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1 GENERAL

1.1 Purpose

1.1.1 The main purpose of this document is to describe functional requirements to the HV equipment and its interfaces for the Norfolk HVDC VSC link. This document covers both onshore and offshore equipment.

1.1.2 All HV equipment shall be robust and reliable throughout the HVDC links specified design lifetime, suitable for operating in onshore and offshore stations. The HV equipment shall be designed to specifications necessary to the operation of each converter station in all possible operation conditions with the lowest possible need for maintenance, but shall still comply with the specified requirements for availability, losses and transmission capacity for the complete HVDC transmission system.

1.1.3 The scope of supply includes:

- engineering, production, specification and testing
- transportation to site
- complete erection
- the complete documentation as per this specification
- supply of necessary tools, spare parts, documentation, manuals and test certificates.

1.1.4 Level of information

This document refers to the document regarding Electrical Philosophy. Documents containing project-specific data refer to this document. Such data documents contain site-specific requirements for a certain wind farm or component.

In this document, the Contractor shall find all the necessary information regarding:

- HSE (oil treatment and containment tank in case of leakage, etc.);
- Compatibility with adjacent systems (interface with the converter, interface with the WF, interfaces in the onshore portion);
- Operation & Maintenance, necessary spares and tools;
- Quality control (FAT, SAT).

1.2 Applicable Standards, Norms & Regulations

The following ***Table 1*** describes the technical regulations applicable to this system or subsystem.

Standard	Title / Description
IEC 62271-1	HV Switchgear and Controlgear Part 1: Common Specifications
IEC 62271-100	HV Switchgear and Controlgear Part 100: AC Circuit Breakers
IEC 62271-200	Switchgear and Controlgear Part 200: - (for voltages below 52kV)
IEC 62271-203	Switchgear and Controlgear Part 203:
IEC 60376	Specification of Technical Grade Sulphur Hexafluoride (SF6) for use in Electrical Equipment (if applicable)
IEC 60480	Guidelines for The Checking and Treatment of Sulphur Hexafluoride (SF6) Taken from Electrical Equipment and Specification for its Re-use (if applicable)
IEC 62271- 4	High-voltage switchgear and control gear - Part 4: Handling procedures for sulphur hexafluoride (SF6) and its mixtures
IEC 62271 - 110	HV switchgear and control gear Part 110: Inductive load switching
IEC 62271-101	High-voltage switchgear and controlgear - Part 101: Synthetic testing
IEC 60376	Specification of technical grade sulphur hexafluoride (SF6) and complementary gases to be used in its mixtures for use in electrical equipment
IEC 60076-6	Power Transformers – Part 6: Reactors
IEC 62001-4	High-voltage direct current (HVDC) systems – Guidance to the specification and design evaluation of AC filters
IEC 62001	High-voltage direct current (HVDC) systems - Guidance to the specification and design evaluation of AC filters
IEC 60871	Shunt capacitors for AC power systems having a rated voltage above 1000V
IEC 60358	Coupling capacitor and capacitor dividers.
IEC 61869-1	Instrument Transformers – Part 1: General requirements
IEC 61869-2	Instrument Transformers – Part 2: Additional requirements for current transformers

