3 – 20% Type 4 and a 20% Type 3 – 80% Type 4 turbine type breakdown should also be considered to account for the unknown and for the possibility of something other than a 50%-50% breakdown. Section 10.X outlines the specific study scenarios related to the wind collector system and wind turbine type breakdown. The Contractor shall ensure that the HVdc system provided meets the performance requirements as specified for the various wind turbine type and wind collector system scenarios. This shall include low voltage protection of the windfarms, wind farm recover rates and their impacts on the voltage and frequency.

4.7. Reactive Power Controls

The Contractor shall design and supply reactive compensation systems including the reactive power controllers for the converter stations which meet the requirements of the Owner's Specification.

Control of the reactive compensation equipment at the converter stations shall be accomplished by the Reactive Power Controller (RPC). The RPC shall be located within the station controls and shall meet all redundancy and separation requirements as specified in Table 10.

The RPC shall have two modes of operation; manual and automatic. In the manual mode of operation all outputs from the controller will be disabled and voltage and switching of reactive power devices will be carried out by the station operator. In the automatic mode, all functions will be active with the operator input limited to set-point and dead-band adjustment.

It shall be possible to place individual equipment comprising the reactive power supply and absorption into manual mode for maintenance purposes.

The reactive power controls shall to the extent possible, minimize operation of on load tap-changers for the converter transformers.

4.7.1. Reactive Power Control Objectives

The RPC shall be designed with the following criteria and design objectives:

1. The RPC shall ensure that sufficient ac filters are in service to meet all harmonic filtering performance and rating requirements.
2. Switching of an ac filter to assist with control of the ac bus voltage is permitted if the ac filter performance and rating requirements are met for all operating conditions.
3. The RPC shall determine the number of ac filters required for operation, either in stand-alone operation or in bipole operation.

4. The RPC shall recognize the limitations of all equipment and shall not initiate control actions which will create an overload condition for any piece of equipment. If limits on MVAr generation on absorption or tap position are encountered, then the controlled quantities shall be allowed to deviate from the set points and the system operator shall be informed that the active set point values are not attainable.
5. If any equipment becomes overloaded due to outages of equipment or changes in the ac system, the RPC shall take action to relieve the overloaded equipment and shall inform the operator that the active set points should be changed.
6. In the event that the RPC cannot alleviate overloading of any component an alarm shall be given to the station operator together with appropriate remedial measures which the operator may take.

Wherever possible, the RPC shall use a combination of voltage measuring transducers to determine the bus voltage and to identify possible transducer errors.

The RPC shall provide the facility to control the following quantities to an adjustable set-point with adjustable dead-bands:

- The ac bus voltage
- The MVAr exchange between the converter bus and the ac system

4.7.2. Dynamic Reactive Power Compensation

4.7.2.1. General

It is the responsibility of the Contractor to ensure that the overvoltages are limited to the values provided in XX and stability is maintained. The strategy provided by the Contractor may contain a Dynamic Reactive Power Compensation Device. In general it is envisioned that such a device shall be an SVC consisting of any combination of TSC, TSR and/or TCR and/or a STATCOM. However, the type of the Dynamic Reactive Power Compensation Device to be supplied shall be determined by the Contractor.

The Contractor shall conduct all system studies required to determine if dynamic reactive power compensation is required to provide mitigation of any overvoltages and system damping.

4.7.2.2. Performance Requirements

The performance of the dynamic reactive compensation device shall be such that it enables the HVdc link to meet the specified performance requirements and provide suitable mitigation of potential overvoltages as specified in this Specification. The dynamic reactive power compensation device shall be capable of fulfilling all requirements for overvoltage mitigation and undervoltage performance with all redundant components (in particular power electronics and cooling plant) out of service.

4.8. Reactive Compensation and Voltage Control

The converter station shall be self-sufficient in terms of reactive power at specified operating conditions in Table 2. The reactive power interchange between the converter stations and the ac system shall be guaranteed by the Contractor and shall be maintained within the limits specified earlier in Table 10.

The reactive power interchange levels shall be determined by measurement using metering accuracy instrumentation to be supplied & installed by the Contractor at the converter stations.

The reactive power control shall be designed for switching and controlling reactive power elements installed.

The Contractor shall perform studies of reactive compensation and voltage control and shall demonstrate to the satisfaction of the Owner that the equipment to be provided meets the requirements of the Specification prior to finalizing any reactive compensation equipment design. The calculations of reactive power interchange and of voltage control shall be based on the most unfavorable combination of tolerances on equipment, connected system configuration and of changes in operating conditions.

If, following manufacture of any equipment, it is found that any relevant parameter is outside the tolerance as assumed in the calculations then the Owner shall have the right to reject the equipment. The Owner may alternatively, instructs the Contractor to provide and install any additional reactive compensation equipment, which the Owner deems necessary to ensure that the equipment to be provided by the Contractor shall meet the Specification. Such equipment shall be provided and installed at no extra cost to the Owner.

4.8.1. **Reactive Power Control and Switching of Elements**

Reactive power control shall be affected by switching shunt connected linear reactive elements which may include reactors, capacitors or harmonic filter banks. In addition the converter valve groups may, if so designed and rated, be operated at increased delay or extinction angle to control reactive power interchange; however the requirements regarding pole voltage, transmitted power, harmonic performance, and component outage shall still be met when operating in this mode.

All switching for reactive power control shall be performed on load by suitably rated circuit breakers. Isolating disconnects shall only be used for maintenance.

The control of reactive power interchange shall be fully automatic and shall be continuously monitored. The control equipment, however, shall allow both automatic and operator initiated switching, in the latter case adequate annunciation shall be provided to the operator.

All filter and capacitor banks and sub-banks shall be capable of being re-energized within 2 minutes of being switched off. The Contractor shall provide any necessary discharge devices.

Switching of any reactive power device (shunt or filter) shall not result in a commutation failure on either pole.

Switching of any reactive power device (shunt or filter) shall not result in a dc control mode change or alter the dc power transfer level. This requirement shall be met after the dc controls have responded but before transformer tap changers or machine exciters have responded.

Each reactive power element shall controlled by its own ac breaker which will allow it to be switched under all load conditions for controlling the reactive power exchange with the system and to be able to be removed from service either temporarily or permanently by any single contingency / fault or outage condition.

The reactive power sources shall be split such that the following conditions are met:

The reactive power interchange requirements specified shall be met with the largest element not available for service up to the rated capacity of the HVdc link. For powers over the rated capacity and up to the overload limits all reactive power sources may be assumed to be available to meet reactive power exchange with the ac system.

The design of the station shall be such that the system recovers from faults, without any reduction in power up to the rated capacity, when the fault results in the outage of the largest bank with one largest sub bank already out of service. The reactive power exchange limits may be relaxed following the fault.

4.8.2. **Voltage Change on Switching**

The switching in and out or a tripping due to faults of a filter sub-bank at the converter stations shall not result in a commutation failure. Such switching shall not alter the dc power transmitted when operating in power control or the pole current when operating in current reference control, after the initial transient. The reactive power exchange values to be maintained at the converter terminals are stated in Table 10 Switching of individual ac filters or shunt capacitor banks shall not cause voltage step changes exceeding the values in the Table 16 below based on the nominal system voltage at minimum short circuit capacity.

Table 16 Voltage Step Change on Capacitor Switching

Number of switching per hour	% Voltage Step Change

<2	3.0%
2-10	2.0%
10-100	1.0%
>100	0.5%

4.9. AC Harmonic Filters

4.9.1. General

The Contractor shall provide ac harmonic filters to reduce the harmonic voltages at the ac buses at the converter stations and to reduce the harmonic currents flowing into the nearby generators to levels which are specified by IEC 61000-3-6.

Each filter bank shall consist of tuned and/or damped sub-banks as required by the Contractor's design. Sub-bank circuit breakers may or may not be employed, based on the Contractor's design.

The ac filters shall be designed and rated for monopolar and bipolar operation of the converters.

The performance requirements shall be met with any one filter bank out of service. The Contractor shall calculate the maximum dc power transfer possible to meet the specified performance limits with two filter banks out of service.

Continuous overload dc power transfer capability shall be sustained with any two filter banks out of service.

The ac filter performance limits shall be met with all combinations of shunt capacitor sub-banks, and ac filter sub-banks that can be in service together subject to the reactive power requirements as specified in Section 2.13 and subject to the maximum and minimum continuous operating voltages given Table 5. The ac filters shall be integrated into the reactive compensation scheme as required.

The ac harmonic filters shall be complete with all capacitors, reactors, resistors, racks, insulators, buswork, ground switches, disconnects, circuit breakers, CTs, PTs, all associated control and protection equipment and equipment necessary for maintenance. The ac harmonic filters shall use as high a proportion of identical interchangeable components as possible in order to simplify maintenance and stocking of spare parts.

The ac filters shall not become overloaded due to any combination of detuning or resonance within the filter banks, resonance between the filter banks and the ac system, for steady state conditions, and short time frequency conditions as stated in Section 2.12.5 and shall remain in service during the above conditions.

The acceptability of the ac harmonic filter designs shall be based on calculated values of performance. Prior to ordering any component the Contractor shall demonstrate, subject to the Owner's review, that the proposed design complies with these Technical Requirements including the requirements on reactive power, overvoltages, and switching.

The calculation of ac filter performance and rating shall be based on values of components, detuning, and harmonic currents, which the Contractor shall determine.

If, at any time, the ac filter design is altered or the basis of any calculated parameter is changed then the Contractor shall resubmit the entire detailed calculations for ac filters to the Owner.

The filters shall be composed of only passive elements such as capacitors, inductors and resistors. Active components are not acceptable.

The noise level of ac harmonic filters under onsite service conditions for all operating conditions considering rated harmonic currents shall not exceed the level determined by the station audible noise design.

If the components as manufactured by the Contractor or the actual generated harmonic voltages or currents fall outside the design limits, then the Contractor shall, without extra charge, take the steps necessary to comply with these Technical Requirements, or, at the discretion of the Owner, shall demonstrate that the as-built filter will still meet these technical requirements.

The Contractor shall prepare and submit a report on the ac filter harmonic studies for review by the Owner.

4.9.2. Definition of Performance

The performance of the ac filters is defined in terms of individual harmonic distortion (D_n), total harmonic distortion (THD), telephone influence factor (TIF), and balanced I·T product. These factors are defined as follows:

Individual harmonic voltage distortion is defined as:

$$D_n = \frac{E_n \times 100\%}{E_1}$$

Equation 1 Individual Harmonic Distortion

Total harmonic voltage distortion is defined as:

$$THD = \sqrt{\sum_{n=2}^{50} \left(\frac{E_n}{E_1}\right)^2} \times 100\%$$

Equation 2 Total Harmonic Voltage Distortion

Telephone influence factor is defined as:

$$TIF = \frac{\sqrt{\sum_{n=1}^{50} (E_n T_n)^2}}{E_1}$$

Equation 3 Telephone Interference Factor

Balanced I·T product is defined as:

$$I \cdot T = \sqrt{\sum_{n=1}^{50} (I_n T_n)^2}$$

Equation 4 Balanced IT

Where	E_n	=	line-to-neutral voltage of harmonic “n” (rms)
	E_1	=	fundamental frequency line-to-neutral voltage (rms)
	T_n	=	telephone influence weighting factor (TIF) at harmonic “n”
	I_n	=	current into power system at harmonic “n” (rms)
	n	=	harmonic number

In the calculation of ac harmonic filter performance, the ac harmonic currents generated by the converters, the reactive compensation and ac harmonic filter impedance, and the ac system harmonic impedance shall be as defined in the following sub-sections.

4.9.3. Converter Harmonic Currents

For the calculation of ac filter performance, both characteristic and non-characteristic ac side harmonic currents from the converters shall be calculated as a function of the dc power transfer over the range from minimum to continuous overload and at nominal and reduced dc voltage operation. Allowance shall be made for ripple in the dc current flowing in the valve windings of the converter transformers due to 60 Hz and harmonic currents induced in the dc current from parallel ac transmission lines. In the calculations, it shall be assumed that:

- The ac system voltage at the converter station ac buses is between the minimum and maximum continuous operating voltages as given in Section 2.12.1 with background harmonic levels as given in Section 2.16.
- The negative phase sequence fundamental frequency ac bus voltage is as specified in Section 2.12.6 for performance.
- The firing angles, commutating reactance, and dc current are at those values, within the limits permitted for operation during steady-state conditions that result in the highest harmonic current at the particular harmonic being considered for the Bipole loading conditions being considered.
- The maximum stray dc current allowed in the design of the converter transformers may be flowing in the converter transformers.

The converter non-characteristic harmonic currents shall be calculated for the simultaneous occurrence of the most onerous conditions of variation of firing angle, commutating reactance, and commutating voltage between phases within a bridge and between bridges in the 12-pulse pair.

When calculating THD, TIF, balanced I·T product, or harmonic currents into the nearby generation or other voltage supporting equipment, a consistent set of harmonic currents calculated at a given dc power transfer level or the maximum harmonic currents over the full power transfer range can be used. If consistent sets of harmonic currents are used, the currents shall be those consistent sets that maximize the THD, TIF, balanced I·T product, and harmonic currents into the nearby electrical equipment.

4.9.4. Filter Detuning

Detuning of filter sub-banks shall be taken into account for both tuned and damped sub-banks. The state of detuning that gives the maximum voltage distortion shall be assumed. The detuning shall include full allowance for the following effects, which shall be assumed to occur simultaneously:

- Normal continuous power frequency variation as given in Table 9
- Ambient temperature conditions, solar heating and variation in component temperature rise above ambient due to loading changes
- Initial mistuning to the maximum extent possible in the design
- Capacitor unit or element failure to the maximum extent possible prior to the Level 2 alarm being generated
- Detuning due to component aging

To reduce the impact of unidirectional effects due to all of the above tolerances adding simultaneously it is permitted to deliberately initially detune a filter sub-bank provided the extreme range of detuning which can then occur is fully taken into account.

4.9.5. AC System Harmonic Impedance

The ac filter performance calculations shall be based solely on the contribution of the HVDC converter station, the ac system harmonic impedance for the station as given in Table 13.

4.9.6. Calculation of Performance

4.9.6.1. General

AC filter performance shall be calculated at the ac bus of each converter station. Background harmonic voltages shall be considered only as they effect generation of harmonics from the converters.

The calculated ac filter performance shall meet the performance criteria for the following conditions:

- Normal dc voltage operation at any dc power transfer level from minimum to continuous overload with all ac filter banks in service or available for service.
- Normal dc voltage operation at any dc power transfer level from minimum to continuous overload with any one ac filter bank not available for service.
- Reduced dc voltage operation on one or both poles with all ac filter banks in service or available for service.

The Contractor shall calculate the performance values for normal dc voltage operation and reduced dc voltage operation over the range of dc power transfer level from minimum to continuous overload with any two filter banks out of service.

The Contractor shall calculate the maximum dc power transfer level possible to meet the specified performance limits with two filter banks out of service.

4.9.6.2. Individual Harmonic Distortion

The harmonic impedance diagram and associated tables in Section XX shall be used for the calculation of individual distortion. The ac system harmonic impedances that maximize the individual harmonic distortion at the converter ac buses at each harmonic shall be selected. The summation shall be made in accordance with Section 7 and Table 3 of IEC 61000-3-6 (2008).

4.9.6.3. Total Harmonic Distortion

The harmonic impedance diagram and associated tables in Section 2 shall be used for the two harmonics that result in the largest calculated values for THD. For all other harmonics, the ac system shall be assumed to be an open circuit. The summation shall be made in accordance with Section 7 and Table 3 of IEC 61000-3-6 (2008).

4.9.6.4. Harmonic Currents Flowing into wind Generators

The Contractor shall perform a study of the wind collector system to determine the total harmonic currents flowing in the wind generators.

4.9.7. Performance Requirements

AC filters shall be capable of providing sufficient filtering of harmonics to meet the filter performance requirements given in Table 17.

Table 17 Filter Performance Criteria

Parameter	Hitchland	Mid Tap	Shelby
D – Individual Distortion (%)	IEC 61000-3-6 limits	IEC 61000-3-6 limits	IEC 61000-3-6 limits
THD – Total Harmonic Distortion (%)	IEC 61000-3-6 limits	IEC 61000-3-6 limits	IEC 61000-3-6 limits
TIF	<40*	<40*	<40*
Balanced I·T Product	<35,000*	<35,000*	<35,000*
* TIF and IT values are preferred limits. The Contractor may propose an alternative with higher TIF			

and IT limits. Any alternative shall clearly present the economic and technical effects. The Engineer is under no obligation to accept any alternative.

AC filter performance shall be calculated as specified in Section 4.9.6.

4.9.8. Rating Requirements

The ac harmonic filters shall have adequate rating for all operating conditions of the converter station up to the following power transfer limits:

- Operation at any voltage within the normal voltage range at any dc power transfer level from minimum to continuous overload with any two filter banks out of service
- Reduced voltage operation on one or both poles with any two filter banks out of service

4.9.9. Calculation of Ratings

4.9.9.1. General

The calculated ratings shall include a margin above any ac filter or filter component protection settings. Short time and transient conditions shall be fully taken into account and, in addition, the harmonic current, filter detuning, and system harmonic impedance definitions given for performance calculations shall be modified as given in the following sub-sections.

4.9.9.2. Harmonic Currents

The harmonic currents shall be calculated as described in Section 4.9.3 except that:

a) The ac system fundamental frequency voltage at the converter station ac buses is between the minimum and maximum continuous operating voltages as given in Section 2.12.1, with background harmonic levels as given in Section 2.16. The ac system fundamental frequency voltage shall be at the value, within the range over which the converter station is required to operate, that results in the highest rating of each individual component for the duration applicable.

b) The negative phase sequence fundamental frequency voltage shall be assumed to be the maximum value for rating as specified in Section 2.12.6.

c) The harmonic current flowing in each filter component shall be increased to account for harmonic current from the ac system.

d) For the harmonic that results in the highest component rating, the current flowing in each of the filter components shall be increased by one of the following methods, whichever results in the largest rating:

   - Method 1 - Increase the harmonic current flowing in each filter component by at least 10%
   - Method 2 - Increase the harmonic current flowing in each filter component assuming the ac system can be represented by a Thévenin voltage source behind the ac system harmonic impedance. The magnitude of the Thévenin voltage source shall be as given in Section XX.

If the individual harmonic voltage exceeds 3%, then the filter component stresses for that harmonic shall be based upon 3% harmonic distortion rather than the value from the Thévenin calculation.

The harmonic impedance of the ac system at each frequency shall be that value within the impedance envelope given in Section 2.17 (and the respective tables) that maximizes the calculated harmonic current in each individual filter component calculated when considering both the source from the ac system and the source from the converters.

The harmonic currents and voltages from the ac system shall be assumed to add arithmetically to the filter currents and voltages that are due to converter operation.

4.9.9.3. Filter Detuning

The state of detuning to be used for component rating calculations shall be chosen to maximize the rating of each component and shall, in addition to the requirements of Sections XX, include frequency variation up to the extremes of the normal continuous frequency range given in Table 9 as applicable, for the duration of the frequency excursion, taking into account capacitor unit or element failure.

In the wind collector system extreme frequency excursions occur under certain contingency conditions. These frequency excursions, which occur infrequently, may result in very high current and voltage amplification due to resonances between the filter banks and between the filter banks and the ac system. The filters shall remain in service during these frequency excursions without damage. For these situations, the Contractor shall make maximum use of the short-time overload capability of the capacitors, reactors and resistors.

4.9.9.4. AC Harmonic Impedance

The harmonic impedance at each harmonic number shall be chosen to maximize the rating of each ac filter component individually with the system harmonic impedances as defined in Table 13.

4.10. DC Filters

DC filters are required to reduce the harmonic currents on the dc side of the transmission lines and keep the induced noise on the nearby telephone lines or communications circuits within acceptable limits as specified in Section 4.10.3.

4.10.1. Design Requirements

The Contractor shall carry out studies, which include the effects of dc-side harmonics from all converter stations. The goal of the design is to achieve the performance values stated in Section 4.10.3.

The performance shall be met with all filters in service.

The dc filter arms may be single tuned, double tuned, or high pass damped arms. Seasonal tuning is not acceptable. The design shall be based on passive dc filters.

The required switches shall be provided by the Contractor. It shall be possible to connect and isolate a single dc filter arm without causing any reduction in transmitted power on the affected pole.

The Contractor shall submit a report to the Owner on the results of these studies for approval.

The acceptability of the dc filter designs shall be based on calculated values of performance. Prior to ordering any component the Contractor shall satisfy the Owner’s Representative that the proposed design complies with the Owner’s Specification in all aspects.

The calculation of dc filter performance and rating shall be based on values of components, detuning, and harmonic voltages and currents. If any new components supplied by the Contractor or the actual generated harmonic voltages or the resultant calculated harmonic currents fall outside the design limits for the conditions specified herein, the Contractor shall, without extra charge, take any steps necessary to comply with the Owner’s requirements or, at the discretion of the Owner, shall demonstrate that the as-built filter will still meet the Owner’s Specification.

There shall be no limitation on the energization of the dc filter arms by reason of ambient temperature, frequency, initial mistuning or dc voltage within the range specified.

The dc filter components shall not become overloaded due to detuning or resonance within the dc filter or between the dc filter arms and the HVdc circuit, or the electrode line, for any combination of conditions for which the converters are capable of continued operation.

The design of the dc filter and the supplied smoothing reactor together with the dc line and the terminal dc equipment shall not introduce resonance at fundamental or second harmonic. The Contractor shall carry out resonant frequency studies.

If, at any time, the dc filter design is altered or the basis of any calculated parameter is changed then the Contractor shall resubmit the entire detailed data and study reports and the entire schedule of technical information for dc filters for approval before any part of the dc filter design is finalized.

The Performance and Rating requirements shall be met with and without the mid-point tap in service.

4.10.2. Calculation of Performance

The performance of the dc filter and neutral capacitor design shall be based on calculated values of equivalent disturbing current. The requirements shall be met at all points along the route of the dc lines (dc pole and DMR/PMR) and at all power levels and operating modes.

The equivalent disturbing current method is based on a concept whereby the total, composite interfering effect of all harmonic frequencies on a power line can be represented by a current at a single frequency which would produce the same interfering effect on adjacent or crossing wire line communication circuits. The equivalent disturbing current includes not only the harmonics which flow in the dc pole conductors and electrode lines but also the harmonics which are induced into the ground wires of the transmission line.

Mutual impedance calculation algorithms require that the ground wires be “eliminated” for this configuration to be used; however, as specified herein, the current flow in the ground wires must be eventually taken into account in the calculation of equivalent disturbing current.

The equivalent disturbing current shall be the psophometric weighted residual current of all harmonics of fundamental frequency from the 2nd to the 60th (i.e. 60-3600 Hz) according to the formula:

$$I_{eq}(x) = \sqrt{[I_{eC}(x)^2 + I_{eS}(x)^2 + I_{eT}(x)^2\,]} \qquad (\text{in mA}_p)$$

Equation 5 Equivalent Disturbing Current

where:

$I_{eq}(x)$ is the 1000 Hz equivalent disturbing current in milliamps (mA_p) psophometrically weighted at any point along the transmission corridors specified herein.

$I_{eC}(x)$ is the magnitude of the RSS equivalent disturbing *current* component due to harmonic voltage sources at the Hitchland station (mA_p).

$I_{eS}(x)$ is the magnitude of the RSS equivalent disturbing current component due to harmonic voltage sources at the Shelby converter station (mA_p).

$I_{eT}(x)$ is the magnitude of the RSS equivalent disturbing current component due to harmonic voltage sources at the Tap station (mA_p).

x denotes the relative location along the transmission corridors.

The equivalent disturbing current at any point along the corridor due to harmonics from Hitchland, Shelby or the Tap converter stations shall be calculated as follows:

$$Ie(x) = \sqrt{\sum_{n=1}^{60}\left(Ir(n,x) \times P(n) \times H_f\right)^2} \qquad \text{(in mAp)}$$

Equation 6 Equivalent Disturbing Current at Any Point

where:

$I_r(n,x)$ is the magnitude of the equivalent residual rms current at each harmonic in milliamps,

$P(n)$ is the psophometric weighting at harmonic "n"

H_f is the coupling factor which represents the normalized frequency dependent effects of typical coupling impedances to open wire circuits. The coupling factor H_f will be assumed to be 1.0 for all frequencies.

n denotes the harmonic number.

The residual current at any point along the transmission corridor due to harmonics from either Hitchland or Shelby shall be calculated by the following vector summation:

$$I_r(n,x) = \sum_{i=1}^{i=mc} I_{p(n,i,x)}$$

Equation 7 Residual Current

Where:

$I_p(n,i,x)$ is the rms current vector in Amps at harmonic "n" flowing in conductor "i" at location "x"

i is the conductor number

mc is the total number of conductors in the transmission corridor including ground wires and the electrode line as applicable.

For the calculations, the dc transmission line and electrode line configuration as shown in Section 2.19 shall be used.

The Contractor shall be responsible for obtaining the relevant earth resistivity used in the calculation as a function of frequency. The internal impedance of the converter station shall be included in the calculation of the harmonic currents.

A full range of reactance of the dc smoothing reactor, including effects of current level and frequency, shall be considered and that value giving the highest equivalent disturbing current shall be assumed.

The stray capacitance of converter valves, transformers and other components shall be modeled.

The calculation of harmonic driving voltage and the allowance to be made for dc filter detuning are described below. The general principle is to determine the specific, practical combination of condition for which the worst possible equivalent disturbing current can occur during steady-state conditions.

4.10.2.1. Harmonic Voltages

As defined above, all harmonics up to the 50th shall be included in the calculation of equivalent disturbing current. The equivalent disturbing current shall be based on a "worst consistent set" of harmonic voltages at either end of the line.

The "worst consistent set" is defined as that set of harmonic driving voltages which could occur at any particular operating condition which results in the highest value of equivalent disturbing current that could occur for a period of longer than ten minutes.

A particular operating condition is defined in terms of:

1. The mode of operation, i.e. bipolar or monopolar in any specified mode of operation
2. The dc voltage anywhere within the normal range for the mode of operation.

3. Reduced dc voltage operation on both poles and reduced dc voltage on one pole with the other pole at full dc voltage.
4. The commutating reactance anywhere within the guaranteed range.
5. The firing angle anywhere within the range applicable to the mode of operation as defined above which shall include firing angles associated with reactive power control and ac filter/reactive power bank switching.
6. Worst case induced voltage from any parallel lines
7. The converter ac bus voltages anywhere within the normal range specified in Section 2.12.1.
8. The maximum 60 Hz negative phase sequence voltage (1%) for achievement of performance limits
9. The dc current anywhere within the range applicable to the mode of operation.
10. Ambient temperature as defined in Section 2.9.1
11. Differences in the smoothing reactor harmonic impedances of the poles

In bipolar operation, the angle between the harmonic voltages generated by the two poles is of equal or greater importance than the difference in magnitude when considering equivalent disturbing current.

In addition to the factors influencing the characteristic harmonic voltages listed above, the variations in commutating reactance between phases and in firing angle between valves will be considered in the calculation of non-characteristic harmonic voltages. Also the negative phase sequence fundamental frequency ac busbar voltage will be assumed to be the appropriate value of the positive sequence voltage for calculation of dc performance and dc rating.

The calculation of harmonic voltages and resultant harmonic currents will also take into account the stray capacitances of the converter equipment, particularly at the triplen harmonics.

Statistical procedures may be used to calculate the non-characteristic harmonic driving voltages. The Contractor will demonstrate that the probability that any single harmonic voltage will exceed the value used in the calculation of equivalent disturbing current does not exceed one percent. Factors which can affect all valve groups equally (such as negative phase sequence voltage, ac system harmonic distortion or differences in reactance or firing angle between 6-pulse bridges forming 12-pulse valve groups which are also likely to be present in other groups) will not be assumed to be statistically distributed.

Statistical procedures will not be used in the calculation of the characteristic harmonic voltages. These must be calculated for the absolute worst case conditions.

The presence of ripple in the valve dc current and the 60 Hz current induced into the dc poles from the parallel ac systems must be considered in the calculation of all harmonic voltages. DC current flowing through the grounded high voltage ac winding of the converter transformers will also be taken into account when calculating the harmonic voltages.

Recognizing the practical difficulty of checking all possible combinations of individual phase and valve commutating reactance and firing angles for each of the main circuit conditions, the highest value of individual harmonic voltage at each harmonic possible for a particular mode of operation may be established. This set of individually maximized values may then be used for calculation of the equivalent disturbing current. This approach may be applied to both characteristic and non-characteristic harmonics or to any combination of harmonics, but the voltage to be used is that resulting in the largest equivalent disturbing current at that particular harmonic.

4.10.2.2. **DC Filter Detuning**

The performance requirements will be met with the dc filter arms detuned. The detuning will be up to the limits resulting from:

- normal power system frequency variation as given in Section 2.12.5

- ambient temperature variations as given in Section 2.9.1 including capacitor unit temperature rise over all environmental and loading conditions
- initial mistuning of the capacitors and reactors to the maximum extent possible
- capacitor unit or element failure up to the maximum possible prior to the level of unit or element failures which requires that the filter arm be disconnected within two hours
- component variation due to aging

The smoothing reactor inductance and bipolar line impedance variation are to be taken into account and the worst combination of parameter variations including detuning giving the highest equivalent disturbing current will be assumed. To minimize the effects of capacitor unit or element failure it is permissible to deliberately detune the filter, provided the consequent full range of detuning is taken into account.

4.10.3. **Performance Criteria**

The dc filters will be designed to meet the performance requirements for any dc power transfer from minimum to maximum rated power in monopolar operation and in bipolar operation.

The equivalent disturbing current at any location along the dc line corridor specified shall not exceed 500 mA for bipolar operation and 1000 mA for monopolar metallic return operation.

The Contractor shall calculate and submit to the Engineer for review the calculated maximum equivalent disturbing current for the following cases without dc filters:

1. bipolar operation up to continuous overload
2. bipolar operation with reduced dc voltage operation on one or both poles
3. monopolar metallic return operation up to continuous overload
4. monopolar ground return operation up to continuous overload

The Contractor shall calculate and submit to Engineer for review the calculated maximum equivalent disturbing current for all operating conditions with dc filters. The operating conditions shall include at least the following:

1. bipolar operation with all dc filters in service
2. bipolar operation with the outage of one dc filter branch at Shelby
3. bipolar operation with the outage of one dc filter branch at Hitchland
4. bipolar operation with the outage of one dc filter branch at the tap
5. monopolar DMR operation with all dc filters in service
6. monopolar PMR operation with all dc filters in service

These equivalent disturbing current values are preferred limits. The Contractor may propose an alternative with higher TIF and IT limits. Any alternative shall clearly present the economic and technical effects. The Contractor is under no obligation to accept any alternative.

4.10.4. **DC Filter Rating**

The rating of the dc filter components shall be based on the assumption that the per pole harmonic voltage is individually maximized at each harmonic for any particular operating mode, and the filter component currents due to the harmonic voltages at both terminals shall be assumed to add arithmetically at each harmonic.

For the rating of the dc filter components, it shall be assumed that any one dc filter arm can be out of service in any converter pole. The dc filters shall be rated for any loading up to the inherent continuous overload capability and short-time overload capability for all operating modes. The Contractor shall also consider the possible impact of reduced voltage operation and increased reactive absorption on the ratings of the dc filters.

Short time and transient conditions as well as operation with discontinuous dc current must be fully taken into account.

Due allowances shall be made for possible current amplification resulting from resonances between the arms of the Contractor’s dc filters.

In the calculation of the impedance of the dc transmission system when used for calculation of dc filter component rating, a ±10 % tolerance in the respective line length shall be included. Maximum ac system voltage and frequency variations as functions of duration specified in Section 2.12 shall be allowed for in the calculation of harmonic voltages and dc filter detuning. In addition capacitor unit or element failures appropriate to the duration for which the dc filter has to remain connected shall be allowed for in the calculation of dc filter detuning.

In addition to the above specific requirements, the dc filter components shall not become overloaded for any conditions for which the HVdc converter valve groups are capable of continuing in operation.

4.10.5. DC Filter Studies

The Contractor shall perform dc filter studies to demonstrate to the satisfaction of the Owner that the requirements of the Owner’s Specification are satisfied and shall submit a report to the Owner for review and approval (as specified elsewhere in the Contract) before any part of the dc filter design is finalized.

4.11. DC Circuit Resonance

The Contractor shall select the main circuit parameters of the supplied equipment in so as to avoid resonances on the bipolar system with an amplification factor greater than one at the fundamental frequency (60 Hz) and at the second harmonic of the fundamental frequency (120 Hz). The Contractor’s design shall minimize the effect of resonance at other frequencies by ensuring that the converter groups provide sufficient positive damping. If necessary, special damping circuits shall be provided.

Amplification factor is defined as the magnitude of the transfer function from a voltage source placed in series with each converter to the voltage at the dc line terminals.

The Contractor’s design shall prevent system instability during all normal and abnormal conditions and shall not result in any operational restriction or detrimental effects on any part of the HVdc system.

In the calculation of the resonant frequencies and amplification factors of the HVdc system, the Contractor shall consider the following:

1. Pole modes and ground modes.
2. Outages of dc filter components.
3. The ac systems shall be assumed to have a harmonic impedance as defined by the positive sequence simulator equivalents given in XXX.

4.12. Insulation Coordination

The Contractor shall be responsible for the overall insulation coordination of all supplied equipment and any existing Celilo converter station equipment that will be retained for the new converter.
The Contractor shall be responsible for the removal of all existing arresters. The design shall be in accordance with the requirements of IEC 60071-1, IEC 60071-2, IEC TS 60071-5 and this section.

The Contractor shall provide surge arresters, surge capacitors, and other devices as required to protect all the equipment within the Contractor's supply from dc, fundamental frequency, dynamic, harmonic, ferro-resonance, switching surge, steep front and lightning impulse overvoltages under all steady state, dynamic, and transient conditions including ac/ dc system disturbances, converter valve or control mal-operation and/or malfunctions.

The Contractor shall satisfy the Owner that the insulation of all equipment within the Contractor’s supply is properly protected and coordinated in accordance with the Contractor's normal practice and with the specific requirements detailed herein.

The insulation coordination shall be designed for all transmitted power levels and operating conditions as specified.

The arrester arrangement and protective levels shall be selected such that, generally, the overvoltages on the ac side are protected by arresters on the ac side, and overvoltages on the dc side are adequately limited by an arrangement of arresters on the dc side.

Critical components of the supplied converter equipment shall be directly protected by arresters connected closest to them.

The arresters installed shall be rated such that these arresters are not overstressed.

The Contractor shall carryout insulation coordination studies for the project. The Contractor shall perform all necessary HVdc simulator and digital studies and shall submit detailed report(s) on insulation coordination to the Owner. The Contractor shall carry out insulation coordination studies for rating of all arresters supplied for the project, establishing the required insulation level for supplied equipment and the clearances between energized parts and between energized parts and ground. The arresters installed shall be rated such that these arresters are not overstressed for all development Phases and all operating modes for the converters. The Contractor shall show that the existing equipment will not be overstressed for all development phases and modes of operation of the converter station.

The report(s) shall detail the characteristics of the surge arresters, energy ratings and shall demonstrate that the selected insulation protective and withstand levels, discharge and coordinating currents, and arrester ratings and discharge capabilities are adequately coordinated and comply with the requirements of this Specification. It shall also detail all insulation and air clearances and leakage distances and shall justify the selected values. The report(s) shall include all assumptions made for the study parameters and describe the types of events modeled (i.e. ac and dc faults, valve hall faults, converter valve or control mis-operations, etc) and identify the decisive cases that establish the insulation design.

A final report containing final recommendations for insulation coordination and arrester requirements shall be furnished by the Contractor prior to issuing the final design and manufacturing the equipment. The final report shall include the system conditions, all assumptions and data to support the Contractor's recommendations. The report(s) shall detail the characteristics of the surge arresters (manufacturer, model, rating, classification, MCOV, TOV capability and protective levels), energy ratings and shall demonstrate that the selected insulation protective and withstand levels, discharge and coordinating currents, and arrester ratings and discharge capabilities are adequate and comply with the requirements of this Specification. The report shall also identify the limits of the various equipment parameters which could affect the insulation coordination. If, at any time, any relevant equipment parameter is altered, the Contractor shall re-perform critical studies, revise and resubmit the report. The report shall also detail all insulation and air clearances and leakage distances and shall justify the selected values. As a visual aid the contractor shall provide a system one-line and equipment layout overview drawing that has reference numbers referring to tables in the report that summarize the specific insulation and arresters

The Contractor shall not finalize the design of any equipment, which might be affected by changes in protective levels until the report(s) has been approved by the Owner.

The report(s) shall detail the limits of all equipment parameters which could affect the insulation coordination. If, at any time, any relevant equipment parameter is altered, the Contractor shall resubmit the report(s).

If, on testing, it is found that any parameter is outside the limits established, then the Owner shall have the right to reject the equipment. At the discretion of the Owner, the Owner may accept the equipment provided that the Contractor demonstrates that the as built equipment shall still meet the requirements of this Specification.

The effect of shielding failure shall be considered in the detailed insulation coordination studies.

4.12.1. **Limitation of Overvoltage**

Blocking of the converter valves to protect them and other dc side equipment from sustained over voltages appearing on the ac system shall not be permitted. The converter station equipment shall be adequately rated to allow deblocking under the maximum over voltage conditions including the dynamic over voltage and any ferro-resonant over voltages which may be present.

The use of converter valve group controls to limit temporary (dynamic) over voltages shall be permitted provided that the valves and other converter equipment are adequately rated and that the Contractor shall demonstrate, to the satisfaction of the Owner, that such action does not restrict the power transfer capability of the HVdc system during or subsequent to the event.

4.12.2. **Requirements**

The contractor is responsible for coordinating the protective levels of arresters within their scope of supply and connected to the ac bus bars at the converter station not to increase the duty on any existing arrestors or result in the stress of any existing equipment.

The Contractor shall take into account the possible ac line discharge energy which could occur in the converter station arresters.

4.12.3. **Definitions**

For the purpose of insulation coordination the following definitions are used in this Section.

4.12.3.1. **DC Voltage**

The dc voltage shall be as defined in IEC 60071-5. Valve winding to ground voltages are to be considered as dc voltages.

Steady state dc voltages are defined as voltages, which can exist for a period in excess of 5 seconds.

Temporary dc voltages are defined as voltages, which can exist for a period in excess of 60 ms.

Transient dc voltages are defined as voltages on the dc side including commutation overshoots, which can exist for a period of less than 60 ms. Switching impulse, lightning impulse and steep front impulse voltages defined below are also referred in this Specification as transient voltages. Unless otherwise stated these definitions of dc voltage shall also be used as the basis for calculation of rated dc voltage for withstand test on all equipment subject to dc stress.

4.12.3.2. **AC 60 Hz Voltage**

The 60 Hz or fundamental frequency voltage shall include the harmonic content of the waveform in the determination of both peak and rms values as necessary for insulation coordination and arrester rating.

Steady state 60 Hz or fundamental frequency voltages are defined as voltages which can exist for more than 5 seconds.

Temporary 60 Hz voltages are defined as voltages which can exist for more than 3 cycles. Temporary 60 Hz voltages may also be referred to as dynamic over voltages.

Transient 60 Hz voltages are defined as 60 Hz or fundamental frequency voltages which can exist for less than 3 cycles.

4.12.3.3. **Switching Impulse Voltages**

Switching impulse voltages are defined as transient voltages which may be superimposed on either dc or 60 Hz voltages which, for the purpose of defining which wave forms occurring in practice shall be tested for or treated as switching surges, have a rise time to crest in excess of 20 microseconds and which may be assumed to have decayed to zero within 10 ms.

4.12.3.4. **Lightning Impulse Voltages**

Lightning impulse voltages are defined as transient voltages which may be superimposed on either dc or 60 Hz voltages which have a rise time to crest of less than 20 microseconds and which may be assumed to have decayed to zero within 0.1 ms.

Lightning impulse voltages need not be caused only by lightning.

4.12.3.5. **Steep Front Impulse Voltages**

Steep front impulse voltages are defined as transient voltages which may be superimposed on either dc or 60 Hz voltages which have a rate of rise of voltage of more than or equal to the values determined during system studies as per IEC-60071-5.

4.12.4. **Determination of Overvoltages**

The Contractor shall determine the highest transient and temporary over voltages, which can occur with the equipment parameters selected and with the ac system and dc line as defined in this Specification. The Contractor shall design the converter equipment to withstand for the maximum continuous ac system voltage at each terminal. A 15% increase in the arrester energy shall be allowed for.

4.12.4.1. **Temporary Overvoltages**

The Contractor shall provide all equipment necessary to limit the temporary over voltage at the ac bus bars of the converter station to XX pu or below with the converter in the blocked condition.

The Contractor shall provide & commission all equipment necessary to limit the temporary 60 Hz voltages on the 345 kV bus bar in both rectifier and inverter mode to:

- XX kV peak phase to ground; and
- XX kV peak phase to phase.

And on the 500kV bus bars in both rectifier and inverter mode to:

- XX kV peak phase to ground; and
- XX kV peak phase to phase.

The actual temporary over voltage shall be determined by the Contractor but equipment shall be designed for temporary over voltage not less than the values given above.

In the calculation of temporary over voltages on the ac side the Contractor shall allow for a bipole block from up to the highest steady state transmission capability of the installation. On the dc side the Contractor shall allow for the maximum load rejection which could occur and which leaves any or both converters deblocked.

The connected ac harmonic filter shall be assumed to be that with the highest MVAr applicable to the mode of operation which does not exceed the maximum reactive power exchange with the ac system as specified.

The converter equipment shall be rated for continued operation under the maximum over voltage conditions to be defined by the Contractor taking into consideration the dynamic over voltage profiles as determined by the design studies to be performed by the Contractor. Irrespective of the over voltage profile derived by the Contractor the equipment shall be rated to withstand an over voltage of at least XX kV pre-disturbance voltage for not less than 5 seconds following deblocking.

Any switching of equipment within the scope of supply, for which Contractor may be called upon to operate at this voltage, in either in a main or backup role and shall have the appropriate capability.

4.12.4.2. **Transient Overvoltages.**

The Contractor shall carry out detailed studies to determine the highest overvoltages which can occur and shall satisfy the Owner that both the chosen insulation levels, and the specified requirements of the selected arresters are adequate. The studies shall cover monopolar and bipolar operation to establish the worst case conditions.

The basis for determination of insulation withstand levels, arrester locations and arrester protective and energy rating characteristics shall include, but not be limited to the temporary overvoltages given in Section 4.12.4.1 and the following overvoltages:

1. Switching and Temporary Overvoltages on the ac Side.

   The following switching and temporary overvoltages caused by switching operations and fault events on the ac side shall be considered:
   a. Overvoltages due to switching, either singly or in any combination of converter transformers, interconnecting transformers, ac harmonic filters, shunt capacitors, ac lines, or other equipment.
   b. Overvoltages due to initiation and clearing of faults at or near the converter ac buses such as 3-phase, 3-phase-to-earth, phase-to-phase, 2-phase-to-earth, or phase-to-earth faults which are cleared by breaker operation.
   c. Ferro-resonance overvoltages resulting from transformer saturation during the switching operations in a. and b. above.
   d. Overvoltages resulting from sudden reduction of transmitted power or load rejection from power levels up to the continuous and short time overload rating of the converters.
   e. Overvoltages resulting from a sudden reduction of dc power due to tripping a portion of the ac network with consequential reduction of the ac system short circuit level to 50 % of the normal minimum value.
   f. Overvoltages within the filter bank generated by flashover or short circuit at the ac filter bus with the system charged to a voltage equal to the switching impulse protective level of the arrester protecting the filter banks.
   g. Overvoltages caused by forced isolation of the converter from the ac system while in operation, due to inadvertent ac breaker operation.