IEC 61869-4	Instrument Transformers – Part 4: Additional requirements for combined transformers – (only in case combined transformers are used)
IEC 61869-5	Instrument Transformers – Part 5: Additional requirements for capacitor voltage transformers
IEC 61869-11	Instrument Transformers – Part 11: Additional requirements for low power passive voltage transformers
IEC 61869-14	Current transformers for DC applications
IEC 61869-15	Voltage transformers for DC applications
IEC 62271	HV Switchgear and Controlgear
IEC 60099-4	Surge Arresters – Part 4: Metal-oxide arresters without gaps for AC systems
IEC 60099-5	Surge Arresters – Part 5: Selection and Application recommendations
IEC 60099-9	Surge Arresters – Part 9: Metal-oxide arresters without gaps for HVDC Converter Stations
CIGRE TB034	Guidelines for the Application of Metal Oxide Arresters without Gaps for HVDC converter stations – (only used as support)
EN 50180	Bushings above 1 kV up to 52 kV and from 250 A to 3,15 kA for liquid filled transformers – (only to be used within applicable voltages)
EN 50181	Plug-in type bushings above 1 kV up to 52 kV and from 250 A to 2,50 kA for equipment other than liquid filled transformer – (only to be used within applicable voltages)
EN 50299	Oil-immersed cable connection assemblies for transformers and reactors having highest voltage for equipment Um from 72,5 kV to 550 kV
IEC 60137	Insulated bushings for alternating voltages above 1000 V
IEC 60168	Tests on indoor and outdoor post insulators of ceramic material or glass for systems with nominal voltages greater than 1000 V
IEC 60815	Selection and dimensioning of high-voltage insulators intended for use in polluted conditions
IEC 61462	Composite hollow insulators - Pressurized and unpressurized insulators for use in electrical equipment with rated voltage greater than 1 000 V - Definitions, test methods, acceptance criteria and design recommendations
IEC 65700	IEC 65700 Bushings for DC application
EN 50341-1	European Standard for Overhead electrical lines exceeding AC 45 kV

European Code 3,	EN 1993 Design of Steel Structures
European Standard ENV 1090-1.	Execution of Steel Structures - Requirements for conformity assessment of structural components'.
European Standard ENV 1090-2	Execution of Steel Structures – Technical Requirements for Steel Structures'.

Table 1 List of applicable standards, norms and regulations

1.3 References

The following ***Table 2*** describes all references used in this document.

No	Document No.	Description
[1]	HVDC-VAT-Z-FD-0001	General Basic Design Concept
[2]	HVDC-VAT-E-FD-8901	Electrical Basis of Design
[3]	HVDC-VAT-E-FD-8906	Studies & Model Concept
[4]	HVDC-VAT-E-FD-8902	Control and Protection Concept
[5]	Onshore HVDC-VAT-E-FD-8001_1	Low voltage distribution system – Onshore
[6]	HVDC-VAT-E-FD-8001_2	Low voltage distribution system – Offshore
[7]	HVDC-VAT-A-AA-0002	Terms & Abbreviations

Table 2 References to additional documentation

1.4 Document Metadata Tags

High Voltage Equipment, Switches, Disconnectors, Voltage transformers, Current transformers, Insulators, Bushings, Gas insulated switchgear, Earth switches, Circuit breakers

2 General

The Contractor shall design and provide all necessary AC & DC equipment including busbar at Onshore Substation (ONS) up to the 400kV AC cable sealing end on the AC side and up to HVDC cable sealing end on the DC cable sealing end on the DC side. For Offshore Substation (OSS), the Contractor shall provide all necessary AC & DC equipment up to the 66kV Inter Array Cable sealing end. All switchgear equipment shall be designed to ensure satisfactory operation and maintenance. Unless otherwise stated, all auxiliary voltages must be in accordance with Low voltage distribution system – Onshore HVDC-VAT-E-FD-8001_1 and Offshore HVDC-VAT-E-FD-8001_2.

The Contractor shall provide all disconnectors and earth switches to enable safe and efficient maintenance of the converter station without the need for the shutdown of equipment that does not require maintenance. Switching devices shall be provided to enable the converter station to be isolated from the dc cables and from the ac network, and to be securely grounded. The bus work, switches and other equipment shall be rated for the maximum continuous and short time overload ratings of the HVDC system. The buswork, switches and other equipment shall not be damaged by the maximum possible fault currents whether caused by fault current or by incorrect operation of the switch. The station layout is arranged by the Contractor such that the manual operation can be performed from a safe location.

2.1 Coating

All components supplied shall be given a sufficient protective treatment to reduce corrosion to a minimum. Note all the paint system shall as a minimum meet class C4 as per ISO 12944. No cutting or drilling of holes is permitted after galvanizing unless special repair methods are applied. Such methods shall be accepted by Employer. All materials used for painting shall be eco-friendly. The surface preparation for the paint systems shall be in compliance with the paint manufacture recommendations. When the work is finished, it shall be inspected jointly by the Contractor and the Employer, and it shall be approved by the Employer.