2. Switching and Temporary Overvoltages on the dc Side.

   The following dc switching and temporary overvoltages resulting from fault events and switching operations on the dc side as well as the ac side overvoltages transmitted through the converter transformer shall be considered:
   a. Overvoltages resulting from dc line pole resonance phenomena due, for example, to energizing the line pole with power frequency voltages caused by the malfunctioning of the dc converters.
   b. Commutation overvoltages during periods of fundamental frequency overvoltage, particularly when operating at maximum possible firing and extinction angles.
   c. Valve firing system malfunction including conditions causing current extinction in a conducting valve or valves in a 6-pulse group.
   d. Blocking of all valves in a converter without initiating bypass pair operation.
   e. Switching surge on healthy dc line pole due to earth fault on other pole.
   f. Uncontrolled energization of an open-ended dc line.
   g. Continuous commutation failure at the inverter and rectifier valve misfire.
   h. Earth faults and short circuits within the valve halls and on dc filter bus.
   i. Induced overvoltages from the temporary, switching and lightning impulse overvoltages on the ac side.

3. Lightning and Steep-Front Surges.

   The following lightning and steep front overvoltages resulting from lightning and faults on the ac and dc systems, shall be considered:
   a. Lightning surges due to both direct strikes and back flashover on the dc line or any of the ac lines connected to the converter stations.

b. Lightning surges due to direct strikes within the converter stations in the event of shielding failures.
c. Steep-fronted surges, especially those resulting from flashover or faults occurring within the valve hall or to earth from the valve windings of the converter transformers.

4.12.4.3. **Arrester Protective Levels**

The transient over voltages imposed across insulation shall be limited by surge arresters. Dynamic over voltages may also be limited by surge arresters but only if the arresters are adequately rated for such duty.

The steep front, lightning impulse, and switching impulse protective levels of the arresters shall be based upon the highest voltage which can appear across the arrester, or combination of arresters where appropriate, when the highest practical discharge currents are flowing in the arresters.

The arrester protective levels shall allow for the possibility of flashovers which could cause high discharge currents in lower rated arresters and unequal sharing of voltage between arresters connected in series. Where multi-column arresters are used or arresters are connected in parallel, unequal sharing of the discharge current shall be taken into account.

The coordinating current shall be determined by the Contractor appropriate to the arrester location and line and equipment parameters.

The arresters shall be capable of discharging without damage to the arrester the energy appropriate to the arrester point of connection during any credible operating temporary and/or transient overvoltage condition. This includes flashovers which cause operation of relatively lower rated arresters, and which result in a larger than normal discharge duty on the arrester. In particular, the arresters mounted across the valve or valve group or valve windings of the converter transformers shall be capable of discharging the dc line pole and associated terminal equipment for the condition that results in maximum discharging duty on the arresters, due to a dc line pole fault on the opposite line pole of the same bipole with consequent flashover to earth of the upper transformer valve winding terminal.

The neutral bus arresters shall be capable of discharging without damage to the arrester, the energy from an ac phase to earth fault on the valve side of the transformer during all conditions, including metallic return. The duration of the overvoltage for a non self-clearing fault shall be limited by the protection. The protection time used in design shall not be shorter than the protection time credible in real operation.

The neutral bus arrestors shall be rated for the loss of the return path during monopolar operation

The discharge current used for arrester coordination at each arrester location shall be determined and justified by the Contractor and stated in the design study report.

Where multicolumn arresters are used or where arresters in separate housings are connected in parallel, unequal sharing of the discharge current shall be taken into account.

Where arresters are connected in series, unequal sharing of voltage between these arresters shall be taken into account. When calculating maximum protective levels for series connected arresters, maximum tolerance arrester characteristics shall be used. When determining the maximum energy requirements for an arrester at a given location, this arrester shall be represented with minimum tolerance characteristics while the rest of the arresters are represented with maximum characteristics.

4.12.5. **Selection of Insulation Level**

The Front of Wave Withstand Level (FWWL), Lightning Impulse Withstand Level (LIWL), and Switching Impulse Withstand Level (SIWL) withstand levels shall be determined from the protective levels afforded by the surge arresters in the location being considered.

Correction factor for project site relative air density shall be included in the determination of the test voltage for air insulation.

The protective levels and withstand levels shall be as per Sections 4.12.5.1 through 4.12.5.3.

4.12.5.1. **AC Side Equipment**

All equipment connected to the ac bus, including insulators and air clearances shall have:

- SIWL is at least 1.15 times the switching impulse protective level;
- LIWL is at least 1.25 times the lightning impulse protective level;
- FWWL which is at least 1.25 times the front of wave protective level.

In addition to the above basic requirement, the SIWL shall not, in any case, be below 1175 kV for all equipment. The LIWL for circuit breakers, bushings and other equipment shall not be below 1550 kV dry and 1050 kV wet. The LIWL for the internal insulation of transformers and reactors shall not be below 1550 kV.

The ac filter capacitors, and shunt capacitors shall have a switching impulse margin 5% higher than specified above, i.e. not less than 1.20 times for SIWL, but retaining 1.25 times for LIWL and FWWL.

The ac filter reactors and resistors and any VTs or PTs within the filter shall have increased margins of not less than 1.30 times protective level for LIWL and FWWL, and of not less than 1.20 times protective level for SIWL.

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4.12.5.2. **Oil Insulated Equipment**

For all equipment with oil insulation and with arresters connected within 5 m of the terminals, the LIWL shall be an IEC standard value. This value shall not, for the internal insulation, be less than:

- 1.15 times the switching impulse protective level;
- 1.20 times the lightning impulse protective level;
- 1550 kV for equipment connected to the 500 kV ac bus.

The SIWL shall not be less than 0.83 times the LIWL as determined above, nor below 1550 kV for equipment connected to the 500 kV ac bus.

The SIWL shall not be less than 0.83 times the LIWL as determined above, nor below XX kV for equipment connected to the 345 kV ac bus.

The FWWL shall not be less than 1.20 times the front of wave protective level.

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4.12.5.3. **DC Side Equipment**

The dc side air clearances, insulators, equipment, dc filter components, shall have:

- SIWL at least 1.20 times the switching impulse protective level.
- LIWL at least 1.25 times the lightning impulse protective level.
- FWWL at least 1.25 time the front of wave protective level.

The neutral side insulation shall be designed with the capability for ungrounded operation to allow for mono-polar metallic return operation.

The presence of harmonic voltages shall be taken into account.

4.12.5.4. **Air Clearances**

The air clearances shall be determined by the Contractor based on the required withstand levels for all waveforms from dc to steep front wave in order to limit the probability of a flashover within the converter station to a target value of one flashover in 10 years on the ac side or one flashover in 10 years on the dc side.

The ac and dc switchyard design shall be compliant with the requirements of the Owner Standards XX.

1. AC Switchyards.
   The layout and arrangement of ac equipment being supplied by the Contractor shall have minimum electrical switchyard clearances as follows:
   a. Phase to ground XX
   b. Phase to phase XX
2. DC Switchyard and Valve Hall.
   Air clearances in the dc switchyard and valve hall shall be determined in accordance with IEC 60071. Atmospheric correction factors shall be applied for non-standard atmospheric conditions in accordance with IEC 60060-1.The correction factors for site altitudes above mean sea level shall be applied as applicable.

The appropriate electrode configuration shall be used for each piece of equipment.

4.12.5.5. Creepage Distances

The creepage distance across the insulation shall be determined by the Contractor and shall be adequate to ensure that the probability of flashover due to failure to withstand the applied steady state voltage shall not exceed one flashover in 75,000 hours of operation on the ac side or one flashover in 150,000 hours on the dc side. The specified probability for flashover shall be considered on per insulator basis only.

4.12.5.6. AC Side

The creepage distance for all ac insulators & bushings shall not be less than 33.8 mm per kV of the maximum normal operating phase to ground voltage at the insulator.

4.12.5.7. DC Side

For all insulators and bushings which are subject to direct voltage stress including converter transformer valve winding bushings and valve winding insulators and wall bushings, the minimum creepage distance (excluding tolerances) shall not be less than given in Table 18.

Table 18 Minimum Creepage Distances

Insulator Type	
Indoor Porcelain/Silicone Rubber for Valve Hall other than valve	20 mm/KV
Outdoor Porcelain Insulators/Bushings	50 mm/kV
Outdoor Silicone Rubber insulators/Bushings	40 mm/kV

Outdoor bushings shall be only of silicone rubber type. The requirement of 14 mm/kV within the valve hall applies to all silicone rubber /porcelain insulators and bushings external to the valve. The valve arrester or any arrester within the valve hall is not considered part of the valve. No oil bushings are accepted in the valve hall.

4.12.5.8. Lightning Shield

To Be Determined XXX.

4.12.5.9. HVac and HVdc Switchyards

The Contractor shall provide adequate overhead shielding to effectively prevent direct lightning strikes to any equipment or energized bus within the ac or dc switchyard areas. The system shall also be designed to provide "effective shielding" to ensure that no insulation flashover can result from atmospheric discharges striking the overhead shielding.

4.13. Interference Communication and Control Systems

The Contractor shall take all the necessary precautions to ensure that there shall be no mal-operation, damage or danger to any equipment, system or personnel due to electromagnetic or electrostatic interference effects. The converter terminal shall neither damage or cause mal-operation of the dc control and protection system or the communication system.

The Contractor shall take all the necessary precautions in the form of noise suppression techniques, shielding and filtering devices to prevent harmful interference which may be generated by the converter terminal to the following systems over the specified frequency ranges:

1. Power line carrier (PLC) - 40 kHz to 500 KHz
2. Radio communication systems - 0.15 MHz to 300 MHz
3. Television systems - 30 MHz to 1000 MHz
4. VHF, UHF & microwave radio systems. - 100MHz to 8500 MHz

Any filtering required to mitigate interference to the specified levels shall be installed at the converter terminal itself unless an alternative arrangement is specifically selected by the Owner at the time of Contract award.

4.13.1. Radio Interference (RI)

The Contractor shall take the necessary precautions in the form of valve hall and building shielding to meet his own requirements plus the following:

1. With the Bipole operating at any of the specified operating modes and power levels and within the design range of firing angles, the radio interference level (RIL) from electromagnetic radiation generated by the converter station shall not exceed 100 microvolt/m under fair weather conditions at any point:

    outside the station fence, and

    500 meters or more from the nearest bus connecting the valve to the converter transformers within the station, and

    at a lateral distance of 30 m from the conductors of any outgoing ac line, HVdc line and electrode line.

    This RIL criterion shall be achieved at all frequencies within the range of 150 kHz to 1000 MHz.

    The design shall provide for quickly adding additional corrective measures, at no extra cost to the Owner, and in a way so as to not jeopardize reliable commercial operation, should the specified performance not be achieved in the actual installation.

2. Measurements of actual RIL at each station shall be made by the Contractor, at points along the above defined contour and at other critical points. For transmission lines, measurement shall be made at a distance of about 1 Km from each station at the midpoint of a span.

Measurements shall be made with the ac switchyard and ac transmission lines energized and the HVdc system in operation.

Measuring instruments shall comply with the American National Standard Institute Specifications for Electromagnetic Noise and Field Strength Instrumentation 10 kHz to 1 GHz, ANSI C63.2 (1 by 160 ms charge & discharge times, 9 kHz bandwidth). The method of measurement shall comply with IEC Standards 61000-4-6 and 61000-4-3 in the frequency range 150 kHz to 1000 MHz.

Measurements shall be made at a quasi-peak setting and shall include at least three complete frequency scans at each selected location. The RIL at a particular frequency and location shall be considered to be the average value of all measurements taken at that frequency and location.

The measuring procedure shall be submitted to the Owner for approval prior to measurements being made and a final report shall be submitted after completion of all measurements.

It is expected that the existing valve hall with its screening will be reused. If the Contractor is required to penetrate the building, they will ensure that the overall integrity of the screening is at least as good or better than the original design.

4.13.1.1. 500 kV AC Equipment

Radio Interference Voltage (RIV), measured at a phase to ground voltage of 365 kV RMS and at a frequency of 1 MHz shall be less than 1000 microvolt.

4.13.2. Television Interference (TVI)

The Television Interference Level (TVIL) generated by "gap type" or "defect" discharges shall not exceed 10 micro volts/m at the Owner’s property line.

The measurements shall be made by the Contractor when the installations are complete and are in operation, in accordance with the measurement procedures defined for signals in IEC Standard 61000-4-3 in the frequency range 30 to 1000 MHz, Instruments in accordance with ANSI C63.3 shall be used. The measuring antenna shall be at a height of 6 m or more above ground.

The procedures shall be submitted to the Owner for approval prior to measurements being made and a final report shall be submitted after completion of all measurements.

4.13.3. Interference with Power-Line Carrier

Requirements eliminated.

4.13.4. Interference with Control System and Other Communication Systems

The Contractor shall take the necessary precautions in the form of noise suppression techniques, shielding and filtering devices to prevent harmful interference from the converter station to any of the control systems and other communication systems such as micro-wave or HF, VHF, and UHF radio systems installed.

4.13.4.1. Design Criteria

In order to meet the above requirements in the converter building, the Contractor shall submit calculations to the Owner including, but not limited to, the following:

1. The predicted radiated and conducted noise levels from the converter valves in the frequency spectra of concern inside the valve halls.
2. The allowable noise levels in the various areas of the converter building, including control room and other identifiable communications rooms in the HVdc station, which shall meet the station interference criteria for communication and control systems.
3. The type of noise interference mitigation measures and their performance details which the Contractor shall provide as part of the scope of supply to reduce the sensitivity to interference of Contractor-supplied control and other equipment.

The Contractor shall guarantee that the interference to communications and control systems shall not exceed the specified interference limits.

4.13.4.2. Interference Limits

- No worse than 1.5 dB decrease in signal-to-noise ratio in the microwave communication system for any voice channel, voice channel slot or group channel slot in the microwave radio system.
- No measurable degradation in data circuit bit error rate or telephone circuit signaling on any circuit in the microwave communication system.

- No worse than 3 dB decrease in signal-to-noise ratio measured at voice frequency on the UHF or VHF radio systems.

4.13.4.3. **Tests**

The Contractor shall perform measurements of actual noise levels, in the frequency spectra of concern, produced due to operation of the converter station and of actual interference to communications and control equipment in accordance with a test program prepared by the Contractor and approved by the Owner.

4.14. Audible Noise

The Contractor shall limit the audible noise for the overall station and the various areas of the converter station buildings to the following values and for all operating conditions and demonstrate by calculation and site measurement that the specified levels will not be exceeded :

Audible Noise Limits

Table 19 Audible Noise Limits

Valve hall (in places where access is permitted during normal operation)	90 dBA
Mechanical equipment indoor areas (measured at 2 meter distance)	75 dBA
Equipment in outdoor areas (measured at 15 meter distance) except as noted below for maximum noise level at the property boundary.	75 dBA
Compressor areas (measured at 2 meter distance)	90 dBA
At the substation property boundary	40 dBA

Audible noise levels shall comply with those listed in the XX and any applicable local ordinances.

Audible noise level limits for the Contractor's equipment shall be those limits determined by the audible noise design or as specified in the relevant equipment specifications whichever is more stringent.

The Contractor shall submit a design report on the audible noise design showing calculations of predicted audible noise for the equipment and demonstrating that the overall audible noise limits for the converter station and converter building areas can be achieved. Noise levels for equipment shall be based on measurements made on existing equipment where possible.

4.14.1. Site measurements

Measurements of audible noise levels shall also be made in accordance with approved procedures prepared by the Contractor. These measurements shall demonstrate that audible noise limits for the overall converter station and converter building areas have been achieved. If the overall audible noise limits for the converter station and converter building areas are not achieved due to the noise of the Contractor's equipment exceeding specified limits, the Contractor shall take the noise abatement measures necessary to achieve the specified audible noise levels at no cost to the Owner.

Details shall be given of measurement equipment, i.e. type, manufacturer, serial number, last calibration date, etc.

Noise surveys shall include both daytime and nighttime measurements.

Noise Reports are to note the date, time and weather condition for each time a set of measurements are taken at the site.

Transformer noise measurements are to be taken in accordance with the latest version of IEC 60076-10 Power Transformers – Part 10: Determination of sound levels.

When measuring transformer sound power levels, record in the report the transformer load, fan operation and tap settings (as per IEC 60076-10) at the time of measurement.

Sources of noise contamination (e.g., adverse weather conditions, other noise sources) are avoided, or if not avoidable, are identified and comment made on their impact on measurements.

Noise measurements shall be taken, as at minimum, at a point on the Northwest corner of the switchyard.

Identify and record any noise sensitive activities in the substation site surroundings and a map showing their location.

The Owner may undertake additional measures over and above those taken by the Contractor to reduce noise levels below the limits specified above. To determine and evaluate the additional measures, the Owner requires the Contractor to submit detailed information on the noise generated by the equipment being supplied and all design calculations and data used in the Contractor's design with the audible noise study report. The data required shall include octave sound power data, or peak octave band sound pressure level at a specified distance for all major noise sources.

4.14.2. **Verification of Performance**

To verify compliance with these requirements, sound levels shall be measured by the Contractor prior to energization and during commissioning around the outside perimeter, within 1 meter, of the fence line of each HVDC station

Measurements shall be made conducted in both C and A weighted networks concurrently.

Measurements shall be made operating over a range of conditions and power transfer levels from minimum to continuous overload. If the specified sound levels are exceeded, then the Contractor shall modify its equipment to meet the specified levels.

The Contractor shall modify the design report for noise to include the results of the noise measurements. Discrepancies between the predicted audible noise levels and the measured results shall be clearly stated with an accompanying explanation.

If the limits are exceeded at the specified contours from the total station perimeter fence line, the Contractor shall provide noise mitigation at no expense to the Purchaser.

4.14.3. **Audible Noise Verification Assessment**

The Contractor shall submit a report to the Owner detailing the results of the Contractor's audible noise measurements and assessment as part of the tests on completion and confirming compliance of those measurements with the performance requirements specified in Section above.

The report shall include all input data including new and existing equipment noise levels and location of noise sources used to produce the results.

Any assumptions made in the noise assessment must be recorded and validated.

The noise report must include a site map/aerial photo showing the exact noise measurement points and measured noise levels.

The report shall include a list of all standards referenced in the text.

5. AC and DC Switchyards

The Contractor shall design the HVdc converter stations including all equipment as required for achieving the Reliability and Availability design targets given in Section 11. The Contractor shall be responsible for the arrangement and layout of the converter station.

The Contractor shall submit detailed single line diagrams, station general arrangements and layout drawings of each converter station for approval and shall not commence the manufacture or procurement of any equipment or start construction prior to approval by the Owner.

5.1. One Line Diagram

One line diagrams are required for the three converter stations

Figure XXX

5.2. AC Switchyard

The Contractor shall design and arrange the layout of the ac switchyard in accordance with the criteria detailed in this Section and elsewhere in this Specification, and in accordance with the Owner's standards and practices

All circuit breakers shall be provided with disconnecting switches to provide actual and visible isolation from any equipment which could be energized/de-energized in any operating mode or arrangement.

The ac switch yard breaker arrangement shall be based on the One Line Diagram (above in Figure XXX).

For the main busses the Contractor may employ strung ACSR and/or rigid aluminum bus.

5.2.1. Design Criteria

The following design criteria shall be met by the Contractor:

No single contingency fault or equipment loss shall cause a bipole outage or a reduction in the transmittable power level to a value that is less than the rating of one pole. Faults in the converter zone, which starts on the converter transformer side of the ac line and filter breakers, includes the bus adjacent to the tie breaker and extends to include the valve group, would be expected to result in a pole outage. Faults on the filter side of the filter breaker and the ac system side of the ac line breakers would be expected to be cleared without a loss of either pole.

5.2.2. AC Harmonic Filters

The filter banks shall be connected to the ac bus bars at each respective converter station's ac switch yard by suitably rated circuit breakers and shall be made up of banks or branches as defined in this Specification.

The filter equipment shall be laid out such that maintenance may safely be carried in accordance with the connecting utilities safety requirements on any bank with the remaining banks in operation.

Capacitor racks shall include provisions for connection of rigging as necessary to extract single capacitor cans, as well as removable connections to allow isolation of individual cans for test purposes.

All filter branches shall be equipped with interlocked grounding switches at both line and neutral ends or at line ends only if the neutral ends are solidly grounded, to ensure that, in the case of an open circuit within the branch, trapped charges cannot occur. The interlock system shall be by key interlocking and shall ensure that the branch cannot be energized until the respective ground switch is fully open.

5.3. DC Power Circuit

5.3.1. Arrangement

The bipolar HVdc system shall be designed with the provision for operation as a monopole in the case of a pole outage or for other reasons. This shall allow at least half power transmission capability for any single contingency outage. Mono-polar operation shall be made via the DMR, or PMR, or DMR and PMR in parallel

Provisions shall be made by the Contractor for the future Phase 2 implementation, which involves a third converter station in Arkansas (multi terminal operation).

5.3.2. DC Power Circuit Switching Requirements

The Contractor shall provide all devices as may be necessary to meet the requirements of this Specification. A typical indicative one line diagram (OLD) for the dc yard is shown in Figure XXX. The OLD is indicative only and all equipment required as per the Technical Specification and for the smooth operation of the system is included in the scope of the Offeror and are the responsibility of the Contractor.

All switches, disconnects and ground switches shall be motor operated and shall be remotely operated with an option to place into manual operation. The valve hall ground disconnects shall be both remotely and locally operated. Position indicators as required for interlocking, remote and local indication shall be provided.

All switches, disconnects or isolators which are used to provide isolation for maintenance on any equipment shall have visible breaks. If a visible break is not inherent then an additional separate isolator having a visible break shall be provided.

The equipment arrangement shall be designed to ensure that no single fault or loss of any piece of equipment can cause or result in a bipolar shutdown or transient reduction in power transfer to less than the rating of one pole.

The dc power circuit arrangement shall provide at least the following functions:

1. Isolating and grounding a dc station pole for maintenance without affecting the power flow on the other pole.
2. Isolating and grounding a dc transmission line pole for maintenance.
3. Isolating and grounding the neutral bus at the converter station for maintenance when operating in monopolar DMR, PMR, or parallel DMR and PMR.
4. Disconnect switches to allow open-line tests.
5. Switching to PMR or parallel DMR with PMR and vice versa during mono-polar operation on one pole without interrupting or reducing dc power transfer during rated power up to the overload rating.
6. Connecting, isolating and grounding of the dc filter branch for maintenance without interrupting or reducing the dc power transfer of the other pole.

5.4. Physical Arrangements

The Contractor shall prepare a layout of the converter stations for the ac and dc switchyards in accordance with the requirements of this Specification.

5.4.1. **Requirements**

The converter station layouts shall incorporate at least the following features:

1. DC switchyard, including dc filters, smoothing reactor, metallic return switches.
2. Converter transformer area and HVac switchyard.
3. Electrical and mechanical station services.
4. Spare equipment and storage facilities.
5. Provision of an area for temporary construction facilities.
6. Fire walls.
7. Cable trenches.
8. Fencing, grounding, lightning protection, landscaping, drainage, etc.

The layout of the converter stations shall provide for the following:

1. Reliable operation.
2. Ease of maintenance and operation.

   The design shall allow:
   - Space for operation of man-lifts (as required for maintenance) around filter banks and shunt reactive devices
   - Space for operation of bucket or crane truck around circuit breakers
   - Adequate access for service trucks shall be provided to all pieces of equipment. Service trucks will typically be 5-ton trucks with a man lift boom.
   - Safe access to all equipment when equipment is out of service
   - A 10 m access area for service equipment shall be provided around the perimeter of the ultimate substation area.
   - Access for removal and re-installation of converter transformers and other transformers shall be provided. Equipment design near transformer removal area shall be designed to minimize the removal of equipment or structures to facilitate the removal of any transformer. This is to include access for heavy transport truck and trailer.
   - Access for removal and re-installation of smoothing reactors and shall be provided. The area near the smoothing reactor shall be designed to minimize the removal of equipment or structures to facilitate the removal of the smoothing reactor. This is to include access for heavy transport truck and trailer.

3. Minimum impact of the failure of any component.
4. Separation of equipment.

The extent to which equipment separation is achieved and how much separation is practical shall be governed by the following:

1. The block of power likely to be affected. As an example, a converter/pole outage is more severe than an ac filter outage and thus deserves greater consideration.
2. The mode and consequence of a failure. The time taken for the repair of the damage and the cost of the repair are to be taken into consideration.

Cables associated with the two poles shall be physically separated from each other. Similarly, power cables and control cables are to be segregated from each other. This shall be done to the extent possible within the work limits of the layout.

The station design shall permit access of personnel to all parts of the converter stations while energized. Thus, generally, all switchyard equipment & all bus work shall be installed with enough safety clearance.

Valve cooling equipment and valve cooling control equipment shall be located outside the valve hall. Valve cooling heat exchangers shall be located where ever possible.

For electrical transmission and distribution facilities utilizing aboveground oil storage containers or oil-filled operational equipment with an aggregate storage capacity of 1,320 gallons or greater, the SPCC regulation applies and is administered by the U.S. EPA.

- The regulation can be found in 40 CFR, Part 112
- The regulation covers all types of oils, both natural and synthetic (including mineral oil)
  - When calculating the aggregate storage capacity for oil storage containers and operational equipment, the shell size of the storage container or potential volume of oil held by the equipment is what matters—not the operational volume of oil stored in the containers.
- When calculating the aggregate storage capacity, only count individual storage containers or equipment that store/hold > 55 gallons (US)
  - Oil-filled electrical operating equipment such as transformers, circuit breakers, and electrical switches count as oil-storage containers

If the equipment under consideration for P&E switchyard & substation facilities meet the specifications described above, control measures like secondary containment and/or diversionary features will be required for the full potential capacity of all applicable containers.

When selecting appropriate control measures (e.g. earthen berms or overfill alarm systems) or secondary containment types (e.g. double-walled containers), the following should be considered:

- The full capacity of the applicable containers or operational equipment (plus rainfall or precipitation events if controls like concrete/earthen dikes or diversionary structures are selected)
- The potential for spilled oil to reach nearby waterways (rivers, streams, shorelines) or manmade features that might be a conduit for spilled oil (like ditches, gullies, storm sewers, or other nearby drainage features).
  - When evaluating potential pathways, we may not take into account existing manmade features that would otherwise prevent, contain, or hinder the flow of spilled oil, e.g. dikes. Must assume these features do not exist.

In addition to USEPA's requirements, TN, OK, and AR have above-ground storage tank (AST) divisions within their respective Corporation Commissions or state EPA/DEQs. Generally, the SPCC requirements described above should suffice for state regulatory purposes but here is the state specific information:

- exempt electrical generating facilities from their AST regulations (Oklahoma);
- Incorporate CFR references, meaning that SPCC & CERCLA should suffice for state requirements (Tennessee); or
- Regulate oil-filled electrical equipment in the same manner as ASTs and provide general guidelines (Arkansas).

Please see, Appendix XXXX for details regarding station's oil spill containment requirements.
EPA Spill Prevention etc as per Jonathan's email

5.4.2. Electrical and Safety Clearances

The electrical and safety clearances for the dc side shall be determined by the Contractor and shall not be less than the clearances applicable for an ac switchyard at the equivalent BIL level. Please see Appendix XXX for each converter station's clearance requirements.

5.4.3. Electric Field Strength

The Contractor is to confirm and ensure adequacy of design in terms of corona performance.

The total electric field including space charge at ground level shall not exceed 20KV/m in the dc yard.

Ion current density shall be less than 20 nA/sqm at ground level.

The Contractor shall furnish all calculations and documents in support of the above during detailed engineering. Measurement of field strength shall be carried out during operation of HVdc terminal.

5.5. Grounding

The Contractor shall provide a switchyard and building grounding system. The design of the grounding system shall be based on IEEE 80 - 2000 "IEEE Guide for Safety in ac Substation Grounding" and shall be based on the ultimate short circuit levels given in Table 3. Only one ground mat (grid) shall be used in a station and it shall be connected to the ground mat in the ac substation at suitable points. Calculations of step and touch potentials shall be carried out by the Contractor using a proven method.

The duration of fault shall be assumed as 0.5 sec for calculation of maximum admissible potentials rise only, otherwise 1 second. The Contractor shall submit complete calculation sheets for the grounding system showing the current components, spacing between the ground conductors, depth & size of ground conductors and dangerous potentials in various critical points. These calculations shall be subject to the Owner's approval. For calculating the conductor size of main mesh a current distribution of 30%-70% may be considered, In case direct current is allowed to pass through mat in any mode of operation, allowance for the same shall be made in design.

The Contractor shall take the necessary ground resistivity measurements to confirm the ground resistivity values to be used in the design. The worst combination of values, as measured at site shall be considered for the design. The effect of change in ground water table shall be considered.

The Contractor shall submit drawings showing, in detail, the grounding system design including connections from the ground mat to the equipment and ground conductor sizes. Conductor shall be oversized to allow for corrosion over a life of 50 years based on minimum resistivity.

See Appendix XXX for the utility or Owner's grounding standard XXXXXX.

5.6. Electrical Buswork

The Contractor shall submit supporting calculations for the bus work to show adequacy of design parameters See utility/Owner standards: XXXXx, *Outdoor: Bus Layout*, STD-DS-000013 *Outdoor: Bus and Bus Fittings*, XXXXX .

5.6.1. Flexible Strain Bus

Joints, splices or repair sleeves in tension busses are not acceptable. During installation particular care shall be taken to ensure that the conductors do not become abraded. Any Section of conductor damaged by the application of gripping attachments or otherwise shall be replaced.

5.7. **Construction Standards**

Please see Appendix XXX for each respective utility/Owner's Standard Construction Specifications.

6. Equipment Specifications

6.1. Thyristor Valves and Associated Equipment

6.1.1. Definitions

1. A 'Valve' is all the components, external to the main assembly which forms one of the six arms of a six-pulse Graetz converter bridge.
2. A 'multiple valve unit' is an assembly of a number of valves mounted into a single structure (these include components mounted on the valve structure, e.g., saturable reactors, surge arresters) which may be considered part of the valve.
3. A 'valve module' is the smallest assembly, comprising a number of thyristor levels, voltage grading and damping components, valve reactors, etc. from which the valve is built up and which exhibits the same electrical properties as the complete valve, but only has a fraction of the full voltage capability of the valve.
4. A 'thyristor level' comprises a single thyristor, control, protection, monitoring, auxiliary power and voltage grading components which make up a single voltage level within the valve.

6.1.2. General Requirements

The valve shall be designed and rated to meet the performance requirements described in Section 4 and as described below. The valves shall be of the indoor air insulated type. They shall be of modular design for ease of maintenance. The proposed thyristor shall be of a type in commercial production with fully proven characteristics.

The valves shall be based on deionized water-cooled design. The number of connections which have to be opened to change modules/thyristors or components shall be minimized.

The Contractor shall ensure that while designing the structure for supporting the MVUs (Multiple Valve Unit), sufficient space between valve Sections is provided to reduce the risk of spread of fire. No oil immersed or filled part is permitted to be used inside the valve. The electronic components located within the valve shall be designed to eliminate overheating and arcing. Only components of low flammability, high reliability and adequate ratings in margins can be used. All the materials employed in the valve shall be non-flammable and shall follow CIGRE recommendations by WG14.01-04 published in report 136. The Contractor shall submit a detailed report regarding the steps taken to prevent a valve fire. The valve support or suspension insulators shall withstand without damage the heat generated in the event of a fire.

Water leaks within the valve must be avoided. However, in the event of a water leak within the valve, it shall be automatically detected and alarmed and such a water leak should not result in a valve failure or degradation. Water leaks within the valve shall produce an alarm and the protective action shall depend on the severity of the water leak. If a minor leak should occur, the operational efficiency of the valve shall in no way be impaired.

The valve shall be designed to prevent corrosion of any component in the valve or valve structure. The Contractor shall submit a report outlining all the corrosion prevention measures within the valve.

Platinum grading electrodes for control of voltage distribution within the valve shall be incorporated. A means of inspecting the condition of the electrodes during maintenance without removing them shall be provided. The electrodes must have a minimum expected life of 25 years.

The status of each thyristor level in the valve while the equipment is in service (energized) shall be monitored, and the Contractor shall demonstrate the reliability of the monitoring equipment. The equipment shall annunciate individual thyristor failures in the control room and shall also alarm when the level of failure is equal to the number of redundant thyristors levels. The Offeror is to state the number of thyristor failures at which a trip of the converter shall be initiated.

Where protective firing is provided, the valve shall be designed to allow protective firing of individual thyristor levels. It shall be possible to detect by the monitoring equipment the turning on of the individual thyristor levels due to protective firing.

6.1.3. **Maintenance**

The valve shall be designed so that it is easy to clean and replace thyristors, modules and components in the valve assembly. It shall be possible to carry out replacement of one module or thyristor or component within two hours from shutdown to start-up excluding time for switching and clearing of the valve hall, but including the time required for identification of the faulty module or component.

The principal maintenance intervals shall not be less than twelve months. The Offeror shall state the maintenance frequency and duration based on a work day of eight hours.

All thyristors, including spare thyristors, shall be identical and interchangeable within the converter station.

The Contractor shall furnish an electric movable platform lift, capable of accessing all equipment within the thyristor valves. The capacity rating of the lift shall be sufficient to allow for the safe completion of all necessary activities associated with valve assembly and maintenance and the lift shall be included as part of the valve delivery at each station. When not in use, the lift will be parked outside the of the valve hall.

The Contractor shall provide, at each station, one complete set of any test equipment including all required accessories necessary for maintenance and fault diagnostics of the thyristor valves.

6.1.4. **Valve Overvoltage Capability**

The valve transient over voltage capability shall be:

1. 15% margin above the arrester switching impulse protective level (SIPL)
2. 15% margin above the arrester lightning impulse protective level (LIPL)
3. 20% margin over the arrester front of wave protective level (FFPL) as determined during studies by the Contractor as outlined in Standard IEC-60071-5.

Where the valve has been provided with protective firing for over voltages in the forward direction, it shall be based on the following conditions:

1. The valve arrester, and not protective firing, shall be the main valve protection against over voltages of either polarity.
2. Protective firing action shall not cause the valve to turn on under dynamic over voltage conditions as defined in Section 4 for which control of the valve is required to be maintained.
3. The minimum protective firing level (PFL), taking into account all manufacturing and other tolerances, shall be at a voltage level of at least 2% above the minimum arrester switching impulse protective level (SIPL) plus tolerances for internal valve voltage distribution.
4. The above restriction on protective firing action threshold level does not apply to the forward recovery protection.

The thyristor valve groups shall be designed such that di/dt and dv/dt to are limited to levels that all components in the valve can safely withstand during a ground fault at any location between the converter transformer and the dc line for all operating conditions. The Contractor shall demonstrate through studies that the thyristor valve groups are designed to safely withstand the values of di/dt and dv/dt of both polarities during all ground fault events including events that occur during valve turn-on, valve turn-off and in the interval immediately after current extinction.

6.1.5. **Valve Transient Overcurrent Capability**

With respect to transient over currents due to faults, the valve shall have the following capabilities:

1. Fault suppression capability which is defined as the ability of the valve to withstand one asymmetrical loop of the highest short-circuit current it shall experience due to any fault and maintain full blocking capability on immediate reapplication of the maximum design fundamental frequency over voltage which can occur simultaneously with the highest value of short circuit over current. The valve condition prior to the fault shall be as follows:
   - All the redundancy is used up
   - The thyristor junction temperature is the maximum it shall reach at nominal rated or any overload current condition
2. Carrying three complete asymmetrical loops of the highest short circuit current the valve shall experience due to any fault without requiring to block any voltage in the forward direction but capable of withstanding, between short-circuit current loops, an ac voltage in the reverse direction corresponding to a recovery voltage equal to the maximum dynamic fundamental frequency over voltage, which can occur simultaneously with the highest value of short-circuit over current, for which the valves remain conducting. The valve pre-fault loading shall be at the overload conditions.
3. After carrying full rated current for 200 ms or any other time and magnitude as verified from studies in bypass operation, the valve shall be able to withstand a positive polarity switching impulse voltage of peak value up to the protective firing voltage level of the valve, occurring in the recovery period of an inverter valve.
4. For these severe faults, the Offeror shall state the time for the converter protection to initiate a trip signal and the time for the ac circuit breaker to clear the fault.
5. For calculation of valve fault currents, consideration shall be given, but not be limited, to the following:
   - a flashover across another valve
   - flashover across the bridge terminals
   - neutral to ground fault of a Wye-connected valve winding of a converter transformer

These calculations and details of the cases considered, the assumptions made, and the method of calculation used in determining the maximum over current used for dimensioning the valve for its transient over current capability, shall be provided within the Offer.

The ratio between the short circuit current value and the thyristor surge current capability shall be stated.

Valve designs which do not allow for the faults mentioned above or use over current diverters are not acceptable.

6.1.6. **Redundancy**

A number of extra thyristor levels shall be included in each valve to allow for failure of individual components between maintenance cycles. Failure of a thyristor level means failure of a thyristor or any associated component in the valve, which functionally reduces the number of thyristor levels in the valve.

The number of redundant thyristors shall be such that the redundancy, as defined, is not exhausted in any valve of the 12-pulse converter during the operating period between scheduled maintenance intervals, assuming no failed thyristors at the beginning of the period and continuous operation without replacement of any thyristors that fail during the period. The redundancy shall not be less than 3.0% of the total number of thyristors in the valve.

The "redundancy" is the number of thyristor levels in a valve in excess of the number which are necessary to ensure that the valve will withstand all specified test voltages.

The 'Redundant Thyristor Factor' (f_r)

$$f_r = \frac{N_t}{N_t - N_r} \quad where$$

$$N_t = total\ number\ of\ thyristor\ levels\ in\ the\ valve$$

$$N_r = the\ redundancy\ in\ the\ valve, as\ defined\ in\ paragraph\ above$$

Equation 8 Redundant Thyristor Factor

The Offeror shall calculate and show the steps within the calculation of the Redundant Thyristor Factor.

6.1.7. Valve Light Guides

The light guides shall be arranged to allow easy access to disconnect or remove. The light guides shall be protected from mechanical damage or abrasion once installed. The light guides shall be suitable for operation in the high dc field environment that should be expected with the operation of the Project. In each valve, installed spare light guides shall be included. The Offeror shall state the number and arrangement of the spare fibers. The life expectancy of the light guides shall be at least 40 years.

6.1.8. Valve Seismic Design

The complete valve assembly shall be designed to meet the IEEE Standard 693 moderate projected seismic performance level. The Contractor or Offeror shall prepare a detailed report on the seismic design of the valve demonstrating qualification at the moderate seismic level.

A seismic risk analysis will be jointly scoped out by the Owner and the Offeror and will be conducted by a third-party consultant in order to determine that the moderate level of seismic activity is an appropriate design approach.

6.1.9. Thyristor Monitoring

The Contractor shall provide equipment which monitors on-line the individual thyristor levels continuously and annunciates individual thyristor failures to the control locations. There shall also be an alarm when the number of failed thyristor levels equals the number of the redundant levels. The thyristor monitoring equipment shall monitor protective firing of any thyristor level.

The Offeror shall state the number of thyristor failures at which a trip of the converter shall be initiated.

An on-line, visual display of the location of failed thyristor levels within the valve structures shall be provided. The message sent to the events recorder shall clearly indicate the location of the faulted thyristor.

As a minimum, the following events shall be detected and alarmed on the station event recorder:

1. Protective firing turn on of individual thyristors
2. Loss of individual thyristor levels
3. Misfiring of individual thyristors
4. Loss of redundancy

6.1.10. Testing

The tests on the thyristor valves, which are to include but not be limited to those in this Section, shall be performed as per the test program and test specification to be submitted for the approval of the Owner prior to commencement of testing. Full details of the test results shall be submitted to the Owner for approval.

The Offeror/Contractor shall submit a test program with test levels and procedures at least 30 days before the scheduled tests are to be performed.

A correction factor shall be applied to test voltages, wherever applicable, based on the data provided for the project site.

When not explicitly stated in the technical specification, testing of the thyristor valves shall be as per Standard IEC 60700-1.

6.1.10.1. **Classification of Tests**

The broad classification of tests is:

1. Type tests: which verify that the valve design shall meet the specified requirements
2. Routine tests: production tests carried out on all valve modules or components

The tests are generally performed on:

- a multiple valve unit (MVU)
- a single valve
- valve modules
- a valve base
- individual valve components

6.1.10.2. **Type Tests**

1. Dielectric tests on valve support
    - Valve support dc voltage test
    - Valve support ac voltage test
    - Switching impulse test on valve support structure
    - Lightning impulse test on valve support structure

2. Dielectric tests on Multiple Valve Unit (MVU):
    - DC voltage test to earth
    - AC voltage test
    - Switching impulse withstand voltage test
    - Lightning impulse withstand voltage test
    - Steep-Front impulse voltage test

3. Dielectric tests between valve terminals:
    - DC withstand voltage test
    - Wet dc withstand voltage test per IEEE 857
    - AC withstand voltage test
    - Switching impulse withstand voltage test
    - Wet switching impulse withstand voltage test per IEEE 857
    - Lightning impulse withstand voltage test
    - Steep-front impulse withstand voltage test
    - Non-periodic firing test

- Test to prove that the PFL is above SIPL by at least 2% excluding redundancy

4. Operational Tests:

- Maximum continuous operating duty tests
- Maximum temporary operating duty tests
- Minimum alternating voltage tests
- Temporary under voltage tests
- Intermittent direct current test
- Valve losses test
- Transient forward voltage during thyristor recovery period
- Short-circuit current without subsequent blocking test
- Short-Circuit current with subsequent blocking test

6.1.10.3. **Wet Type Tests**

These tests shall be carried out according to IEEE Std. 857, both dc and switching impulse tests shall be performed.

6.1.10.4. **Routine Tests**

1. Connection checks
2. Voltage grading circuit test
3. Check of auxiliaries
4. Firing checks
5. Voltage withstand checks
6. Pressure test at an overpressure of 1.5 pu of the design pressure
7. Tests on individual valve components

6.1.10.5. **Check for Degradation of Valve Components of Multiple Valve Units, Valves, and Modules**

1. Prior to the start of the type tests, multiple valve units, valves, and modules (referred to as "test objects"), shall be demonstrated to pass the routine test procedure described below, together with any other commissioning checks that may be required to demonstrate that the equipment is initially in the correct working condition.
2. Prior to the commencement of testing, the Contractor shall define the maximum permissible change in snubber / damping circuit impedance for which the valve has been designed. In the event of a change in impedance greater than this value, the associated thyristor level shall be considered to have failed.
3. Check of the grading network impedance of each thyristor level at low and high frequency
4. Check of the gate unit power supply charging
5. Check of thyristor gating in response to optical signals
6. Check of functionality of the monitoring circuits for the thyristor control unit
7. Check of electronic dV/dt protection

8. Power frequency withstand test of each thyristor level
9. Switching impulse test in both forward and reverse direction. Voltage level for protective firing is also checked
10. Voltage divider impedance check
11. After each individual test, every single thyristor shall be checked for short-circuit with the monitoring system. At the completion of the type test program, all the test objects shall undergo another repetition of the above routine test procedure. Thyristor level short circuit occurring during the repeated routine tests shall be counted as part of the criteria for acceptance.

If faults or degradation not leading to a thyristor short circuit are discovered during the type tests, then the number and distribution of faults shall be assessed by the Owner and the manufacturer to determine whether systematic or random failures have occurred.

6.1.10.6. Criteria for Successful Type Testing

The acceptance criterion shall be based on Standard IEC 60700-1.

6.2. Valve Cooling Systems

The Contractor shall provide reliable and efficient cooling systems for the HVdc converter valves.

The valve cooling systems shall provide adequate cooling for operation under all conditions up to and including maximum specified nominal continuous power transfer, inherent continuous overload and specified short-time overload at the maximum specified ambient temperature conditions.

For cooling of valves, the Contractor shall use a closed loop deionized water cooling system. Operation of the valve cooling system and its subsystems shall be fully automatic with facility for manual operation. The valve cooling control system shall be protected against external electromagnetic interference.