3 Gas Insulated Switchgear (GIS)

3.1 General

3.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in "Electrical Basis of Design - HVDC-VAT-E-FD-8901".

3.1.2 Rated power

The rated power shall be defined by Contractor. The rated power of the Gas Insulated Swichgear (GIS) shall be compliant with all the operating ranges determined by the VSC converter designer.

3.1.3 GIS Requirements

The GIS shall comply with:

- IEC 62271-1 HV Switchgear and Controlgear Part 1: Common Specifications
- IEC 62271-100 HV Switchgear and Controlgear Part 100: AC Circuit Breakers
- IEC 62271-200 HV Switchgear and Controlgear Part 200 – In case of <52kV:
- IEC 62271-203 HV Switchgear and Controlgear Part 203 – In case of >52kV:
- IEC 60376 - Specification of Technical Grade Sulphur Hexafluoride (SF6) for use in Electrical Equipment (if applicable)
- IEC 62271-4 - High Voltage Switchgear and Controlgear – Part 303 Use and Handling of Sulphur Hexafluoride (if applicable)
- IEC 60480 - Guidelines for The Checking and Treatment of Sulphur Hexafluoride (SF6) Taken from Electrical Equipment and Specification for its Re-use (if applicable)

In the interest of safety, reliability and serviceability, the offered switchgear shall meet the following minimum requirements:

- The GIS design shall permit installation, extension, safe operation and maintenance (preventative and corrective) with a maximum of one busbar section and its associated feeder circuits out of service simultaneously.
- The GIS switchgear shall be of modular design offering high degree of flexibility. Each module shall be completed with SF6 gas/vacuum/air insulated circuit breaker (with manual and motorized operation), disconnectors, maintenance grounding switches, fast earthing switches, voltage transformers, current transformers, bus and elbow sections,

cable end enclosures, local control cubicle and all necessary components required for safe and reliable operation and maintenance.

- The sections shall be arranged to minimize the quantity of gas that has to be evacuated and then recharged before and after maintaining any item of equipment.
- The design of the enclosure assemblies shall be such that in the event of a fault, the damaged items can be replaced with minimum disturbance to the adjacent compartments.
- In GIS where applicable, all the three phases of the busbars and associated equipment are to be encapsulated in a single gas filled metallic enclosure. If not applicable Contractor shall clearly state why.
- The busbars shall be sub-divided into compartments including the associated busbar load breaker or bus sectionalising & earthing.
- All grounding connections must remain operational during and after an arc fault. Moreover, proper grounding for mitigation of over voltages during disconnector operation shall be included.
- The number of transport/shipping splits shall be minimized to keep installation time of GIS to a minimum.
- The contours of energized metal parts of the GIS and any other accessory shall be such as to eliminate areas or points of high electrostatic field concentrations. Surfaces shall be smooth with no projection or irregularities, which may cause corona.
- Arc faults caused by external reasons shall be positively confined to the originating compartment and shall not spread to other parts of the switchgear. In case of any internal arc fault in a busbar section, busbar load breaker or circuit breaker (where applicable), repair works must be possible without interrupting complete power transfer and it must be possible keep at least one busbar section and the undisturbed bays connected to this bus section in operation, in case of single busbar only the undisturbed bays connected to the undisturbed busbar section in operation.
- Each bay module should be equipped with suitable arrangement for easy dismantling and refitting during maintenance/service without disturbing other units.
- The modular design of the GIS switchgear is to be implemented so that, the minimum on-site dielectric tests shall be needed after maintenance, repair after failure or extension.
- The GIS switchgear shall be of indoor type.

The Contractor shall co-ordinate with the Inter Array cable Contractor and DC cable Contractor to provide correct type of interconnection facilities on the switchgears

For Offshore Substation, the WTG-side GIS Transformer feeder shall have separate cores available for the connection of PQM (for e.g. ELSPEC) as specified by the Employer in C&P HVDC-VAT-E-FD-8902. The assembled equipment shall be capable of withstanding the electrical, mechanical and thermal ratings of the specified system. All joints and connections shall withstand the forces of expansion, contraction, vibration and without deformation or malfunction and leakage.