6.2.1. Reliability Criteria

The following general requirements shall apply to the design of the cooling system:

- The primary valve cooling system including control and protection shall be designed and developed on a per-pole basis. Thus, each pole shall have its own independent cooling system.
- Evaporative cooling will not be accepted.
- The system shall be designed such that, in case of auxiliary power failure for up to three minutes, no shutdown of plant or reduction in power transmission would be required. For this purpose, a UPS shall be provided which will be capable of running the valve cooling system for at least three minutes. With the UPS in service, the converter should not trip nor reduce the transmission capability upon loss of auxiliary power supply for the duration of the changeover to a redundant power supply.

6.2.2. Description of the Cooling System

6.2.2.1. Fine Water Circuit

The fine water circuit shall consist of a main circuit and a water treatment circuit. The cooling medium in the fine water circuit shall be deionized water. The circuit shall be provided with an expansion tank with level transducers. The expansion tank can be either of the open or pressurized design. The level transducers shall be used for control of the makeup water for the system and for detection of leaks. Full redundancy of the cooling pumps must be provided. Either two 100% pumps or three 50% pumps options are acceptable.

Part of the main flow shall be circulated in the water treatment circuit. The water treatment circuit shall consist of oxygen removers (if required), ion exchangers and mechanical filter. Sensors shall be provided for measuring conductivity of the water, both in the main cooling circuit and in the treatment circuit at the exit side of the ion exchange tanks. The water treatment circuit shall be provided with a makeup pump and associated valves and strainers. Redundant deionizer shall be provided to allow for the replacement of the resin without a shutdown.

The deionized water from the thyristor valves shall be cooled through heat exchangers. Full redundancy for these heat exchangers shall be supplied. The deionized water shall be cooled through air cooled heat exchangers or, if two loop cooling is used, through a water/water heat exchanger. One redundant unit shall be provided by the Contractor over and above the quantity required to achieve the operating requirements. Only dry type coolers will be accepted.

6.2.2.2. Cooling Control and Protection Equipment

The valve cooling control equipment shall be specially designed for application to the cooling system for thyristor valves and shall monitor its own operation and the condition of cooling water. There shall be two redundant control systems such that either or both are in ACTIVE mode. Each system shall be self-checking and an automatic changeover to the other system shall take place in the case of failure of the active system. The transfer of control from one control system to another shall not result in a disturbance of power transfer on the HVdc transmission system. It shall be possible to perform maintenance or make modifications to the standby control system while the main control system remains in service.

The control cubicle shall be tested along with the main water cooling circuit, excluding air cooled liquid cooler, at manufacturer's plant.

At least the following protection functions shall be provided with alarm and trip levels:

- Loss of flow
- Total pump failure
- Inlet water over temperature
- Return water over temperature
- High deionized water conductivity
- Expansion tank low water level
- Water leak detection
- Nitrogen bottle pressure (if provided)
- Fan failure

6.2.2.3. Design Criteria for the Cooling System

To ensure high reliability, the following main components shall be supplied with redundancy in order to increase the availability:

- Main circulation water pump
- One air cooled liquid cooler (n + 1 coolers)
- Bypass valves
- Transducers
- Nitrogen bottles (if applicable)
- Ion exchanger (resin bed) plus filter

- Deionized water heat exchanger

The materials in contact with the deionized cooling water shall be stainless steel. The material for the air cooled liquid cooler shall be selected in order to minimize the risk of corrosion.

Flow meters shall be installed to measure total fine water flow and the flow into the individual valves. The flow measurements shall be displayed at some location in the vicinity of the cooling pumps or cooling controls and on the Operator Control and Display.

6.2.2.4. **Measures to Prevent Water Leakage**

The design of the valve cooling system shall be made to minimize leakages. The following precautions shall be taken to minimize the risk of water leakage from the system.

- Choice of water pipe joint.
- Number of water pipe joints in the system shall be kept as low as possible, particularly in the thyristor valves.
- Velocity of deionised water in the pipes and in the thyristor heat sinks shall be kept low enough to prevent cavitation.
- Water circulation within the pipes shall be free from trapped air bubbles.

6.2.2.5. **Condensation Control**

In order to avoid condensation at the pipe lines within the thyristor valves, the inlet fine water temperature shall be kept in an appropriate range. Dew point monitoring inside the valve hall shall be provided and alarm/trip shall be initiated in case of risk of condensation in the valve hall.

6.2.2.6. **Leakage Detection**

There shall be three leakage detection methods used in parallel by the cooling control system. These methods can, depending on the nature of the leakage, generate trip of the converter and cooling system.

Independent of the detection methods, alarms for frequent make-up and for long make-up, when automatic make-up of cooling water is used, shall be provided. The total schematic of valve cooling system with valve positions, flow, temperature, make-up details, fan status, conductivity, pump running etc. shall be made available to the Operator Control and Display.

6.2.2.7. **Measures to Prevent Freezing**

If the Offeror proposes a single circuit cooling system, some means shall be provided to prevent the possibility of freezing in the event of sub-freezing ambient temperatures concurrent with shutdown. Heaters to keep the water above the freezing point may be provided in addition to the means for rapid draining of the outdoor heat exchangers. For a two-loop system, the addition of glycol for the secondary circuit will be permitted and heaters will be unnecessary.

6.2.2.8. **Motors and Drives**

Installed pump and fan motors shall have an overall vibration level of less than 0.05 in/sec rms after installation.

Motor bearings shall be maintenance free for the life of the bearing and have an L10 reliability of at least 50,000 hours. The Contractor shall provide recommended maintenance intervals for the motors. Motors shall meet Standard IEEE 841: IEEE Standard for Petroleum and Chemical Industry-Premium-Efficiency, Severe-Duty, Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors-Up to and Including 370 kW (500 HP). If variable frequency drives are used, it is the Contractor’s responsibility to design and install the motors and drives in such a way as to avoid bearing currents.

6.2.2.9. Redundancy

In addition to the measures stated in Section 6.2.2.3, the cooling system shall be based on n-1 redundancy. The Contractor shall design the cooling system with the following redundancy at a minimum:

1. Cooling pumps
2. Heat exchangers
3. Cooling fans
4. Resin beds
5. Valve cooling controls and protection
6. Valve hall air conditioning cooling units

The loss of a single major valve cooling system component, or both valve hall air handling units, shall not result in the reduction of the nominal continuous rating, inherent continuous rating or short-time rating of the converter for any specified ambient condition.

Only one pump shall be normally operating and the second pump shall be in stand-by. Should a pump failure occur, the second pump shall automatically switch-in without shutting down the converter. The converter shall not trip in the event of a cooling system pump change over.

Automatic, scheduled changeover of the cooling pumps and fans shall be provided. The schedule shall have a user settable changeover time per unit. Manual switchover shall also be provided.

The pumps shall have leak-proof mechanical seals.

Redundant flow, pressure and temperature measurements shall be provided. Redundant temperature measurements must be taken at the inlet and outlet locations. Redundant ambient temperature measurements must also be provided.

The system shall be designed to allow replacement of pumps, fans and heat exchanger units without shutdown of the system or tripping the converter.

6.3. HVDC Controls and Protection System

The Contractor shall provide a fully redundant control and protection system necessary for the converter station. The control and protection system supplied shall be based on the most modern and proven, state-of-the-art technology. Control of the converter station shall be organized in a hierarchical fashion both in terms of its function and location in a logical manner.

The Contractor shall also provide the equipment necessary for the control, protection and interlocking of all equipment within their scope of supply.

The Contractor shall be responsible for the complete coordination of controls, protections, interlocking and switching sequences within the station. The control and protection equipment shall satisfy the Reliability and Availability requirements specified.

The Contractor shall design the equipment to operate in the environment of an HVdc converter station. In particular, all necessary measures shall be taken to ensure satisfactory operation under the worst case of harmonic currents and voltages present in the station/system as well as the electrical noise & radio interference generated by the converter station. The Contractor shall be responsible for the design, testing, and commissioning of the control and protection to ensure its successful and reliable implementation and function.

The equipment shall be designed to operate with the environmental conditions as specified. The control and protection system shall satisfy the general technical requirements specified.

All protection settings shall be properly coordinated with the discharge currents of arresters and capacitors located in the various zones for all operating modes.

The controls shall be able to support point-to-point operation from any converter to any other converter and multi-terminal operation with any of the three converters operating either in inverter or rectifier mode. The controls shall enable smooth transition, with no interruption of power transfer when transitioning between the various control modes.

The requirements specified herein shall be considered as the minimal requirements. The Contractor shall provide any other protective features required and/or deemed necessary by the Contractor for the equipment within their scope of supply.

No single processor shall use more than 75% of its available processing power and shall have 75% of its memory remaining after being programmed by the Contractor.

6.3.1. Design Objectives

The overall design of the control and protection systems needs to meet a number of design objectives being sought by the Owner. The design objectives are:

1. Redundancy and physical diversity
2. Modular design and future proofing
3. Configurability, maintainability, and modification of control system software

The principles to be applied to the design of the control system include the following.

6.3.2. Redundancy and Physical Diversity

Great importance is attached to a high degree of control system hardware and software reliability and redundancy. The control system, including individual functions cannot be exposed to a single point of failure.

Redundancy shall be provided in all supplied controls.

At any time, one of the duplicate control systems shall be active and the other inactive in a hot standby mode with an automatic/manual changeover selection facility. The duplicated control system shall be designed so that the control system not in use can be tested and serviced during normal operation of the HVdc link.

The redundancy in control and protection shall be so arranged such that loss of one auxiliary power system does not result in the loss of control or protection systems.

No single failure of a main power supply, auxiliary power supply, a control card, a transmitter, faulty measurement system, etc. should lead to either blocking of the converter, reduction in dc power, or loss of the control and protection system.

The stated redundancy shall be provided regardless of any reliability or performance calculations.

6.3.3. Modular Design and Future Proofing

The control system shall be designed in a modular fashion which will allow the Owner to modify or change individual control blocks in the future, without impacting the other control functions. The modular design shall seek to limit the interdependence of various blocks, and allow for changes to be made in one without adversely affecting the others.

The Contractor shall provide sufficient information on the interface between the pole controls and valve base electronics in order to allow replacement of the HVdc controls at some time in the future, independent of the valve base electronics by any supplier. This shall include, but not be limited to, all signals, timing diagrams, I/O interfaces, I/O signal lists and sequences.

6.3.4. Configurability, Maintainability and Modification of Control System Software

The software design shall be structured in such a way, and be sufficiently flexible, that the Owner can make modifications or expansion to the system in the future. As such, the vendor shall identify the operating system, programming language and environment, and development platform for all levels of control hierarchy including but not limited to VBE, operator interface, and master control.

6.3.5. Noise Immunity of Control System

The control and protection circuits, including the firing control and protection circuits on the high voltage valves, shall be immune to interference from such sources as:

1. Abnormally high and unbalanced power frequency currents flowing in the busbars and ground grid resulting from ground faults within the converter station.
2. Radiated frequency (up to hundreds of kilohertz) voltage and current transients from switching of isolators and circuit-breakers in the HVdc switchyards, including switching of large capacitive and reactive loads.
3. Transients resulting from switching of thyristor valves.
4. Radiated frequency (up to the megahertz region) current and voltage transients resulting from switching of contactors and relays feeding inductive loads.
5. Radiated signals form walkie-talkie radios, cell phones, Bluetooth and wifi signals with transmitter power output levels up to five watts.
6. Radiated signals from mobile and aircraft radios with outputs of up to 100 watts in the VHF and UHF frequency bands, where such radios are operated outside the station control building.

Where sensitive circuits require special shielding, the Contractor shall use a control cubicle cabinet suitable for such purposes and shall provide filtering and/or isolation on all signal lines. Where appropriate, all signal lines shall meet the surge withstand capability test requirements as per Owner's specific requirements. The use of separate shielded rooms for isolating such equipment from electromagnetic interference shall be avoided.

6.3.6. Separation

Separation requirements given for the HVdc Controls shall also apply for protection equipment.

Systems A and B shall be identical in all respects and physically, electrically and operationally independent such that the proper operation of each system shall not be compromised, in any respect, by the shutdown of the other system.

Maximum electrical and physical separation shall be maintained between Systems A and B and between the protection systems and control systems. Whenever integrated control and protection systems are provided, utmost care shall be taken in the design to ensure that the systems meet high reliability and availability, as required for HVdc stations and associated ac systems.

Main and back-up protection systems shall be fed by independent, separate devices. For example separate CTs or separate DCCTs and shall use different dc power supplies for each redundant device.

6.3.7. Control System General Principles

The general concepts of the control systems shall be based on the following:

1. Wherever feasible, the controls are to be segregated to control the smallest unit or block of power.
2. It shall be possible to select any of the converter stations or a future remote operating location as the Master Controlling station. Changes made from the Master Controlling station in power order, current order, control mode selection and sequences, for each pole, shall be automatically executed at the slave station through the telecommunication link without operator assistance.

3. A manual converter trip function shall be provided for each converter that is independent of the Operator Control and Display system.
4. The converter controls shall automatically coordinate sequences for start-up/shut-down of the converter.
5. If reduction in power flow is made in any pole below the ordered value due to the sudden loss of pole capability, the controls shall automatically maintain ordered power flow by increasing power in the other pole within the capability of the converter (including that of overload) as specified. This shall take place even when one of the poles is manually blocked when the system is in bipolar mode of operation. Conversely, when the second pole is brought-in in bipolar mode, the controls shall automatically ramp up the power in the incoming pole while ramping down the power on the other pole until balanced bipolar mode of operation is achieved, subject to any existing limits on pole power.
6. On failure of the telecommunication system(s), the HVdc controls shall ensure that power transmission is maintained at the last ordered value prior to failure of telecommunication system(s).
7. Even during a telecom failure, it shall be possible to change power both in response to manual power order changes and power modulation signals without any risk of current margin loss.
8. The controls shall be designed to provide power flow in both directions. Power flow limits shall be designed so that different limits apply to each power direction. Any of the three terminals shall be able to act as a rectifier or inverter
9. The controls shall ensure smooth transition without any ac or dc system disturbance when transferring from any one operating mode to another operating mode.
10. The power setting shall be adjustable by an operator in selected steps, from the minimum operating limit to the maximum overload rating of the pole. Such changes shall be effected at a linear rate defined by a settable ramp time. The ramp time will be settable in 1 second increments from 0 to 3600 seconds. After any ramp is finished the ramp time will revert to a settable default value. Additionally, the power order shall be dynamically set based on the available wind power to ensure that zero power exchange occurs with AC grid at the XX station.
11. Power shall be allowed to be transmitted under conditions of partial or complete loss of the ac filters and/ or abnormal frequency (within specified limits), resulting in higher than normal distortion. All measures necessary to prevent instability caused by distortion in the ac waveform or by magnification of harmonics in the ac voltage waveform, shall be provided.
12. The controls shall provide a high speed of response and accurate, stable, and drift free operation over the complete operating range.
13. The controls shall minimize generation of non-characteristic harmonics.
14. The controls shall be utilized for limiting fault current and to assist in smooth and rapid recovery from both ac and dc system faults.
15. The controls shall provide protective limits including low voltage and current limits to protect the HVdc converter equipment and properly coordinate all such limits between the three terminals.
16. The controls provided shall be arranged such that testing and maintenance can be carried out on any pole without affecting the operation of the other operating pole.
17. The controls shall minimize inverter commutation failure during system disturbances. The Contractor shall choose appropriate commutation margin angle to minimize probability of commutation failures. The objective shall be to achieve less than 10% probability of commutation failure for voltage reductions up to 15% (85% ac voltage) on any of the phases of the ac commutating voltage in inverter operation. The Contractor shall carry out necessary studies for minimizing commutation failure due to switching of transformers, filter banks, shunt reactors, lines etc. terminating at or near the converter station. The control system shall prevent occurrence of

commutation failure during switching of equipment including converter transformer within the converter station.

18. The controls shall incorporate any other special features based on the Contractor's experience that may be of significant relevance/benefit to the overall control and protection of the HVdc system and converter equipment.
19. The controls shall limit and protect against all HVdc line resonance phenomena.

6.3.8. Control Functions

The following control functions shall be provided as a minimum:

- Energize and connect sequence
- Deblock & Block sequence
- De-energize and disconnect sequence
- Reactive power and filter branch control
- Open-line test
- Open-converter test
- Power order and ramp time
- Power direction selection
- Reduced voltage operation parameters and return to normal voltage operation
- Power runback for remedial action schemes
- Dc and ac voltage-dependent current limits
- Reduced voltage restart
- Damping control (input only)
- Manual current order entry
- Dc Voltage set point
- Reduced voltage operation parameters or return to normal voltage operation
- Tap changer control
- Perform fast ramping as needed in response to external inputs
- Provide the appropriate signals to the converter station Remedial Action Scheme (RAS) controller
- Multi-terminal operation

6.3.9. Basic HVDC Operating Configurations and Control Modes

The HVdc link shall be capable of operating in the following configurations:

1. Normal Bipole Mode – Pole 1 and Pole 2 shall be capable of operating in balanced bipolar mode with both poles transmitting power in the same direction. The unbalance in current between the two poles being less than 1%. This can be with full voltage or reduced voltage in one or both poles.
2. Monopole Operation – Each Pole shall be capable of operating in monopole mode with a dedicated metallic return (DMR), or with the other pole conductor as a metallic return (pole metallic return or PMR), or with both the DMR and PMR in parallel.

3. Pole Power Direction Selection – Pole 1 and Pole 2 shall be independently capable of operating with power transfer in either direction, in bipole and monopole modes for testing purposes only.

The above configurations shall be applicable whether running in a point-to-point mode or multi-terminal mode.

The HVdc system shall have the following control modes:

1. Bipole Power Control
2. Pole Current Control
3. Emergency Current Control

6.3.9.1. **Bipole Power Control**

Bipole Power Control shall be the most common control mode. While in Bipole Power Control mode, the active control location will specify the desired power order in megawatts (MW) and the desired ramp duration in seconds. The ramp duration shall be adjustable between 0 seconds and 3600 seconds in one second increments.

A bipole ramp stop function shall also be provided which, when activated, shall cause the ramp to end and the power order to remain at the value reached when the ramp stop function was executed.

The power controls shall ensure that equal currents will normally flow in each dc line pole conductor and that the difference in pole currents flowing in the DMR does not exceed 1%.

If the power order to either pole following the allocation calculation exceeds the capability of the equipment in that pole, because of equipment outage or other reason, then the excess portion of the power order shall be allocated to the other pole up to the capability of the other pole including overload.

When a pole is in power control, all HVdc supplementary modulation controls and HVdc runbacks shall remain active.

6.3.9.2. **Pole Current Control**

Pole Current Control shall be locally or remotely controlled. Pole current control would generally be utilized under abnormal system conditions or during testing. While in current control mode, the active control location will specify the desired current order in amperes (A) and the desired ramp time in seconds.

If Pole Current Control is selected while in power control mode, the default current order shall be such that the transfer is bumpless during the change-over of control modes.

When a pole is in current control, all HVdc supplementary modulation controls and HVdc runbacks shall remain active.

It shall be possible to operate with one pole in current control and the other pole in power control.

If the pole in current control is removed from service (blocked) manually or by protection, the healthy pole which is in power control should compensate for its power subject to any limits on the healthy pole.

6.3.9.3. **Emergency Current Control**

An Emergency Current Control mode of operation shall be provided to permit operation of the HVdc system when telecommunication equipment or the communication channels required for coordination of current orders are not available for an extended duration. This mode of operation shall be operator-initiated only, and it shall be assumed that voice communication between the three converter stations is available. During operator-initiated switchover to and from this mode of operation, there shall be no change in measured dc power and dc current.

The Emergency Current Control mode shall be provided separately for each pole. When a pole is in Emergency Current Control, all HVdc supplementary modulation controls shall be inactive in this pole.

For the purpose of testing, the Contractor shall provide control features located at the appropriate control panel such that constant current control operation is possible with current order synchronization via the communication channels. The Contractor may modify or override the constant power control mode, as appropriate for this testing, as long as the reference setting can be set from the existing operator setting devices provided for constant power control or emergency current control. When operating in this mode, the modulation signals shall remain active below the current margin.

6.3.9.4. **HVDC Control Features**

The control systems shall be provided with all the features required to maintain the controlled signals such as dc power, dc current, dc voltage and firing angle within the HVdc power circuit steady-state limits. The capability of the controls shall be utilized both to limit transient overcurrents and overvoltages to within the limits of the Contractor's equipment and to ensure stable recovery within the specified response times from both ac and HVdc system faults.

The Contractor shall provide a report for the Owner's approval during the design phase of the Contract describing the control system equipment and the design principles of each of the control functions provided.

The Contractor shall provide a function that maintains synchronism of the current orders of the rectifier and inverter stations such that a current margin of not less than 10% is always preserved for all current order changes.

Voltage Regulation

The measured rectifier converter terminal dc voltage to ground of each pole shall be controlled to the rated value. The control circuit shall take into account the fact that the HVdc system is bi-directional.

6.3.9.5. **Voltage Dependent Current Limits**

DC current order limits resulting from low dc voltage shall be provided to control the HVdc system performance during transient ac and HVdc system disturbances, and to protect the HVdc system equipment, if required. These limits shall have adjustable voltage and current settings, and independently adjustable ramp function or time constants to control rate of current limit application and release. Current order limits shall be coordinated in order to maintain the current margin. The Contractor shall design the control system and voltage dependent current limits in order to accomplish dc current reduction during AC system faults, if studies demonstrate that such control action is beneficial to overall system performance.

6.3.9.6. **Control Mode Change for AC Voltage Changes**

The dc controls shall not change control modes during and following a 2.5 % decrease in rectifier ac bus voltage, or a 2.5 % increase in inverter ac bus voltage, based on rated ac bus voltage values given in Table 5 Normal Steady State Voltages.

6.3.9.7. **Control System Accuracy**

The HVdc control system shall be designed to achieve stable, drift-free operation, and maintain measured values accurate to within ±1 % of the rated power order and within ±0.5 % of the rated current order, over the complete range of operation during steady-state conditions.

6.3.9.8. **Stability of the HVDC Control System**

The HVdc controls shall have the capability of maintaining a stable dc power transfer and converter operation under all conditions of voltage and frequency variation of the ac systems defined in Section 2.12

Stable dc power transfer and converter operation shall be maintained under conditions of loss of an ac filter bank, even when the remaining filters are operating at their maximum design loading.

In the design of the controls, features shall be provided to prevent steady-state instability for any reason including instability caused by distortion in the ac voltage waveform (such as core saturation instability).

6.3.9.9. Effect of Communication Failures

Failure of the Owner's communication system or back-up communication system resulting in the loss of control signal updating shall result in the maximum bipole power being limited to a level where the fault recovery performance is still met. If the signal updating fails during processing of a ramped power or current order change, the system shall be designed to prevent system collapse due to loss of current margin.

Detection and annunciation of communication system failures shall be provided.

Performance requirements with respect to recovery times are given in Section 4.

6.3.9.10. Fast Ramp Capability

Three independent digital inputs shall be provided to accommodate three independent fast ramps as described below. These digital inputs shall be capable of accepting 24VDC or 120VDC voltages.

If a digital input is activated, the controls shall ramp down to a predetermined power level, at a predetermined ramp duration, provided the current power is above the ramp's level. Each ramp duration shall be independently adjustable from 0 sec to 60 seconds in steps of 0.1 second. Each ramp power level will be adjustable from XXX to XXX in steps of 1MW. Also, the controls shall not allow a new power order above any active ramp's power level.

6.3.9.11. Control System Maintenance Facilities

The Contractor shall supply complete documentation of the control system software, including all source code which is completely viewable and modifiable. Compilers and other software needed to modify the code shall also be supplied.

An engineering work station shall be supplied which will include all source code, a license for the development software used to compile the high level software into downloadable form.

The Contractor shall provide software updates for 20 years after the completion of commissioning.

The Contractor shall provide circuit diagrams, schematic diagrams, component layouts and printed circuit board layouts for all control equipment supplied.

6.3.10. Protections

The requirements specified herein are the minimum. The Contractor shall be responsible for defining the actual protection requirements and schemes for the complete converter station, associated ac switchyard and, dc overhead and dedicated metallic return lines.

All the protective devices shall be capable of responding correctly to all internal or external faults even in the presence of the harmonic currents produced by the converters and during system frequency excursions.

Clear indication of the operation of each of the protections shall be displayed on the operator control displays.

Main protection, including redundancy, shall be provided to ensure safe shutdown of equipment. Back-up protection shall also be provided to protect equipment in the event of main protection failure. Maximum electrical and physical separation shall be maintained between main and back-up systems and between the protection systems and control systems. Whenever integrated control and protection systems are provided, utmost care shall be taken in the design to ensure that the system has high reliability and availability as required for HVdc stations and associated ac systems.

The protection equipment shall be designed to be fail-safe and shall ensure high security, so as to prevent unnecessary shutdowns or outage due to protection equipment failures. This shall be achieved by organizing all the protections covered in this Section or elsewhere in the Technical Specification, into two systems, A & B, where both A & B systems are active, tripping through an "OR" gate. Each of the systems shall include the main and back-up protections specified. Systems A & B shall be identical in all respects and physically, electrically, and operationally independent such that the proper operation of each system shall not be compromised, in any respect, by the shutdown of the other system. Provisions shall be included to isolate outputs from a protection system that is in maintenance mode.

System B cannot be considered the back-up for system A and vice versa and if one system is out of operation, the remaining system must contain both main and back-up protections.

Generally the main and back-up protections shall utilize different principles. Where utilization of different principles is not possible, backup protections utilizing similar principles shall be employed. Main and Back-up protections shall be fed by independent, separate measuring devices, for example separate CTs or separate DCCT measuring devices and shall use different dc power supplies.

The protection must be easy to maintain and have a monitoring system to make diagnostics and replacement easy for service personnel. The monitoring system must issue an alarm in case of defects in the protection.

In the event of a trip, the protections must be manually reset. The station not suffering a fault shall go into blocked or a stand-by mode for start-up.

The redundant protection systems A and B must be supplied from two separate power supplies to fulfill the redundancy requirement throughout the complete protection system.

6.3.10.1. **Converter Protections**

The Contractor shall provide adequate protection to ensure that all converter equipment is fully protected and shall ensure that all protections are properly coordinated even without telecommunication between the three converter stations.

DC side protections shall be provided against at least the following abnormalities:

1. Converter short circuit
2. Converter over current
3. Converter/bridge differential protection
4. Valve short circuit
5. Excessive dc harmonic voltages
6. Valve failure to fire and unintended firing
7. Persistent commutation failure
8. Pole differential protection
9. DC side overvoltages
10. Abnormal firing angles
11. Continuous by-pass pair operation
12. Inadvertent pulse blocking
13. Neutral bus overvoltage

The Contractor shall also provide any additional protection, which the Contractor deems necessary or desirable for further protection of the converters.

Protection shall be provided to prevent “converter start” should there be a permanent ground fault on the ac connections to the converter valves or into an open pole line under normal conditions.

Converter commutation failure protection shall, in addition to normal protection, include fast-acting circuits to take precautionary control action to minimize the occurrence of commutation failures.

Tripping of ac circuit breakers for permanent pole and valve faults, as well as for any other protection(s) for which the Contractor deems it necessary to trip the ac supply breakers, shall be a lockout function. Care must be taken to ensure that, upon clearing of the ac breakers, the connected ac filters shall not discharge into the converter transformers.

6.3.10.2. **Converter Transformer Protections**

The Contractor shall provide equipment to fully protect each converter transformer. The protection supplied by the Contractor shall include at least the following forms of protection:

1. High-speed biased differential protection with harmonic restraint
2. Transformer H.V. line side differential protection
3. Overcurrent protection on the primary side and secondary side
4. Ground overcurrent protection on grounded HV Wye-connected winding
5. Thermal protection
6. Transformer gas relay
7. Tap changer gas relay
8. Winding temperature trip and oil temperature trip
9. Pressure relay/pressure relief device, separate for tank and tap changer compartment
10. Numerical restricted earth fault protection (inrush and residual flux protection)
11. Converter transformer core saturation protection (inverse time dc overcurrent)
12. Any other protective feature deemed necessary for the Contractor's equipment

6.3.10.3. **AC Filter Protections**

Each filter branch shall be protected against damage by the following but not be limited to:

1. Overcurrent (fundamental and harmonic overload)
2. Overvoltage
3. Capacitor unbalance including backup protection
4. Phase-to-ground faults
5. Filter detuning
6. Filter differential protection

Suitable capacitor failure protection and alarms shall be provided

Tripping of filters shall not be initiated by over or under-frequency

All the filter protections shall be designed so that annunciations obtained are on a phase basis for ease of identifying the faulty phase of the filter branch.

6.3.10.4. **Under and Over Frequency Protections**

In the event of the steady state frequency going outside the specified limits, the Contractor shall provide suitable protections to ensure the safety of the HVdc system. The Contractor shall explain the operational restrictions on the HVdc system during over/under-frequency of the connected ac system.

6.3.10.5. **DC Line Protection**

The Contractor shall provide all the protection equipment required for detection of dc transmission line faults, during any mode of operation (bipolar operation, monopolar with DMR) at any physical point on the dc overhead lines. The protection shall:

1. Detect, at high speed, faults on a dc transmission line. The protection shall not operate for faults on the other pole line conductor and it will discriminate between dc line faults and other faults such as commutation failures or faults inside the converter station such as dc filter faults. Such faults shall not cause the dc line protection to operate.

2. Clear faults by control action as required and restore power transmission to pre-fault levels at a variable ramp rate and with a variable dead time.
3. The number of restarts can be manually set, including the number of full voltage restarts prior to a reduced voltage restart which shall not be less than XXX kV. For insulation coordination studies, assume three unsuccessful, full-voltage restarts followed by one reduced-voltage restart.
4. There will be one reduced-voltage restart. The reduced-voltage setting shall be adjustable down to 70% dc voltage.
5. Safely shut-down the pole for sustained faults which cannot be cleared by control action.
6. Provide adequate back-up protection to cover failure of primary protection and allow safe shut-down
7. For line fault clearing sequences, the fault deionization time setting for each restart shall be adjustable to a preset value between 100 ms and one second.
8. The contractor shall also supply dc line protection capable of detecting high impedance faults or open circuits of the transmission line. Such protection is based on line differential current measurements.
9. The line protection shall be capable of determining the faulted dc line zone considering the presence of the tap
10. The dc line restarts shall take into consideration the presence of the tap and the coordination of the three converter stations.

6.3.10.6. Open Line Test

It shall be possible to deblock a converter pole into an open circuit to build up voltage to test the local HV converter equipment or line without the other converter connected to it. The Contractor shall provide the equipment and control and protection schemes necessary to permit such testing and shall design equipment accordingly. Such facilities shall be provided only as a local control function. In this test mode, deblocking of remote station poles shall be inhibited.

6.3.10.7. Metallic Return (DMR) Protection and Supervision

The Contractor shall provide the necessary equipment to detect faults on the metallic return under all conditions. The fault detection system shall initiate alarms and appropriate automatic sequences. In the event of an open metallic line, the detection shall command the closure of the station ground switch (Neutral Bus Ground Switch or NBGS) during bipolar operation.

The protection scheme shall continuously monitor the DMR and give indication of fault location.

The following minimum requirements shall be met:

a) Detection and action due to a ground fault on any conductor
b) Detection and action due to an open circuit of a conductor

6.3.10.8. AC Bus Protection

The Contractor shall provide all equipment needed for adequate protection of ac buses and shall coordinate with the Owner for each converter station's ac protection standards.

6.3.10.9. AC Line Protection

The Contractor shall provide appropriate current transformer signals in order to reestablish the bus's differential protections for the ac switchyard which includes the transmission lines system.

6.3.10.10. Special Protection System or Remedial Schemes

6.3.11. Equipment Control and Interlocking

A key interlock system shall be provided to permit entry into restricted areas such as the valve hall only under safe conditions, i.e., when the converter is stopped and ac & dc connections to the valves are isolated & grounded.

Disconnects and grounding switches shall be electrically interlocked so that they can be operated only if conditions are safe. Grounding switches shall also be mechanically interlocked with the associated disconnect switches.

Interlocks, including those above, shall permit, if required, isolation of zones within the station so as to allow safe maintenance of major equipment, such as ac filters, and converter transformers.

The Contractor shall provide all the necessary equipment for carrying out automatic sequential operations in the ac switchyard, dc switchyard and converter areas initiated by operator command, protective sequences, or automatic logic.

The Contractor shall ensure that the automatic sequence and interlocking systems are designed to ensure complete safety of personnel, hazard-free equipment operation, and fail-safe operation in the event of component failure.

Such interlocking shall also be provided for all those areas where personnel entry is prohibited during energized conditions.

The interlocking provided for switching equipment shall be such that it does not restrict maintenance of the equipment when de-energized.

6.3.12. Control and Protection Test Facilities

The Contractor shall provide test facilities and test equipment to enable safe and comprehensive testing of the complete control and protection system, without having to disable interlocks and without affecting the power flow.

Provision of monitoring points and other facilities within the control or protection cubicles, for ease of testing, shall, as far as possible, not involve shorting of the main CT secondary circuits feeding any of the protections. The test facility for the control and protection system proposed by the Contractor shall be approved by the Owner during detailed engineering.

6.3.13. Interface with Converter Station Equipment

The HVdc Contractor shall be responsible for arranging the signals required in the converter station for control and protection purposes such as run back control, frequency control and interface with the converter station's telecommunication system. This shall include implementation, including supply and installation of terminal boards, signal conditioning equipment, and supply, laying and termination of cables to relevant HVdc and HVac equipment. If, during detailed system studies, it is determined that any specific signal is required from remote generation and/or substations for the purpose of controlling an HVdc station, the respective Owner shall provide these signals.

It is expected that some level of integration with the wind farms may be required in order to schedule power, limit over-voltages and allow for improved fault performance. The Bidder is expected to develop a list of required interface points to their controls and potential high level interface points to the wind farms.

In case any transducer/signal conditioning is required; the Contractor shall supply and commission the same.

6.4. Operator Control and Display

A complete, redundant Operator Control and Display system shall be provided at each converter station to allow the operator to start, stop, operate, and monitor the HVdc system.

Power orders for the system are input from any of the system's converter stations by the Operator or automatically through the SCADA remote.

The redundant, computer-based system shall be a highly reliable, integrated system which shall provide operators with status and control displays, alarming and monitoring system.

The redundant operator control display computers and engineering workstations located at each converter station, shall be connected to 60 Hz,110 Vac which will be connected to a UPS that shall be provided to allow the operator to monitor the status of all the switching devices, operating mode and conditions of the bipole and provide a means of adjusting all operating parameters.

Solid-state hard drives shall be used. In addition to the standard 24" desk-top displays. All screens shall be capable of independent display of any of the operator's screens.

An indication of the necessary pre-start conditions or the interlocking conditions required prior to start-up shall be indicated to allow for troubleshooting. Provision for a manual control mode shall be provided. A transfer from automatic to manual control shall be bumpless and shall not change the operating point of the HVdc converter. All protective functions shall remain in-service during manual operation.

The Contractor shall provide support for the supplied Operator Control and Display systems and engineering workstations and the optional replacement of them in ten (10) years.

6.4.1. Control and Monitoring Facilities

The Contractor shall ensure that the converter stations have facilities that include, but are not limited to:

1. All control, status, and alarm signal points required to operate the HVdc transmission system.
2. Each control point shall be operable from every operator control location. The system shall be programmable to restrict operation of each control point to specified operator control locations as determined by the Owner.
3. The alarms generated at the local level shall be able to be grouped into meaningful groups of alarms for presentation to operators and dispatchers.
4. Messages for control purposes shall be of a "check-back-before-execute" type.
5. Set-points shall have a resolution of at least 0.1 % of the total range of the set-point.
6. Control of any new and existing equipment, such as, but not limited to, ac circuit breakers, disconnects, and grounding switches.
7. Control location selection options shall be provided at the station control desk to enable the operator to control the HVdc system and/or the HVac yard of any converter station from either local or remote.
8. The operator shall be able to energize, de-energize, stop (block) or start (deblock) the bipole or an individual pole at each converter station.
9. Automatic sequences shall be provided to fulfill the preconditions for deblocking and other operator functions as described in this Section.
10. The operator shall be able to select the voltage set point, manual current order, tap position, power flow direction, power order, ac bus voltage set point, reactive power set point and ramp time.
11. Interlocks shall be provided which shall prevent the operator from changing power direction while the HVdc system is in operation or while there exists any condition(s),

which on reversal of dc power direction, would result in damage to the converter equipment.

12. Apart from the necessary information exchanged between the two control systems in the converter stations, provision shall be made for additional measurements and status indications to be transmitted in both directions specified by the Owner.
13. User-defined authorities and password control administration shall be provided to restrict operational control as per North American Electric Reliability Corporation (NERC) Critical Infrastructure Protection (CIP) standards and requirements.

6.4.1.1. **Automatic Switching Sequences**

Switching sequences shall be active only for switching at the respective converter stations. In addition to individual control of all motorized switches from the operator control locations, the Contractor shall provide, at a minimum, automatic sequences for energizing/de-energizing converters on the ac side, starting and stopping of the poles, connecting/isolating the dc converter poles, grounding and un-grounding poles, switching dc filters, and open line testing. All applicable switching sequences shall be applied for all modes of operation, as required.

Inter-station coordination for automatic sequences shall be provided for the pole via the HVdc telecommunication system.

In the event of a sequence failure, adequate annunciation shall be provided to enable the operator to troubleshoot and correct the problem in order to continue the sequence. Also, in the event of a sequence failure, no equipment shall be left in a hazardous state.

For sequence control programs which, upon completion, define the state of operation of the valve group and pole, the Contractor shall provide a feature to prevent unintentional notification of change-of-state if a failure should occur, such as transient loss of auxiliary power.

The Contractor shall provide a report to the Owner for review and approval (as specified elsewhere in the Contract) during the design phase of the work describing the sequence and the final position of disconnect switches and circuit breakers in every automatic switching operation.

<u>Converter AC Side Energization/De-energization</u>

The Contractor shall provide an appropriate control sequence for operator-initiated connection/disconnection of the converter to the ac bus. The operator shall be able to initiate switching of each converter within each converter station, separately.

The control sequence shall be designed to accommodate control of all breakers associated with the converter line entry. For each breaker associated with a converter line entry, an indication that the operator has initiated an ac breaker close/open command shall be provided. The Contractor shall integrate this signal as necessary into the energization/de-energization sequence and shall issue a close/open release signal to permit the operator-initiated command to operate the breaker.

<u>DC Side Connecting/Isolating Converter Poles</u>

The control sequence shall connect/isolate the converter pole to the dc line and the pole neutral bus when initiated by operator command. The operator shall be able to switch each converter pole, separately.

The Contractor shall be permitted to use the connect/isolate sequence for protection functions. The Contractor shall provide any synchronization between connect/isolate sequences for the three converter stations necessary for protection schemes.

The HVdc equipment shall be provided with the capability to isolate a faulted converter pole without stopping the other converter pole, including conditions when the faulted pole is blocked and/or when there is a ground fault within the pole on the valve group side of the low voltage, high-speed switch.

The HVdc system shall be capable of switching from monopolar DMR return to monopolar DMR and PMR in parallel and back to DMR only without the shutdown of the operating pole.

Grounding and Un-grounding

In addition, the Contractor shall provide the following sequences to facilitate the preparation of the pole for maintenance and restoration to service:

(a) Isolation and Grounding Sequence

This sequence shall, after checking that the converter pole is de-energized from ac and dc source, open the pole neutral high-speed switch, open the dc line disconnect switch, open the pole neutral bus disconnect switch, and open the converter transformer ac side disconnect switch and then close all motor operated grounding switches in the valve hall.

(b) Unearth Pole Sequence

This sequence shall, after checking that all maintenance keys have been properly returned, open all of the grounding switches in the valve hall.

Starting and Stopping of Converter Poles/Bipole

The control sequence for starting/stopping a converter pole shall consist of deblocking/blocking of the converter pole or bipole. The operator shall be able to initiate starting/stopping of each converter pole in each converter station, separately, if monopole start/stop is selected.

The pole or bipole stop sequence shall ramp the dc power/current of the pole or bipole, as applicable, to minimum dc power or current at the preset pole or bipole power/current ramp rate before blocking the pole.

The bipole start sequence shall be designed to start both poles which are energized and in the “ready to start” state. The poles shall be capable of starting at the minimum power/current order then ramping up to the power/current order setting during the preset power/current ramp time. If both poles are not “ready to start” and bipolar start/stop is selected, then neither pole shall be capable of starting if the start sequence is initiated.

The control sequence logic shall include features to synchronize start-up of the converter pole in each station. The pole connect sequence in both stations shall be complete before valve group start is permitted. Should the converter at any station fail to start within one minute of starting a converter at another station, any started converter shall be stopped.

The Contractor is permitted to use the stop control sequence for protection-initiated stopping of valve group operation.

The Contractor shall ensure that the converters are brought into operation or taken out of service with minimal disturbance to the ac system and the other converter pole in service.

The operator shall be able to start-up and shut-down converter poles when the communication system is out-of-service, but with voice communication available.

The control sequence shall automatically stop a remote converter station converter pole when the local converter pole is stopped by protection. When the communication system is out-of-service, a backup converter pole shutdown system shall be provided.

Starting and stopping sequences should consider point-to-point and multi-terminal operation. When running in multi-terminal operation, any single converter should be able to start or stop without disrupting the power transfer.

DC Filter Switching

The operator shall be able to connect/isolate each dc filter bank in each pole, separately.

When the dc filter switching control sequence is initiated, the sequence shall carry out the required control action to achieve safe switching conditions. The sequence of operation of the dc filter disconnect and grounding switches shall not allow dc current to flow into the station earth mat and shall be timed to avoid possibly damaging or disruptive discharge currents.

In the event of a fault within a dc filter requiring disconnection of that filter, the filter shall be automatically disconnected.

A separate automatic switching sequence shall be provided for the purpose of connecting/disconnecting each dc filter. It shall be possible to connect and disconnect the dc filter for maintenance.

6.4.2. Operator Control Locations and Functions

The operator control facilities shall be located in the following areas and consist of the following:

(a) Local Control:

The local control shall consist of a control console consisting of a redundant Operator Control and Display computer using an industry standard personal computer running with dual 24" widescreen LCD monitors. This control console shall be capable of controlling the complete dc system and the associated ac systems. If a computer is required for the maintenance, troubleshooting and polling of relay, control and protection devices, this shall be separate from the supplied Operator Control and Display computers.

The local Operator Control and Display systems shall be referred to as the local control computers.

Local control will be used as follows:

- For commissioning
- For routine operation
- For maintenance

(b) Remote Control:

The Contractor shall provide sufficient information to the SCADA remote for the Owner to replicate all of the converter stations status, alarm, and measurement displays at the control centers.

6.4.2.1. Remote Control Computer and Local Control Computer

The functionality of the supplied Operator Control and Display shall include but not be limited to:

1. Ability for the operator to set commands (start/stop, voltage set-point order, MVAR order, etc.). All operator commands shall be of select->execute type.
2. Analog parameters (voltages, currents, MVAR flows, temperatures, cooling system parameters, etc.)
3. Open-close control and status indication for the HVac circuit breakers
4. Open-close control and status indication for the disconnect switches
5. Selection between enabling/disabling the various HVdc automatic control functions
6. Active alarms and annunciations
7. All select and setting functions required for operation, maintenance, and testing of the HVdc protection and control system
8. Indication of the status of the HVdc control and operational elements
9. A date and time-tagged event list for all protective and control device operations for evaluation of test results. All digital points to be time-tagged to 1 ms accuracy.
10. The Contractor-supplied Operator Control and Display shall display an accurate representation of the HVdc system and subsystems. At a minimum the following displays shall be included:
    a. Overall HVdc single line diagram (SLD) including all switches and control and monitoring points.

b. SLD of all three converter stations

c. SLD of auxiliaries

d. SLD of valve cooling systems

e. Reactive Power Control (RPC) Overview

11. All screens shall contain a user defined “dashboard” that contains, at a minimum:

a. Pole currents

b. Pole voltages

c. Pole power

d. Power order

e. Bipole power

f. Neutral current

6.4.3. NERC-CIP Requirements

All HVdc controls and protections, the SCADA systems, and all telecommunications are subject to NERC-CIP security requirements. See Appendices XXXX

6.4.4. Alarm and Status Monitoring, Sequential Event Recording

The Contractor shall provide a sequence of events recorder (SER) of which each protective circuit and all points in the complete HVdc system which can change status for both existing and supplied equipment. The SER shall be equipped with an alarm and/or status which is registered and shown on the redundant operator display with indication of:

- Priority
- Identification number/component number and clear text
- Time (year, date, hour, minute, second, millisecond)
- Condition (high-low, out-in)
- Acknowledged/not acknowledged

In order to make it possible for the Operator to evaluate the fault situation, the system shall contain an alarm priority order divided into levels. The fault condition giving the alarm normally is indicated first, possibly with a special marking. The respective converter station requires the following alarm levels:

- Minor (green text)
- Warning (yellow text)
- Emergency or trip (red text)

The alarms and statuses shall have an interactive online feature which shall be invoked by clicking on the desired alarm. It shall give the Operator a meaningful indication of the condition and support them in the interpretation of the alarm.

The SER function shall provide an output that will be sent via the SCADA remote to a central SER logging function at each converter station’s control center.

Within the control system, grouping of alarms and statuses must be possible. The grouping shall be created by use of logical operators such as AND, OR, XOR, NAND, etc. All indications (also summary indications) shall, if desired, be included in the alarm groups which can be remotely transmitted and presented locally. A given data point must be able to appear in several sum indications. Summary alarms shall be able to report all state changes on included alarms.

It shall be possible to inhibit all grouped and individual statuses and/or alarms at each control location, independently, for maintenance purposes. It shall be possible to query the SER system to provide a list of inhibited statuses and/or alarms. Upon release of the inhibited statuses and alarms, the points shall be updated and any un-acknowledged points shall be displayed.

The SER shall have the capability to search and sort up to at least ninety (90) days of data. The SER data past ninety (90) days shall be archived and saved to a redundant substation–hardened, local database server in the converter station's standard database.

The alarms and status indications shall be given, in order that the Operator can quickly get a survey of which installation is faulty.

On all graphic displays, message lines must be present at the top or bottom of the Operator Control and Display showing a number of unaccepted alarms with priority. It shall be possible to accept the alarms on a display joint or individually thus allowing for possible further alarms to be shown in the message lines.

It shall be possible to show all the alarms on the Operator Control and Display as an alarm list and to accept each alarm individually, for each page, or according to priority. It shall not be possible to accept alarms which are not shown.

It shall be possible, directly from the message lines, to select a faulty unit and then select, according to the need, the control group display where the faulty unit is shown or the curve display if the alarm is based on an analog signal. The measured value up to the time of the alarm shall be shown.

6.4.5. Data Logging and Trend Recording

The Operator Control and Display shall be supplied with an interactive trending system for users. It shall trend data for a minimum duration of seven days, with the capability of archiving the data offline. The trending system shall sample each monitored point at least every two seconds. The trending system shall be capable of displaying four individual plots with up to ten curves per plot. At a minimum, the following trends shall be included for each station:

1. DC Power
2. RMS voltage
3. Reactive Power Consumption
4. Valve cooling system inlet and outlet temperatures
5. Ambient temperature
6. Valve hall temperature
7. HVdc transfer capability
8. DC voltage
9. DC current
10. DC neutral current
11. Real and reactive power exchange with the ac systems
12. Real and reactive power exchange with the windfarms

The Contractor shall submit to the Owner, a list of recommended trending for the equipment within their scope of supply.

6.4.5.1. Continuous Data Monitoring

The Contractor shall implement a continuous data stream in C37.117 format (PMU-like), time-synched with GPS, for the following quantities for each pole:

1. DC voltage
2. DC current
3. DC power
4. DC power order
5. DC current order
6. Converter firing angle
7. Converter gamma angle
8. Transformer tap position
9. AC positive sequence voltage magnitude phasor (angle and magnitude)
10. AC positive sequence current magnitude phasor (angle and magnitude)
11. AC positive sequence MWs
12. AC positive sequence MVARs

Please see Appendix XX for the IEEE C37.117 Synchrophasor standard. Data shall be measured at the rate of 60 frames/second.

The Owner will provide equipment to receive the data.

6.4.6. HVDC SCADA Interfaces

The information interface between the HVdc controls and the converter station SCADA system shall accommodate the following:

1. Transmission of power orders from the SCADA remote to the HVdc controls
2. Transmission of all statuses, measurements, alarms and SER data from the HVdc controls to the SCADA remote. These points shall be able to be grouped.

6.4.7. Communication

The Contractor shall provide their own data and voice communication facilities during the Contract Period.

All communication equipment shall be 48 V and supplied via dual, redundant sources.

The communications equipment shall have a very high availability. The Contractor’s design shall provide diversity for the various communication cables and equipment locations.

6.4.7.1. Communication between Converter Stations

See Appendix XX for a description of the communication circuits between the converter stations.

6.4.7.2. Communication to Remote Control Centers

The interface to each converter station’s SCADA remote shall be done using the XXX (serial) protocol through a gateway system provided by the Contractor. The required statuses and control and operating points shall be determined by the Contractor and approved by the Owner.

6.4.8. Transient/Digital Fault Recorders (TFR or DFR)

The Contractor shall provide a digital fault recorder for each pole. The TFR shall provide the means to provide a Comtrade file. The TFR will be connected to both A and B protection and control systems.

The TFR resolution shall allow AC and DC voltages and control and protection signals to be recorded with at least 100 measured points per cycle of fundamental frequency.

The TFR shall be synchronized to the station GPS clock.

The TFR of each pole shall record all necessary signals to enable troubleshooting and event analysis, including, as a minimum:

1. Valve group firing pulses, delay angle response, and extinction angle response (digital or analog pulse harp)
2. Valve group thyristor stack voltages and currents (wye and delta-connected valves)
3. DC line voltages
4. DC neutral bus voltages
5. DC line currents (Currents in each HV conductor and each DMR)
6. DC neutral bus currents
7. MRTB Currents
8. DC power
9. DC current order
10. AC bus voltages (phase – ground, 3 phases)
11. AC line currents (3 phases)
12. AC transformer primary currents (3 phases, wye & delta)
13. AC transformer secondary currents (3 phases, , wye & delta)
14. AC filter currents (3 phases, each filter individually)
15. Firing angle
16. Inverter valve group extinction angle
17. All trips and breaker statuses
18. All incoming AC line currents
19. DC control mode
20. AC bus frequency
21. AC reactive power
22. AC real power
23. Filter statuses
24. Metallic return current
25. Station ground current
26. Signals which modulate bipole power order, pole current order, or other controller references.

Triggering of the TFR shall include, but not be limited to the following inputs (any one or more of the following to initiate a trigger):

1. Pole block/ deblock
2. Pole commutation fail
3. Pole firing pulse loss
4. Pole DC Prot dv/dt trig.
5. Pole metallic return sequence initiated
6. AC overvoltage/ undervoltage protection operated
7. Telecommunication failure

8. Specified rate of change of key values (e.g. DC voltage and current)
9. Manual triggering
10. Breaker operations
11. Any activation of a runback or modulation

Individual triggering points shall be able to be deactivated

6.4.9. System Indications and Power Measuring Facilities

The Contractor shall provide measured values from the dc and ac system in the station control room that shall include, but not be limited to:

1. Bipole power order
2. Bipole power
3. Pole power
4. Pole dc voltage
5. Pole dc current
6. Metallic return line current
7. Pole neutral bus voltage
8. Ac bus voltage
9. Ac bus frequency
10. Converter reactive power (Mvars)
11. Mvar output at each AC filter
12. Tap changer position
13. XXxkV ac line currents
14. XXXkV ac line MW and MVArs

6.4.10. Energy Metering

Each converter station will supply energy metering equipment for installation by the Contractor. The Contractor shall provide sufficient voltage and current measurements, power, and connection to the converter station telecommunications system.

6.4.11. DC Line Fault Location Equipment

The contractor shall supply dc line fault locators that shall monitor the entire dc line length.

The dc line fault locators shall continuously monitor the complete length of the HVdc line (both conductors). The dc line fault locators shall detect transient and sustained faults on the HVdc line, calculate the location of each fault, and display the distance to each fault and the time of occurrence of each fault in the control room. The location of each dc line fault shall be provided automatically for each and every fault. The accuracy of the detection shall be ±0.5 km.

6.5. Surge Arresters

The Contractor shall supply the dc and ac surge arresters necessary for the protection of the equipment associated with the converter station and include it in the scope of supply, in accordance with the requirements of the Specification.

All arresters shall be of hermetically sealed units, self-supporting construction and generally suitable for mounting on the support structures in the ac & dc yard. Arresters without insulator housing shall be acceptable provided they are installed in a controlled environment however, such design should have been in satisfactory operation in a similar environment for at least three years on the date of award of the Contract.

All arresters shall be of the gapless metal oxide type with no series spark gaps.

Standards IEC60071-5 and IEC 60099-5 and applicable CIGRE publications shall be applied for selection and dimensioning of surge arresters.

6.5.1. Duty Requirements

The protective characteristics and discharge duties with respect to the intended dc and ac application shall be determined by the Contractor. The arresters shall provide consistent protection to their associated equipment against overvoltages produced by lightning, switching, station internal or external faults, and other system disturbances.

The arresters shall be rated and tested such that they are able to discharge a specified, maximum energy due to the application of temporary voltages of form and magnitude which can occur in-service, as determined by the insulation coordination studies to be carried out by the Contractor, without entering the temperature region where thermal runaway could result upon subsequent application of maximum transient and steady-state voltage conditions.

Particular attention shall be given to the high discharge currents which some of the arresters may experience in-service due to the requirements to discharge the energy of the ac filters, shunt capacitors, dc line, and reactive compensating equipment or in other circumstances.

The design of the arresters shall take into account and shall maximize the degree of current-sharing between multiple arresters. Similarly, the design shall also take into account and shall maximize the degree of current sharing between parallel columns of the same arrester.

The arresters shall be thermally stable to provide a life expectancy of 50 years under the site conditions.

The Contractor shall pay special attention to the ac & dc filter arresters as they are subject to high frequency voltage stresses. The Contractor shall calculate additional watt losses because of this combination and suitably demonstrate the capability of the arresters during testing.

The surge arresters shall be suitable for single phase auto-re-closures on the XXX kV lines.

6.5.2. Tests

The arresters shall be tested to verify all specified protective characteristics and duty cycles as determined by studies carried out by the Contractor.

In accordance with the requirements of the surge arresters, the contractor shall carry out type, acceptance, and routine tests as per IEC-60099 and IEC TC No. 37 WG4 for metal-oxide surge arresters.

The following additional type tests shall also be conducted along with other type tests as per IEC 60099 and IEC TC 37-WG4:

a) Radio Interference Voltage (RIV) test

b) Seismic withstand test

c) Contamination test for dc yard arresters (as per IEC draft “Artificial Pollution Test with respect to thermal stress on multiunit metal oxide surge arrester”)

Each metal oxide block shall be tested to the guaranteed specific energy capability in addition to the routine / acceptance test as per IEC-60099-4/ IEC TC 37 -WG4.

6.6. Converter Transformers

The converter transformer shall be designed, manufactured, tested, delivered, installed, and commissioned in accordance with this Specification.

When shipping the transformer units to the converter stations, any permits and all rigging is the responsibility of the Contractor. The Contractor shall provide a specific plan describing the path and equipment to be used to transport the units from the factory to the Contractor-supplied pad at each station. This information is to be provided at the time the drawings are submitted, or 120 days after Contract Award.

The converter transformers shall comply with the relevant IEEE and IEC standards for HVdc converter transformers. For specification of ancillary items like bushings, current transformers, etc, relevant Sections of this Specification shall be applicable unless otherwise specified.

6.6.1. General Requirements

The converter transformers shall be designed electrically and mechanically for operating conditions suitable to converter operation which shall include, but not be limited to, the following requirements:

1. An electrical insulation system which accounts for the windings being subjected to an ac voltage of distorted sinusoidal wave shape in combination with a dc voltage stress.
2. The cumulative effect of electrodynamic forces produced during valve commutation or other short-circuit condition imposed by valve design limitations and valve group operation.
3. Harmonic currents due to converter operation with particular reference to additional, stray losses resulting from these harmonic currents. The harmonic levels shall include those generated by the converter equipment (based on Contractor studies) and those present in the system and provided in this Specification. The spectrum shall be used to calculate the total harmonic losses after the winding, eddy, and stray components are determined. The effects of the total harmonic losses shall be used when performing the Heat Run Test.
4. Impedance matching between units to minimize the generation of non-characteristic harmonics.
5. DC magnetizing currents due to slight displacement in the timing of the valve firing or due to other dc sources such as aluminum plants, pipeline protection, geo-magnetic disturbance etc
6. The large number of tap changes which are associated with HVdc converter operation
7. Stresses due to normal control operation such as blocking, deblocking and polarity reversal
8. Stresses due to transient faults on the dc terminals and on the dc transmission line
9. The transformer design and noise level shall account for dc residual currents and the dc current flowing in the station ground mat during various operating modes. The minimum assumed dc current shall be 10 Amps per transformer entering through the neutral.
10. The converter transformer shall be designed for worst case harmonic currents including 3rd harmonics. For the purpose of designing the transformers, converter currents calculated for filter design may be used.
11. The cooling system of the transformer shall be so designed that during total failure of power supply to cooling fans and oil pumps, the transformer shall be able to operate at full rated load for at least five (5) minutes and the calculated hot spot temperature shall not be exceeded.
12. The transformer shall be able to operate at 10% overvoltage or 10% over-current on every tap without harmful effects on the transformer.
13. The maximum flux density shall not exceed 1.9 Tesla in any part of the core and yoke at the rated MVA, frequency, and at a 10 percent, continuous overvoltage condition.
14. The transformers shall be designed to suppress maximum harmonic voltage, especially the third and fifth harmonics, so as to minimize interference with communication circuits.

15. The transformers shall be capable of being loaded in accordance with IEC-60076-7 up to loads of 150%. The Company is open to discussion on how this can be optimized with the expected wind generation.
16. The transformer and all its accessories including CTs, etc. shall be designed to withstand, without damage, the thermal and mechanical effects of any external short circuit to ground and also of short circuits at the terminals of any winding for a period of two seconds.
17. The transformers shall be capable of withstanding thermal and mechanical stresses caused by symmetrical or asymmetrical faults on any winding.
18. The transformers shall withstand combined voltage and frequency fluctuations which produce the following over-fluxing condition :
    1. 125% for one minute
    2. 140% for five seconds
19. The Contractor shall submit over-fluxing characteristics up to 170%.

6.6.2. AC Line side

The line windings of the converter transformers shall be suitable for connecting to the ac system in accordance with this Specification.

6.6.3. Saturation of Converter Transformers

Direct current can be induced to flow in the windings of converter transformers by firing angle unbalance, positive sequence second harmonic voltages on the converter ac buses, fundamental frequency current in the dc line, effects from geomagnetic induced currents, and by the potential difference of the converter station with respect to remote ground due to current injection into the ground return during monopolar ground return operation.

The Contractor shall calculate the net direct current flowing in the windings of the converter transformer from all causes and shall provide primary equipment and control and protection features which will allow for unrestricted operation of the HVdc system in any of the operating modes without any equipment loss of life or reduction in performance.

For the purposes of these calculations the Contractor shall assume:

1. Firing angle unbalance to the greatest extent possible consistent with the design of the Contractor's controls
2. Positive sequence second harmonic voltages on the converter ac buses equal to the maximum 60 Hz negative phase sequence voltage for determination of component ratings as given in Section 2.12.6.
3. Direct current in the converter transformer winding caused by fundamental frequency current in the dc line. The Contractor shall calculate the fundamental frequency current in the dc line and the resultant direct current in the windings of the converter transformers caused by the presence of ac lines in the vicinity of the dc line.
4. A minimum of 10 Adc per phase flowing in the converter transformer line side windings due to GIC. This value will be confirmed by the Purchaser after the Commencement Date.

The design value of direct current in the windings of the converter transformers shall be taken to be 1.2 times the arithmetic sum of the calculated direct currents due to the causes listed above.

Converter transformer design reports submitted by the Contractor shall demonstrate, to the Engineer's satisfaction that the converter transformers can withstand the currents specified and shall include the impact of the direct current on converter transformer heating, losses and audible noise.

The Contractor shall ensure that the converter transformers shall be designed to withstand any high unidirectional current components caused by discharges of the capacitance of the transmission line in any credible HVdc normal and abnormal operating condition including but not limited to commutation failures, blocking inverter without bypass-pair and faults to ground.

6.6.4. Transformer Characteristics

6.6.4.1. Rating

The converter transformers shall be rated to satisfy the performance requirements of the converter station as specified in Section 4 of this Specification. The rating shall be based on OFAF or ODAF cooling.

6.6.4.2. Temperature Rise

The Contractor shall provide thermally upgraded winding insulation. Thermally upgraded paper shall meet the life criteria defined in ANSI/IEEE C57.100. The temperature rise shall be limited to the following values after allowing for additional losses associated with converter transformers.

The ambient conditions under which the transformer will be operated are provided in Section XXX.

For maximum daily average air temperature of 20 °C at the converter station and maximum ambient air temperature of 49 °C :

Loading	Average Winding Temp Rise	Top Oil Temp. Rise
Nominal Rating (Maximum Current) (Without Redundant Cooling In)	45°C	40°C
At overload rating	50°C	45°C

6.6.4.3. Impedance

The tolerances of the guaranteed value shall meet the performance requirements of Section 4 and shall apply to all tap changer positions. The impedance value variations shall be as follows:

Table 20 Impedance Value Variations

Deviation from specified value	Maximum ±5% on all taps
Variation between individual phases	Maximum ±3% on the same tap position
Variation between transformer units	Maximum ±3% on the same tap position
Variation between star and delta units	Maximum ±3% on the same tap position

6.6.4.4. On-Load Taps

The Contractor shall be responsible for selecting the rating, the number of on-load taps, the size of steps, as well as the voltage range covered, so that the converter station and the entire HVdc system can operate at rated output throughout the voltage range. The on-load taps shall comply with IEC 60214, and selected in accordance with IEC 60542 and shall be suitable for bi-directional power flow. The voltage range shall be sufficient to meet all the voltage combinations for all the working conditions. The transformer power at any tap shall be not less than that corresponding to the principal tap. Manual and automatic control of the tap changers of the converter transformers shall be provided in the control room. All leads shall be sized such that the temperature rise of the leads shall not exceed the temperature rise limits of the winding to which they are associated with. All tapping leads shall be adequately supported and spaced to withstand short circuits forces.

6.6.4.5. Insulation Levels

The insulation levels on the line side and valve side shall be determined by the Contractor in accordance with the requirements of this Specification. In addition, the H-Winding insulation level shall be based on those provided in IEEE C57.12.00-2010 Table 5 where the voltage in column 1 exceeds the rated maximum system voltage; and, the valve winding insulation levels shall exceed those provided by the method provided in IEEE C57.129 Clause 5.11 when tested in accordance with Clause 8, using the expected maximum system voltage and referring to Table 6.

6.6.4.6. Current Transformers

The Contractor shall be responsible for selecting the number and characteristics of the current transformers (bushing CTs) to meet the protection, control and metering requirements of the converter station in accordance with this specification. The current transformers shall be designed and tested in accordance with the relevant standards.

6.6.4.7. Test Radio Interference Voltage (RIV)

The maximum RIV for each unit shall not be more than 2500 µV at 115% of the rms phase-to-ground test voltage at a frequency of 1 MHz.

6.6.4.8. Sound Pressure Level

The transformer shall meet the audible sound emission requirements at rated voltage and frequency, per IEEE C57.129 and C57.12.90. The standard IEEE test for audible sound emission will be required at the factory.

SOUND LEVEL (maximum dBA allowed at any MVA) 75 dBA

6.6.4.9. Supply of Transformer Auxiliaries

Each transformer shall be fed from two distinct XXX.

6.6.5. General Arrangement

The Contractor shall design the converter transformers with provision to replace any failed unit by a spare unit, without de-energizing any other equipment in the station other than that of the affected pole. The spare unit shall be provided completely assembled with bushings, coolers, oil, control panel, etc. ready to operate at all times on short notice. The location of the spare unit shall be in the same yard as the failed unit.

It shall be possible to replace a failed transformer within 72 hours. The permissible 72 hour replacement duration shall include the removal of and subsequent replacement of any other equipment such as fire walls, surge arresters, and busbars which may be necessary to facilitate the transformer replacement. The necessary tools required for spare transformer replacement shall be provided as a part of erection tools. Fire walls between each of the converter transformers shall be designed for easy removal and replacement if required during the replacement of a failed unit.

6.6.6. Construction

The features and construction details of each transformer shall be in accordance with the following minimum requirements stated hereunder.

6.6.6.1. Transformer Core

1. The core shall be constructed from high grade, non-ageing, cold rolled, grain oriented silicon steel laminations.

2. The design of the magnetic circuit shall be such as to avoid static discharges, avoid development of short circuit paths within itself or to the grounded clamping structure and avoid production of flux components at right angles to the plane of laminations which may cause local heating.
3. The core shall be of mitred construction with the steel properly stacked and all insulation designed so that no detrimental changes in physical or electrical properties shall occur during the life of the transformer.
4. The core and winding shall be capable of withstanding shock during transport, installation, and service. Adequate provision shall be made to prevent movement of the core and winding relative to the tank during these conditions.
5. All steel Sections used for supporting the core shall be thoroughly sand-blasted after cutting, drilling, and welding.
6. When bell-type tank construction is adopted, suitable projecting guides shall be provided on core assembly to facilitate removal of the bell cover.
7. Each core lamination shall be insulated with a material that shall not deteriorate due to pressure and hot oil over the lifetime of the transformer.
8. The supporting frame work of the core shall be designed to avoid presence of pockets which would prevent complete emptying of tank through drain valve or cause trapping of air during oil filling.
9. Adequate lifting lugs shall be provided to enable the core and windings to be lifted.
10. Core clamps shall be electrically connected to external ground, via adequately rated bushings, in a similar manner to that of core.

6.6.6.2. **Transformer Windings**

Windings are to be designed and constructed in accordance with the following requirements.

1. The conductors shall be of enamelled copper, free from scales and burrs as per IEC 60317. The enameling or any other similar protection of the brazing area shall be discussed during detail engineering.
2. The insulation of transformers' windings and connections shall be free from insulating compounds which are liable to soften, ooze out, shrink or collapse and be non-catalytic and chemically inactive in transformer oil during service.
3. The coil assembly and insulating spacers shall be arranged to ensure free circulation of oil and to reduce the hot spot temperature of the winding.
4. The coils shall be made up, shaped, and braced to provide for expansion and contraction due to temperature variations and drying operations.
5. The conductor shall be transposed at sufficient intervals in order to minimize eddy currents and to equalise the distribution of currents and temperature along the winding.
6. The thickness of inter-disc or inter-turn segments provided for horizontal oil flow shall be such that oil can flow freely to all parts of the winding
7. Tapping shall be so arranged as to preserve the magnetic balance of the transformer at all voltage ratios.
8. The Continuously Transposed Cable shall be free of inter-strand shorts after the winding is complete and verified with the use of a low voltage bell or buzzer. The Continuously Transposed Cable shall be checked for inter-strand shorts prior to the removal of the winding from the winding lathe.

6.6.6.3. **Insulating Oil**

1. The insulating oil used shall be pure inhibited mineral oil, clean & free from matters which are likely to impair its insulating properties. Oil shall conform to IEC-60296. Oil samples shall be tested as follows:
2. Prior to filling the main tank on-site, the oil shall be tested for:
    - Break-down voltage
    - Moisture content
    - Tan delta at 90 deg.C
    - Resistivity at 90 deg.C
    - Interfacial tension
3. The contractor shall carry out the oil testing outlined in ASTM D1275 and shall also perform a covered conductor deposit (ccd) test for each batch of oil at the refineries and shall despatch only after both the tests are passed successfully. The detailed test requirements shall be indicated by the Offeror in their tender.
4. Prior to energization of converter transformer at site, the oil shall meet the following properties:

1)	BDV, KV rms (min)	60 kV rms
2)	Moisture content (Max.)	15 ppm
3)	Tan delta at 90 deg.C (Max)	0.005
4)	Resistivity at 90 deg.C (Min)	1x1012 ohm-cm
5)	Interfacial Tension (Min)	0.03 N/m

5. A sufficient quantity of oil necessary for first filling of each tank, coolers, and radiator at the proper level, including spare units, along with 20% (of one complete transformer) extra oil shall be supplied to the site. The 20% spare oil shall be supplied in non-returnable containers suitable for outdoor storage.
6. The Contractor shall furnish test certificates from the supplier of oil for all properties.

6.6.6.4. **Conservator Tank**

1. The conservator tank shall have adequate capacity between highest and lowest visible-levels to meet the requirement of expansion of total cold oil volume in the transformer and cooling equipment from minimum ambient temperature to 100^{O}C.
2. The conservator shall be positioned so as not to obstruct the electrical connection to the transformer.

6.6.6.5. **Dehydrating Filter Breather**

The conservator shall be fitted with a regenerative-style, dehydrating filter breather. It shall be designed so that:

1. Passage of air is through a dust filter and silica gel,
2. Moisture absorption is indicated by a change in color of the tinted crystals that can be easily observed from a distance,
3. Breather is mounted not more than 1400 mm above rail top level.

6.6.6.6. Bushings

The bushings shall generally conform to the requirements specified in Section XX.

The bushings would normally be mounted on turrets and the top of the turret provided with vent pipes routed to the gas relay. The line-side bushings can be either oil-filled or composite gas-filled. All the valve-side bushings shall be of dry type/ SF6 gas-filled composite silicon rubber type insulator.

6.6.6.7. Bushing Current Transformer

The current transformers shall comply with relevant IS/IEC standards. It shall be possible to remove turret-mounted current transformers from the transformer tank without removing the tank cover.

6.6.6.8. Terminal Markings

Bushings shall be marked with identifying signs that make clear which are the primary and secondary terminals of the transformer.

6.6.6.9. Neutral Grounding Arrangement

The neutral terminals of the winding of the transformers shall be connected to an overhead common aluminum tubular bus, supported from tank and fire walls by using porcelain insulators. The overhead common ground bus shall be brought to the ground level at a convenient point for connection to the ground network through 4-hole NEMA pads. The connection shall be made by using two (2), bolted neutral grounding terminals with necessary accessories.

6.6.6.10. On Line Monitoring System

All the converter transformers (each unit), including the spare units, shall have dedicated, online, continuous monitoring of at least the following fault gases in transformer oil:

1. Oxygen (O2)
2. Nitrogen (N2)
3. Hydrogen (H2)
4. Carbon Monoxide (CO)
5. Carbon Dioxide (Co2)
6. Methane (CH4)
7. Ethane (C2H5)
8. Ethylene (C2H4)
9. Acetylene (C2H2)
10. Moisture content

The instrument should be controlled by a fully-embedded processor with over two years of data at a default sampling rate of 6-hourly, stored internally.

Modules should be available for connection via RS232, RS485, ETHERNET, PSTN modem and GSM or CDMA wireless modems.

Input oil temperature range: up to 120deg. With discrete sampling, there shall be no averaging of Dissolved Gas Analysis (DGA) results. The data shall be transmitted to a remote computer located in a control room (using standard software). The integrated alarm function can be triggered on specific gas levels.

6.6.6.11. Auxiliary Power Supply for OLTC, Cooler Control and Power Circuit

Two auxiliary power supplies, 240 or 480 volt, 3 phase, 4 wire, shall be provided at cooler cabinet for OLTC and cooler control and power circuit. All loads shall be fed by one of the two feeders through an electrically-interlocked, automatic transfer switch housed in the cooler control cabinet for load tap changer control and cooler circuits.

If the control circuit is operated by dc supply, then suitable main and standby converters shall be provided by the Contractor to be operated from an ac power source. Necessary isolating switches and MCBs or MCCBs shall be provided at suitable points as per approved scheme.

6.6.7. Tap Changing Equipment

The requirement for tap changing equipment, diverter switch, and filtration are provided here and in Appendix XX.

6.6.7.1. Tap Change Switch General Requirement

The OLTC shall be motor-operated for local as well as remote operation. An external handle shall also be provided for emergency, local manual operation. This hand wheel/handle shall be suitable for operation by a person standing at ground level.

The remote OLTC control shall have provision to raise or lower taps only for the complete bank of single phase transformers. Individual, single-phase OLTC operation shall not be possible from the remote control panel. An indicating device shall be provided to show the tap in use.

The OLTC shall be designed for a minimum of 250,000 operations without repair or change of any part including oil. Any items required during routine maintenance of OLTC up to 250,000 operations shall be supplied by the Contractor. The OLTC shall be designed for a contact life of at least 600,000 operations.

6.6.7.2. On Load Tap Changing (OLTC) Gear

Each transformer shall be provided with voltage control equipment of the tap changing type for varying its effective transformation ratio whilst the transformer is on-load and without producing phase displacement.

The details of the method of diversion of the load current during tap changing, the mechanical construction of the gear, and the control features for OLTC gear shall be submitted.

The requirements of on-load tap changing equipment are given below:

1. The mechanism shall be designed to withstand forces resulting from external short circuits under the most unfavorable conditions.
2. The current-diverting contacts shall be housed in a separate chamber. Suitably rated metal oxide varistors (MOV) shall be installed across each tap.
3. Necessary tools shall be supplied for maintenance of OLTC gear. All oil chambers shall have an oil filling and drain plug, an oil sampling valve, and a relief vent. Suitable signaling shall also be provided for faults within the tap changer tank. The diverter switch or arcing switch shall be designed so as to ensure that its operation, when activated, shall be completed independently of the control relays or switches, failure of auxiliary supplies etc. To meet any contingency which may result in incomplete operation of the diverter switch, adequate means shall be provided to safeguard the transformer and its ancillary equipment.
4. The tap changer shall be mounted such that the cover of transformer can be lifted without removing connections between the windings and tap changer. Local OLTC control cabinets shall be mounted on the tank in an accessible position. It shall be adequately ventilated and provided with anti-condensation metal clad heaters. All contactors, relays, coils, and other parts shall be protected against corrosion and deterioration due to condensation, fungi, etc.
5. The operating mechanism for the OLTC shall be designed to go through one step of tap change per command. Subsequent tap changes shall be initiated only by a new or repeat command.
6. Each OLTC shall be equipped with a time-delayed “incomplete step change” alarm if the tap changer fails to make a successful tap change. The alarm shall not operate for momentary loss of auxiliary power.

7. Provision shall be made in the local OLTC control cabinet to provide tap-position indication for each (single-phase) transformer. The Contractor shall also provide tap-position indication in the control room for each single-phase unit, separately.
8. Limit switches shall be provided to prevent overrunning of the operating mechanism and shall be directly connected in the circuit of the operating motor. In addition, a mechanical stop shall be provided to prevent over-running of the operating mechanism under any condition.
9. A thermal device or other means shall be provided to protect the motor and control circuit. All relays, switches, MCBs etc. shall be mounted in the local OLTC control cabinet and shall be clearly marked for the purposes of identification.
10. A seven-digit counter shall be fitted to the tap-changing equipment to indicate the number of operations completed.
11. It shall not be possible to operate the electric drive when the manual operating gear is in use.
12. It shall not be possible for any two controls to be in operation at the same time.
13. The equipment shall be suitable for supervisory control and indication with “make before break”, multi-way switch, having one potential free contact for each tap position. This switch shall be provided in addition to any other switch(es) which may be required for remote tap position indication.
14. Operation from the local or remote control switch shall cause one tap movement only until the control switch is returned to the off position between successive operations.
15. All electrical control switches and the local operating gear shall be clearly labeled in a suitable manner to indicate the direction of tap changing.
16. Transfer of source on failure of one ac supply shall not affect the tap changer.

6.6.8. **Cooling Equipment**

The transformer cooling shall be Oil Forced Air Forced (OFAF) or Oil Direct Air Forced (ODAF). The cooling system for each transformer unit shall be independent and complete in itself. In addition, the cooling equipment shall conform to the following requirements:

1. The transformer cooling equipment shall consist of a number of detachable-type unit coolers. The coolers could be either tank-mounted or separately installed.
2. Each unit cooler shall have its own cooling fans, oil pumps, oil flow indicator, shut-off valves at the top and bottom, lifting lugs, top and bottom oil filling valves, air release plug at the top, a drain and sampling valve and thermometer pocket fitted with captive screw cap on the inlet and outlet.
3. The total capacity of coolers furnished for each transformer unit shall be suitable for operating the transformer for all HVdc station ratings.
4. Each cooling fan shall be suitably protected by a wire guard. The exhaust air flow from any given cooling fan shall not be directed towards the main tank in any case.
5. Oil pumps shall be provided for each unit cooler. Necessary measures shall be taken to prevent mal-operation of the gas relay when all oil pumps are simultaneously put into service.
6. An oil flow indicator shall be provided for the confirmation of the oil pump operating in a normal state. Provision shall be made in the flow indicator to indicate reverse flow of oil/loss of oil flow. Information including pump running status and flow indication shall be integrated with HVdc SCADA systems.
7. Cooling fans and oil pump motors shall conform to IEC 60034.
8. The cooler and its accessories shall preferably be hot-dip galvanised or otherwise corrosion resistant paint shall be applied.

6.6.8.1. **Cooling Equipment Control (OFAF or ODAF Cooling)**

The forced cooling equipment (unit by unit) shall come into operation automatically by pre-set contacts of winding temperature indicator. In addition to the automatic, load-dependent control, manual control capability for cooler fans and oil pumps shall also be provided.

6.6.8.2. **Indicating Devices**

At least the following lamp indications shall be provided in the cooler control cabinet:

1. Cooler main supply failure
2. Cooler supply changeover
3. Cooler standby supply failure
4. Control supply failure
5. Cooling unit failure of each unit cooler
6. No oil flow/reverse oil flow for pumps
7. Common thermal overload trip

6.6.8.3. **Valves**

A 4-inch (~100mm) butterfly valve meeting the requirements of API 609 shall be installed on the highest point practical on the side wall of the transformer tank (Table XXXX, Specific Valve Requirements Table) below. The flanged valve shall be mounted on a flanged fitting.

The flange opening shall not be blocked by obstructions in the tank.

The flange face shall be on the side of the transformer tank and have a 32-microinch finish.

An oil-tight blanking plate shall be provided to cap off the 4 inch butterfly valve. This blanking plate shall provide a weather-tight, mineral oil leak-tight and a vacuum-tight seal when installed on the 4 inch butterfly valve.

The flange may be located on a manhole cover.

The valve, flange, and blanking plate outer surfaces shall be designed to be resistant to outdoor weather. Materials shall have rust resistant surfaces or coatings.

Must be a bolted-style flange.

All ball valves shall meet the following requirements:

1. Vacuum proof
2. 1/4 Turn Indicating
3. Lockable in both open and closed positions
4. API 607 or equivalent fire safety rating
5. Carbon steel or stainless steel body
6. Stainless steel ball, stem, backing nut
7. Flange connections shall be designed for gasket use only (exceptions noted in Specific Valve Requirements Table)
8. Unibody construction, multi-piece bolted bodies not allowed
9. Full size port
10. Flange connections unless otherwise specified
11. Rust resistance surface or coating
12. Welded Valves shall have a carbon or stainless steel body

13. Class 150 flanged valves may be either a carbon steel or stainless steel body.

All butterfly valves shall meet the following requirements:

1. Vacuum proof
2. 1/4 Turn Indicating
3. Lockable in both open and closed positions
4. Minimum Oil flow restriction
5. API 609 rating, must be category B pressure/temperature-rated. Must meet class 150 rating.
6. Flange connections unless otherwise specified should be in accordance with ASME 16.5 flange ratings.
7. Carbon steel or stainless steel body
8. Include oil-tight blanking plates

8. Table XXX Specific Valve Requirements

VALVE LOCATION BELOW			
Valve Identification	**Valve Description**	**Construction**	**Location**
Oil processing vacuum valve Item A	4 inch butterfly valve (for oil processing)	- Include oil-tight blanking plate. Flanged valve.	Side of transformer tank near the transformer lid.
Drain valve (also called lower filter valve). -If transformer oil capacity is greater than 10,000 gallons, provide two valves adjacent to each other to allow quicker oil removal. Item B	2 inch ball valve (for removing transformer oil)	- Welded to tank with no threaded connections between valve and tank. - 2 inch NPT female discharge end fitted with pipe plug.	- Center bottom of one side of tank. -Minimum 18" separation
Fill valve (also called upper filter valve) Item C	2 inch ball valve (for vacuum filling of transformer)	- Welded to tank with no threaded connections between valve and tank. - 2 inch NPT female discharge end fitted with pipe plug.	- Near top of tank wall. - Away from tank processing valve. - Opposite side from drain valve(s). - Oil flow during filling will not damage internal transformer parts.
Upper vacuum valve Item D	2 inch ball valve (vacuum connection during oil filling and	Welded to conservator; - 2 inch NPT female outer end	- Horizontal mounting. - Highest practical

VALVE LOCATION BELOW			
Valve Identification	**Valve Description**	**Construction**	**Location**
	processing)	fitted with pipe plug.	point on conservator
Tank venting valve Item E	½-inch ball valve (vacuum gauge connection during oil processing and filling)	Female threaded ends	Horizontal position on main tank. Near conservator shut-off valve. Permanently installed.
Gas in Oil Monitoring Valve (Item F - not shown)	2 inch ball valve carbon or stainless (Future installation of GIO monitor)	Welded to cooler return manifold, outer end fitted with pipe plug. Output not more than 6-1/2 inches from oil flow.	Lower cooler manifold (oil return).
Buchholz Relay Isolation Valve (also used as conservator shutoff valve) - Two valves required for each Buchholz relay Item G	Ball valve size determined by conservator piping	Capable of holding full head of oil in conservator.	Both sides of Buchholz relay
Gas Sampling Valve (Item H - not shown)	1/4-inch stainless steel ball valve (for taking gas samples from Buchholz relay)	Stainless steel tubing from Buchholz to gas sampling device Female NPT thread connections both ends	Located so that samples can be taken with the equipment energized.
Pressure Equalization valve (Item I)	1 inch ball valve (For pressure equalization of conservator air cell during vacuum processing and oil filling)		One (1) valve between conservator air and oil spaces. One (1) valve between air cell and LTC conservator
Oil Pump Isolation valves (Item J - not shown)	Butterfly Valves For isolation of cooling pumps. Permits removal of oil pump without draining either the pump or the cooler.		One (1) valve between pump and tank. One (1) valve between pump and cooler. If one side of pump is connected to the tank, the tank side valve may also serve

VALVE LOCATION BELOW			
Valve Identification	**Valve Description**	**Construction**	**Location**
			as the Cooler Shutoff Valve.
Radiator Isolation valves (Item K - not shown)	Butterfly Valves For isolation of radiators/coolers Permits removal of radiator without draining oil from tank	-Include oil-tight blanking plate - Lower valve welded to tank. (no gaskets between valve and tank) - Upper valve either welded to tank or connected to flange if return connection from cooler connects to the tank lid.	Between radiator and tank - top and bottom open and closed positions must be clearly indicated
LTC Protective relay isolation valve (Item L)	1 inch ball valve		Located between LTC conservator and LTC protective relay
Sudden Pressure Isolation valve (Item M--not shown)	-Ball valve		Isolation for sudden pressure relay, if required. Manufacturer to determine location.
Conservator Drain valve (Item N)	1 inch ball valve	Female NPT thread connections both ends Open end to be plugged	For conservator tank draining
LTC Conservator Drain valve (Item O –not shown)	1 inch ball valve	Female NPT thread connections both ends Open end to be plugged	For LTC conservator tank draining
All ball valves associated with the LTC filtration, if required, shall be 1 inch (Item P – not shown)	Valves required for LTC filtration system (not shown)		LTC filtration system
Oil Sampling valve	Not Required		

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Valve Attachment Requirements:

Welded valves shall be adequately cooled during welding attachment to prevent seal damage.

Valve connections which are allowed:

1. Flanged type (preferred)
2. Socket welded end
3. Threaded with a sealing weld

Valve connections which are not allowed:

1. Threaded valve connection only without weld
2. Butt welded valve connection

6.6.8.4. Local OLTC Control Cabinet and Cooler Control Cabinet

Each transformer unit shall be provided with one local OLTC control cabinet & one cooler control cabinet.

1. A thermostat-controlled space heater and cubicle lighting with ON-OFF switch shall be provided in each cubicle.
2. All the CT secondary terminals in the cooler control cabinet shall have provision for short circuiting to avoid CT open-circuit while it is not in use.
3. The cooler control cabinet shall have all necessary devices meant for cooler control. Temperature indicator devices for each (single phase) transformer unit shall be provided on a separate panel mounted on the transformer. All the contacts of various protective devices mounted on the transformer shall also be wired up to the terminal board in the cooler control cabinet. All the secondary terminals of the bushing CT's shall also be wired up to the terminal board at the cooler control cabinet.
4. The cooler control cabinet shall have two Sections. One Section shall have the control equipment exclusively meant for cooler control. The other Section shall house the devices meant for combined OLTC control, aux., CTs and the terminal boards meant for termination of various alarm and trip contacts as well as various bushing CT secondary. Alternatively the two Sections may be provided as two separate cubicles.
5. The temperature indicators shall be mounted such that the dials are not more than 1200 mm from ground level. A glazed door of suitable size shall be provided for convenience of reading.

6.6.9. Fittings

6.6.10. Design Review

The transformers shall be designed, manufactured, and tested in accordance with the best international engineering practices under strict quality control to meet the requirement stipulated in the technical specification. Adequate safety margin with respect to thermal, mechanical, dielectric and electrical stress etc. shall be maintained during design, selection of raw material, manufacturing process etc. so that the transformer provided shall require minimal maintenance.

Design reviews shall be conducted by the Owner or an appointed Consultant during the procurement process for the transformers, however the entire responsibility of design shall be with the manufacturer.

The Owner and /or Consultant may also visit the manufacturer's works to inspect/review design, manufacturing and test facilities.

The preliminary and final drawings shall be in accordance with and include items listed in Section 9 Documentation.

6.6.10.1. Design Review during Detailed Engineering

The design review shall commence after placement of award with the successful Offeror and shall be finalized before commencement of manufacturing activity. These design reviews shall be carried out in detail to the design of the transformer under the scope of this specification.

The design review shall be conducted, generally, following the "Guidelines for conducting design reviews for transformers 100 MVA and 123 kV and above" prepared by CIGRE SC A2 Working Group 12.22 as mentioned in CIGRE JTF B4.04/A2-1. Also the IEC-61378 under the general title "Converter Transformer: Part- 2: Transformer for HVdc applications" is to be referenced for design purposes.

The manufacturer shall provide all necessary information, drawings, and calculations during design review to demonstrate that the transformer meets the requirements for short circuit strength and durability. The latest recommendations of IEC and CIGRE SC 12 shall be applied for short circuit withstand evaluation.

The manufacturer shall be required to demonstrate the use of adequate safety margins for thermal, mechanical, dielectric and vibration etc. design to take into account the uncertainties of the design and manufacturing processes.