3.2 Design

The division of gas compartments shall be done in such a way that the pressure-rise in a gas chamber, e.g. caused by an arc fault current does not reach a value which can burst the enclosure. Any omission of bursting plates on the gas compartments shall be justified by the Contractor. Operation of one busbar section shall be possible even if one incoming transformer feeder is faulty.

The design shall be such that where access is required to a gas zone (compartment) for preventive or corrective maintenance the adjacent gas zones on either side of that compartment shall be reduced to atmosphere pressure to avoid personnel working against the fully pressurised compartments. Alternative solutions could be proposed by the Contractor for Employer's review and the proposed methods shall not pose any safety issues for maintenance personnel. Reducing the gas pressure of the zone containing the point(s) of isolation is not acceptable. The gas tight support insulating barriers shall be capable of withstanding a pressure differential of atmospheric pressure on one side, and on the other side a pressure equal to the design gas pressure or the maximum gas pressure under conditions of an internal fault, if this is greater. Buffer zones may be required, for example between circuit breakers and busbar selector disconnectors.

The Contractor shall calculate the requirements to the size of pressure relief (rupture disk) of the switchgear. Overpressure created by arcing within the enclosure shall preferably be relieved by means of bursting discs venting into the atmosphere. The method of pressure release shall prevent permanent distortion of adjacent enclosures. Pressure relief by collapse of internal gas barriers, is not acceptable. The arrangement of any pressure relief device shall be such that any expulsion of disc debris or gas will be directed in a manner that shall not endanger any personnel or adjacent equipment. Relief vents shall be provided with deflectors or vent pipes as appropriate to satisfy this requirement.

All gas zones shall be filled to the design pressure with pure SF_6 gas to EN 60376.Each gas density device shall be connected to the gas compartment via a self-sealing valve to facilitate easy removal of the device for maintenance. The pressure in each gas compartment shall be indicated and monitored, e.g. with a manometer and /or density monitor. The devices shall provide continuous and automatic monitoring of the gas pressure and alarm thresholds of the gas..

The SF6 gas monitoring device shall have two supervision and alarm settings. These shall be set so that, an advanced warning can be given that the gas density/pressure is reducing to an unacceptable level. It shall be ensured that there is no chance of the gas liquefying at the lowest ambient temperature.

The gas monitoring device shall monitor at least the following status, locally and remotely:

- “Gas Refill” Level- This will be used to enunciate the need for gas refilling.
- “Breaker Block” Level- This is the minimum gas density at which the manufacturer shall guarantee the rated fault interrupting capability of the breaker. At this level, the device contact shall trip the breaker and block the closing circuits.
- “Over pressure” alarm level- This alarm level shall be provided to indicate abnormal pressure rise in the gas compartment.

An audible alarm scheme to warn operators of a major loss of SF6 gas shall be provided within the GIS hall. Visual indication(s) shall be provided outside at all entrances leading to the GIS to indicate an alarm has operated.

The gas barrier insulators sealing to the conductors and the enclosure wall shall be designed to withstand the maximum pressure difference that could occur across the barrier, i.e. maximum operating pressure at one side while a vacuum is drawn at the other side.

When installed, the switchgear shall be filled with gas to the manufacture operating pressure with a moisture content not exceeding the permissible content, cf. IEC 62271-200 or IEC 62271-203.

An additional volume of SF6 gas (spare) for compensation of possible losses during maintenance and services for the life time shall be supplied by the Contractor in sealed cylinders with a uniform size. The volume of spare gas shall be estimated with environmental and availability considerations in mind.

All gas compartments shall be fitted with filter material which absorbs the residual moisture and moisture entering inside the enclosure. Filters in gas compartments with switching devices must also be capable to absorb the gas decomposition products resulting from the switching arc.

Gas tight seals shall be provided between enclosures and at positions where sliding or rotating shafts enter a compartment. The material for the seals shall be non-deteriorating and the seals shall be capable of withstanding the gas pressures of the compartments under all service conditions. The gas seals shall remain serviceable for at least the design lifetime of the substation without exceeding the specified gas leak rate.