The scope of such a design review shall at least include the following:

1. Core and magnetic design
2. Winding and tapping design
3. Short-circuit withstand capability
4. Thermal design including review of localized potential hot areas
5. Cooling design
6. Overload capability
7. Losses (IEC-61378-2)
8. Seismic design (as applicable)
9. Insulation levels (IEC-61378-2)
10. Tank and accessories
11. Bushings and barrier system
12. Tap changers
13. Protective devices
14. Fans, pumps, and radiators
15. Sensors and protective devices
16. Oil and oil preservation system
17. Corrosion protection
18. Electrical and physical interfaces with substation
19. Grounding
20. Processing and assembly
21. Testing capabilities
22. Testing (IEC-61378-2 Section 10) including DGA Acceptance Criteria after dielectric tests.
23. Transport and storage
24. Sensitivity of design to specified parameters
25. Sound level (IEC-61378-2)
26. Spares, inter-changeability and standardization
27. Maintainability
28. Short circuit impedance tolerance (IEC-61378-2)
29. Selection of current rating of tap-changer in line with clause 14.2 of IEC 61378

6.6.11. **Inspection**

The Contractor shall carry out a comprehensive inspection program during manufacture of the transformer. The Contractor shall furnish a comprehensive Manufacturing Quality Plan (MQP) which shall cover the detailed inspection of various components of the transformer. The MQP should cover at least the following items/activities given below:

1. Tank and conservator

2. Core
3. Insulation material
4. Winding
5. Checks before drying process
6. Checks during drying process
7. Assembled transformer

6.6.12. Testing

The Contractor shall carry out all specified type-tests and routine tests on the transformers as specified in Section 1.2.3.4 Type Testing. Type tests shall be carried out on the first transformer of each type & rating and routine tests on all transformers. Tests shall also be carried out on transformers, their tap changers, bushings and other components in accordance with IEC 61378, 60076, 60214 & 60270 and as detailed below.

6.6.12.1. Tap Changer Tests

Type-test reports for the same design of tap-changer, already tested in another project and offered in this project shall be accepted by the Owner only if the tap changer offered is identical to the one offered in this project.

1. Type Tests
    - Temperature rise of contacts
    - Switching tests including service duty tests & breaking capacity tests
    - Transition impedance test
    - Mechanical endurance test
    - Dielectrics tests (power frequency and impulse)
2. Routine Tests
    - Mechanical tests
    - Dielectric test on auxiliary circuits

6.6.12.2. Transformer Tests

1. Routine Tests
    - Polarity and vector group (10.3 of IEC 60076-1)
    - Voltage ratio test (10.3 of IEC 60076-1)
    - Winding resistance measurement (10.2 of IEC 60076-1)
    - No-load losses and currents (at 90%, 100%, & 110% voltage)
    - Impedance and load-loss measurement (at 75 deg. C, nominal & extreme taps), procedure shall be as per clause 10.3 of IEC 61378-2 and clause 10.4 and 10.5 of IEC 60076-1.
    - Oil samples (IEC 60567)
    - Switching impulse test shall be as per clause 10.4.1 and clause 15 of IEC 60076-3.
    - Lightning impulse shall be with full wave & chopped wave as per clause 10.4.2 of IEC 61378-2 and clause 13 & 14 of IEC 60076-3.

- DC separate source withstand test including partial discharge and acoustic detection measurement as per clause 10.4.3 of IEC 61378-2.
- Polarity reversal including partial discharge (PD) measurements as per test levels and duration specified in clause 10.4.4 of IEC 61378-2.
- AC separate source withstand test (clause 10.4.5 of IEC 61378-2 and clause 11 of IEC 60076-3).
- Induced overvoltage test and partial discharge measurement (clause 10.4.6 of IEC 61378-2 and clause 12 of IEC 60076-3) PD shall be less than 300PC as per IEC, however, negative tolerance as indicated in IEC shall not be allowed.
- 2 hour,110% overvoltage test at rated frequency and with partial discharge measurement at 30 minute intervals. Partial discharge shall not exceed background level at any time. PD measurement shall be generally in accordance with IEC 61378-2.
- Test of the magnetic circuit insulation and associated insulation (3 kV dc, one minute)
- Insulation resistance test for auxiliary wiring at 2 kV RMS for one minute
- Bushing current transformer tests
- Bushing voltage transformer tests, if applicable
- Insulation power factor tests (at 20 deg. C, before & after dielectric test)
- High voltage withstand test on auxiliary equipment & wiring
- Magnetization characteristic test
- Frequency response analysis (FRA) per Unit 4, Appendix 46
- Temperature rise test (as per clause 10.5 of IEC 61378-2)
- Each tank wall surface and cover shall be scanned for hotspots with an infrared thermometer in the last hour of the temperature rise test. There shall be a minimum of nine, evenly distributed points measured about each tank wall surface or cover. The location and measured temperatures of the tank wall and cover shall be identified on a scaled-down version of the outline drawing that shall be included in the test report. Further, the tank wall hot spot location and temperature shall also be identified. In addition to the requirements given in the standards, the following shall be ensured during the heat run test.
- The transformer shall be loaded at 1.0 pu rating till steady state temperature is reached. The loading shall then be increased to 1.1 pu for two hours without switching-in additional coolers. After these two hours, the transformer shall continue to be loaded at 1.1 pu with additional coolers, if required, till steady-state temperatures are achieved. The average winding temperature rise and the top oil temperature rise shall be recorded for all the three ratings stated above.
- For the evaluation of gas analysis in temperature rise test, the procedure shall be as per IEC 60567 and results shall be interpreted as per IEC 60599.
- Oil samples shall be taken for analysis at the beginning, during, and at the end of the test sequence. The samples taken during the test sequences shall be taken at the end of major tests as agreed between the Owner and Contractor. The samples at the beginning and end of the test sequence shall be analyzed. If a difference in the analysis of the oil is detected, the intermediate sample should then be analyzed.

a. The high voltage dielectric tests shall be carried out after completion of the heat run test in the following sequence:

    - DGA

- Lightning Impulse Test
- Switching Impulse Test
- DC Voltage Withstand and dc Partial Discharge Tests
- Polarity Reversal Test
- Applied Power Frequency Voltage Tests
- Induced Potential Test and ac Partial Discharge Test
- 12-hour no-load test at 110% of rated voltage at rated frequency
- Repeat DGA and comparison of oil results with previous DGA

2. Type Tests

- Audible noise test in accordance with IEC 60076-10
- RIV test
- Pressure relief device test
- Oil leakage, vacuum, and pressure tests on transformer tank
- Measurement of capacitance and tan delta to determine capacitance between winding and ground
- Measurement of power consumed by fans and oil pumps
- Measurement of harmonic level in no-load current (at 90%, 100% & 110% of nominal voltage)
- Measurement of load losses at 60Hz and 180Hz.
- One cabinet of each type shall be tested.
- Short-circuit withstand test (clause 2 of IEC 60076-5) shall be demonstrated by calculation only
- In addition, a high frequency model of the transformer shall be established through low voltage measurements (refer clause 11 of IEC 61378-2)

6.6.12.3. Bushings

All the bushings shall be subject to type, routine, and special tests. The ac bushings shall be tested as per IEC 60137 and the valve-side bushings shall be tested as per IEC 62199. A sealed bushing design will not be considered.

6.6.12.4. Tank Tests

1. Oil Leakage Test

All tanks and oil filled compartments shall be tested for oil tightness by being completely filled with air or oil of a viscosity not greater than that of insulating oil at the ambient temperature and applying a pressure equal to the normal pressure plus 35 kN/m^2 measured at the base of the tank.

The pressure shall be maintained for a period of not less than 24 hours for oil and one hour for air during which time no leak shall occur.

2. Vacuum Test

One transformer tank of each size shall be subjected to the specified vacuum. The tank, designed for full vacuum, shall be tested at an internal pressure of 3.33 kN/m^2 absolute (25 tor) for one hour. The permanent deflection of flat plate after the vacuum has been released shall not exceed the values specified below:

Horizontal Length of flat plate	Permanent deflection in mm
Up to and including 750	5
751 to 1250	6.5
1251 to 1750	8.0
1751 to 2000	9.5
2001 to 2250	11.0
2251 to 2500	12.5
2501 to 3000	16.0
Above 300	19.0

3. Pressure Test

   One transformer tank of each size together with its radiator, conservator vessel and other fittings shall be subjected to a pressure corresponding to twice the normal head of oil or to the normal pressure plus 35 kN/m^2 (whichever is lower) measured at the base of the tank and maintained for one hour. The permanent deflection of flat plates after the excess pressure has been released shall not exceed the figure specified above for vacuum test

6.6.13. Transportation

Shipping requirements are provided below.

The Contractor shall dispatch the transformer filled with an atmosphere of Nitrogen or dry air. Necessary arrangement shall be ensured by the Contractor to take care of pressure drop of the nitrogen/dry air during transit and storage until completion of oil filling during erection. A gas pressure testing valve with necessary pressure gauge and adaptor valve shall be provided.

The transformers shall also be fitted with sufficient numbers of impact recorders (a minimum of three) during transportation to measure the movement due to impact in all three directions. The Contractor shall submit the impact recorder reports within three weeks of receipt of transformer at-site.

6.7. Smoothing Reactor

The Contractor shall supply the smoothing reactor(s) that is necessary for the satisfactory operation of the HVdc transmission system. Only air-insulated type smoothing reactors shall be supplied. A design where the main smoothing reactor is located in the neutral bus shall not be accepted.

6.7.1. Rating

The reactors shall withstand the electrical and mechanical stresses resulting from harmonics and surge currents and shall be rated to satisfy the specified performance requirement. The thermal insulation class of the winding shall be minimum “F” or higher, nevertheless allowed temperature-rise shall not exceed those stated for class “B”, both for outdoor or indoor installation, as indicate in IEC 60085 or in IEEE 1277™-2010, Table 3.

The value of the reactor inductance at maximum and minimum dc current, along with all levels of current in between, shall be determined by the Offeror/Contractor and be compatible with the particular system design.

The Offeror/Contractor shall supply a curve of inductance versus current from minimum dc current to maximum fault current.

When deciding the value of inductance of the reactor, due consideration shall be given to the risk for resonance with the dc line. The Contractor shall show results of simulator or other studies indicating that necessary measures have been taken to avoid such resonance.

The insulation withstand capability shall be demonstrated especially when the smoothing reactor is subject to a DC fault to ground at its terminals or nearby in the converter station or on the dc line. If a number of units are connected in series to meet the inductance value, the Contractor shall demonstrate how the voltage shall distribute across the units especially under fast transients resulting from dc faults.

The materials and design of the smoothing reactor shall resist tracking of the winding insulation in polluted conditions as specified in Section 4.12. The Contractor shall determine the maximum design voltage gradient at the surface of the reactor and shall describe the design measures taken to ensure that tracking does not occur under these conditions.

The smoothing reactor shall have Class F insulation and shall be designed to meet the most limiting of the following absolute hot-spot temperatures:

- Nominal Continuous rating
- Inherent Continuous rating
- Short-time Overload rating
- Reduced voltage operation at maximum power transfer in this mode

The Contractor shall demonstrate, by calculation, that the hot-spot temperatures will not exceed the above limits. The hot-spot temperature rise shall be determined by considering all losses in the reactor due to dc current as well as harmonic currents and eddy current losses.

All losses in the reactor including those resulting from harmonic currents shall be calculated. The winding losses due to harmonic currents shall be determined by calculations using harmonic current amplitudes and corresponding harmonic resistance. The harmonic resistance shall be determined by bridge measurement.

The losses shall be determined as per IEC 61803.

6.7.2. Testing

The type tests shall be performed in accordance with IEEE 1277. The support insulators and other accessories shall be tested as specified elsewhere. In addition, any other test specified in IEC 60076-6 shall also be conducted. Additions and exceptions are listed below

6.7.2.1. Type Tests

The following type tests shall be performed on one reactor of each type & rating:

1. Temperature rise tests:

These tests are to be carried out at maximum current for nominal and overload ratings with due allowance made for additional losses resulting from harmonic loading. Corrections shall be applied based on actual losses fed during testing to account for total losses.

Second harmonic current shall be considered for calculation of the equivalent test current for temperature rise test.

2. Measurement of high frequency impedance:

It shall be measured on a series of points at low voltage with a variable frequency generator, from zero to 3600 Hz, terminal to terminal.

3. External radio interference measurement and corona:

The RIV shall not exceed 1000 micro volts at 1 MHz when measurement is made with a test voltage having peak value equal to 130% of maximum continuous direct voltage.

If the connector is not available at the time of test, these tests shall be made on the bushing and the connector separately; otherwise, the test shall be carried out combined with the connector and the bushing:

- Wet Switching Impulse tests on insulator column
- Wet Direct Voltage tests on insulator column

6.7.2.2. **Routine Tests**

The following routine tests shall be performed on each reactor:

1. Winding resistance (cold resistance with dc) measurement
2. Determination of total loss
3. Measurement of inductance under power frequency excitation with a current RMS value of the order of 10 percent of the rated dc current value
4. Dielectric tests
5. Measurement of resistance at 60 Hz
6. AC power test

After above tests are completed, the inductance measurement at 60 Hz (including measurement of the dc resistance) and the loss measurement shall be repeated.

6.8. <u>AC Harmonic Filter Equipment</u>

The Contractor shall provide ac (harmonic) filters required to meet harmonic and reactive power interchange requirements specified in Table 10. For the purposes of this Specification, any conventional linear shunt capacitors, reactors, and resistors shall be considered included as part of the ac harmonic filter.

The Contractor shall demonstrate to the satisfaction of the Owner that the equipment to be installed for ac harmonic filtering and reactive power interchange control meets the requirements of this Specification before any equipment is put into service.

The Owner shall, at its discretion, have the right to reject any component which fails to meet this Specification or which does not meet the limits of tolerance established by the Contractor and used in the calculations demonstrating that the ac harmonic filter shall meet the performance requirements .

The Contractor shall specify the values and tolerances for capacitance, power factor, dielectric losses, rated voltage, the frequency coefficient and the temperature coefficient. The values and tolerances of inductance and resistance for reactors and resistors shall also be included.

There shall be no limitation to the energization of any ac filter or shunt capacitor bank by reason of temperature, frequency, or ac busbar voltage within the range applicable for valve group operation.

For the purposes of dimensioning the reactive power supply and absorption equipment, the reactive power generated by filter and capacitor banks shall be calculated assuming a capacitor mean dielectric temperature of 25 °C and all capacitor elements in-service.

6.8.1. General Requirements

6.8.1.1. Harmonic Filters

The ac filters shall be made up of capacitors, reactors and, if necessary, resistors conforming to the requirements as described herein. The ac filter shall use as high a proportion of identical, interchangeable components as possible in order to simplify maintenance and stocking of spare parts, in particular tuned arm inductors (if used).

The individual ac filter branches shall, wherever possible, be designed so that common spares may be used.

6.8.1.2. Switches

AC circuit breakers, disconnects/isolators and ground switches shall be provided by the Contractor for the ac filter banks as required. The devices to be used for switching of filter banks shall be designed and built to be suitable for frequent switching of the banks as shall be required for reactive power interchange control. The Contractor shall demonstrate, to the satisfaction of the Owner that the equipment being provided shall not require maintenance more frequently than the normal maintenance interval quoted by the Contractor in the Offer.

The switching devices shall be rated for switching of highly inductive or capacitive loads, as appropriate, at voltage levels for which they are required to operate.

6.8.2. Capacitors

6.8.2.1. Definitions

For the purposes of this clause, the following definitions shall be applicable:

1. Capacitor Element – The single wound Section comprising aluminum foil and kraft paper and/or plastic film as appropriate.
2. Capacitor Unit or Capacitor Can – The stainless steel case complete with bushing(s), internal discharge and grading resistors, capacitor elements connected in series and parallel, internal connections and, if used, element fuses.
3. Series Group – All capacitor units connected in parallel at any one voltage level.
4. Capacitor Rack – The steel framework supporting one or more series groups including interconnection bus work and insulators, as required.
5. Capacitor Stack – One or more capacitor racks supported on one set of base insulators including inter-rack insulators and rack-to-rack connections.
6. Capacitor Bank – The three-phase set of capacitor units which may be represented as a single, lumped capacitor in a single line diagram and which comprises one or more capacitor stacks and is complete with all interconnections and protective and monitoring devices.

6.8.2.2. CAPACITOR UNIT FAILURE DETECTION

The Contractor shall provide at least three stages of capacitor unit or element failure detection. The first alarm stage shall generate an alarm and the filter branch shall continue in-service until the next maintenance period. The second alarm stage shall generate a separate alarm and a delayed trip signal which may disconnect the branch after five days. The third alarm stage may cause an immediate disconnection of the branch.

The first stage unit failure alarm shall be set at the number of units corresponding to the greater of:

- 0.5% of the total number of units in the applicable filter capacitor bank or,
- One capacitor unit

Equipment shall be provided to detect, while de-energized, the number of failed elements in the filter capacitor bank or any part thereof. The first stage element failure alarm shall be set to limit the expected frequency of operation of this alarm to one per bank, per year.

The second stage alarm level shall be set such that the expected frequency of operation of this alarm shall not be less than twice the element failures corresponding to the first level alarm.

The third stage (trip) level shall be set to avoid avalanche failure of filter capacitor units but shall not be at loss of fewer elements or units than required to generate the second stage alarm.

6.8.2.3. **Banks**

The capacitor banks shall have sufficient strength to withstand, without damage or loss of life, mechanical loads both while in operation and during erection. The loads shall include electromagnetic forces including those during faults internal and external to the capacitor bank, wind loading, forces due to expansion and contraction due to ambient temperature and load variation, and seismic effects all as specified in the Specification.

6.8.2.4. **Stacks**

Unless otherwise specified, each capacitor stack shall be mounted on a support structure and insulators to allow safe access for personnel in the station to the capacitor area for visual inspection of the capacitors with the banks energized. When de-energized for maintenance, sufficient space shall be provided to allow the removal and replacement of capacitor units with the Contractor-supplied equipment. The stacks shall be free of audible vibration. All structural members shall be electrically connected to the station ground mat and shall be of galvanised structural steel.

6.8.2.5. **Racks**

The capacitor racks shall be supplied complete with all capacitor units, rails, insulators, and connections and shall be equipped with lifting eyes to facilitate easy assembly into the stacks. The racks shall be constructed of galvanized structural steel. No drilling shall be permitted after galvanizing. Each rack shall be clearly labelled with the weight of the fully equipped rack, the phase and bank of which it forms a part. All capacitor units, including spares, shall have the actual, measured capacitance stamped on a permanent nameplate. The maximum and minimum capacitor unit capacitance’s which may be substituted into the rack as spares shall be suitably identified. Suitable warning labels shall be affixed. The rack shall be provided with adequate connections for grounding. Steel rack components shall not be used as an electrical bus.

6.8.2.6. **Units**

The capacitor units shall be supplied with stainless steel cases and shall be designed to allow for expansion and contraction due to all ambient and loading conditions expected during the life of the unit including short-term and transient conditions.

Each capacitor unit shall be mounted so that it can be easily removed from the rack and replaced without removing other units or disassembling any portion of the rack. Each capacitor unit shall be furnished with lifting eyes or similar provision for lifting the unit to and from the rack.

The dielectric fluid used within the capacitor unit shall be environmentally safe and biodegradable. It shall be as little toxic and corrosive as possible. The Contractor shall provide the Owner with a sample of the proposed fluid and Contractor tests must demonstrate that PCB levels are not detectable. All units must be labelled to indicate that they are “non-PCB”.

The current, voltage and kVAr rating of the capacitor units as well as the capacitance shall be derived from the bank rating as determined by the Contractor and shall be given on the capacitor unit nameplate. In addition, the measured capacitance and loss factor of the unit shall be indicated on the nameplate in a suitable manner. Unless approved by the Owner, internal resistors are required to reduce the voltage between the terminals to 50V in five minutes.

The current, voltage and kVAr rating of the capacitor units, as well as the capacitance, shall be derived from the bank rating as determined by the Contractor and shall be given on the capacitor unit nameplate. In addition, the measured unit capacitance and loss factor shall be indicated on the nameplate in a suitable manner.

Internally, fused capacitors or fuseless capacitors are both acceptable.

6.8.2.7. Insulators

All rack and bus insulators as well as the insulators used to insulate each stack of capacitor racks from ground shall be pin cap or post type. The minimum nominal voltage rating shall be 15 kV, and the low frequency wet withstand voltage rating of all insulators used to insulate within or between the capacitor racks of a stack shall not be less than three times the actual voltage stress across the insulators. If the bank is furnished with graded insulation the minimum rated voltage of the insulators shall be 15 kV.

6.8.2.8. Design Requirements

The capacitors shall, except as otherwise specified, be designed and rated in accordance with the latest version of IEC 60871 and IEEE Standard 18, whichever provides the most conservative design. The capacitors shall be tested as per the above standards at the ambient temperatures specified in the standards. The Contractor shall, however, forward for the Owner's approval extrapolated values and documentation for the reference temperature of 30°C, equal to the annual mean dry bulb temperature. The capacitors shall be suitable for outdoor installation.

6.8.2.9. Tests on Capacitor Units

The tests shall be in accordance with the latest issue of IEC publication 60871, IEEE Standard 18 and each respective converter station's requirements except as otherwise specified below. Failure of any unit to meet any test requirement shall constitute grounds for the Owner to reject the unit, all units in the batch, or all units of the type as appropriate to the form of test in which the failure occurred. The following definitions to the tests shall apply:

1. The rated voltage U_r of an ac filter capacitor bank shall be defined as:

$$U_r = U_h + \sqrt{\sum_{n=1}^{n=60} U^2{}_n}$$

Equation 9 Rated Voltage of Capacitor Bank

Where:

U_h= Fundamental frequency rms voltage (or the greatest individual harmonic voltage)

U_n= Nth harmonic frequency rms voltage (n≠1 or the individual harmonic order with the greatest voltage) which can appear across the capacitor bank for steady state under the most onerous conditions of the ac bus voltage, dc load and filter detuning.

Calculations establishing the conformity of the design to the guaranteed availability shall be furnished by the contractor to the Owner for approval.

2. The rated harmonic frequency is defined as the frequency at which the impedance of the filter branch is lowest.

3. Failure of any element shall be considered as failure of the unit to withstand any voltage test. In other tests, any parameter falling outside the design limits as specified by the Contractor and approved by the Owner shall constitute a failure of the unit to pass the test. Tests to be performed by the Contractor shall include, but not be limited to the tests described below.

6.8.2.10. Type Tests

The type tests shall be performed on at least two capacitor units of each type with further provisions that:

1. In case of capacitor units being manufactured at different plants, capacitor units from each plant shall be type tested.
2. If the design has been changed by the Supplier in any way during the course of manufacture, the Owner shall have the right to have the type tests repeated on the new design at no extra cost.
3. A type test shall be deemed to have been passed if all the selected units pass the tests individually unless otherwise specified in a test.
4. The type tests required shall be as per IEC 60871, IEEE18 and the Owner's specific specification requirements.

6.8.2.11. Routine Tests

Routine tests shall be performed on every unit according to IEC-60871, IEEE Standard 18 and Owner's capacitor specification, if applicable.

6.8.2.12. Spares Requirement

The Contractor shall supply spare capacitor units of each type and rating in a quantity of at least 1% (but a minimum of two units) of the total number of units of that type used in capacitor banks and filters. However, at least one unit of each tolerance class of each type shall be supplied unless any spare unit can be used to replace any failed unit of the same type irrespective of tolerance class.

6.8.2.13. Maintenance

The filter bank, including its associated capacitor unit, shall be designed for maintenance-free operation to the greatest extent possible. Maintenance shall only be required following a second-stage alarm or a protective trip. Maintenance procedures to detect, remove, and replace a failed unit shall be described in detail in the instruction manual. All measurement and capacitor lifting equipment shall be supplied by the Contractor. During commissioning, baseline measurements shall be made by the Contractor to verify the health of the bank and provide a reference that future measurements may be compared against.

6.8.3. Reactors

6.8.3.1. General Requirements

Reactors for ac harmonic filter branches, including other reactors such as current limiting reactors on shunt capacitor banks, etc. for reactive power control shall generally be constructed and tested in accordance with the latest issue of IEC-60289 as appropriate to the type of reactor provided or IEEE C57.16, whichever provides the most conservative design.

The Contractor shall specify, subject to the approval of the Owner, the acceptance limits applicable to all tested parameters. These limits shall not be less restrictive than the assumptions used in calculating the reactor rating as defined in Section 4.9. Only dry type reactors shall be provided. They shall be mounted such that there is negligible mutual coupling between phases or between filter branches and adequate precautions shall be taken to prevent overheating of any magnetic material located in the magnetic field of the reactor.

The reactors shall be suitable for outdoor installation and shall not contain any moving parts. They may be equipped with offload taps or adjustable links to allow accurate filter branch tuning during initial commissioning of the filters only.

The reactors shall be provided with lifting eyes to facilitate rapid erection and replacement. The reactors shall be constructed with sufficient strength to withstand, without damage or loss of life, the mechanical forces both while in-service and during erection.

6.8.3.2. Tests on Reactors

The reactors of each type and rating shall be subjected to type and routine tests in accordance with the relevant standards and the tests described herein:

For the purposes of tests, the following definitions, in addition to those given in the relevant standards, shall be applicable:

1. The rated harmonic frequency shall be the frequency at which the branch impedance is minimum.
2. The rated voltage shall be the peak value of the arithmetic sum of 60 Hz voltage and all harmonic voltages which can occur across the reactor for a period in excess of 10 minutes under the most onerous conditions of ac bus voltage, dc load, and filter detuning.
3. The rated current shall be that 60 Hz current which shall produce the same losses as the most onerous combination of 60 Hz and harmonic currents, for the loading conditions as in 2 above, and using the results of type tests to calculate the total losses. For multi-coil reactors, tests shall be performed on one coil, as relevant.

Tests performed on reactors shall include, but not be limited to, the following tests.

6.8.3.3. Type Tests

Type tests shall be conducted on one reactor of each type and rating in the sequence given below.

1. Temperature rise test

A heat run test under conditions similar to the actual site installation shall be made in order to demonstrate that the thermal stability and design temperatures are not exceeded. The losses caused by each of the major current components shall be calculated for the warm reactor. The currents shall be those calculated for rating purposes. The losses for the reactor shall be summed and a test current at fundamental frequency giving equal losses in the warm reactor shall be calculated. The Contractor shall support, by measurements, the inductance versus frequency relationship needed for the calculations.

The equivalent 60 Hz test current shall be calculated by the following formula:

$$I_t^2 * R_F = I_F^2 * R_F + \sum_{n=2}^{n=60} I_{Hn}^2 * R_{Hn}$$

Equation 10 Equivalent 60 HZ Current

Where,

I_t = equivalent test current (60 Hz)

I_F = maximum continuous fundamental current (60 Hz)

I_{Hn} = maximum continuous nth harmonic current

R_F = loss resistance at fundamental frequency, corrected to maximum working temperature

R_{Hn}=loss resistance at nth harmonic frequency, corrected to maximum working temperature.

The resistance values, R_{Hn}, used in the formula, shall be verified by measurements.

The duration of the test shall be the time required for the temperature to reach steady-state conditions but in any case not less than two hours.

The temperature of all the components shall be measured at the end of the test and shall be corrected to maximum ambient temperature. It shall be demonstrated that no part of the reactors including support, support insulators, or connections shall be above the maximum continuous operating temperature, as applicable, for the class of insulation used.

2. Measurement of variation of inductance and resistance with frequency

The variation of inductance and resistance with frequency shall be measured at nominal tap and a convenient ambient temperature over the range from dc to 3 kHz.

3. Measurement of inductance

Test shall be performed as per IEC-60076-6.

4. Lightning Impulse Voltage Test (Wet)

The following impulses with crest value as determined in accordance with Section 4.12 shall be applied to one terminal with the other terminal grounded;

- reduced wave
- five full waves

Both positive and negative polarity shall be applied. The waveform shall be as close as possible to standard 1.2/50 µs impulse.

6.8.3.4. **Routine Tests**

1. Measurement of dc resistance

The dc resistance shall be measured, corrected to 50ºC.

2. Measurement of inductance

The inductance shall be measured at all taps at both 60 Hz and rated harmonic frequency at any convenient ambient temperature. The inductance at rated harmonic frequency shall be corrected to the value at either 75ºC or average winding rise +20ºC ambient with the reactor operating at rated current as defined in Section 6.8.3.3, above, and this shall be designated as rated inductance of the reactor at each tap.

3. Measurement of resistance

The 60 Hz and rated harmonic frequency resistance shall be measured at all taps and at any convenient ambient temperature on every reactor. The resistance at rated harmonic frequency shall be corrected to the value at 85ºC ambient with the reactor operating at rated current as defined in Section 6.8.3.3., above, and this shall be designated as rated resistance of the reactor at each tap.

4. Lightning Impulse Voltage Test, Dry

The following impulses with crest value as determined in accordance with Section 4.12 shall be applied to one terminal with the other terminal grounded;

- reduced wave
- five full waves

Both positive and negative polarity shall be applied. The waveform shall be as close as possible to standard 1.2/50 µs impulse.

6.8.4. Resistors

6.8.4.1. General requirements

The resistors for ac filter duty shall be of minimum possible inductance. The inductance of the resistors within the filter design shall be verified by test by resistor manufacturer. The resistors shall be suitable for outdoor installation and air insulated. The resistors shall be provided with lifting eyes to facilitate rapid installation and replacement. The resistors shall be constructed with sufficient strength to withstand, without damage or loss of life, mechanical forces both while in-operation during normal & abnormal conditions and during erection.

6.8.4.2. Test on resistors

The Contractor shall propose a list of production and design tests for the ac filter resistors for the approval of the Owner and shall specify limits of acceptance of all tested parameters. These limits shall not be less restrictive than the assumptions used in calculating the resistor rating. The rated harmonic frequency, voltage and current shall be defined as for the ac filter reactor Section 6.8.3.3. Tests performed by the Contractor shall include, but not be limited to the tests described below.

6.8.4.3. Type Tests

Type tests shall be performed on one resistor of each type and rating in the sequence given below:

1. Temperature Rise and Thermal Stability Test

   A heat run test under conditions similar to the actual site installation shall be made in order to demonstrate that the thermal stability and design temperatures are not exceeded.

   The losses caused by each of the major current components shall be calculated for the warm resistor. The currents shall be those calculated for rating purposes. The losses for the resistors shall be summed and a test current of fundamental frequency giving equal losses in the warm resistor shall be calculated. The Contractor shall support, by measurements, the resistance versus frequency relationship needed for the calculations.

   The equivalent 60 Hz test current shall be calculated by the following formula:

$$I_t^2 * R_f = I_F^2 * R_F \sum_{n=2}^{n=60} I_{Hn}^2 * R_{Hn}$$

Equation 9 Equivalent Test Current

   Where:

   I_t = equivalent test current (60 Hz)

   I_F = maximum continuous fundamental current (60Hz)

   I_{Hn} = maximum continuous nth harmonic current

   R_F = loss resistance at fundamental frequency, corrected to maximum working temperature

   R_{Hn} = loss resistance at nth harmonic frequency, corrected to maximum working temperature

   The resistance values, R_{Hn}, used in the formula, shall be verified by measurements. The duration of the test shall be the time required for temperature to reach steady-state conditions but in any case not less than two hours.

   The temperature of all the components shall be measured at the end of the test and shall be corrected to maximum ambient temperature. It shall be demonstrated that no part of the resistors including support, support insulators, or connections shall be above the maximum continuous operating temperature recommended.

2. Measurement of inductance

Measurement of inductance at 60 Hz and rated harmonic frequency shall be measured over the full operating range of temperatures.

3. Lightning Impulse Voltage Test (Wet)

The following impulses with crest value as determined in accordance with Section 4.12 shall be applied to one terminal with the other terminal grounded;

- reduced wave
- five full waves

Both positive and negative polarity shall be applied.

The waveform shall be as close as technically possible to standard 1.2/50 µs impulse. If modules are tested, the test voltage shall be defined as follows:

$$U_{test} = k * \frac{U}{n}$$

Equation 11 Test Voltage

Where, U = lightning impulse withstand voltage for the complete resistor

n = number of modules in series

k = factor for consideration of maximum possible non-linear voltage distribution between modules.

No flashovers or breakdowns are permitted.

6.8.4.4. Routine Tests

Routine tests shall be performed on every resistor.

1. Measurement of resistance

The resistance shall be measured at dc, at 60 Hz, and at rated harmonic frequency over the full operating range of temperatures. The obtained results, after allowing for temperature corrections, shall be within the tolerance limits as guaranteed by the Contractor.

2. Voltage withstand test

Each resistor shall be subjected to a one minute, 60 Hz ac voltage test applied between resistor grid and housing. Connections between the resistor grid and the housing shall be disconnected for the purpose of the test. No flashover or breakdowns are permitted. If modules are tested, the test voltage shall be defined as follows:

$U_{test} = k * \frac{U}{2n}$ (for resistors with midpoint-connected housing)

$U_{test} = k * \frac{U}{n}$ (for resistors without midpoint-connected housing)

Equation 12 Test Voltage for Resistor

Where,

U = test voltage for the complete resistor

n = number of modules in series

k = factor for consideration of maximum possible non-linear non linear voltage distribution between modules

6.9. DC Filters

The Contractor shall provide the dc (harmonic) filters in accordance with the requirements of Section 4.10. The support structures needed for filter capacitors shall also be designed, manufactured, and supplied by the Contractor.

The dc filter branches shall be made up of capacitors, reactors, and, if necessary, resistors conforming to the requirements as described herein.

The dc filters shall have sufficient strength to withstand, without damage or loss of life, loads due to wind, electromagnetic forces from short circuits and any other cause, and other forces in operation or during erection, including temperature effects.

The dc filter capacitors, reactors, and resistors shall meet the requirements, unless specified otherwise, regarding type, production, and batch sample tests as applicable to the ac filter capacitors, reactors, and resistors, respectively, with suitable modifications as detailed herein. The Contractor shall submit, for the approval of the Owner, a detailed program of tests to be performed on the capacitors, reactors, resistors and other filter components which shall include type tests, batch sample tests, and routine tests. The detailed test program shall include, but not be limited to, the tests specified in this Section. The Contractor shall specify the value and tolerances for capacitance, power factor, dielectric losses, rated voltage, the frequency coefficient, and the temperature coefficient. The value and tolerances of inductance and resistance for reactors and resistors shall also be included.

6.9.1. DC Capacitors

The Contractor shall supply the capacitors in accordance with the applicable requirements of IEC-60871. The definitions given in Section 6.8.2 apply equally to dc filter capacitors. The capacitor units used in filter banks shall be interchangeable wherever possible in order to reduce spare requirements and simplify maintenance procedures. Individual capacitor units shall be connected in series and parallel and mounted in racks and stacks.

Each capacitor unit shall be provided with internal discharge resistors which shall discharge the unit from peak operating voltage to less than 50 volts within five minutes unless otherwise approved by the Owner. The impregnate used in the capacitor units shall be environmentally safe and biodegradable. The Contractor shall provide the Owner with a sample of the proposed fluid and Contractor tests must demonstrate that PCB levels are not detectable. All units must be labelled to indicate that they are “non-PCB”. The capacitor units shall be suitable for continuous dc voltage and harmonic voltage stress.

The capacitor unit internal hot spot temperature shall be restricted to that temperature at which 1.1 times the rated direct voltage can be withstood continuously.

6.9.1.1. Capacitor Fuses

For fuseless or internally fused capacitor units, the Contractor shall provide equipment to detect, off-load, the faulty units.

6.9.1.2. General Design requirements

The dc filter capacitors shall comply with the design requirements specified for ac filter capacitors in Section 6.8.2.8.

6.9.1.3. Capacitor Tests

For the purpose of tests, the following definitions shall apply:

1. The rated dc voltage (U_{DC_Rated}), of a capacitor unit shall be defined as the maximum continuous dc pole voltage divided by the number of capacitor units in series and multiplied by a factor based on the largest degree of inequality of voltage distribution with up to the maximum permissible number of units or elements out-of-service.
2. An arithmetic sum of all harmonic voltages is used to calculate peak voltage rating of a capacitor unit.

3. The rated harmonic frequency(s) shall be the frequency(s) at which the impedance of the filter arm is lowest.

4. The maximum hot spot temperature shall be defined as the highest temperature which can occur anywhere within the capacitor unit, complete with grading resistors, having the highest dc voltage and the highest harmonic current which can occur under rating conditions for a period in excess of 10 minutes. This condition shall be based on the maximum detuning possible prior to operation of the third stage capacitor unit or element failure alarm, and due allowance shall be made for increase of the ambient air temperature due to other units and radiated heat from adjacent units. The most adverse distribution of unit capacitances and of failed units or elements within the dc filter must be assumed in the calculations of the unit harmonic current.

5. The equivalent ac kVAr of the capacitor unit shall be defined as the kVAr at rated frequency which results in the same maximum hot spot temperature as defined in 4., above. A method for verification may be suggested by the Contractor.

6. The rated voltage, U_{Rated}, of a capacitor unit shall be defined as :

$$U_{Rated} = U_{DC\_Rated} + \sqrt{2} * U_{AC\_Rated}$$

Equation 13 Rated Voltage for a Capacitor Unit

Where,

U_{DC_Rated} = rated dc voltage as defined above

$\sqrt{2}*U_{AC\_Rated}$= rated ac voltage as defined above.

Failure of any unit to meet any test requirement shall constitute grounds for the Owner to reject the unit, all units in the batch, or all units of the type, as appropriate, to the form of test in which the failure occurred.

6.9.1.4. **Type Tests**

The type tests shall be carried out in accordance with the relevant standards and Owner's standards on at least two units of each type, with the following additional requirements.

In the case of capacitor units manufactured at different plants, capacitor units from each plant shall be type-tested.

If the design has been changed in any way during the course of manufacture, the Owner shall have the right to have the type tests repeated on the new design at no extra cost. A type test shall be deemed to have been passed if all the selected units pass the tests individually unless otherwise specified in a test. The Contractor shall perform type tests to demonstrate the suitability of the capacitor unit design for dc filter application and to establish the limits for batch and routine tests. The additional and/or modified tests shall include, but not be limited to, the following:

1. Measurement of the capacitance dependence on temperature - determine capacitance as a function of mean dielectric temperature at both 60 Hz and rated harmonic frequency for the full range of temperatures from minimum ambient to maximum hot spot temperature as defined in Section 6.9.1.3, above.

2. Measurement of capacitance dependence on frequency - determination of capacitance as a function of frequency at maximum hot spot temperature as defined in Section 6.9.1.3, above, for all frequencies from 120 Hz to 3600 Hz

3. Long Duration DC Withstand Test

   Long duration dc withstand test with the capacitor unit mean dielectric temperature equal to the maximum hot spot temperature as defined in Section 6.9.1.3above. This test shall have a duration of not less than one month and shall be performed with a direct voltage not less than 1.2 times the rated dc voltage as defined above.

4. Polarity Reversal Test

   A voltage of 1.1 times the rated capacitor unit dc voltage shall be applied for two hours. The voltage shall then be suddenly reversed to the same value of opposite polarity and held for two hours. After two hours, a new reversal shall be performed. The test shall be performed with the unit mean dielectric temperature equal to the maximum hot spot temperature as defined in Section 6.9.1.3 above. The unit shall withstand at least three successive long duration dc withstand tests with the capacitor unit mean dielectric temperature equal to the maximum hot spot temperature as defined in Section 6.9.1.3, above. This test shall have a duration of not less than one month and shall be performed with a direct voltage not less than 1.2 times the rated dc voltage as defined above.

   Voltage reversals shall occur without damage to the capacitor unit. In case of difficulty in performing the test at temperatures as specified above, the Contractor shall propose an alternate test method for the approval of the Owner.

5. Element Failure Test

   To demonstrate that a fuseless unit (if proposed) can withstand rated dc voltage and rated harmonic loading without case rupture with failed elements. In addition to the above special type tests, the Contractor shall perform the following type tests as specified in IEC- 60871 with modifications as described.

6. Thermal Stability Test

   The thermal stability test shall include measurement of internal hot spot and the applied ac voltage shall be selected to give 1.44 times the total losses, including grading resistor losses, corresponding to rated dc voltage and rated ac kVAr as defined in Sections 6.9.1.3, above.

7. Loss Tangent Test

   The capacitor loss tangent test shall be at rated frequency. Rated frequency implies the power system frequency given in system parameter in Section 2.12.5. The Contractor shall propose a suitable method for the above.

8. Power Frequency Withstand Test (Wet)

   The power frequency wet withstand test voltage shall be determined from the rated lightning impulse withstand voltage of the unit which shall be derived from the bank withstand voltage in the same way as unit dc voltage is derived from dc pole voltage as specified in 6.9.1.3, above. The test voltage shall be the highest voltage given in IEC-60871 for the lightning impulse withstand voltage so calculated.

9. Lighting Impulse Test

   The lightning impulse test voltage shall be as defined in 8, above.

10. Short Circuit Discharge Test

   For the short circuit discharge test the capacitor unit shall be charged to a voltage corresponding to U_{SIPL}. A direct short circuit shall then be applied between the bushings with the shortest possible leads. The unit shall withstand five (5) discharges within 10 minutes.

6.9.1.5. **Batch Test**

A batch is all capacitor units of a type impregnated at one time. Tests shall be done on 2% of the batch or one unit of each type, whichever is the greater. If one or more units fail(s) in any of the batch tests it is permissible for all the remaining units in the batch to be subjected individually to the test or tests, otherwise the whole batch shall be rejected.

1. Temperature Coefficient

The capacitance shall be measured at rated harmonic frequency and at sufficient mean dielectric temperatures between 0^{O}C and the maximum hot spot temperature to allow the maximum temperature coefficient of capacitance to be established.

2. Power Factor at Elevated Temperature

The power factor shall be measured on the sample units heated to maximum permissible dielectric temperature as per IEC-60871. The power factor shall not be higher than 0.2 W/kVAr over the value obtained at room temperature in the corresponding production test. The measurement shall be made at a voltage equal to U_{DC_Rated} /√2 (60 Hz). At least two units from each production batch shall be selected for the test.

3. Impregnant Test

The Contractor shall propose and conduct tests which, subject to the approval of the Owner, shall be performed on the impregnant used for each batch of capacitor units processed at one time in order to demonstrate that the chemical and electrical characteristics of the impregnant are adequate for the intended use.

6.9.1.6. **Routine Tests**

Routine tests shall be performed on every unit in accordance with IEC-60871 except as modified herein:

1. Capacitance Test

A capacitance test shall be carried out at rated harmonic frequency as per IEC or alternatively at 60 Hz and corrected using the batch and type test results to give the capacitance at 25^{O}C and rated harmonic frequency. The capacitance shall meet the tolerance on rated capacitance at rated harmonic frequency required for individual units. The capacitance shall be measured before and after the short time over-voltage test and the values corrected to the same dielectric temperature. No capacitance change shall be apparent from these measurements.

2. Capacitance Loss Test

The capacitance and power factor shall be measured at a voltage equal to U_{Rated}/√2 (60 Hz). The capacitance value shall be corrected to a reference temperature of 25^{O}C. The measured value shall be within the tolerances specified for the design.

3. Voltage Test

The voltage test between terminals shall be a dc test with the test voltage based on the switching impulse withstand level, U_{SIWL}, defined for the bank. The capacitor units shall withstand a dc test voltage corresponding to a bank voltage of 1.1 times U_{SIWL} for 10 seconds. If the calculated test voltage is less than 2.0 times U_{Rated}, the voltage shall be increased to this value.

4. AC Voltage Test between terminals and container (or enclosure).

6.9.2. **Filter Reactor and Resistor Units**

The requirements of Sections 6.8.3 and 6.8.4 shall apply equally to the dc filter reactors and resistors.

6.10. **HVDC Switchgear**

The Contractor shall provide all the required switches (circuit breakers), disconnects, isolators, and grounding switches to meet the electrical performance requirements of this Specification.

The switchgear shall be rated for the voltage, current, and switching duty required by the application and satisfy the requirements of the specifications and standards. As no standard exists for such dc equipment, the relevant portion of the corresponding standard for ac equipment shall be applicable to the extent possible.

No re-strikes and re-ignition shall be allowed across the main contacts of the switches. Opening of series main contacts on any pole shall be fully synchronized and shall meet the requirements imposed by the operating conditions.

When units with series-connected interrupters are supplied, the Contractor shall ensure equal voltage distribution across the interrupter heads.

The switches, which are current interrupting or making devices, shall generally comply with the requirements, as specified for HVac Circuit Breakers (as appropriate to dc switches). The following switches shall have dc current commutating or switching capability: neutral bus ground switch (NBGS), neutral bus switch (NBS), metallic return transfer breaker (MRTB), and ground return transfer switch (GRTS), where applicable, and shall be provided with current measuring devices.

The disconnect switches, isolators, and grounding switches shall also comply with the requirements, as specified, for HVac isolators & grounding switches.

6.10.1. **Requirements**

6.10.1.1. **Type of Disconnects**

Disconnect and ground switches shall be vertical type or horizontal center-break or double-break type. All disconnect switches shall be motor operated with provision to operate manually. A comprehensive interlocking scheme shall be incorporated to prevent false operation.

Special consideration shall be given for corona design of disconnect switches and ground switches to be installed in the valve hall building.

6.10.2. **Tests**

The Contractor shall submit a test program which describes the tests and test levels, in accordance with the requirements.

Type tests shall be carried out on one item of each type & rating being supplied.

6.10.2.1. **Switches / Breakers**

The switches shall be tested in accordance with the requirements of the applicable standards and will include at least the following additional tests (as applicable).

<u>Type tests:</u>

Mechanical tests

Temperature rise

Dielectric tests (dry & wet)

> The dielectric tests shall be carried out according to the requirements of the applicable IEC standards. In addition, the switches shall be subjected to a lightning and switching impulse test across the open contacts whereby the full lightning impulse and switching impulse voltage to

ground is applied to one terminal and a dc voltage equal to the maximum rated voltage of neutral bus to ground is applied to the other terminal with opposite polarity to that of the impulse.

- Test on auxiliary & control circuit
- Short time current test
- Radio interference voltage and corona test
- Mechanical and thermal tests on porcelain, if used
- Over-pressure test on breaking element
- Commutating current test on MRTB, GRTS, NBS and NBGS, where applicable
- DC withstand tests

The dc withstand tests shall consist of the application of a test voltage U_t for one hour of: $U_t = 1.5\ U_S$.

Where:

U_S = the maximum rated dc voltage of the switch

Test shall be performed:

- with the switch contacts open and the test voltage applied to each terminal with the opposite terminal and frame grounded and
- with the switch contacts closed and the test voltage applied to one terminal with the frame grounded.

For switches with grading resistors: On a complete switch with all contacts open, a test voltage of 1.1 U_S shall be applied for one hour to one terminal, with the opposite terminal and frame grounded.

<u>Routine Tests:</u>

1. Bushing tests
2. Pressure tests
3. Measurement of resistance of main circuit
4. Leakage tests
5. Resistor, heater and coil check tests
6. Control and secondary wiring check tests
7. Clearance and mechanical adjustment check tests
8. Mechanical operation tests
9. Timing tests
10. Stored energy system tests
11. Conductivity of current path tests
12. Voltage grading element tests
13. Low frequency withstand voltage tests on control and secondary wiring
14. Dielectric tests on main insulating components
15. Hydraulic system tests

6.10.2.2. Disconnects, Isolators, and Grounding Switches

The disconnects, isolators, and grounding switches shall be tested in accordance with the requirements of the applicable standards with at least the following additional type tests on one item of each type and rating to be supplied:

DC Withstand Tests

The test shall consist of the application of a test voltage U_t as follows:

$U_t = 1.5\ U_S$ for one hour

U_S = the maximum rated dc voltage of the unit to be tested.

For outdoor equipment, the test shall be carried out under wet conditions. The water shall be applied as specified in IEC-60060.

The unit shall be open for the test. One terminal shall be grounded and the dc test voltage shall be negative. The test shall be repeated on the other terminal.

Locked Blade Tests on both Opening and Closing Cycles

The test shall be performed on one fully-equipped unit and shall utilize the maximum supply voltage on the control and motor circuits. The test shall clearly demonstrate that the motor supply MCBs/ MCCBs shall operate before any deformation of the mechanism linkages or switch parts has taken place. In all cases the main switch and its auxiliary switches shall remain in their correct relative positions at all times.

Mechanical Operation

The test unit shall be subjected to a “2000 mechanical operation” test to demonstrate that the switch is capable of 2000 operations without failure of any mechanical part.

RIV Test

Radio influence voltage shall not exceed 1000 micro-volts at 1000 kHz when tested at voltage levels 30% above the maximum rated dc voltage of the related equipment.

The high speed neutral bus ground switches shall be capable of being opened by operator control from the control room provided that appropriate interlocks are observed.

6.11. HVdc Insulators, Bushings, Buses, and Hardware

The Contractor shall furnish all bus work necessary to meet the operational & performance requirement of this Specification. Please see Section 6.15 for additional information on HVac Insulators, Bushings, Buses, and Hardware.

All HVdc insulators, bushings, buses, conductors, connectors, and hardware etc. shall be in accordance with the relevant standards. All bushings inside valve halls including wall bushings shall be silicone rubber housing and silicone rubber sheds with no oil. Such bushings can be either dry or Sulfur Hexafluoride (SF6) filled. Corona shields shall be provided, as required.

6.11.1. Bushings, Support Insulators, String Insulators, and Hardware

The insulation levels shall be determined by the Contractor in accordance with Section 4.12 of this Specification. Joints in the housing or the conductor are to be avoided; if joints in the housing cannot be avoided the specified creepage and strike distances are to be adhered to. Joints in condenser cores shall not be accepted.

Additional type tests to be carried out if joint is provided in bushing housing as follows:

- Mechanical Bonding test at jointed Section
- Tracking and Erosion Test (IEC-60587)
- Water diffusion test (samples to be taken from jointed area)
- Gas leakage test followed by mechanical tests at the joint area

It is preferred that the outdoor dc yard insulators are silicone rubber. However porcelain insulators are acceptable.

6.11.2. Tubular Bus Conductors, Flexible Bus-Bars

The size of the tubular bus-conductors, number of conductors per pole, along with their configuration, shall be determined by the Contractor.

6.11.3. Type Tests

The type tests for HVdc insulators, bushings, busses, conductors etc. shall be in accordance with the applicable IEC Standards. A unit of each type & rating shall be type tested. In addition, the following special type tests shall also be carried out on a unit of each type and rating.

6.11.3.1. Lightning Impulse Test on Insulators

Standard lightning impulse tests shall be carried out in accordance with the relevant IEC standards at the voltage levels corresponding to the equipment Lightning Impulse Withstand Level (LIWL) to ground.

The lightning impulse waves shall be positive polarity for insulators.

6.11.3.2. Switching Surge Test

For outdoor insulators, one insulator stack of each type shall be selected at random. Both positive and negative switching surge tests shall be carried out under wet test conditions.

These tests are to prove that the insulation has a no more than 2.3% probability of flashover (2 standard deviations below critical flashover) in accordance with IEC publication. The test would be deemed to be successful if there are no flashovers during the first fifteen applications of voltage. If only one flashover occurs during the application of these 15 shots, the test sequence shall be repeated and, provided no further flashover occurs, only then the test shall be considered successful.

The same test shall be performed on indoor insulators, however, in this case the insulators can be tested dry. The switching surge voltage waveform shall be such that the time-to-crest shall be between 100 and 300 microseconds, and the time-to-decay to half of crest value shall be 3000 microseconds with no negative tolerance.

6.11.3.3. DC Withstand Test on Insulators

An outdoor insulator of each type shall be subjected to a wet withstand test as per Section 10.2.2 of IEC 62199 with water applied according to the requirements of IEC 60060-1.

For indoor insulators this test shall be performed dry.

6.11.3.4. DC Withstand Test on Bushings

An outdoor bushing of each type shall be subjected to a wet withstand test as per Section 10.2.2 of IEC 62199 with water applied according to the requirements of IEC 60060-1.

The bushing shall be considered to have passed the test if no flashover or puncture occurs. If there is a puncture, the bushing shall be considered to have failed the test. If a flashover occurs, the test shall be repeated only once. If during the repeated test, flashover or puncture occurs, the bushing shall be considered to have failed the test.

For bushings which are exclusively used indoor, the above test shall be performed dry (converter transformer valve winding bushings through the valve hall, if applicable).

6.11.3.5. **Lightning Impulse Test on Bushings**

Standard lightning impulse tests shall be carried out in accordance with the relevant IEC standards at the voltage levels corresponding to the equipment LIWL to ground.

The lightning impulse waves shall be negative polarity.

6.11.3.6. **Switching Surge Test on Bushings**

For outdoor bushings, one of each type shall be tested. Both positive and negative switching surge tests shall be carried out under wet conditions.

The bushing shall be considered to have passed the test if no flashover or puncture occurs. If there is a puncture, the bushing shall be considered to have failed the test. If a flashover occurs, the test shall be repeated only once. If, during the repeated test, flashover or puncture occurs, the bushing shall be considered to have failed the test.

The same test shall be performed on indoor bushings, however, in this case the bushings can be tested dry.

The switching surge voltage waveform shall be such that the time-to-crest shall be between 100 and 300 microseconds and the time–to-decay to half of crest value shall be 3000 microseconds with no negative tolerance.

6.11.3.7. **Temperature Rise Test on Bushings**

Temperature rise test shall be conducted as per IEC-60137 corresponding to the overload current level.

6.11.3.8. **Radio Influence Voltage**

For bushings and insulators Radio Influence Voltage shall not exceed 1000 microvolt at 1000 kHz when the insulators and bushings are tested at voltage levels 30% above the maximum dc voltage of the related equipment.

6.11.4. **Routine Tests on Bushings and Insulators**

The routine tests shall be performed as called for in the applicable standards.

6.12. **DC Measuring Devices**

The Contractor shall supply all HVdc measuring devices that are necessary for control, protection, interlocking, and measurement to ensure safe and reliable operation of the converter station and the associated HVac equipment in accordance with the requirements of the Specification.

Included with the supply of measuring devices shall be all necessary indoor cubicles and outdoor cabinets for mounting the associated equipment and for housing the secondary cable terminations & other necessary ancillaries.

A buffered output, in addition to those defined in the specifications, from each measuring device shall be provided as spare. The Contractor shall ensure that the accuracy of all measuring equipment is adequate for its specific purpose.

The Contractor shall provide transient response characteristics and frequency response characteristics (at least up to and including 1500 Hz) of all measuring devices based on factory tests.

Insulation requirements shall be determined by the Contractor.

6.12.1. DC Voltage Measuring Devices

6.12.1.1. General Requirements

A proven type of resistive and compensated voltage divider shall be provided for dc voltage measurement. The accuracy of the device shall not vary more than 0.5% with an ambient temperature change of ±40^{O}C.

The overall voltage measuring system shall have an accuracy of at least 1.0% of full range. The response time shall not be longer than 150 microseconds, the overshoot of not more than 20% at that rise time. The measuring system shall achieve proper operation of the control and protection system to which it is connected.

The measurement over-range shall be sufficient to measure voltages up to 1.5 p.u. of its intended range.

Complete isolation of the output signal from the HV system is desirable. If the output signal is not completely isolated from the HV connection, protection shall be provided to limit the possible output signal voltages to less than 2 kV in the event of a fault on the device.

All low-level signals shall be cabled separately from high-level signals.

The divider shall be so arranged that no leakage current on the surface of the insulator can pass to the measuring circuit. The insulator shall, for this reason, be continuous without any metallic intermediate flanges. Furthermore, the interior of the divider shall be so arranged that interior leakage currents do not influence the measurement.

Voltage dividers with composite or silicon rubber housing and using SF6 as an insulating medium are acceptable.

6.12.1.2. Testing

The tests for the HVdc voltage measuring devices shall demonstrate the performance of the overall dc measurement system, not only the voltage divider, and shall include, but not be limited to, the following tests.

For performing factory tests on the complete measuring system, the connecting cable to be used on-site shall be simulated.

Type Tests (The type tests shall be performed on one unit of each type and rating.)

1. Measure of resistance linearity from 0.1 to 1.5 p.u. voltage. The test shall be carried out with at least seven (7) voltage levels at approximately equal steps, with both polarities
2. Transient response test demonstrating the dc voltage measuring system response to a step voltage input
3. Dielectric tests on complete divider unit which shall include wet switching surge, lightning impulse, and wet dc voltage withstand
4. Frequency response test demonstrating the dc measuring system's ac measurement ratio shift, up to at least 1500 Hz
5. Thermal stability test

Routine Tests

1. Determination of resistance during manufacture
2. Insulation test of the low voltage circuit at 2 kV for one minute
3. Calibration test demonstrating the dc measurement ratio and the ac measurement ratio at 60 Hz and 720 Hz
4. Check of voltage limiting devices
5. Radio interference and partial discharge test

6. Oil leakage test (if applicable). Oil filled equipment shall be subjected to an internal over pressure period of 12 hours. The unit must be oil-tight during this time
7. Gas tightening test for SF6 gas-filled voltage dividers
8. Dry dc withstand test

6.12.2. DC Current Measuring Equipment

6.12.2.1. General Requirements

DC current measuring devices (DC Current Transformers or DCCTs) supplied can be either shunt type measuring devices or zero flux type measuring devices. For each DCCT the Contractor shall provide all necessary auxiliary power plus all the equipment necessary to deliver the measured signal to the control and protection as well as for any other purposes within the converter station.

The output signal shall be of sufficient magnitude to ensure that the signal is usable at all levels of primary current from 1% to 300% of the rated current, with a measurement output possible up to 600% before saturation of the output signal occurs.

In the event of high current (up to 0.2 seconds of short circuit current), the DCCT shall remain unsaturated for 20 ms or longer. This time shall be measured from the instant the current attains 10 p.u.

Sufficient buffered outputs shall be provided at the time of the initial installation for all future output signal requirements. Calibration and test facilities shall be available on site.

For free standing DCCT of the zero flux type, the core & coil assembly shall be housed in an oil filled porcelain or dry silicone rubber insulator enclosure. The core & coil assembly for bushing-mounted DCCT shall be mounted around the bushing.

Where shunt type DCCT with optical transmission system are provided, the design shall take into consideration the environmental conditions.

The housings of the dc measuring systems and associated electronics shall be suitably designed to perform reliably under the site environmental conditions.

6.12.2.2. Stationary Accuracy

The composite accuracy of all dc current measurement systems used for protection purposes shall be equal to or better than +/- 2% of rated dc current up to 120% of the maximum rated current and +/- 10% of rated dc current up to 1.2 times peak calculated fault dc current.

All dc current measuring systems used for control purposes shall have a composite accuracy of +/- 0.75% of rated dc current from minimum rated current to 120% of the maximum rated current and +/- 10% of rated dc current from 120% up to 300% of the rated current.

All DCCTs used for corresponding functions, e.g. pole differential protection etc., shall have matching accuracies equal to or better than +/- 2% of rated current up to 300% of the rated current.

6.12.2.3. Dynamic Accuracy

The response of the measuring systems shall be such that a linear current change within 150% of maximum rated current and with a rise time of 45 ms, is tracked by the DCCT output with an error which does not exceed +0%,-2% of rated current on any point of the curve. The rise time is defined as the time required for the current to change from 10% to 90% of the full current change. The frequency response shall be within +3% at 1500 Hz.

6.12.2.4. Step Response

The step response of the DCCT shall be such that the output signal rise time for a steep input current step is less than 0.4 ms. The steepness shall be basically a step.

6.12.2.5. **Testing**

The program of tests for the dc current measuring system shall include, but not necessarily be limited to the following:

Type Tests

The type tests shall be conducted on one unit of each type & rating of all types of DCCT measuring systems.

1. DC current measurement system accuracy test up to 300% of the rated current at rated design burden
2. Step response test of dc current measuring system
    - 0 p.u. - 1 p.u.,
    - 1 p.u. - 0 p.u.,
    - 0.5 p.u. - 0.25 p.u., and
    - 0.5 p.u. - 0.75 p.u.

(The acceptable levels of overshoot & settling time to 1.5% of current shall be specified by the Contractor while writing the detailed equipment Specification).

3. The measuring system behavior at high currents shall be tested with a step current.
4. Temperature range test

   The output voltage shall be recorded as a function of the temperature at rated current over the full temperature range as specified. A functional performance test at elevated ambient temperature shall also be performed for the measuring systems in accordance with IEC 68.2.2.
5. Transient immunity test
6. Dielectric tests on the DCCT insulation system for the free standing type DCCT and on the housing carrying the optical fibers for a shunt type DCCT
7. Temperature rise test

Routine Tests

1. A DC current measurement accuracy test up to 100% maximum rated current including a check for matching accuracy
2. Dynamic accuracy test with 0.5-0.25 p.u., 0.5-0.75 p.u. steps
3. Insulation test of output windings at 2 kV, one minute
4. Ratio test
5. Induced voltage test for core & coil verification
6. DC dry withstand test and internal partial discharge for zero flux type DCCT with free standing housing and on the housing carrying the optical fibers for a shunt type DCCT
7. Temperature rise test
8. Power factor test
9. Oil leakage test (if applicable). Oil filled equipment shall be subjected to an internal oil over pressure for a period of 12 hours. The unit shall be oil-tight during the 12 hour period.
10. Demonstration of the DCCT measuring system accuracy over the operating range and for step input current of 0.5 p.u. - 0.25 p.u. and 0.5 p.u. - 0.75 p.u.

6.13. AC Measurement

Detailed requirements for oil immersed instrument transformers are specified in XXX.

6.13.1. Voltage Measurement

The Contractor shall provide voltage measurement devices (PTs) required by the Contractor for correct operation of the ac and dc control and protection.

PTs on the line side of the converter transformers shall have revenue class accuracy.

All PT secondary fuses shall have a lockout capability to comply with CSA standard Z460-05.

6.13.2. Current Measurement

The Contractor shall provide high voltage outdoor free standing CTs in accordance with the requirements of CAN/CSA C60044-1 and as specified herein. The CTs shall accurately measure harmonic currents at least up to the 50th harmonic.

The Contractor shall provide CTs for protection of filter sub-banks as required by its design.

The CTs in the line side bushings of the converter transformer shall have revenue class accuracy.

The Contractor shall supply marshalling boxes for connection of CT secondary leads.

Oil filled current transformers shall incorporate a means for oil sampling. This would be done with the CT de-energized and only with the manufacturers approved devices and procedures. This would not be a routine test but only done after 10 years in-service or when the CTs condition is suspect as evidenced by other tests.

6.14. HVAC Circuit Breakers and Disconnects

The Contractor shall supply the required motor-operated high voltage ac disconnect switches.

Disconnect switches shall comply with the following:

- the Contractor shall propose current ratings for sub-bank disconnects (if any) for review by the Owner
- rated to operate with the bus voltages specified in Section 2.12
- meet the insulation requirements of Section 4.12
- rated for the short circuit level specified in Section 2.12
- provided with an integral ground switch

Disconnectors and earthing switches shall operate at normal ratings for eight years before any maintenance is required which includes lubrication of, or adjustments to, the main contacts, linkages or bearings.

Dead tank HVAC breakers shall be used for the line switching, bus tie, and filter groups. See Appendix XX for Owner's circuit breaker requirements

6.15. HVAC Insulators, Buses, and Hardware

The Contractor shall supply all required HVAC insulators, buses, and hardware

For bus support and apparatus insulators the Owner may prefer the following:

Bus – The Owner prefers round tubular 5” bus, rated for a minimum of 4000A. This bus should be specified as 6101-T6 at 57% conductivity and schedule 80. Expansion joints are required every 90 feet or whenever the force would cause a malfunction or damage to connected equipment. Vibration dampers are required for 5” bus runs greater than 21 feet. Seismic connections are required to provide “slack” based on maximum equipment movement.

Bus Fittings – Since cast fittings are a known failure point during a seismic event, the Owner may prefer those fabricated from 6061-T6 wrought aluminum. The present exceptions to the “no cast” rule are nonstructural items like corona end bells and balls, and the short radius bends for 2, 3, and 5 inch bus on low voltage bus at 34.5kV and below.

Bus Joints - The Owner prefers welded bus fittings. This method of connection is known to be seismically stronger.

See, Appendix XX Bus and Bus Fittings, STD-XXXXXX and Substation Design Policy, Outdoor Insulators XXXXx

6.16. Cabling Systems

See Cable, Control, Copper shielded, XXXXXXx Appendix XX.

6.17. Electrical Station Services

The Contractor shall supply the electrical auxiliary systems at the converter station, in line with the performance, reliability, and availability requirements.

The electrical station services shall be in accordance with all relevant standards, shall satisfy the general Technical Requirements, and shall be designed to operate in the environmental and system conditions specified in Table 2 Site and Environmental Data.

The electrical station systems shall comprise the following voltage classes:

1. XXX kV, 60 Hz
2. 480 V (3 phase), 240/120 V (1 phase), 4 wire, 60 Hz,
3. 125 V dc unearthed system
4. 24 V dc, positive pole directly earthed,

Complete independence of the operation of the two poles of the HVdc bipole shall be achievable.

The auxiliaries shall be capable of riding through all under/over frequency conditions and all over/under voltage conditions as specified in Sections 2 Table 6 Table 9 without loss of supply to the main HVdc power circuits or shutdown of any auxiliary system. No single component shall be capable of causing a bipole outage.

6.17.1. Station Services Primary Supply Sources

The auxiliary power will be fed from see

6.17.2. Load Classes

Essential loads: These are the loads whose failure will affect the converter station operation. These loads may include, but are not limited to, the cooling and other auxiliaries of the converters, the cooling of transformers, valve hall cooling, etc. In addition, loads that must remain in operation in case of complete loss of the ac power supply shall also be included in essential loads. These loads shall include, but not be limited to, the station battery chargers, the alarm system, disconnecting switching and circuit breakers operating mechanism, the emergency lighting, fans to keep over pressure in valve halls, etc.

Normal loads*:* The loads, whose failure would not affect converter station operation. These loads shall include, but not be limited to, the lighting in the switchyard and control building, control and relay building, air-conditioning of areas other than control room, air compressors, and normal and fire-fighting water pumps.

6.17.3. Basic Design Criteria

The station services distribution systems shall be designed so that the possibility of a single contingency affecting the auxiliary system of both poles is minimized; the failure or the disconnection for maintenance of any motor, feeder, motor control center, 480 V power center or station service transformer shall not affect the power transmission capability.

To achieve the above criteria, the following facilities shall be incorporated, by the Contractor, in the design of the auxiliary systems:

1. Highly reliable duplicated primary supply sources, with automatic change-over facilities
2. Completely separated secondary distribution (480 V) systems for the auxiliaries of each pole
3. Duplicated essential loads (e.g., cooling pumps, fans, heat exchangers, etc.) shall be supplied by two different 480 V power centers
4. In order to limit fault currents, to prevent back feed into the ac bus, and to ensure independence of supply sources, parallel operation between station service transformers shall not be permitted at any voltage level.
5. Differential bus and cable protection on all primary XXX kV supply connections to ensure fast selective protection.

6.17.4. Main Distribution Switchgear

The Contractor shall supply the main XXkV distribution switchgear. The main XX kV distribution switchgear shall consist of metal clad switchgear with withdrawable circuit breakers, in accordance with the Standards and shall be equipped with the required number of circuit breakers. The voltage class shall be XX kV and the short circuit capability of XX kA

6.17.5. Secondary distribution System

The 480 V secondary distribution systems shall be made up of power centers serving the different classes of loads either directly or through motor control centers. Two separate 480 V power centers, one for each pole, shall be provided. Each power center shall be fed by the two independent station service feeders.

Each power center shall consist of two bus Sections, supplied through the two station service transformers XX kV/ 480 V. Each transformer and each bus Section of the 480 V power center shall be rated adequately. The two Sections shall be interconnected through a bus tie breaker. An automatic transfer scheme shall be incorporated within each power center.

The 480 V power centers shall be of the metal enclosed switchgear type.

The two Sections of power control centers feeding the duplicated loads, like pumps, fans, etc. as well as the duplicated supply circuits shall be physically independent, permanently energized, and fed by different Sections of the 480 V power centers. A tie circuit breaker shall be provided between the two Sections of the power control centers feeding the duplicated loads, in order that when one Section is out for maintenance or fault, the other Section can supply all the loads.

6.17.6. Motor Control Centers

The motor control centers (MCC) shall be provided in accordance with relevant standards. The MCC shall be located near the supplied loads.

6.17.7. Station DC Supplies

The station dc supplies for the operation and control/protection of the converter station and associated ac switchyard shall be designed to meet the needs of the following:

- DC loads of HVac and HVdc switchyards
- auxiliary services control
- circuit breakers
- valve and pole control and protection

For each pole, a 125 V dc battery system will be required. Each battery system shall consist of redundant chargers, one battery bank, and one distribution panel. The Contractor shall ensure that outage of any one independent system does not cause interruption of any system/subsystem and power flow.

6.17.7.1. General Requirements

The battery, battery chargers, and dc distribution panels shall be designed according to the Owner's Substation Control Batteries and Chargers Appendix XX. Each group of battery chargers shall have its own ac supply connected to a different 480 V power center.

The capacity of the batteries for the dc systems to be provided by the Contractor shall be determined and stated in the Offeror's bid. They shall be able to operate for a minimum of eight hours when supplying full load without the chargers.

The dc distribution shall be provided with standard relays for earth leakage detection.

6.17.8. Spare Feeders

The auxiliary power system shall be equipped with at least 15% spare feeders, but not less than one shall be provided on all 480 V switchgears, power centers, and motor control centers as well as on all dc distribution boards.

6.17.9. Uninterruptable Power System (UPS)

The rating of the UPS shall be decided by the Contractor. The UPS system shall provide continuous ac power to critical loads in the event of power failure. The critical loads shall include at least the valve cooling system pumps, operator control, the alarm system, computer systems, and printers in the control room.

The Contractor will supply one full rated UPS system per pole

The UPS shall consist of, but not be limited to, the following main components:

• The battery charger

• Maintenance-free battery

• The static inverter

The UPS shall be designed for continuous duty, on-line operation and shall be based on solid-state design technology to provide uninterrupted power supply for critical loads mentioned above.

Each UPS system provided by the Contractor shall include all of the following sub-systems as well as any other components and support hardware necessary for complete and proper operation of the UPS:

1. Rectifier/charger unit
2. Inverter unit
3. Battery Low Voltage Disconnect device
4. Static bypass switches
5. Manual maintenance bypass switches
6. Load transformer and filters
7. Control panels, automatic controls and protection
8. Hardware and software as required for parallel operation of UPS systems
9. All necessary cables, MCBs/ switches/ fuses

UPS for valve cooling shall be rated for three minutes. However, UPS for operator control system, computer system & printers etc. shall be rated for 30 minutes.

6.17.10. **Lighting**

6.17.11. **Batteries**

6.17.12. **Wiring and Terminal Blocks**

7. Mechanical Services

7.1. Environmental Control

Air conditioning and/or other environmental control systems shall be provided for all buildings, and process areas under the Contractor's scope of work to ensure the proper operation of converter equipment under the range of climatic and internal conditions to which the stations may be subjected. These systems shall provide for personnel comfort and equipment operational reliability. Redundant air conditioning with no single point of failure shall be provided to maintain environmental requirements.

7.1.1. Scope

Areas requiring environment control shall include, but not be limited to:

- Control rooms.
- Valve halls.
- Any structure intended to be used by operating or maintenance personnel and placed in the ac or dc switchyard by the Contractor, such as a building to house protective relays or other control or protection equipment.
- Any new structure placed by the Contractor in which equipment requires environmental control.
- Any room or building that houses batteries

Included are devices comprising of all mechanical auxiliary systems for the converter stations. The main systems to be provided are:

- Water distribution within the station from a point of supply of raw water at the terminal station fence.
- Environmental control in buildings wherever required.
- Fire detection and protection systems.
- Permanent handling and processing facilities for insulating oil for transformers, reactors and other oil filled equipment.
- Emergency fire diesel sets.
- Water distribution system for sanitary services.
- Building Management System.
- Hoists, chain pulley blocks for installation and maintenance of indoor equipment and motor/hydraulic operated man lift up to about 25 meters or as suitable for maintenance of outdoor equipment.

7.2. General Requirements

All mechanical works shall satisfy the general technical requirements and shall be designed to operate in the ambient/system conditions specified in Section 2.9.1.

The following requirements shall be met with the equipment supplied by the Contractor:

- The equipment shall be designed and constructed for safe, proper and continuous operation under all conditions described or implied in the Specification, without undue strain, vibration, corrosion or other operating difficulties.

- Parts shall be designed and supported to permit free expansion and contraction without causing leakage, distortion or excessive strain on the equipment.

- Parts subject to wear, corrosion or other deterioration or requiring adjustment, inspection or repair, a list of which shall be provided for maintenance purposes, shall be readily accessible and capable of easy removal for repair or replacement.

- All heavy components shall be provided with convenient means for slinging or handling during installation and maintenance.
- No auxiliary system shall be common to both poles. Emergency connections between poles shall be provided but the two systems shall be separated in the normal mode of operation. This principle of pole separation shall apply to all systems including water supply. However, common firefighting pumps can be used.
- Within a system, stand-by and/or duplicate equipment shall be provided with a minimum of two for each major component such as, pumps, heaters, strainers, fans or operationally separate cells of cooling towers or heat exchangers. Thus, loss of a single element of auxiliary plant shall not result in any loss of converter rating under any combination of load and ambient conditions. Loss of a second element of auxiliary plant of the same type and duty shall not reduce the station capability by more than the equivalent of the output of one pole.
- Duplicate and/or stand-by equipment shall automatically be brought on the system, based on a predetermined cycle, such as to allow equal wear and tear.
- Unless otherwise specified, all equipment serviced by a duplicate or stand-by shall, on detection of failure, automatically isolate. The corresponding duplicate or stand-by equipment shall automatically take over the failed equipment.
- Loss of any equipment or system shall automatically be alarmed at operation control center with display of events in SCADA system.

The principles detailed above need not be applied to systems upon which the conversion equipment does not depend for operation.

No mechanical equipment shall be installed on the roof of the converter building, i.e. valve halls and service building.

7.2.1. **Design Requirements**

The control room and all other areas occupied by site personnel shall be environmentally controlled suitable for comfortable 24 hour occupancy.

The environmental control system for the valve halls shall provide a constant positive pressure to prevent infiltration of contaminants from the outside and ensure that condensation shall not occur on the valve hall plant during outages when the valve is not operating or during start-up during cold conditions.

Cooling for the valve halls shall be designed to limit the temperature in the valve hall to 50ºC/122ºF.

The system shall provide for manual smoke purging of each valve hall and reset of fire detection systems. All environmental controls shall be monitored in the main control room.

The environmental conditions in the valve halls shall be determined and documented by the Contractor based on equipment requirements. Documentation shall include proper settings for environmental control and equipment dictating the required settings.

7.3. Fire Detection and Protection Systems

A comprehensive fire detection and protection system covering all areas of the station shall be provided for all equipment which is critical to station operation and also for equipment having a significant fire hazard because of its construction or content e.g. oil filled equipment. The system shall conform to NFPA 850. The fire detection system shall be connected to the fire alarm control panel with display equipment in each converter station control room and to the building ventilation/air conditioning control system. See Appendix XXX for details. A written Fire Risk Program with Owner's approval shall be provided on site to include at minimum, fire safety information for all personnel to familiarize with fire prevention procedures, site emergency alarming and reporting procedures. A written Fire Emergency Plan shall be provided on site for personnel to know how to respond to fire alarms and fire supervisory systems, how to notify key site operators, management, and security forces.

7.3.1. Definitions

Fire protection: This broad term encompasses all aspects of fire safety and includes: building construction and fixed building fire features, fire suppression, fire detection and fire water systems. Fire protection is concerned with preventing or minimizing the direct and indirect consequences of fire. It also includes the aspect of released gases, and smoke and water damage from fire as they relate to fire protection.

Fire Detection System: Any system designed and installed to detect or limit the extent of equipment, building fire damage or enhance life safety. These include automatic fire detection, occupant warning, manual fire alarm, fire alarm reporting systems and adequately trained station personnel.

7.3.2. Scope

The following specific equipment and areas of the converter station shall be protected against fire. Depending on the design and layout of the station other areas not specifically included, but requiring fire protection shall also be provided with fire protection system by the Contractor at no extra cost:

- Converter transformers
- All buildings (including control and protection, storage, and battery buildings)
- Cable galleries and vaults

7.3.3. Design Criteria

In the areas of the station containing electronic equipment, relays and switchgear; the use of water shall not be permitted. These areas include, but are not limited to the following:

- Converter valve halls
- Converter auxiliary building
- Control kiosks
- Control and protection buildings
- Control room

Steel work design shall be such that the effects of a major equipment fire shall be minimized in order to reduce the amount of consequential damage which may be caused and to reduce risk of further failures being caused.

As far as possible suitable fire Sectionalization shall be done in case of cable galleries, cable vaults, and cable rooms, electrical equipment rooms etc. Also, wherever cables pass through walls/floors, they shall be sealed.

7.3.4. Fire Detection and Alarm System

The Contractor shall supply a fire detection and alarm system, which has to be completely independent from the fire protection system, consisting of manual break glass alarms, automatic fire detectors and all necessary equipment to complete the system, which shall initiate alarms on the station fire alarm control panel installed in the control room. This system shall be electrically supervised against failure on the detection and alarm circuits. In case of a failure of an alarm circuit, a visual and audible alarm, different from those for fire detection, shall indicate on the station fire alarm control panel.

Operation of any manual alarm or automatic detector shall initiate the following:

- Initiation of the visual and audible alarm on the station fire alarm control panel, indicating the area or the location of the originating alarm.
- Automatic shutdown of the air conditioning and ventilation and opening of the exhaust systems.
- Annunciation of the fire alarm in the station alarm monitoring reporting system.
- Operation of fire bells throughout the station.

7.3.5. Valve Hall Fire Detection System

The valve halls shall be supplied with a fire and smoke detection system based on sensitive sampling principles (VESDA or similar type system) per NFPA. Each valve hall shall have a redundant system with backup power so one system can be taken out of service while maintaining a second active fire detection system. In addition arc detectors and heat detectors shall be installed inside the valve halls at appropriate locations. The valve hall fire and smoke detection system shall initiate an alarm in the control room.

7.3.6. Control and Protection Buildings

Fire detection shall be provided for all control and protection buildings placed in the converter station's switchyards.

7.3.7. Converter Transformer Fire Walls

Each converter transformer shall be protected by fire walls of a 4 hour fire rating. If the converter transformers are adjacent to the valve hall, the wall of the valve hall adjacent to the transformers will also need to have a 4 hour fire rating.

7.3.8. Smoke Detectors

All indoor areas, other than valve hall (specified earlier), shall be provided with smoke detectors. At least two smoke detectors employing different principles of detection shall be provided in each fire zone. The spacing and location of smoke detectors shall be in accordance with NFPA-72-E standards and shall consider the conditions such as air velocity, average ambient temperature, particle size etc, the number of detectors required for a complete coverage and the location of detectors with respect to ventilation and air conditioning facilities.

7.3.9. Thermal Detectors

All areas where there will be any soldering, metal cutting or welding, loading bays or release of gases, shall be provided with thermal detectors. Battery rooms shall be provided with explosion proof thermal detectors.

The thermal detector shall be plug-in type, combined rate-of-rise and fixed-temperature detectors.

7.3.10. Air Duct Detectors

Detectors shall be designed for detection of combustible gases, fire and smoke in air conditioning and ventilation ducts. Each detector shall consist of an ionization type plug-in detector complete with a self-contained control and a LED alarm indicator. Detectors shall be installed in the air inlet ducts.

7.3.11. Manual Break Glass Box Alarms

Manual break glass box alarms shall be provided adjacent to the automatically protected areas and equipment and at strategic and prominent positions throughout the installation and near all room exits.

7.3.12. Audible Devices

Audible devices shall be supplied and installed in strategic locations at the station such as station control room, lobbies etc.
The sound level of the audible devices shall be determined suitably based on background noise levels.

7.4. Fire Protection System

The fire protection system shall include:

- Portable extinguishers
- Approved gaseous fire extinguishing systems for electronic compartments.
- Fire hydrants and fire hose reels
- Deluge systems
- All components and accessories required to complete the system

The fire suppression pertaining to the deluge and fire hydrants shall be connected to any existing or planned water system.

8. Testing and Commissioning

The Owner's staff will be actively involved in testing and commissioning. Participation by the Owner's staff will be mutually agreed upon by the Contractor and Owner along with each respective converter station's staff. The general Contract requirements relating to audit, inspection, and testing shall be in accordance with Section XXX.

8.1. Master Test and Inspection Plan

The Contractor shall submit a master test and inspection plan which shall include a testing schedule and program for all tests and inspections to be undertaken during the Contract. The master test and inspection plan shall include:

1. Inspection and Test Plan (ITP) described in Section 13
2. Manufacturer's type tests
3. Factory test plans which include the order in which the factory tests will be conducted and the test method being used
4. Site test program, including test plans for each component or subsystem and any tests which have the potential to impact operational equipment or that include connection to the operational power system
5. Commissioning of completed equipment into each converter station's ac network, including timing and sequencing to meet the required in-service dates, and tests after commissioning.
6. The trial operation period
7. The master test and inspection plan shall be submitted to the Owner three months prior to the commencement of factory tests and at least six months prior to commencement of any inspection and tests on site.

8.2. Testing

All equipment within the Scope of Supply shall be tested for the purpose of demonstrating that it meets the specified requirements and fulfills the guarantees. The Contractor is responsible for carrying out the tests.

The Contractor shall perform appropriate testing at a sufficiently early stage such that modification of possible non-conformities shall not delay completion of the work.

Early stage testing shall include but not be limited to:

1. Manufacturing type tests of primary and secondary equipment
2. Factory testing
3. On-Site testing and commissioning
4. Testing of components (see "Part 1 Component and Pre-commissioning Tests") and sub-systems (see "Part 2 – Sub-system Tests") during construction
5. System tests (see "Part 3 – System Tests") of the all equipment within the Scope of Supply after installation. System tests will include back-to-back tests of the converters in order to test at full dc voltage and current.
6. Trial Operation Period (see "Part 4 - Post Commissioning and Load Checks") for a period of time after successful completion of the System Tests.

8.2.1. Manufacturer's Type Tests

The HVdc control system, converter transformers and HVdc thyristor valves must be type-tested. Test reports from other projects are not acceptable.

For other equipment, the Contractor may offer type-tested equipment for the Project and the Owner may accept the equipment type test reports in lieu of performing type tests under the following conditions:

1. Type tests shall be in accordance with the latest version of the relevant specified standards and the type test reports are not more than five (5) years old from the date of completion of manufacturing of the equipment.
2. The type tested equipment shall be of the same design, insulation class, and rating as the equipment offered under this Contract.
3. Existing type test reports shall be accompanied with the design reports of the type-tested equipment and the equipment to be supplied, along with a report detailing the levels under which the supplied equipment would have been type tested in order to allow a determination of the acceptability of the type tests provided.
4. Where type tests are more than five years old, the requirement for new type tests will be at the Owner's discretion. The Contractor shall be responsible for any further type tests if required by the Owner.
5. Acceptance of the type test reports shall be at the discretion of the Owner.
6. Any type tests to be performed shall be witnessed by the Owner unless authority to proceed with the tests in the absence of the Owner's Representative is received in writing or by email.

8.2.2. Factory Testing Before Delivery (Routine Tests, Factory Acceptance Tests, etc.)

Factory testing shall include but may not be limited to:

1. Apparatus, equipment, and system tests to demonstrate the fulfillment of the specified requirements and the ability of the equipment to perform correctly.
2. Routine tests as stated in the Owner's Requirements and in line with all referenced standards and regulations.

The following requirements shall apply to factory testing:

1. Factory acceptance tests shall be performed prior to shipping for complete installations to the maximum extent possible (e.g., control system).
2. All individual components shall be subjected to manufacturing tests in accordance with the applicable standards listed in the Owner Requirements and as identified necessary by the Contractor.
3. The Contractor shall make provision to receive the Owner's personnel on the Contractor's or manufacturer's premises to participate in testing and associated activities. The number of personnel and duration of visits shall be agreed to with the Owner.
4. The Owner shall have the ability to witness all tests to be carried out unless permission to proceed with the test in the Owner's absence has been obtained from the Owner.
5. Testing must be performed on the actual equipment which will be shipped to site.
6. Subsequent changes to the equipment following completion of factory system testing shall not occur without agreement with the Owner and updated documentation shall be provided.
7. The results of type tests and the off-site tests shall be forwarded to the Owner upon completion. The Owner's acceptance shall be obtained prior to the shipping of the equipment.

8. Upon completion of the factory system testing the Contractor shall provide:
    - Test reports
    - Software programmable logic block diagrams
    - Schedules of control and protection settings and parameters
    - Simulation models of the tested control and protection systems.

8.2.3. Factory System Testing of Control and Protection Systems

Factory system testing of the complete control and protection system shall be performed by the Contractor to ensure that the control and protection hardware and software meets all of the Owner's Requirements for point-to-point operation from any converter to any other converter and multi-terminal operation.

Verification of actual control and protection hardware and software shall be performed by running the project-specific control systems together with a real-time simulator implementing a network equivalent together with the HVDC model and other model system components.

8.3. On-Site Testing and Commissioning

The Contractor shall prepare and carry out a comprehensive commissioning program for the equipment within its Scope of Supply. The test program shall demonstrate the overall operation of the HVdc system including the dc transmission line. The Contractor shall coordinate with the Owner's personnel and other contractors, as required, to carry out the commissioning.

The Owner will:

1. During the course of the Contract, appoint a Commissioning Engineer(s) who will coordinate all of the testing work under this contract with the requirements of the Owner.
2. Ensure that the Commissioning Engineer is familiar with HVdc technology and the requirements of each converter station's safety and operating requirements.
3. Arrange for availability of required operating staff to meet the requirements of the testing program.
4. Witness all tests to be carried out unless permission to proceed with the test in the absence of the Owner's Commissioning Engineer has been obtained from the Owner.

The Contractor shall:

1. Arrange and undertake all testing and commissioning of equipment supplied or modified by the Contractor in accordance with the testing procedures specified in the Contract documents and the Contractor's test program which includes any minimum requirements listed in the Owner's Requirements.
2. Carry out sufficient mechanical and electrical operational tests during the construction period to ensure that faults and defects are detected as early as possible.
3. Provide adequate and competent staff, experienced in all aspects involved in testing the converter equipment and putting it into service in order to meet the requirements of the testing program.
4. Cooperate with the Contractor's Commissioning Engineer and other contractors so that testing proceeds expeditiously and efficiently.
5. Ensure that the converter equipment is in a safe and proper condition prior to commencing any testing.

6. Run the equipment or allow it to be run, at the Owner's Representative's direction, at any time before taking over, provided that in the Contractor's opinion it is safe to do so.
7. Expeditiously ascertain reasons for and arrange for action to correct defects to the satisfaction of Owner's Representative..
8. Indicate and carry out additional tests, as considered necessary, to ensure that the installation is in compliance with the Owner's Requirements and relevant regulations and is in proper operating condition.
9. Use outage dates provided by Owner's Representative for commissioning.
10. Provide all equipment necessary for testing and commissioning. Test and measuring equipment shall be suitable in all respects for the types of measurements and tests being carried out, with appropriate accuracy and precision, and provide proof that all test instruments are correctly calibrated prior to testing.
11. At least six (6) months prior to the commencement of energized site testing and the commissioning phase, the Contractor shall submit to Owner's Representative a detailed on-site test program. The program may be split into logical Sections such as bays or circuits and shall contain copies of the manufacturer's factory test results. The commissioning test plan shall contain a time schedule of the tests and the power levels that will be achieved during the tests (power profile).

The on-site test program shall include a complete description of all tests required from commencement of pre-commissioning until final commissioning where the equipment has come under operational control. The on-site test program shall include as a minimum, but not be limited to, the following:

- Inspection and Test Plans (ITP)
- a copy of the commissioning plan.

There shall be four parts to the on-site testing for individual stages of the Project and also for combined stages where appropriate:

Part 1 – Component and Pre-Commissioning Tests

Includes, but is not limited to, checking to see if components have sustained damage in transit, have been properly installed, are safe to energize, and will operate as designed.