All apparatus necessary for filling, evacuating, and recycling the SF6 gas into and from the switchgear equipment, as well as all necessary pipes, couplings, flexible hoses, tubes and valves for coupling to the switchgear equipment together with a detailed description of their procedure shall be supplied by GIS supplier, in order to ease any maintenance work.

It shall be tested and verified that the maximum gas loss does not exceed 0.5% (Percentages by weight) per gas compartment per year and replenishment of gas shall not be necessary for the life time of the project.

3.2.1 Insulation level of the GIS

Please refer to the document "HVDC-VAT-E-FD-0001 - Electrical of Basic Design."

3.2.2 Partial discharge monitoring

This specification does not require that online partial discharge monitoring equipment is supplied and installed along with the installation, but that the partial discharge sensors shall be made available to connect to an external monitoring device without requiring an outage to any part of the switchgear. The partial discharge sensors shall have sufficient sensitivity to detect an apparent charge of 5pC at any part of the GIS to identify possible material and manufacturing defects. The Contractor shall propose partial discharge sensors and its position to enable effective detection of partial discharge. For permanent installed sensors, it shall be provided according to Contractors design and knowledge, each section of the busbar, Bus Sections and Bus Couplers (where applicable). One sensor shall be provided for each phase where the phases are in an individual metal enclosure.

The Contractor shall supply suitable test equipment, interface transducers and connections to fully test the equipment offered. The GIS shall be demonstrated to be partial discharge free (< 5pC) once commissioned.

3.2.3 Sulphur Hexafluoride Gas (SF6) & Handling Equipment

A mobile gas handling plant for filling, evacuating, and processing the SF6 gas in the switchgear equipment shall be supplied to enable any maintenance work to be carried out. The plant shall include all the necessary gas cylinders and fittings for temporarily storing the evacuated SF6 gas as well as any other gases that may be used in the maintenance process.

Self-sealing valves shall be used to facilitate easy connection and removal of all hoses to gas filling points and gas handling and storage equipment.

The Contractor shall submit a procedure outlining their proposed SF6 Safe Systems of Work for work on the GIS

3.2.4 GIS – Circuit breakers

See section 4 CB

3.2.5 GIS – Disconnectors

GIS disconnectors shall be provided with lockout facilities to prevent operation at less than the minimum functional pressure or density. See also section 5

3.2.6 GIS – Earth Switches

The earth switches may require to be closed onto the de-energised busbars to mitigate trap charges. In this case, all busbar sections shall be provided with an earth switch suitably rated to close onto to a live busbar, neither degrading nor damaging adjacent chambers, with fully rated short circuit making capacity as per IEC 62271-102 Class E1 or higher. If Earth switches at cable entry points to GIS substations are required to closing onto an energised circuit, then it shall be rated as per IEC 62271-102 Class E1. The Contractor shall select either Class E0 or Class E1 depending upon the operational procedures of the electrical network.

3.2.7 GIS – Local Control Cubicle

Local control cubicles are to be supplied as part of the contract to operate primary equipment from the GIS hall. The GIS shall also be controllable from local and remote control via Substation Control System

The primary equipment shall be designed to allow electrical and mechanical interlocks where required.

Any plug and socket cable connections between switchgear sections and their associated local control cubicles shall be provided with a secure means of locking the connection to prevent inadvertent disconnection. Integrity of such connections shall be supervised at all times.

3.2.8 GIS – Cable connection

Contractor shall include testing points that allows Employer to test cables connecting to the GIS without the GIS influencing the test results.

3.3 Testing

It shall be possible to test all gas monitoring relays without deenergizing the primary equipment and without reducing pressure in the main section. Disconnecting type plugs and sockets shall be used for test purposes; the pressure/density device shall be suitable for connecting to the male portion of the plug. Two potential free electrical contacts shall be provided with any alarm condition.

3.3.1 Inter-array Cable Testing

Contractor shall provide testing that Employer can use to test Employers Inter-array cables. The Testing point shall allow Employer to practically connect into the GIS and test the cables. These testing point shall not restrict any necessary cable test. Hence testing from the back end of the T connectors shall not be used unless Contractor provides proof that no other solutions are possible. The tests Employer expect to apply are as per the following sub section but not limited to them.

NOTE: AS PER EALIER DISCUSSIONS (DECISION PAPER 074) CONTROCTOR HAS AGREED TO SUPPLY RELEVANT IAC TESTING POINT WITHOUT ADDED COST TO EMPLOYER. FURTHERMORE EMPLOYER WILL SUPPLY IAC T - CONNECTORS INCLUDING RELEVANT 66KV SURGE ARRESTOR. A STUDY WILL BE EXECUTED DURING DETAIL DESIGN TO FINALISE SURGE ARRESTOR VALUES TO SUPPORT EMPLOYER WITH PURCUREMENT PROCESS.

3.3.1.1 AC Voltage Test (Per string/Per cable Section) Withstand Test:

An AC voltage withstand test at 2xU0= 72 kV (r.m.s.) for 1h with a frequency between 10Hz and 500Hz in accordance with IEC 63026shall be performed. No breakdown shall occur.

Partial Discharge and Tan δ Measurement: Tan δ and Partial discharge shall be measured and recorded during the AC voltage test.

- Tan δ measurement shall be performed at U0 and results shall comply with IEC63026 and Cable Manufacturer acceptance Criteria for new cables.
- Partial discharge technology shall be agreed with the Employer prior to the test and PD shall be measured based on IEC 60270 and IEC 60885-3 during the whole withstand test at each 0.2U0 increments (starting from 0.2U0 up to 2U0). The number and locations of the PD sensors shall be defined in a way that can cover the whole length of the test object.
- PD calibration shall be carried out to identify the background noise level. No Partial Discharge shall be detected above the background noise level below and equal to 1.5U0 within the whole test object.
- If PD inception voltage is above 1.5U0 and PD value is in excess of 500pC, the Contractor shall carry out remedial works to locate and clear the source of PD and the affected section shall be retested. The Contractor shall be able to pinpoint the exact location of the PD(with 10m accuracy).

Alternative:

As an alternative the Contractor may propose a test with DAC technology to the Employer for approval based on IEEE 400.4 and IEC 60060-3.

- The DAC test shall follow below minimum requirement:
- Voltage level for max of 2U0 starting from 0.2U0 (with 0.2 increments)
- Min 50 excitations from 0.2 to max 2U0 for PD and Tan Delta (5shots at each increments)
- Min 50 excitations at max 2U0 for withstand test (with PD monitoring)
- Frequency between 20Hz to 500Hz,
- PD Mapping using TDR analysis method for localization of PD events.
- No breakdown shall occur during the DAC test. The PD pass/fail criteria shall follow the same requirement as above.

After AC high voltage test, test object shall be fully discharged using an approved solution ensuring that a minimum required discharge time specified by the Cable Manufacturer and accepted by the Employer will be achieved.

- A 10kV Insulation Resistance (IR) test shall be performed for 5min after the completion of the withstand test and results shall be recorded after 1min, 2min and 5min and compared with the IR test results before the AC voltage test. The dielectric ratio shall increase over time. (Not required after DAC test).

3.3.1.2 Soak Test (Per String/Per cable section)

4 A 24 h soak test at U0 will be performed by the Employer.AC Circuit Breakers

4.1 General

4.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in “Electrical Basis of Design - HVDC-VAT-E-FD-0001”.

4.1.2 Rated power

The rated power shall be defined by Contractor. The rated power of the Circuit breaker shall be compliant with all the operating ranges determined by the VSC converter designer.

4.1.3 ACCB Requirements

The Circuit breakers shall comply with:

- IEC 62271-1 HV Switchgear and Controlgear Part 1: Common Specifications
- IEC 62271- 4 High-voltage switchgear and control gear - Part 4: Handling procedures for sulphur hexafluoride (SF6) and its mixtures
- IEC 62271 - 110 HV switchgear and control gear Part 110: Inductive load switching
- IEC 62271-100 HV Switchgear and Controlgear Part 100: AC Circuit Breakers
- IEC 62271-101 High-voltage switchgear and controlgear - Part 101: Synthetic testing
- IEC 60480 Guidelines for the checking and treatment of Sulfur Hexafluoride (SF6) taken from electrical equipment and specification for its re-use
- IEC 60376 Specification of technical grade sulphur hexafluoride (SF6) and complementary gases to be used in its mixtures for use in electrical equipment

Outdoor circuit breaker shall preferably have composite insulators and shall be of the non-helical type. Circuit breakers shall have two opening coils on different magnetic systems.