Part 2 – Sub-System Tests

Required to prove a group of components work satisfactorily together as a functional unit. These tests are done without primary power being applied, but should be as extensive as possible to prove all equipment operates correctly. Where equipment interfaces with equipment supplied by others, the Contractor shall coordinate with the Owner in carrying out functional tests for such equipment.

Part 3 – System Tests

For tests that involve energizing with primary power; these tests demonstrate that the converter equipment operate correctly and the controls and protections function correctly and will integrate with multi-terminal operation. Final adjustments to equipment for satisfactory operation shall be made. Dates for these tests will be arranged by the Contractor in consultation with Owner's Representative.

Part 4 – Post-Commissioning and Load Checks (during the Trial Operation Period)

Confirm equipment is operating correctly under normal load conditions and tests may involve the proving of safety devices.

Successful completion of all tests in Parts 1 to 4 shall be a prerequisite for the Owner to accept the converter station.

8.3.1. Testing of Components and Sub-systems during Construction (Part 1 and 2 Tests)

Component and sub-system tests will prove the components and sub-systems comply with this Technical Specification and relevant standards, as stated. The majority of tests will be completed prior to connection to the operational power system. Where practicable, component and subsystem tests will culminate with equipment being proven by energization at HV through connection to the operational power system.

Operational control of the components or subsystems will pass to the Owner once it is able to be connected to the power system or energized at HV by a switching action and Operational Acceptance has been issued. At this point, the Owner's converter station operating practices and procedures will apply, including the need to obtain permits for access to work on equipment.

Any tests which have the potential to impact operational equipment or has a connection to the operational power system will require Owner approval.

Test results shall be submitted to the Owner's Commissioning Engineer for review and/or approval (as specified elsewhere in the Contract).

It is expected, as a minimum, the tests described below will be performed.

8.3.2. Erection Checks

The checks shall be carried out on all equipment after completion of erection/installation in accordance with the relevant approved commissioning procedures to be submitted by the Contractor. These checks shall ensure that the equipment has sustained no damage in transit, has been properly erected / installed, is correctly set, and is ready for energization or start-up.

These checks shall be carried on all equipment after completion of erection according to the approved field quality plan/installation manual of the individual equipment. The checks shall include, but not be limited to, the following:

1. Visual examination
2. Checking of nameplates for equipment designation and relevant data
3. Torque check of electrical connections and mechanical joints
4. Check of tightness of cable terminations, cable tags, and cable glands
5. Check of cabling i.e. cable trenches, ladders and cable dressing
6. Electrical clearance measurement.

8.3.3. Equipment Tests

After completion of erection checks, equipment tests shall be conducted. These tests shall verify the proper function of the individual equipment. The tests shall conform to the approved field quality plan/procedures. The Contractor shall, in the quality plans, specify the tests required for each equipment type in the station.

The equipment tests shall be in accordance with the standards, practices, codes & Specifications, as applicable, as well as specified below.

1. All checks and tests specified by the manufacturer's drawings and manuals as well as all tests specified in the relevant field quality plan
2. Pressure test on all pneumatic lines at a minimum of 1.5 times the rated pressure and leakage test as per relevant standards
3. Insulation resistance checks on primary equipment consisting of power factor tests and hi-pot tests

4. Insulation resistance check of control cables, motor etc
5. Resistance measurements of transformers, reactors, filter resistors, etc
6. Wiring continuity and insulation resistance tests, including checks for cables emanating from the existing facilities
7. Functional tests on control, protection, and alarm circuits including relay and control settings, checks on software-based equipment and all operator displays and control for equipment which have not undergone Factory System Tests and for equipment/systems where modifications have taken place
8. Checks of all interlocks including interlocks to interfacing equipment located in the existing utility's switchyard
9. Checks of all alarms & annunciations
10. Single point grounding checks for all equipment including CT secondary circuits
11. Diagnostic demonstration of software functions for control, protection, and measuring
12. System and redundant equipment switchover function including switchover for transformer cooling bank
13. Functional tests on auxiliaries & all auxiliary systems
14. Check for air distribution, humidity, and temperature on air conditioning system
15. Mechanical balancing, alignment, capacity and vibration checks
16. Check for oil leakage
17. Check for oil level
18. Insulating oil tests
19. Dissolved gas analysis
20. Breaker and dc switches checks
21. AC and dc disconnects checks
22. Measuring equipment/system checks
23. Valve cooling system checks

8.3.4. Sub-System Tests

After successful completion of equipment tests on relevant equipment, sub-system tests shall be conducted. In the sub-system tests, the function of the equipment is verified. The test shall be conducted in accordance with the approved Commissioning Instructions. The major sub-systems are:

1. AC switchyard
2. AC filters
3. Converter transformer
4. HVdc converter (thyristor valves, smoothing reactors etc.)
5. DC switchyard
6. DC filters
7. Electrical auxiliary power system
8. Valve cooling systems
9. Control, protection, alarm, monitoring, & reporting system
10. Fire detection and protection systems

11. Air conditioning and ventilation systems
12. Station service systems
13. Fault locator

8.4. System Tests (“Part 3 Tests”) and Commissioning

In conjunction with each converter station, the Contractor shall commission the equipment or components supplied within the scope of the Contract.

The end-to-end energized testing shall conform to IEC PAS 61975, *System Tests for high-voltage direct current (HVDC) installations* and IEEE 1378, *IEEE Guide for Commissioning High-Voltage Direct-Current (HVDC) Converter Stations and Associated Transmission Systems*.

Prior to the Trial Operation Period, a program of system tests will be performed.

It is expected that the test plan will include, but not be limited to the following (although not necessarily in order of the actual test plan):

1. Tests of the station in stand-alone and back-to-back
2. Tests to check inter-station coordination of controls and alarm circuits with all required telecommunication circuits in operation
3. Deblock and block tests
4. Protection checks
5. End-to-end HVdc power transmission tests in monopolar metallic return and bipolar modes, with and without telecommunications and in both power directions
6. Multi-terminal HVdc power transmission tests in monopolar metallic return and bipolar modes, with and without telecommunications and in both power directions
7. Transient and dynamic control tests
8. Operation at reduced voltage
9. Operation at minimum power
10. Operation at nominal power
11. Operation at overload
12. Reactive power control, in both power directions and with a weak ac system
13. AC filter switching
14. Operation with DC filter disconnected
15. Inverter current control mode
16. Back-up control modes during loss of telecom including operating with power orders originating from each converter station’s control centers
17. Control system step changes
18. AC system disturbances and faults
19. Inverter commutation failure
20. Power reversal
21. DC line faults
22. Converter transformer energization
23. AC/DC auxiliary supply changeovers and/or failures

24. Telecommunication system transfer and/or failures
25. Harmonic measurements (ac and dc)
26. Runback and other special controls
27. Full rated current tests with the station short-circuited and in back-to-back configuration
28. Heat run test until transformer temperatures stabilize for a minimum duration of eight hours during back-to-back/Multi-terminal testing

8.4.1. Coordination of Commissioning Activities

The Owner's Commissioning Engineer(s) and site staff will be responsible for scheduling necessary outages and coordinating testing with converter station operations staff. The needs of the each converter station's power system will always prevail in scheduling tests and making available test power.

8.4.2. Commissioning System Tests

Completion of these tests will require coordination with each utility's system operations to ensure suitable system conditions are available at the time of testing (e.g., sufficient levels of generation and reserves being available). The Owner's Representative will coordinate these arrangements with the respective utilities.

The Contractor shall be responsible for monitoring performance of the equipment, making adjustments when necessary, and for requesting repeat tests, as appropriate.

8.4.3. Field Acceptance Testing

Each converter station will undergo a Field Acceptance Test including staged fault tests at the conclusion of the Contractor's commissioning tests. The tests will be performed in accordance with the Owner-developed and Contractor-reviewed test plan. Faults may be applied to various points along the transmission line, to the ac bus at each terminal, and to various ac lines connected to the each terminal.

The Contractor will be notified of the type, time, and site selection that field acceptance tests are to be performed on each converter station. The Contractor shall have a representative present to act as a technical advisor if test or equipment problems are encountered. Final energization authority and outage coordination will be the responsibility of the Owner. These tests are under the jurisdiction of the Owner in collaboration with each utility dispatcher and may be delayed or discontinued if required by system conditions.

If equipment furnished by the contractor fails during the acceptance testing, it shall be repaired and defective parts replaced or redesigned. However, after determination of a major failure and a failure review, it may be necessary, at the Contractors expense, to perform additional field-acceptance test to verify that the design meets the intended application.

Major Failure of a field acceptance test shall be deemed to occur when the equipment under test experiences failures, unsafe operating conditions are disclosed, or when major functions repeatedly malfunction.

The Contractor shall reimburse the Owner for additional testing costs incurred if it is necessary to repeat unsuccessful tests or uncompleted tests as a result of performance within the Contractor's scope of responsibility.

8.4.4. Timing and Sequencing of Commissioning Activities

System commissioning tests often require that substantial blocks of power be transmitted over the system. Scheduling these power transfers and any outages associated with testing must be done at least 35 days before the test is expected. The Owner's Representative will see that the outages and power schedules are approved after the Contractor supplies the test plans.

8.4.5. Review of Test Results

The manufacturer's test reports for all equipment shall be reviewed and approved (as specified elsewhere in the Specification) by the Contractor to ensure that all checks in the ITP have been carried out and recorded. If the same tests are called for in specific Sections and in the manufacturer's manuals the tests need not be duplicated.

Where the specified requirements set a lower standard, the manufacturer's instructions shall prevail.

The results of all inspections and tests shall be compared with design specifications, manufacturer's factory test results, and results from other identical equipment. Any equipment with test results outside typical serviceability criteria that could affect its service life shall not be placed in-service without the agreement of the Owner's Representative.

Suspect test results shall be referred to the Owner's Representative immediately with appropriate recommendations for further tests, replacement, or repairs.

8.5. Trial Operation

The Trial Operation period shall take place after completion of the various commissioning tests and correction of punch-list items discovered during commissioning. The purpose is to satisfy the Owner and the Contractor that equipment is fit for its purpose and is working satisfactorily under normal operating conditions. The trial operation period is 45 consecutive days.

The principles of trial operation are:

1. Upon successful completion of all commissioning tests, the Contractor shall advise the Owner, in writing, that the equipment is ready for trial operation.
2. A necessary pre-condition for trial operation is that all spare components are on-site and that all plant documentation is on-site and has been revised to reflect any changes made prior to the start of trial operation.
3. The Contractor shall remain responsible for the equipment under trial and will remain so until the equipment is accepted by the Owner and each respective utility.
4. Owner and the Contractor will agree on the time at which the trial operation period will begin.
5. Trial operation period will be carried out in such a way that the converter station will be operated in commercial service.
6. During trial operation, each converter station is free to switch between any redundant systems, and exercise the controls in manual and/or automatic modes in order to prove all systems under operation.
7. During the trial operation period, the equipment will be subject to the normal operating, maintenance, and safety practices of each converter station/utility.
8. With agreement of the utility, the Contractor may request that trial operation period be stopped to make repairs or alterations. Before any remedial action is taken, the Contractor shall seek the approval of the Owner. Stopping of trial operation will require that the trial operation period be re-started.
9. In the event of a fault that requires termination of trial operation, the Contractor may request the Owner to continue to operate the equipment for the purpose of testing or to obtain more information about the fault so that remedial measures may be defined.

The following criteria will be used to establish the success of trial operation:

1. Stable operation for all system configurations and operation modes
2. No failure to start or stop or to connect/disconnect reactive power banks as needed
3. No main circuit equipment fault

4. No auxiliary system fault
5. No control system fault
6. No unintended switchover to redundant pump or fan
7. No stall or malfunction of a control system device or input/output unit
8. No communication equipment malfunctions for equipment provided by the Contractor
9. No ac or dc protection malfunctions
10. No emergency repair is required.

If any of the above criteria is not fulfilled, the trial operation period will be stopped and the Contractor shall implement any remedial measures needed after which the Trial Operation period shall be re-started from the beginning. Depending on the length of Trial Operation period completed prior to failure, and the nature of the fault or malfunction and other pertinent considerations, the Owner may, at its sole discretion, allow a shorter period of repeat Trial Operation period after restoration of the equipment to operation.

8.5.1. Support by the Contractor during the Trial Operation Period

In addition to any other support provided by the Contractor, the Contractor is required to provide engineering and technical assistance and support during the Trial Operation. Such support shall include, as a minimum:

1. Site engineering resources to enable emergency repair work to be completed and verified to a standard satisfactory to the Contractor and the Owner. If this is not possible, collect information needed to refer the problem to off-site personnel for resolution.
2. Site repair personnel to carry defect repair work. This shall include, but not be limited to implementing, implement and testing remedial measures and design changes in accordance with instructions received from local or off-site engineering or design support personnel.
3. Engineering support personnel based at off-site locations to provide design and support services. This will include, but not be limited to receiving, receive information on performance or failures and analyzing the probable causes and defining solutions.

9. Documentation

All documentation shall be written in the English language and sufficiently detailed to allow for all maintenance, control modification, and future training to be performed without the manufacturer's support.

All technical descriptions, specifications, literature, correspondence, prints, drawings, instruction manuals, test reports (both factory and site), progress photographs, booklets, schedules, and supplementary data or documents furnished in compliance with the requirements of the Contract, shall become the property of the Owner and the costs shall be considered as included in the Contract price.

The Owner shall have the right to make copies of any documents, data, reports, information, etc. supplied by the Contractor in connection with the Contract. The Owner shall not impart the information of these documents to any other manufacturer or competitor but the Owner is free to use these for preparation of technical papers, reports, etc.

The Contractor shall submit a consolidated list of all symbols used in any drawing, data, and information under three separate headings namely Civil, Mechanical or Electrical. If symbols other than IEEE are used, the Contractor shall submit a consolidated list of these symbols and their significance under a separate Section.

The Contractor is not required to supply detailed drawings for the purpose of manufacturing but in case such information is specifically requested by the Owner during vendor selection, finalization of Contract, design review by the Owner/ utilities involved and/or an appointed consultant or during execution of the Contract, the Offeror / Contractor shall comply with the same.

9.1. Contractor Documentation

The Contractor's documentation is to provide information necessary for design, construction, maintenance, and troubleshooting activities. The Owner reviews are to assure that the drawings contain the required information. The Owner will comment when discrepancies are noted during the review of documents. Comments on the documentation do not constitute a contract Change.

Table 21outlines the Contractor's documentation requirements.

Table 21 Contractor Documentation

Title	Review Quantity		Final Quantity		Revision
	Paper	Digital	Paper	Digital	
Construction & Installation Drawings	0	1	5	1	As Required
Construction Material Submittal	0	1	5	1	As Required
Equipment Drawings	0	1	5	1	As Required
Instruction Books	0	1	5	1	As Required
Inventory List	0	1	5	1	Prior to shipment
Maintenance Schedule	0	1	5	1	90 Days After Acceptance of facilities
Master Project Schedule	0	1	5	1	Prior to Project Review Meetings(PRM)s
Master Test Plan	0	1	5	1	4 months after award
Software Documentation	0	1	5	1	As Required
System Study Reports	0	1	5	1	As Required

Test Reports	0	1	5	1	As Required
Test Plans	0	1	5	1	As Required
Users Manuals	0	1	5	1	As Required
Training Manuals	1	1	30	1	30 Days before start of class

9.1.1. Document Submittal

Each document shall be identified by a drawing number and date, Owner contract or purchase order number (release number when applicable) and the corresponding line item number(s). The catalogue number for the equipment contained in the document shall also be shown. The preferred location for this information is the lower right-hand corner of the document. All documents and revisions shall be accurate, complete, and include the latest revisions when submitted.

Each submittal shall be accompanied by a letter of transmittal to the Owner or an assigned specification group, with a copy to the Contracting Officer, containing a list of the individual documents, including their title, document number, and revision number. Any subsequent drawings submitted that supersede a previous document shall be noted with a reference to the new document number and the document it has superseded. If any document submitted for review deviates from previously reviewed documents, these deviations shall be described in the transmittal letter.

9.1.2. Reproduction and Use

The Owner shall have the right to reproduce and use all documentation as provided by the provisions of this Specification.

9.1.3. Drawing Review

The Owner will return to the Contractor one reviewed copy of each drawing submitted, within 30 calendar days after receipt.

Each drawing returned will be appropriately stamped with one of the following categories:

REVIEWED – NO COMMENTS - No re-submittal required. The drawing has been reviewed and no comments are made. Finals may be sent.

REVIEWED with COMMENTS - This category has two sub categories. Re-submittal for review is required or re-submittal for review is not required. Whether re-submittal for review is required or not will be noted on the drawing.

Once drawings have been returned to the manufacturer marked “Reviewed, No Comments” or “Reviewed with Comments/No Re-submittal Required”, a “Final” or “For Record” set of drawings shall be submitted with a clear reference that these drawings are submitted for “Record” or as “Finals” in the transmittal letter. These drawings will not be returned to the Contractor. If changes are made in the material or equipment after any drawing review, the Contractor shall revise the appropriate drawing and resubmit for review in accordance with Section 13. When a drawing has been changed or superseded, the new drawing shall state the number of the revision or superseded drawing and note the reason for the change.

These approved documents shall be considered as the working documents. However, the Technical Specification and connected documents shall prevail over these documents in case a decision is required for interpretation.

Prior to the start of Trial Operation of the HVdc station, the Contractor shall supply copies of the last revision of all drawings produced for this project, stamped as "AS BUILT".

9.1.4. As-Built Drawings

If drawing changes are made during construction that are within the Contractor's Scope of Supply, the Contractor shall revise the appropriate drawings for review in accordance with the Section concerning SUBMITTALS, and resubmit within 45 calendar days of acceptance.

9.1.5. Drawing Format

The Contractor shall submit, in digital format, in addition to the specified drawings requirements, all construction and installation drawings pertaining to architectural, civil, mechanical, and electrical activities. Bills of materials, drawing number lists, schematics, interconnection, wiring and cable diagrams and schedule, conduit layout and details, and grounding layout and details shall be included. Refer to Section XX for further details. The format shall be the following:

1) MicroStation format (.dgn) – preferred, or Autocad (.dwg) – acceptable. However, the original design format of the drawing file is required (not converted) regardless of the type submitted. Each drawing should be located in a separate drawing file.

2) Files in MicroStation format should be version-compatible with and readable by the Owner's system and MicroStation version and submitted using either the DOS Copy, Windows copy or Compatible WinZip utility either on a DC-R or DVD-R.

3) The Owner title block shall be a part of each drawing. The Contractor may request a copy of the Owner CAD title block cell. The Owner title block shall include:

    - "Drawing Title" shall indicate the major equipment or system of which the drawing is applicable
    - Date of revision
    - Sign-off date
    - Contract number
    - Drawing numbers will be provided by the utility after contract award.
    - The border and title block shall not be expanded and shall remain as a cell.

4) All drawings shall use English or Metric with English equivalent or English with Metric equivalent, units of weights and measures as currently used in the United States. The Contractor shall be consistent in the units used throughout the Contract.

5) All schematic and wiring diagrams shall use ANSI Y14a standard drafting symbols and IEEE device function designation system exclusively.

6) All plan views, Sections, elevation and details associated with the layout, schematic, and wiring interconnection diagrams shall be incorporated on a Standard A1-size drawing.

Equipment Drawings

The type of drawings shall include but not limited to the following:

- Interconnection Diagrams
- Conduit Diagrams
- Cable Diagrams
- Telecommunications Diagrams
- Civil Design Diagrams
- Bills of Material

- Schematic Diagrams
- Layout and Wiring Diagrams
- Seismic Loading Diagrams
- Nameplate Diagrams
- Protection Coordination Curves
- Equipment Diagrams
- Foundation Diagrams.
- Control and Protection Cubical Diagrams

All equipment with physical wiring shall be fully documented, including wire color and designation, terminal block designation and cabinet designation in such a way that the Owner can determine how the equipment has been wired.

The Contractor shall provide separate sets of drawings for each control cubicle. Typical drawings for similar cubicles shall not be accepted. If there are several cubicles per system, then one common bill of materials and one system schematic diagram may be provided. Such system schematic diagrams shall show the control scheme for the particular system in its entirety and shall be laid out on the minimum number of drawings sheets consistent with clarity and legibility.

9.1.6. Informational Manual

Informational documentation shall be provided to the Owner and to each of the respective converter station utility's dispatchers:

1. An overview of the function and theory of operation of the system covering all functions provided by the system in a condensed form from the operations overview.
2. Overview of the switching and clearance arrangements.
3. Overview of malfunctions and corresponding alarms. (Human interface to the system, including any settings or adjustments that the dispatcher would be expected to perform.)

9.1.7. Instruction Manual

The Contractor shall furnish a set of instruction manuals for all the equipment as applicable. Clarity and readability shall be of the highest commercial standards. The manuals shall be oriented toward operation, maintenance, and trouble shooting of the equipment without the services of a manufacturer's representative. The portions devoted to descriptive matter and theory shall be limited to those which are essential to the proper understanding of the equipment for satisfactory operation, maintenance, and troubleshooting.

The instruction manuals shall include, but not be limited to, the following:

1. Manufacturer's definitions:
    - All terminology particular to the Contractor's equipment shall be clearly explained in a supplementary Section with the heading "Definitions".
2. Factory specification of the equipment.
3. Shipping instructions, warehouse storage, and handling instructions.
4. Parts and factory service instruction:

- Factory repair policy and detailed description of the procedure to obtain spare parts or factory service: (1) under normal conditions, (2) under emergency conditions. Specify the mailing address and telephone number(s) of the service department.

5. Installation instructions:

    - Installation instructions and information to supplement the installation drawings shall be furnished. This information shall include safety precautions, power requirements, assembly procedures, grounding instructions, alignment instructions, installation test requirements, and details associated with equipment testing to verify proper performance.

6. Preventive maintenance instructions:

    - Preventive maintenance instructions shall be furnished for all subsystems along with an indication of manufacturer's maintenance intervals. These instructions shall include required test procedures, alignment instructions, cleaning requirements and instructions for visual examinations. The manual shall include a table indicating the average man-hours required to complete a maintenance action, outage time if an outage is required, and on-line/off-line requirement for the maintenance action. The maintenance instructions shall include the manufacturer's typical readings at all test points. A list of all tools needed to install or maintain the equipment shall be provided.

7. Troubleshooting instructions:

    - The troubleshooting instructions shall be to the "spare parts" level with adequate details for quick and efficient location of the cause for the equipment malfunction.

8. Special tools:

    - Information on the use of special tools and test equipment as well as precautions to protect personnel and equipment shall be included.

9. Repair instructions:

    - Repair instructions shall be provided for the removal, repair, adjustment, and replacement of all items which are within the ability of field repair, as determined by the Owner. Electrical and mechanical schematic diagrams; parts location illustrations or other methods of parts location information; photographs, interconnection cabling, wiring diagrams, and exploded and Sectional views giving details of mechanical assemblies shall be provided as necessary for supplemental test.

10. Mechanical items:

    - For mechanical items, information on tolerances, clearances, wear limits, and maximum bolt-down torques shall be supplied.

11. Parts information:

    - This section shall contain a complete parts list and sub-sections which include a breakdown of the smallest assembly considered a replacement part, showing name and description, catalog number, quantity used, and reference by item number on the applicable drawing. The description shall include electrical and mechanical ratings, settings, nameplate drawings, additional instructions or instruction books, testing requirements, wire list, curves, drawings, and inspection and installation instructions.

12. Spare parts:

    - Spare parts as recommended by the manufacturer, including the descriptive information listed in the preceding paragraph regarding “parts information”.

9.1.8. Maintenance Schedule

The Contractor shall prepare a comprehensive maintenance schedule listing the required maintenance for all equipment. This schedule shall cover a complete maintenance cycle. A complete maintenance cycle is the time required for each item of maintenance to be completed once.

9.1.9. Master Project Schedule

The project schedule shall be provided in a format compatible with the latest version of Microsoft Project. The project schedule shall be used for management purposes and updated prior to project review meetings.

9.1.10. Master Test Plan

The Contractor shall submit a master test plan and program indicating the order in which the tests will be conducted and the test method being used along with required instrumentation. Within 90 Days after Contract Award, the Contractor shall submit a preliminary master test plan.

9.1.11. Software Documentation

Include a system overview and detailed information pertaining to the individual systems and subsystems as shown on a Contractor-supplied outline, logic, schematic, and one-line diagrams. Specifically the Contractor is required to provide a narrative describing the control and protection logic of each function such that the operating principles can be readily understood. The Contractor is not required to explain the operation of sub-units (integrated circuits, etc.) which make-up the control and protection system. The instructions shall describe the controller/user interface in detail, including instructions and examples for calculating and setting all user-controlled parameters.

The software design document will detail the design of the controller software. This will include the following:

1. Software overview:

    - This overview will include a list of controller algorithms and a description of how each of these algorithms interrelates with the others. This description shall be provided in two forms, as a narrative and as software control flow diagrams.

2. Documentation of individual modules:

    - The controller software design document shall include separate documentation for each controller algorithm.

3. Data dictionary:

    - Provide a description of each data element used in the controller software.

4. Error messages list:

    - The error messages list will be a source of information on error messages issued by the controller. Include error messages generated by the operating system, hardware diagnostics, application programs, etc.

9.1.12. Installation Procedure

This section shall include a detailed step-by-step instruction of the HVdc control equipment test procedure and calibration.

9.1.13. System Study Reports

The Contractor shall provide, as part of the supplied Contractor Documentation, any study reports that are generated as part of this Project.

9.1.13.1. Design Reports

All design reports, including the valve design report, shall be provided in the English language.

9.1.14. Test Reports

The Contractor shall prepare test reports in accordance with Section 13. Formal test reports are required for all tests listed in the master test plan. The test reports will include the subject test plan, required data and discrepancy reports or failure reports resulting from performance of the test.

9.1.15. Training Manuals

The Contractor shall provide training manuals and course outlines for the Owner's review 60 days prior to the start of training. Seven days prior to the start of class, copies of the training material shall be provided for each student. The training manuals shall include appropriate portions of the instruction manuals and will be retained by the student. The training material shall be written so that they can be used at a future date to re-train existing employees and to train new employees.

10. System Studies by the Contractor

10.1. General

The Contractor shall submit all reports on the system studies, engineering and design, and shall satisfy the Owner as to the completeness and accuracy of the studies to be carried out in accordance with the Contract.

The Contractor shall carry out comprehensive studies for the project. The Contractor shall perform all studies according to the schedule established for the Contract. The Contractor shall also carry out all studies which are necessary for completion of the design and engineering, whether these have been mentioned in the Purchaser's Requirements or not. The Purchaser shall have the right to observe and participate in the studies performed as part of the Contract, and shall have access to all data and software models necessary for a complete understanding of the purpose and procedure of such studies as well as the validity of the results. The Purchaser shall, from time to time, notify in advance to the Contractor which of the aforesaid studies he wishes to observe and participate in and the Contractor shall give the Purchaser at least thirty days prior notice before commencement of the above said studies.

All studies shall be repeated during the detailed engineering of the project conforming to the technical specification requirements and all Plant would be provided and rated as per final study result. Some of the studies to be performed during the progress of the Works shall be performed by the Contractor in consultation and/or with the participation of the Purchaser. Regarding participation of Purchaser in various studies, a firm schedule for every such study shall be agreed prior to start of the engineering work.

The study reports shall include, but not be limited to the following:
(a) Study objectives.
(b) Initial conditions, data and assumptions.
(c) Codes, standards and criteria used in the studies.
(d) Description of means and methods used in the studies.
(e) Computer models and data used in the studies to represent the Contractor's Plant and the Purchaser's Plant.
(f) Summary of study results including a statement identifying limiting conditions for Plant or system design.
(g) Conclusions.

Items a) through e) above shall be submitted to the Purchaser for review and/or approval (as specified elsewhere in the Contract) and comment before the studies start.

The Contractor shall demonstrate to the Purchaser in items f) and g) that the Plant as designed will meet the specified performance.

The Contractor shall use proven software/hardware tools in the system studies for this HVdc project. The Purchaser will only accept study results generated with tools known to the Purchaser. The Purchaser is familiar with PSS/E and PSCAD. PSS/E version 32 and PSCAD Version 4.5.3 are preferred.

The Purchaser will provide data which shall be used by the Contractor in performing the studies specified. The Contractor shall have his database approved by the Purchaser prior to commencement of the studies during detailed engineering.

The Contractor shall carry out and report on the system studies specified herein and any additional studies which are determined to be necessary for the design of a multi-terminal HVdc scheme. The cost of any additional studies determined to be necessary shall be included in the Contract Price. All studies shall consider all modes of operation (point to point, multi-terminal, etc).

The Contractor shall perform studies to confirm that the performance and ratings of all equipment to be supplied for the project meet the requirements of the technical specification.

The Contractor shall satisfy the Purchaser as to the adequacy of the studies carried out in accordance with the Contract.

These studies shall include, but not be limited to the following:

1. Main circuit calculation.
2. Power Circuit Arrangement Study.
3. Thermal Rating Study for key equipment.
4. Load Flow/Short-circuit and Stability Studies.
5. Studies for Reactive Power Compensation and Balance (including any potential dynamic reactive power devices).
6. Temporary overvoltage and ferro-resonance overvoltage studies.
7. Studies on Overvoltage Protection and Insulation Co-ordination.
8. AC and DC filter design, performance and ratings, including measurements of initial and final harmonics.
9. Study of dc terminal over voltages resulting from line fault with and without dc filters.
10. AC Breaker Requirement Study for any new and existing breakers (including TRV).
11. DC Switch Requirements Studies, including the DMR.
12. Reliability and Availability.
13. Loss Verification Study and Measurements.
14. Studies for Bipolar Balance Operation with Grounding net/station grounding as temporary grounding.
15. Studies of dc Current Flowing through Windings of Converter Transformers.
16. Bushing flashover.
17. DC resonance study.
18. SSR/SSTI Study
19. Islanded mode.
20. Integration and operation of tap.
21. AC/DC parallel line interaction and blocking filter design study.
22. Radio interference and electric and magnetic fields study.
23. Audible Noise.
24. Step and touch potential study.
25. Evaluation of network representation.
26. HVdc control, protection and communication studies.
27. Multi-terminal operation study.
28. Commissioning studies.
29. Supplementary HVdc controls.
30. Switching sequences studies.
31. HVdc runbacks/ Special Protection Schemes (i.e. loss of bipole/pole).

The following Sections specify selected studies in more detail.

10.1.1. Main Power Circuit Study

This study shall establish and document the main circuit design parameters of the converter stations as well as the operating characteristics during steady-state operation. This shall include the summary of converter parameters, calculation of main circuit and converter transformer rating, and determination of tap changer range and calculation of reactive power as a function of dc current.

The variation of resistance of dc transmission line and neutral return circuit under various ambient and operating conditions, tolerance of equipment, measuring and control errors and dead-bands shall be considered in the studies.

The Contractor shall state the total commutating reactance including contribution from all applicable sources and state the contribution of those sources.

The Contractor shall provide a report describing the arrangement and equipment ratings for the dc power circuit.

10.1.2. Power Circuit Arrangement Study

A circuit diagram showing the power circuit equipment supplied by the Contractor shall be provided. The Contractor shall demonstrate to the Company's satisfaction that its design of power circuit arrangement can meet the requirement of all operating modes and will provide for isolation for maintenance.

10.1.3. Thermal Rating Study for Key Equipment

Studies of thermal ratings for key equipment, such as thyristor valves, converter transformers, dc smoothing reactors, etc. shall be carried out by the Contractor. It shall be demonstrated by the Contractor to the Owner's satisfaction that the hot spot temperature or thyristor junction temperature will not exceed the values stated by the Contractor and the temperatures guaranteed by the equipment manufacturers. The demonstration shall consider operation at any permitted condition or mode and the maximum ambient temperature conditions possible for the installation location of a given piece of equipment. The demonstration shall include the effects of the following factors:

a. solar heat gain
b. elevated temperatures in valve halls
c. faults such as valve short circuits (single and multiple loop) or long duration commutation failures
d. operation to the rated capability of the equipment including overload
e. the influence of harmonic currents
f. dc current flowing in transformers up to the limits guaranteed by the Contractor

Values of thermal capacitance and thermal resistance used in the studies shall be guaranteed by the Contractor and verification of these parameters shall be submitted, subject to the Owner's satisfaction.

10.1.4. Load Flow Study

The scope of the load flow study is the analysis of balanced steady-state operation of the power system in the presence of HVdc during normal operation conditions, different continuous overload operation conditions and post-contingency operation conditions. The power flow study shall be conducted to assess the compliance of the operation of HVdc link and its interaction with the AC power system, with the system performance standards defined in this standard XXX.

10.1.5. Reactive Power Management Study

It shall be demonstrated by the Contractor's studies that the reactive power supply and absorption requirements can be met at all dc power transfer levels in the range of power transfer guaranteed by the Contractor under all operating conditions given in these Technical Requirements.

The report shall also address overvoltage control at each converter station. The switching of reactive power within the limits of unbalance of reactive power shall be demonstrated.

10.1.6. Overvoltage Protection and Insulation Co-ordination

This study shall determine overvoltage levels and the insulation co-ordination of all equipment at each converter station.

The Contractor shall conduct PSCAD/EMTDC studies to determine transient overvoltage stresses (including excessive valve recovery voltages) resulting from power system transients and credible Bipole mal-operations. The Contractor shall verify that all equipment (including any capacitor discharge circuits) is adequately protected and equipment insulation levels (BIL and BSL), creepage and clearances, and arrester ratings have been properly specified for both AC and DC side equipment.

The Contractor shall demonstrate in this study that the overvoltage levels that occur will not exceed the capabilities of nearby existing equipment including arrester energy levels. The Contractor shall give consideration to events that may affect all HVdc systems.

The worst combination of operating conditions including conditions of in-service equipment and duration of protections shall be used for overvoltage protection and insulation coordination studies.
Clearances shall be dimensioned in accordance with the insulation levels, taking into account the safety and maintenance, ambient conditions at each station as well as the requirements of the national authorities.

For the insulation coordination study, multiple-strokes shall be assumed as a normal occurrence. Investigations shall include the protective capability and energy requirements of the arresters and their ability to withstand all transient and temporary system overvoltages, including those occurring in connection with load rejection, with and without a symmetrical and unsymmetrical fault, filter switching and transformer energization. This capability shall be demonstrated assuming that the arrester(s) have discharged maximum energy immediately prior to the fault condition.

The report shall clearly specify how the valves are protected (e.g. surge arresters, VBO protective firing) and what insulation margins have been achieved.

10.1.7. AC Filter Design Study

AC side harmonics and ac filters shall be studied by the Contractor to demonstrate that the ac filters are designed correctly and will meet the filtering performance requirements in the various operating conditions.

The rating requirements of every component of the ac filters shall be determined by the Contractor through studies and all the components shall be specified according to the study results.
In the study of filter performance and ratings, all possible operating conditions and combinations of filters switched on for those conditions shall be considered.

The Contractor shall determine the influence of background harmonics on both filtering performance and ratings of filter components.

In addition, the studies shall demonstrate that ac filters and shunt capacitors provided in their scope do not cause any resonance with the power system and that the specified harmonic performance will be met under the worst conditions.

The study report shall include tables of all the values of all converter currents calculated and used for performance and rating.

10.1.8. DC Filter Design Study

DC side harmonics and dc filters shall be studied by the Contractor to demonstrate that the filters are designed correctly and will meet the filtering performance requirements in the various operation conditions.

The Contractor shall consider all operating conditions.

The rating requirements of every component of the dc filters shall be determined by the Contractor through studies and all the components shall be specified according to the study results.

In the study of filter performance and ratings, all possible operating conditions and combinations of filters switched on for those conditions shall be considered.

In addition, the studies shall demonstrate that the dc filters do not cause any resonance with the dc transmission line.

Due consideration shall be given to the multi-terminal operation and the contribution of each converter station shall be taken into consideration for performance and rating calculations.

10.1.9. DC Switches Duty Requirement Study

The study shall provide the details related to rating and dimensioning of the high voltage switches including the neutral bus switches grounding switch. The results of the study shall justify the proper rating of the equipment.

10.1.10. Availability and Reliability

Availability and reliability studies shall be carried out by the Contractor to demonstrate that its design will meet the requirements of availability, reliability and maintainability of these Technical Requirements.

Reliability indices of all components in the scope of supply used in the reliability calculation shall be supported by documents provided by the Contractor, including warranty of failure rates, operation experience of similar equipment and components as well as other values guaranteed by the Contractor.

10.1.11. DC current through converter transformer windings

DC current flowing in windings of converter transformers shall be calculated by the Contractor and the final value of dc current chosen for the design of converter transformers shall be subject to the Company’s review, while maintaining the requirements of Section 6.6.3. The Contractor shall state how these currents are taken into account in the design of the converter transformers.

Reports shall be submitted to the Company to demonstrate that the effect on losses and audible noise will not exceed that guaranteed by the Contractor and the hot spot temperature caused by normal operation stresses added with the effect of dc currents will not exceed that guaranteed by the Contractor.

10.1.12. DC resonance study

A study shall be performed in order to evaluate the total resonance within the dc system. It must be shown that resonance at low order harmonics is avoided by suitable choice of smoothing reactor size or dc filters.

When determining the value of inductance for the reactor, due consideration shall be given to the risk of resonance and the generation of excessive overvoltages when disturbances occur in the ac networks. It must also be demonstrated that possible low order harmonics in the ac grid will not result in amplifications, causing dc saturation of transformers or equipment overload. Both pole mode and common mode resonances shall be considered. The equivalent circuits used in the resonance study shall be presented.

10.1.13. **Sub-synchronous Resonance, SSTI and SSCI Study**

The Contractor shall perform a Sub-Synchronous Resonance (SSR), Sub-synchronous Torsional Interactions (SSTI) and Sub-synchronous Control Interaction (SSCI) study. This Study shall demonstrate that any SSR, SSTI or SSCI between the HVdc system and wind plants, generator-turbine units, series capacitors, other HVdc systems and FACTS devices in the ac systems are well damped. The Contractor shall further demonstrate that there are no adverse interactions between the HVdc controllers and the wind plant controllers.

SSR and SSTI studies shall be performed in two stages; a screening study followed by a detailed study using small signal stability assessment and/or EMT simulations for the identified potential issues at the screening stage.

Regardless of screening study results, a detailed study shall be required using small signal stability assessment and/or EMT simulations to demonstrate the controller interactions between the wind plants and HVdc system.

10.1.14. **AC/DC Parallel Line Interaction and Blocking Filter Design Study**

This study shall identify the level of 60 Hz current induced into the dc line from parallel ac transmission lines in the same or adjacent right of way. The study shall identify mitigation methods and establish the need for 60 Hz blocking filters in the dc circuit.

10.1.15. **Multi-Terminal Operation Study**

The Contractor shall carry out a Multi-Terminal Operation study to verify the future integration of a mid-point tap for all possible modes of operation with the tap operating as either an inverter or rectifier and allow for fast power reversal with minimal impact to the other terminals.

10.1.16. **Radio interference and electric and magnetic fields study**

A study shall cover the overall EMC strategy for the converter stations. The general concept of the measures taken to ensure reliable operation of the HVdc link with respect to EMC shall be included in the report. Reference shall be made to Cigre Technical Brochure No. 124, ‘Guide on EMC in power plants and substations’ and shall comply with IEC61000.

All equipment in converter stations has to operate in an electromagnetically harsh environment due to the occurrence of electromagnetic disturbances. These disturbances are most commonly generated by:

- Operation of equipment in the converter stations themselves
- Operation of circuit breakers and disconnects in the connected high voltage networks
- Operation of protective and auxiliary relays
- Use of radio equipment and mobile telephone equipment
- Thunderstorms
- Geomagnetic storms
- Electrostatically charged operators
- Interaction with adjacent power networks.

All of these sources generate fields that may influence the behaviour of the control, protection and metering equipment and other secondary equipment.

The Contractor has the full responsibility for the desired and error-free operation of all equipment within the converter stations under all normal and abnormal conditions in the converter stations including during electromagnetic disturbances. This responsibility shall be reflected in the following items:

- Contractor shall develop a detailed project specific EMC-concept that is applicable to both converter stations.
- Contractor shall develop the lightning protection concept of the station and coordinate this with the converter station layouts.
- Contractor shall define EMC requirements for equipment that is not a part of the scope of supply but that will be installed by other parties involved in the project.

The Contractor shall ensure that all equipment supplied is insensitive to any signals emitted by wireless communication equipment.

The Contractor shall present a concept for the total handling of corona in the converter stations. All equipment, connections and bus-works must be taken into consideration. The influence on both the radio interference levels as well as the acoustic noise levels must be stated.

The concept must aim for a minimum level of corona in the stations during normal operating conditions with maximum operating voltages.

The EMC capability shall be checked and verified during system tests on the completed plant by measuring the actual disturbance voltages on the equipment during the various operating tests.

10.1.17. **Audible noise study**

The study shall cover the acoustic noise calculation for the converter stations. The study must demonstrate that the limits as specified in Section 4.14 are met. The results shall be verified during the commissioning. Background noise must also be taken into account.

A description of the method used for the calculation of audible noise and of the method to be used for verification on the completed station shall be presented.

Noise power levels of the major noise source shall be given, both as spectrum values and as equivalent A-weighted power level. The harmonic spectrum used for determination of noise power levels shall be stated.

10.1.18. **Evaluation of network representation**

As a minimum this study shall compare the network representation in the power system dynamics program used by the Contractor with the complete PSSE model provided by the Owner. The study shall ensure that the Contractor’s represented network model for the studies and Company’s complete network comply with each other. The evaluation must compare but not to be limited to the ac system performance and response during ac faults (single phase and three phases) and power swings. The evaluation shall be approved by the Company.

10.1.19. **Studies for the Control, Protection and Communication Systems**

The Contractor shall perform all system studies for determining the performance of control and protection, design studies on software/hardware for control and protection system, development studies, key techniques study, commissioning and acceptance test studies, etc. and submit study and design reports to the Owner.

The Contractor's study reports shall include, but not be limited to, the following study results:

1. Dynamic Performance Study.

2. Multi-terminal control strategy.
3. Hierarchical Structure of the Control and Protection.
4. Redundancy of the Control and Protection Systems.
5. DC Power and Current Control Modes and Features.
6. Switching Sequences and interlocking.
7. Telecommunication interface requirements.
8. Control for converter transformer tap changer.
9. Fault location study.
10. Harmonic measurement.
11. Commutation failure performance study.
12. AC & DC System Protections.

For each protection, the report shall include the following:

1. Purpose of the protection.
2. Principle of protection operation.
3. Required accuracy of measuring signals.
4. Fault detection and coordination between the dc controls and the protection and ac protection.
5. Consequences of protection operation.
6. Redundancy of protection and operation of backup protection.
7. Detailed calculations of the protection settings together with limiting fault cases and/or criteria that determine these settings.
8. Description of the applicable protection in case of loss of telecommunication.

10.1.20. HVdc Supplementary Controls

The study shall include at least the following:

1. Criteria for operation of supplementary modulation controls.
2. Coordination of supplementary modulation controls.
3. Demonstration of the supplementary modulation controls.
4. Operator operation, including control and monitoring features.
5. Description, emphasizing reliability/availability and maintenance features.

10.1.21. HVdc Runbacks

The study shall include at least the following:

1. Criteria for operation of HVdc runbacks.
2. Coordination of HVdc runbacks.
3. Demonstration of the application of HVdc runbacks.
4. Operator operation, including control and monitoring features.
5. Description, emphasizing reliability/availability and maintenance features.

The reports shall include the studies of the following control modes of converter stations and actual performance of converter and possible fault condition being taken into account:

1. Power ramp down.
2. Power ramp up.
3. Abnormal AC voltage and frequency control.

4. Supplementary modulation signals and HVdc runbacks.

10.2. Wind Sensitivity Study

As the wind collector system and the exact amount and breakdown of Type 3 and Type 4 wind farms have not yet been determined, the Contractor shall perform the following sensitivity studies:

- 80% type 3 windfarms 20% type 4 windfarms
- 20% type 3 windfarms 80% type 4 windfarms
- 50% type 3 windfarms 50% type 4 windfarms
- Four different wind collector system scenarios

These studies shall be performed on the provided PSS/E and PSCAD models.

10.3. Digital Models

The following models will be provided to the Contractor for use in the studies:

- For PSS/E Powerflow Studies: PSS/E v33 full network power flow models at summer light system loads and summer peak loads (year 2019)
    - Bipolar full power transfer
    - Monopolar minimum power transfer
    - Corresponding base cases (without the PnE project)

- For PSS/E Dynamic Studies: PSS/E v32 full network power flow and dynamic models at light system loads (year 2019)
    - Bipolar full power transfer
    - Corresponding base case (without the PnE project)

- PSS/E equivalent network power flow and dynamic models at light system loads (year 2019), stemming from the full network PSS/E v32 cases listed above for the PSS/E Dynamic Studies
    - Bipolar full power transfer

  PSCAD models using the equivalent network model at light system loads (year 2019), stemming from the PSS/E equivalent network models listed above

For all PSSE and PSCAD models listed above, the following variations of the cases are provided to represent the three possible DC configurations at the approximate maximum and minimum loading levels:

Maximum power transfer (bipolar):

For all PSSE and PSCAD models listed above, the following variations of the cases are provided to represent the three possible DC configurations at the approximate maximum and minimum loading levels:

Maximum power transfer cases (bipolar):

- 3-terminal: rectifier 4265 MW (Oklahoma)-inverter 500 MW (Arkansas)-3500 MW inverter (Tennessee)

- 3-terminal: rectifier 3180 MW (Oklahoma)-500 MW rectifier (Arkansas)-3500 MW inverter (Tennessee)
- 2-terminal: rectifier 3720 MW (Oklahoma)-3500 MW inverter (Tennessee)

Minimum power transfer cases (monopolar) (provided for PSSE Powerflow Studies only):

- 3-terminal: rectifier 120 MW (Oklahoma)-inverter 26 MW (Arkansas)-93 MW inverter (Tennessee)
- 3-terminal: rectifier 107 MW (Oklahoma)-26 MW rectifier (Arkansas)-133 MW inverter (Tennessee)
- 2-terminal: rectifier 106 MW (Oklahoma)-106 MW inverter (Tennessee)

In addition, each case is provided as four variations to represent four possible wind collector system scenarios.

Dynamics data is provided in the form of PSSE dynamic data files. PSSE dynamic data is provided for use in PSSE v32.

In the PSSE power flow cases provided, the HVdc link has been modelled as a load at the appropriate buses to represent the approximate real and reactive power at each of the converters. These loads are to be replaced by the Bidder's actual HVdc model.

An interconnection requirement is that only Type 3 or Type 4 wind turbine generators (WTGs) be permitted to interconnect to the P&E HVac collector system. Since the actual breakdown of Type 3 and Type 4 generators that will actually interconnect is not yet known, it is recommended that 50% of Type 3 and 50% of Type 4 WTGs breakdown be assumed for each interconnecting wind farm, however sensitivity analysis should be performed to study an 80%-20% split as well as mentioned in Section 10.2 The total amount of WTGs interconnected to P&E HVac should be sufficient to deliver the required rated power to the rectifier.

In the PSS/E dynamic data that is provided, 50% Type 3 and 50% Type 4 WTG models have been included to represent the PnE wind farms for each of the four wind collector system scenarios. It is the vendor's responsibility to create the sensitivity cases to study the 80%-20% and 20%-80% breakdown of Type 3 and Type 4 wind farms. The Type 3 wind farms are represented by the GE 1.5 MW WTG models (GEWTG2, GEWTE2, GEWTT1, GEWGC1, GEWTA1, GEWTP1, GEWPLT), and the Type 4 wind farms are represented by the Siemens 2.3 MW WTG models (SWTGU1, SWTEU1). These models are available with the standard PSSE v32 installation, although they do require their object codes to be linked to the DSUSR.dll. It is the Contractor's responsibility to ensure that these models are behaving as expected in their studies. The vendor may also replace these models with other validated Type 3 and Type 4 wind farm models.

Add reference to PSSE modelling package information

The full power system model shall be used whenever possible for the particular study item. For some study items, where it may be very difficult or unnecessary to use the whole system model, equivalent models may be utilized subject to the Owner's approval.

The PSCAD equivalents contain ideal sources representing the wind and loads/ideal sources representing the HVdc system. The Bidder/Contractor is to replace these with their models.

10.4. Models to be provided by the Contractor

The Contractor shall provide the following models of all supplied main circuit Plant and controls systems and protection to the Owner upon the completion of design studies.

1. PSCAD V4.5.3
2. PSS/E V32

The PSCAD digital model shall be valid for a frequency range from 0.0Hz (steady-state) to high frequencies, including step responses.

The software for the digital model shall include:

1. Transfer function block diagrams (showing the performance) along with the parameters.
2. Input and output variables of each transfer function block (showing the performance) along with their standardized system.
3. Flow charts/logic diagrams of the entire control features.
4. Any dynamic reactive compensation devices
5. Any added wind farm models

10.5. System Equivalents

Equivalents of the ac systems have been prepared and are provided. The equivalents are to be used only for the purposes for which they are designated. The system equivalent may be utilized subject to the Owner's approval.

10.5.1. Reduced Network and Dynamic Model - Equivalents for Simulator and PSCAD Studies

The equivalent networks should not be used for:

1. AC filter studies.
2. The sole tool for insulation co-ordination studies.
3. Demonstration of ac steady-state voltage regulation studies.
4. The sole tool for dynamic overvoltage studies.

Static RLC Equivalents - The static RLC equivalents may be determined by the Contractor based on the system data. Such static RLC equivalents shall only be used for:

1. Development and evaluation of dc system control and protection functions.
2. Evaluation of performance of the AC-DC system for different dc system control modes.
3. Evaluation of dc system performance for dc side disturbances such as converter blocking, pole blocking, dc link faults, and valve winding faults.
4. Demonstration of the dc system response in accordance with the specified response criteria.
5. Demonstration of the dc system transient response for reactive bank switching.
6. Sub-system functional testing of actual site controls.

10.6. Faults for Performance Demonstrations

The Contractor shall demonstrate to each utility that the HVdc Link will meet all performance criteria when subjected to the faults listed in Table 22 below.

The fault response shall be demonstrated for:

- 2019 Light system load.

The fault response shall be demonstrated for:

1. 3-terminal: rectifier 4265 MW (Oklahoma)-inverter 500 MW (Arkansas)-3500 MW inverter (Tennessee)
2. 3-terminal: rectifier XXX MW (Oklahoma)-500 MW rectifier (Arkansas)-3500 MW inverter (Tennessee)

3. 2-terminal: rectifier 3720 MW (Oklahoma)-3500 MW inverter (Tennessee)

The fault response shall be demonstrated on some or all of the following:

1. The full system model (supplied in PSS/E format).
2. The PSCAD equivalent.
3. The HVdc simulator.
4. Staged faults during commissioning.

The Contractor will also determine the maximum transfers that meet performance criteria with no telecommunications.

Table 22 Faults for Performance Demonstrations

	Full System	**PSCAD**	**Simulator**	**Commissioning**
AC system remote and bus faults cleared normally				
	√	√	√	
	√	√	√	
	Full System	**PSCAD**	**Simulator**	**Commissioning**
AC Line faults with successful and unsuccessful auto-reclose				
	√	√	√	
	√	√	√	
	Full System	**PSCAD**	**Simulator**	**Commissioning**
AC Line faults with CB-Fail and breaker fail protection				
	√	√	√	
	√	√	√	
	Full System	**PSCAD**	**Simulator**	**Commissioning**
Machine Tripping				
	√			
	√			
	Full System	**PSCAD**	**Simulator**	**Commissioning**
Transformer Energization				
	√	√	√	√
	√	√	√	√
	Full System	**PSCAD**	**Simulator**	**Commissioning**

DC Faults				
Bipole Trip	√	√	√	
Pole Trip	√	√	√	
Pole DC Line Fault	√	√	√	
Inverter Commutation failure	√	√	√	
Tap Inverter Commutation failure	√	√	√	
Tap Trip	√	√	√	
Pole rectifier trip	√	√	√	

10.7. Commissioning Studies

The Contractor shall perform any system studies needed to determine information for commissioning or to resolve problems discovered in the course of commissioning.

The Contractor will provide input to outage studies performed in coordination with the Purchaser to optimize the construction sequence to minimize the outages required for the project.

The Contractor, where necessary, may request additional data and information from the Engineer.

11. Guarantees

The parameters to be guaranteed by the Contractor are:

- Availability
- Reliability
- Station Efficiency
- Station Power Rating
- Thyristor Failure Rate
- Capacitor Failure Rate

The above guarantees shall be provided by the Contractor to the Owner on a Bipole basis for each station.

11.1. Technical Performance Requirements

The guarantees listed above are specific performance guarantees and must be met by the Contractor in accordance with the requirements of this Section. Other Sections of the Technical Specification give further requirements on specific equipment and on the stations and these requirements must be fulfilled by the Contractor prior to the Owner accepting the equipment and each converter station.

11.2. Reliability and Availability of the Station

11.2.1. Definitions

11.2.1.1. Outage Terms

Outage

The state in which equipment or a unit of equipment is unavailable for normal operation due to an event directly related to the equipment or a unit of equipment.

Scheduled Outage

Scheduled Outage is an outage which can be scheduled at least one week in advance. This includes planned maintenance, normally conducted on an annual basis, and any unplanned maintenance or repair which can be deferred at least one week subsequent to discovery of the need for maintenance or repair. If the outage is extended due to additional work which would have otherwise caused a Forced Outage, the excess period is counted as a Forced Outage.

Forced Outage

The state in which equipment is unavailable for normal operation due to an equipment failure, but is not part of a Scheduled Outage, i.e., an outage which is not a Scheduled Outage.

Pole Outages

An outage which causes a reduction in the bipole dc power system transfer capacity equal to the power rating of one pole.

Bipole Outages

An outage which causes a reduction in the bipolar dc system power transfer capacity equal to the power rating of the bipole.

11.2.1.2. **Capacity Terms**

Maximum Continuous Capacity (P_m)

The maximum bipolar station capacity (MW) for which continuous operation under normal conditions is possible referenced at the rectifier station dc bus as defined in Section 2.

Outage Capacity (P_o)

The capacity reduction in MW the outage would have caused if the station was operating at its maximum continuous capacity (Pm) at the time of the outage.

Outage Derating Factor (ODF)

The ratio of outage capacity (P_o) to maximum continuous capacity (P_m).

$ODF = P_o / P_m$

11.2.1.3. **Outage Duration Terms**

Actual Outage Duration (AOD)

The time elapsed, in hours, between the start and the end of an outage. The time shall be counted to the nearest 1/10th of an hour. Time less than 1/10 of an hour shall be counted as having duration of 1/10 of an hour.

Equivalent Outage Duration (EOD)

The AOD in hours, multiplied by the ODF, so as to account for partial loss of capacity.

EOD = AOD x ODF

Each EOD may be classified according to the type of outage involved, i.e., Equivalent Forced Outage Duration (EFOD) and Equivalent Scheduled Outage Duration (ESOD).

11.2.1.4. **Time Categories**

Period Hours (PH)

In a full year, the Period Hours are 8760 hours (8784 hours in a leap year). If the equipment is commissioned part way through a calendar year, the Period Hours shall be proportionately less than 8760 hours, except that verification of guarantees shall not be calculated proportionately.

Actual Outage Hours (AOH)

The sum of AODs within the reporting period.

AOH = Σ AOD

The AOH may be classified according to the type of outage involved, i.e., Actual Forced Outage Hours (AFOH) and Actual Scheduled Outage Hours (ASOH).

Equivalent Outage Hours (EOH)

The sum of all EODs within the reporting period.

EOH = Σ EOD

The EOHs may be classified according to the type of outage involved, i.e., equivalent forced outage hours (EFOH) and equivalent scheduled outage hours (ESOH). If outage duration overlaps the beginning or end of a reporting period, only the EOD which occurs within the reporting period shall be included in the EOH.

11.2.1.5. **Availability and Reliability Terms**

Energy Unavailability (EU)

Energy Unavailability is a measure of the energy which could not be transmitted due to (scheduled or forced) outages. The impact of overload capability of the individual poles shall not be considered for calculating the Energy Unavailability.

Energy Unavailability % (EU) = EOH/PH x 100

Forced Energy Unavailability % (FEU) = EFOH/PH x 100

Scheduled Energy Unavailability % (SEU) = ESOH/PH x 100

Energy Availability (EA)

A measure of the energy which could have been transmitted except for capacity limitations due to outages, arising from any cause, either forced or scheduled.

Energy Availability % (EA) = (100 - EU)

Energy Utilization (U)

A factor giving a measure of energy actually transmitted over the system.

Energy Utilization % (U) = [Total energy transmitted / (P_m x PH)] x 100]

Reliability

Reliability shall be calculated according to the number of forced outages or curtailments that occur involving poles and the bipole, in a single year,

the Equivalent Outage Frequency (EOF) shall be calculated

as follows:

EOF = (number of single pole outages on first pole)+ (number of single pole outages on second pole)+ (number of bipole outages) x 2

11.3. Scope of Requirements

The converter station shall be engineered to meet "design target" values for availability and reliability, as outlined herein. The Contractor shall also guarantee the availability and reliability of the system to the performance levels specified herein.

Availability and reliability requirements shall apply to the converter stations within the Contractor's Scope of Work. Availability and reliability requirements shall not apply to HVdc transmission lines, dedicated metallic return or any other equipment outside the Contractor's Scope of Work.

The specifications included in the contract shall exclude the effect of certain outages and curtailment events described below which are beyond the Contractor's control. The outage and curtailment events affecting station capacity that will be excluded are as follows:

a) Misuse, operator error or other human causes which contravenes the Contractor's operating and maintenance instructions.

b) Environmental conditions or ac system conditions outside the design criteria given in these Specifications.

c) Force majeure events beyond control of the Contractor and the utility e.g. landslides, tornados, earthquake shock beyond the seismic criteria of these Specifications, and fire arising from causes outside the Contractor's control or Scope of Work.

Circumstances that cause curtailment of the capacity that will be included in the availability and reliability assessment and which can result in a forced outage include, but are not limited to:

a) Failure of equipment

b) Failure or delay to start a pole/bipole

c) Failure of interlocks that delay switching or restoration of equipment

d) Failure to complete switching sequences

e) Failure to recover within the times specified following ac/dc system faults

f) Reduction in dc power transmission capacity

Although outages and curtailment of station capacity caused by failures in equipment outside the Contractor's Scope of Work are not included in the availability and reliability assessment, the Contractor shall design the station to function as set forth in the Specifications during any known potential fault or failure in the HVdc line or equipment which interfaces with the equipment within the Contractor's Scope of Work.

If the transfer capacity of the HVdc system is reduced due to the failure of equipment that is not within the HVdc Contractor's Scope of Work, then the event shall be treated as if the station had been operating at rated power for such period. But if any maintenance is performed during such period then the event shall be counted as an outage (forced or scheduled) for the duration of the maintenance operation.

11.3.1. Guarantees Required

The reliability and availability of the entire bipole, herein referred to as Hitchland, Entergy Tap and Shelby converter stations, shall be guaranteed by the Contractor. The operation of the bipole shall be monitored by the Contractor during a thirty-six (36) month guarantee period, not to exceed seventy-two (72) months.

To ensure that the performance meets the Forced Energy Unavailability (FEU), Energy Availability (EA) and Reliability guarantees, ten percent (10%) of the total cumulative contract value will be withheld until the Owner determines the guarantees are met. If the Contractor meets the FEU, EA and Reliability guarantees as defined in Sections 11.6 and 11.7, for twelve (12) consecutive months (to begin immediately following successful trial operation), the contractor shall be paid three percent (3%) cumulative contract value. If the Contractor meets the FEU, EA and Reliability guarantees for a second consecutive twelve (12) month period, the contractor shall be paid another three percent (3%) of the cumulative contract value. If the Contractor meets the FEU, EA and Reliability guarantees for a third consecutive twelve (12) month period, the contractor shall receive the final retainage balance for four percent (4%) of the cumulative contract value. At this time the guarantee period will be deemed satisfied.

NOTE: If the contractor fails to meet the guaranteed requirements at any time during **a twelve (12) consecutive month period** (as specified in Section 11) then no payments shall be made. In the event of a failure**, at any time during the guarantee period,** the clock will be reset thereby restarting **the twelve (12) month period.**

11.4. Design Principles

The objective for the design of the converter station will be to achieve a high level of availability and reliability.

Except where greater reliability requirements are specified in the Specification, the design basis for the converter station will require that no single contingency will cause a bipole outage. In the case of an outage involving one pole, the other pole shall have the capacity to carry any overload as required by the Performance Requirements in Section 4.

The design of the controls and protections, directly associated with the transmission of power, shall ensure that the normal failure modes for components will not result in a reduction in the station capacity or in a hazardous operating condition for the equipment or the operator.

The design of the auxiliary system and associated controls and protections shall ensure that a single contingency will not cause a reduction in the converter station capability.

11.5. Availability and Reliability Calculations

The definitions for "availability" and "outage state conditions" are provided in Section 11.2. The basis period for availability and reliability calculations shall be twelve (12) consecutive months (one year). The guarantees shall remain in effect for a period of thirty six (36) months (i.e. three years), or any valid extension (failure to meet the guarantee requirement) thereof, commencing six (6) months after successful completion of trial operation of the converter stations in bipolar mode.

The Contractor shall provide calculations that demonstrate that the design for the converter stations will meet the specified guarantees and design target values for availability and reliability. The Contractor shall include these calculations with its bid proposal. The Contractor shall specify the duration for any annual planned maintenance activities. The calculations should clearly identify the expected availability and reliability of the system based on the Contractor's recommendations for mandatory spare parts/equipment.

Outage times for repair, maintenance, and replacement of components shall be calculated as if all items in the Contractor's lists of recommended spare parts are in inventory or readily available and according to the Contractor's schedule for recommended maintenance.

11.6. Availability Requirements

The Contractor shall guarantee the following availability requirements for the converter station. The availability requirements shall be calculated for the bipole, on a consecutive twelve (12) month's basis, utilizing the Contractor's recommended list of spare parts/equipment.

The Forced Energy Unavailability (FEU) shall be calculated each year, for three consecutive years. If the FEU is **≤0.5%** for each year, then the FEU guarantee shall be considered fulfilled and the withheld payment can be made to the Contractor according to Section 11.3.1.

Annual energy availability (including the recommended maintenance outages and any repair outages) shall be calculated for each year for three consecutive years. If energy availability is **≥ 98.5%** for each year, then the availability guarantee shall be considered fulfilled and the withheld payment can be made to the Contractor according to Section 11.3.1.

The fulfillment of the Availability Guarantees shall be as follows:

Forced Energy Unavailability (FEU):

For fulfillment of FEU, the following shall apply:

1. If the FEU is greater than the guaranteed value of 0.5% in any year, the guarantee period shall be extended for a one (1) year period for a maximum three (3) years (the guarantee extension period).
2. If, at the end of the guarantee extension period, the FEU in the best three (3) years (out of a total period including extended year(s) – maximum of six (6) years) is ≤0.5%, the FEU guarantee shall be considered fulfilled and the withheld payment can be made to the Contractor according to Section 11.3.1.
3. If the FEU value is not fulfilled, the Contractor shall correct all design deficiencies and equipment defects at no cost to the Owner.
4. After correction of such deficiencies and defects:
   a) If the average annual FEU calculated over a two (2) year period is ≤0.5%,(excluding the previous years and the period for correcting the deficiencies), then the FEU guarantee shall be considered fulfilled and the withheld payment can be made to the Contractor according to Section 11.3.1.
   b) If the average annual FEU calculated over a two (2) year period is ≤2.0% (excluding the previous years and the period for correcting deficiencies), then the FEU guarantee shall be considered fulfilled. However the contractor shall forfeit the remaining portion of any withheld payment.

Energy Availability (EA)

1. If the annual Energy Availability (EA) is below the guaranteed value of ≥98.5%, for any year, the guarantee period shall be extended for a one (1) year period for a maximum of three (3) years.
2. If at the end of the guarantee extension period, the energy availability (EA) in the best three (3) years (out of a total period including extended year(s)) is ≥98.5%, the energy availability (EA) guarantee shall be considered fulfilled and the withheld payment can be made to the Contractor according to Section 11.3.1.
3. If the annual EA is not fulfilled, the Contractor shall correct all design deficiencies and equipment defects at no cost to the Owner.
4. After correction of such deficiencies and defects:
    a. If the average annual EA calculated over the two (2) year period is ≥98.5%, (excluding the previous years and the period for correcting the deficiencies), then the EA guarantee shall be considered fulfilled and the withheld payment can be made to the Contractor according to Section 11.3.1.
    b. If the average annual EA calculated over the two (2) year period is ≥97%, (excluding the previous years and the period for correcting deficiencies), then the availability guarantee shall be considered fulfilled and the Contractor shall forfeit the remaining portion of the withheld payment.

11.7. Reliability Requirements

11.7.1. Requirements

In assessing reliability, the following events in addition to those listed in Section 11.2.1, shall constitute a bipole forced outage:

a) A bipole shutdown
b) A reduction of HVdc system capacity for any reason, that exceeds the capacity of one pole
c) A pole shutdown followed by unsuccessful pole metallic return switching

The calculated reliability of the converter station shall be equal to or exceed the design target values discussed below. In addition, subject to the terms and conditions specified in the Contract, the annual reliability shall be equal to or exceed the guaranteed values stated in the Contractor's Offer.

The average number of forced outage and curtailment occurrences per year (12 months) for the converter station shall not exceed the following values:

- Number of pole outages per year, per pole = 3
- Number of bipole outages per year = 0.1

The Contractor shall guarantee these values in their offer.

11.7.2. Fulfillment of Reliability Guarantee

The Owner shall monitor the operation of the converter stations during the three (3) year guarantee period for availability and reliability. The Owner shall conduct an annual appraisal of reliability performance.

With respect to the guaranteed reliability values for curtailment in HVdc system capacity, the following shall apply:

If the number of occurrences in any year of the three (3) year guarantee period exceeds the guaranteed value, the guarantee period shall be extended for a one (1) year period for a maximum of three (3) years.

1. If at the end of the extended guarantee period, the number of occurrences in the best three (3) years including the extended year(s), is less than or equal to the guaranteed value, the reliability

guarantee shall be considered fulfilled and the withheld payment can be made to the Contractor according to Section 11.3.1.

2. If the reliability guarantee is not fulfilled, the Contractor shall correct all design deficiencies and equipment defects at no cost to the Owner.

3. After correction of such deficiencies and defects, if the number of occurrences per year, averaged over an additional two (2) year period, (excluding the prior year(s) and the period for correcting such deficiencies) is still above the guaranteed value, the Contractor shall forfeit the remaining portion of the withheld payment.

11.8. Station Losses and Loss Evaluation

The losses for the converter stations shall be determined in accordance with IEC Standard 61803 “Determination of power losses in high voltage direct current (HVdc) converter stations with line-commutated converters". Losses shall be determined at standard reference ambient conditions specified in IEC Standard 61803, except that the assumed dry bulb ambient temperature shall be 20 °C. The Offeror shall provide total bipole station loss values using the form of kilowatts to the nearest 0.1 kW for the following load conditions at the specified per unit load levels in Table 23:

1. Rectifier operation at a level that will allow 3500MW to be delivered to the ac terminals of the inverter and 500MW to the ac terminals of the tap, concurrently, at the required current, with 600 kVdc and 345 kV ac bus voltage.
2. Tap operation at 500 MW (at the ac terminal), at the required dc current and dc voltage and 500 kV ac bus voltage.
3. Inverter operation at 3500 MW (at the ac terminal) at the required dc current and dc voltage and 500 kV ac bus voltage.

Table 23 Total Bipole Station Losses

	Rating		
DC Load / Rating	Rectifier XXX MW (required to deliver 500MW to the tap and 3500MW to the inverter at 600kV)	Tap 500 MW	Inverter 3500 MW
1.00 pu			
0.75 pu			
0.50 pu			
0.25 pu			
No Load			

The following converter load duty profile shall be assumed for calculating total average station losses to be used in bid evaluation:

- 1.00 pu power 20% of the time
- 0.50 pu power 60% of the time

- 0.25 pu power 20% of the time

Auxiliary power requirements shall be calculated from the efficiency of all motors necessary to provide the required cooling, but excluding redundant motors.

Total average station losses (TSL) shall be determined as follows:

$$TSL = 0.2 \times P_{1.0pu} + 0.6 \times P_{0.5pu} + 0.2 \times P_{0.25pu}$$

Where P_x is the total station operating loss at the x per unit load level of the required rectifier rating. Similar calculations are required for the tap and inverter stations.

11.8.1. Guaranteed Station Losses

The Contractor shall guarantee the total average bipole station losses (TSL) for the multi-terminal configuration.

The Contractor shall submit to the Owner a comprehensive loss calculation study report indicating losses derived in accordance with IEC Standard 61803 and utilizing, to the maximum extent possible, losses measured during type tests and routine tests of the various station equipment. For each applicable class of equipment defined in Section 5 of IEC Standard 61803 and for each operating state, the report shall show derivation details and identify where measured values have been used. The values of calculated losses (where measurements are not possible) shall be indicated in the equipment specification and shall indicate tolerance limits for individual items.

The total average station losses evaluated on a bipole basis (TSL) shall not be more than 15% above the guaranteed value. If the total average station losses exceeds 115% of the guaranteed value on a bipole basis, the Contractor shall replace any equipment necessary to achieve losses less than 115% of the guaranteed loss value.

11.8.2. Evaluation of Losses

For the purposes of bid evaluation and contract price adjustment, the following quantities are defined:

1. TSLP = Proposed average total station losses defined as the value of TSL in the Offeror's proposal.
2. TSLG = Guaranteed average total station losses defined as the value of TSL quoted by the contract awardee at the time of contract award.
3. TSLA = Actual average total station losses defined as the value of TSL determined from measured and derived values indicated in the loss calculation study report.

11.8.2.1. Evaluation

For bid evaluation, the capitalized cost of average total station losses (CCL) is determined as follows:

CCL = TSLP x $6888/kW

CCL will be added to the Offeror's bid price.

11.8.2.2. Payment

If the actual average total station losses (TSLA) exceed the guaranteed average total station losses (TSLG), the contract price will be reduced by the capitalized cost of the difference:

Contract loss adjustment = (TSLA – TSLG) x$6888/kW

No adjustment will be made when actual losses are less than guaranteed losses.

The Owner reserves the option to measure total station losses (TSLM) during commissioning by operating the two poles in a back-to-back configuration. Values of total station losses measured at the load levels in Table 11 XXX, above, will be used to determine the average total station losses (TSLM).

Should losses measured during commissioning exceed 102% of TSLG, the contract price will be reduced by the capitalized value of the losses that exceed 102% of TSLG determined as follows:

Contract loss adjustment = (TSLM – 1.02 x TSLG) x$6888/kW

No adjustment will be made when measured losses are less than 102% of guaranteed losses.

If TSLA exceeds TSLG and TSLM exceeds 102% of TSLG, the Owner, at its sole discretion, will determine which adjustment to apply.

11.9. Maximum Thyristor Failure Rate Guarantee

The maximum annual guaranteed thyristor failure rate shall not exceed 0.1% per 12 pulse valve group. The failure rate shall not include failures directly attributable to operating and maintenance errors.

Prior to the start of the guarantee period, any faulty thyristors shall be replaced. Thereafter, faulty thyristors may be replaced only after each twelve (12) month period. If the Contractor desires to replace thyristors within the twelve (12) month period, the guarantee period shall restart from the time the thyristor was replaced. During the guarantee period the Contractor shall replace all failed thyristors at no cost to the Owner.

The Contractor shall monitor the thyristor failure rate over a three (3) year period starting six (6) months after the conclusion of the trial operation of the station. If the average failure rate of thyristors of the bipole proves to be within the guaranteed value, the guarantee shall be considered fulfilled. If the average failure rate of thyristors of the bipole exceeds the guaranteed value, the guarantee period shall be extended by one (1) year. If the average thyristor failure rate calculated for three (3) out of four (4) years, (excluding the year with the highest thyristor failure rate), is equal to or lower than the guaranteed value, then the thyristor failure rate guarantee shall be considered fulfilled.

If the annual thyristor failure rate averaged over the best three (3) years is above the guaranteed value, the Contractor shall supply, without any additional cost to the Owner, additional spare thyristors in an amount equal to twenty (20) times the difference between the actual annual failure rate averaged over the best three (3) years and the guaranteed annual failure rate. The performance calculations shall be done for a complete bipole.

11.10. AC/DC Filter Capacitor Failure Rate Guarantee

11.10.1. High Voltage Capacitors

The Contractor shall guarantee the ac and dc filter and ac shunt capacitor unit maximum annual failure rates stated in the Proposal. The guaranteed maximum annual failure rate for each type of capacitor shall not be more than 0.2% per year.

A capacitor unit shall be considered to have failed when the number of failed elements reaches the point to activate the Level 1 alarm of the unbalance protection.

The failure of capacitors will be monitored by the Owner. The capacitor unit annual failure rate in service will be calculated based on the actual level of capacitor unit or element failures during the Performance Guarantee Period. If the actual average annual failure rate exceeds the guaranteed failure rate, the Purchaser may apply remedies stated in Section 11.3.1.

The above shall apply to each type of capacitor unit supplied individually where type refers to the unit capacitance and voltage, current, and kvar rating.

11.10.2. Low Voltage Capacitor

If the number of failures of low voltage capacitors during the three (3) year guarantee period exceeds two (2) or fifty percent (50%) of the spares, whichever is less, the Contractor shall supply a number of additional spares (at no cost to the Owner) equal to twice the number that failed during the three (3) year guarantee period.

12. Preparation For Delivery

The Contractor shall prepare the equipment, accessories, and spare parts for shipment in such a manner as to protect them from damage in transit. Any materials to be returned to the vendor after shipment or installation shall bear identification of material ownership and shipping address. Materials not so marked may be disposed.

12.1. Shipping Marks

Mark shipping packages plainly and by an indelible stencil or firmly fastened weatherproof tag with the following information:

Customer Name "Station A" e.g.
Destination
PO Number and Release Number (when applicable)
PO Item Number(s)
Quantity & Owner's location Catalog ID Number

12.2. Shipping Documents

- Within forty-eight (48) hours after each shipment, the shipping manifest and packing slip should be e-mailed to the Contracting Officer's Technical Representative (COTR).
- Include the following information on the shipping manifests and packing lists:

  a) PO number
  b) PO line item number
  c) Product name
  d) Respective Customer Catalog ID number
  e) Signature of the Contractor's authorized representative, and date of signature
  f) Gross weight/Qty

What to do if damage occurs?

Does a rep from the Contractor need to be present during unpackaging in order to verify the state of the product?

What are the insurance requirements? Is this for the Contractor to determine?

Anything specific regarding shipment of transformers and how oil is procured that will eventually be added to the transformers?

Etc.

13. Quality Assurance Requirements

13.1. Scope

This Section outlines the policies and procedures to assure that purchased equipment and materials conform to the quality requirements of this Specification and to ISO9001.

13.2. General Quality Program Requirements

All contractors are required to have a quality program instituted at the site where supplies and materials are manufactured. The Contractor's quality program is to assure that provided equipment and materials are in compliance with the requirements of referenced specifications.

If review and acceptance of the Contractor's quality program was considered as an evaluation factor for award, any subsequent changes in the contractor's quality program, after award, will be subject to the Owner's review. The program is subject to disapproval if the program is determined to fail to accomplish its objectives.

All services, materials, components and equipment covered under this Specification shall be engineered, designed, procured, manufactured, erected, commissioned and tested, at all stages, in accordance with a comprehensive Quality Assurance Program. An indicative program of quality assurance to be carried out by the Contractor for various items shall be given in the Bid.

It is the Contractor's responsibility to document and implement such agreed program for the project as a whole as well as for individual equipment. Detailed Quality Plans for manufacturing and field activities shall be drawn up by the Contractor and shall be submitted to the Owner for approval.

The Contractor shall furnish a list of approved suppliers to the Owner with their bid.

An Engineering and Design Plan shall identify the studies (as required by the specification and Contractors internal design procedures), document overall detailed design, and communicate how defining interfaces and controlling changes interface with the Quality Assurance Program. The program shall be designed to meet performance requirements of the project by achieving quality, reliability, and schedule objectives.

The Manufacturing Quality Plan shall list, in detail for each component or piece of equipment, all the various tests/inspections that are to be carried out per the requirements of this Specification and the standards mentioned herein. Additionally, the Quality Plan (QP) shall include the Quality practices and procedures followed by the Contractor's Quality Control Organization, the relevant reference documents and standards, acceptance norms, inspection documents etc., during all stages of materials procurement, manufacture, assembly, final testing/performance testing, and preparation for shipping from the factory to the project sites.

The Field Quality Plan shall detail, for all equipment, the quality practices and procedures to be followed by the Contractor's Quality Control Organization during the various stages of site activities. These activities include (but are not limited to) transport of equipment, receipt of materials/equipment, inspection of materials/equipment, storage of materials/equipment, and installation of equipment at the each project site. (See Section 13.8)

The Contractor shall also furnish, with the QP, copies of the reference documents/plant standards/acceptance norms/tests and inspection procedures etc., as referenced in the QP's. These QP's and reference documents / standards etc. shall be subject to the Owner's approval without which manufacture of equipment or materials at the expense of the Owner shall not proceed.

In these approved QP's, the Owner shall identify inspection points and tests/checks which shall be carried out in the presence of the Owner's Contracting Officer's Technical Representative (COTR) and beyond which the work shall not proceed without written consent of the COTR. All deviations from the Specification, approved QP's and applicable standards must be documented and provided to the Owner for approval and disposition.

No material shall be dispatched from the Manufacturer's facilities before it is accepted subsequent to pre-dispatch, final inspection including verification of records of all previous tests/inspections by the Owner's COTR, and duly authorized for dispatch via issuance of Material Inspection Clearance Certificate. Before making request for issuance of the certificate, the Contractor shall ensure that approval of type tests, data sheets, drawings etc. has been obtained from the Owner. All materials used by or supplied by the Contractor] shall be accompanied by valid materials certificates and tests and inspection reports. These certificates and reports shall indicate the sheet numbers or other such acceptable identification numbers of the material. The material certified shall also have the identification details stamped on it.

All vendors proposed by the Contractor for procurement of materials, components, and equipment shall be subject to the Owner's approval. Quality Plans of all Owner-approved vendors shall be supplied, and approved by the Owner and shall form part of the purchase order between the Contractor and the vendor.

As a part of quality assurance of the engineering and design, technical review meetings (TRM) shall be conducted between the Owner's COTR and/or their consultants/representatives and the Contractor and/or their sub-Contractor(s). The duration and cycle of such TRMs shall be as frequent as required to meet specified time schedules. The TRMs shall be held at a mutually agreed upon location.

The Contractor shall agree upon a schedule of submission of documents concerning the Quality Assurance Program within two months of the effective date of the Contract. This schedule shall indicate the list of mutually agreed items/equipment for which QP's shall be submitted by the Contractor and the dates for the submissions. The Contractor shall ensure that the submissions are timed such that all relevant approvals are obtained from the Owner in a timely manner before the commencement of the manufacture for any equipment.

The documents that shall be submitted by the Contractor to the Owner for review and approval as per the agreed schedule include:

- Quality Assurance (QA) Manuals
- QP's (Inspection & Test Plans) for all equipment/materials manufactured in the Contractor's works and/or in the sub-Contractor's works
- Purchase Specifications for equipment procured from sub-contractors
- Contractor's assessment reports of their sub-contractors
- Field QP's for all on-site activities (See Section 13.8)
- Reference documents referred to in QP's
- Erection, commissioning, operation and maintenance manuals

13.3. General Quality Program Requirements Inspection and Test Plan Requirements

An Inspection and Test Plan shall be provided within 30 days after Award of Contract. The plan shall encompass all areas of production including materials, components, sub-assemblies, end items, and preparation for delivery. The Inspection and Test Plan shall include:

- Production flow and inspection stations beginning with receiving inspection
- Characteristics to be inspected
- Cross-reference to detailed inspection and test procedures
- Sampling plan
- Coordination of inspection and tests to be witnessed by the Owner or Owner's COTR
- Data to be submitted to the Owner
- Nonconformance instructions

13.3.1. Inspection and Testing

The following Sections outline the procedures for inspection and testing

13.3.1.1. Advance Notice

If the Owner elects to witness inspections and tests designated in this Specification, the Contractor shall not proceed without the Owner's COTR being present for observation unless a waiver is granted by the designated COTR. The Contractor shall coordinate with the COTR by direct personal contact not less than 14 calendar days before the date when supplies or equipment will be ready for inspection or tests. If inspection and test will be performed outside the continental United States, 30-calendar days advance notice shall be furnished. Dates for inspection and tests shown on the submitted events schedule do not fulfill this advance notice requirement.

13.3.2. Inspection and Test Reports

Copies of the Inspection and Test Reports required by the Specification or the Contract shall be delivered to the COTR within 14 calendar days after completion of tests. Reports shall include, but not be limited to, the following:

- Description of supplies or equipment
- The Owner's contract number, delivery order number (when applicable), and item number, applicable Owner Technical Specification, quantity, serial numbers, and reference to applicable drawings by number, revision, and date
- When, where, and how each of the tests were performed, and standards used for test procedures and results, including pass/fail criteria, and non-conforming characteristics shall be identified
- Test data obtained during the testing shall be provided. Certifications of compliance are not acceptable.
- List of personnel performing and witnessing the tests and signature of a Contractor's representative

13.3.3. Quality Assurance Document Package

The Contractor shall submit the following QA documents to the Owner. These documents shall be in accordance with the approved QP's for the applicable equipment. The documents shall include, but not be limited to, the following:

- Routine test reports & acceptance test reports
- Type test reports
- Quality records, etc. corresponding to items identified in the QP
- Inspection reports for customer inspection points
- Reports on repair/modification carried out to make the item/equipment acceptable
- Non-destructive examination result reports including radiography interpretation reports, wherever applicable

The above documents are required to be submitted with the required number of copies within three weeks after dispatch of equipment.

13.3.4. Measuring and Test Equipment

All test and measurement equipment shall be periodically calibrated against a standard of greater accuracy and a known relationship to U.S. national standards or other basic standards.

13.4. <u>Prior Data</u>

Design or qualification test reports that meet the requirements of the Inspection and Test Reports and are based on tests performed prior to Contract award, may be accepted unless stated otherwise in the Specification, provided that the test requirements and the equipment design have not changed and that the time limitations stated in paragraph "1" below are met. If the design tests were performed and test reports submitted on a previous owner's contract, the Contractor may reference that contract, and furnish copies of the reports as specified in paragraph Inspection and Test Reports. If the previous contract that the reports were submitted on is within five years of award of Contract, a letter referencing that contract may be submitted in lieu of design test report submittal. Partial sets of design test reports will not be acceptable. Data shall be submitted at least 15 days prior to production, or within 45 calendar days after award of Contract, whichever is earlier. If the reports are not complete, do not meet the Owner's requirements, or if the equipment being furnished includes design changes from the equipment tested, the Owner may require performance of the specified tests, at no additional cost to the Owner. The Contract award shall not be construed as acceptance of any test report submitted prior to award.

1. Prior data will only be accepted for design tests performed within the five years prior to award of Contract. Design tests that have not been performed during this five year period shall be repeated.
2. Any and all exceptions to paragraph "1" shall be requested by the Contractor at the time proposals are submitted and must be approved by the Contracting Officer prior to award of Contract.

13.5. Certifications

Certifications of compliance, when required by the Specification and in the quantity specified, shall be delivered to the COTR and shall meet the following requirements:

- Certifications shall contain a statement that the supplies being offered have been found to be in compliance with the requirements of the Specification.
- The COTR shall approve on the basis of a personal review of the supporting documentation.
- Data and other documentation supporting the certification shall be on file and shall be available for review and verification by the COTR before or after release of equipment or materials.

13.6. Quality Assurance Program Audit

The Owner reserves the right to carry out a quality audit of the systems and procedures of the Contractor's and their sub-contractor's (sub-vendor's) quality management and control activities. The Contractor shall provide all necessary assistance to enable the Owner carry out such audit.

13.7. Construction Site Quality Assurance Requirements

13.7.1. Quality Requirements

This Section describes the quality assurance and quality control requirements that shall be implemented at the converter stations.

The Contractor shall provide a safety plan in compliance with the Owner's requirements as specified in "Safety, Health and Security Plan". The Owner also reserves the right to perform quality inspections by the Owner's inspectors under the direction of the Owner's Senior Construction Manager at any time, without notice. Quality issues will be brought to the immediate attention of the Contractor's Quality Control Manager. Safety issues will result in an immediate work stoppage.

13.7.1.1. References

American Society for Testing and Materials (ASTM)

ASTM C 1021 - Standard Practice for Laboratories Engaged in Testing of Building Sealants; 2008

ASTM C 1077 - Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation; 2007a

ASTM C 1093 - Standard Practice for Accreditation of Testing Agencies for Masonry; 2007

ASTM D 3740 - Standard Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction; 2004a

ASTM E 329 - Standard Specification for Agencies Engaged Construction Inspection and/or Testing; 2007a

ASTM E 543 - Standard Specification for Agencies Performing Nondestructive Testing; 2008

13.7.2. Quality Control

- Contractor Responsibilities: Unless otherwise indicated, provide specified quality control services.
    - Unless indicated as the Owner's responsibility, engage qualified inspection or testing agencies to perform quality-control services and implement the Quality Control Plan.
    - Notify the Owner's Contractor Site Manager and the inspection or testing agencies at least 24 hours in advance of time when work that requires testing or inspecting will be performed.
    - Submit certified, written reports of each quality control service.
    - Testing and inspecting requested by Contractor and not required by the Contract Documents are Contractor's responsibility.
- Manufacturer's Field Services: Where specified, engage a factory-authorized service representative to inspect field-assembled components and equipment installation, including service connections; report results in writing.
- Retesting and Re-inspecting: Provide additional quality control services, including re-testing and re-inspecting for work that is revised or fails to comply with Contract requirements.
- Testing Agency Responsibilities: Provide qualified personnel to perform required tests and inspections.
    - Notify the Contractor Site Manager //8promptly of irregularities or deficiencies observed in the work during tests and inspections
    - Interpret tests and inspections and state in each report whether tested and inspected work complies with or deviates from requirements
    - Submit a certified written report, in duplicate, of each test, inspection, and similar quality-control service through Contractor.
    - Do not release, revoke, alter, or increase requirements of the Contract Documents or approve or accept any portion of the work
    - Perform only the duties necessary to conduct the inspection and testing
- Approval of the QC Plan: Obtain approval of the QC Plan prior to the start of construction. The Contracting Officer may require changes in the QC Plan and operations as necessary, including removal of personnel, to ensure the specified quality of work is achieved.

13.7.2.1. Quality Control Program Requirements

The Contractor shall establish and maintain a Quality Control (QC) Program consisting of:

- QC Organization,
- QC Plan,
- Testing,
- Completion inspections,
- QC meetings,

- Submittal review and approval, and
- QC certifications and documentation necessary to provide materials, equipment, workmanship, fabrication, construction and operations, which comply with the requirements of this Specification.

The QC Program shall cover on-site and off-site work and shall be keyed to the work sequence.

Preliminary Work Authorized Prior to Approval: The only work that is authorized to proceed prior to the approval of the QC Plan is mobilization of storage and office trailers, temporary utilities and surveying, unless otherwise directed by the Contractor Site Manager.

Notification of Changes: Notify the Contractor Site Manager of any proposed QC Plan change, including changes in the QC Organization personnel. Send written notification a minimum of seven days prior to a proposed change. Proposed changes are subject to acceptance by the Owner's Senior Construction Manager.