The CB with spring-stored energy operating mechanism are preferred. It shall be possible to tighten the spring manually in case of power failure.

The CB to be fitted with a stainless steel or aluminium weatherproof mechanism and control cubicle containing the operating mechanism, auxiliary switches, electrical interlocks, ON/OFF indicator, local control switch and local/remote changeover switch with padlocking facilities, SF6 gas control and monitoring equipment and complete in all details, including specialist tools. Circuit breaker to be suitable for auto-reclosing and shall incorporate a lock out facility for low gas density.

Circuit breakers shall have two electrically separated tripping circuits and shall be able to switch off correctly even if both circuits are energized simultaneously. The two circuits shall be kept separate in cables, multiple plugs, ducts, etc. to the extent possible. It shall be equipped with anti-pumping function and in addition, single pole operated circuit breakers shall have phase discrepancy control. Circuit breakers shall be prepared for single pole closing operation unless previously agreed with Employer, Contractor shall provide relevant information to deviate from requirement. The single pole closing operation shall be convertible to three pole closing operation. It shall be equipped with a point of wave controller to control the breaker operation. In case TSO Inrush requirements can be met by three pole operation Employer would prefer three pole operation. The POW controller shall be programmed according to system studies and be fine-tuned at site during commissioning. The POW for controlling transformer in-rush currents shall measure/calculate the residual flux in the transformer and calculate the appropriate point on wave for switching each phase. In case residual flux calculation are not used this shall be approved by Employer. The POW shall be capable of an accuracy of at least ±1ms around the target point on wave. The required accuracy shall be achieved at all operating temperatures and across the full range of control voltage.

Circuit breakers for capacitive current switching shall be class C2 in accordance with IEC 62271-100.

The design of the circuit breaker shall be such that inspection and replacement of contacts, nozzles, molecular sieves and any worn or damaged component including replacement of an entire circuit breaker shall be conducted with a minimum of outages.

The circuit breaker shall be fitted with reliable open/closed position indicators easily visible from ground level. The impulse and steady state noise levels of the circuit breaker during mechanical operations shall not exceed the limits specified by relevant health and safety regulations. A suitably sized molecular sieve shall be used in the circuit breaker tank to absorb any moisture and contaminants till next service of CB. A fail safe three-stage gas pressure alarm and lock out system with local and remote indications shall be provided on each circuit breaker

4.2 Design

In the circuit breaker operating mechanism it shall be possible to set the control to local/remote in case of AIS. Furthermore when local control is chosen, no interlocking must interfere with the operation. The local/remote switch shall have a separate individual alarm. The light and heating shall be equipped with a separate power supply different from the main motor power supply. The light and heating power supply shall have a separate individual alarm apart from the main alarm. In case of GIS light can be omitted.

Circuit breaker status and spring charge/uncharged must be readable by a means of mechanical indication on the breaker and shall be readable locally whilst the equipment is live. It is to be furnished with push buttons for 3-phase open and close. AIS Circuit breakers shall allow manual open operation by mechanical emergency open device. Such emergency operation shall not require control voltage to be present. Circuit breakers shall be equipped with operation counters. They shall be impossible to reset and shall count one operation for every close and an open sequence. The CB shall be provided with necessary make/break signal contact for local and remote signalling, Mimic diagrams and voltage indicators.

In the case of SF6 circuit breakers, the gas leakage shall not exceed 0.5 % of the gas quantity per year and SF6 density monitor shall be installed. This requirement is applicable for each individual SF6 compartment. The SF6 gas shall comply with IEC 60376. The use and handling of SF6 gas shall comply with IEC 62271-4. It shall be possible to add SF6 gas to the circuit breaker while the circuit breaker is energised without infringing the electrical safety clearance. The density of the arc extinguishing media (for e.g. SF6) and insulation shall be monitored, the gauge shall be a gas density gauge (preferred) or temperature compensated pressure gauge. Discrete low-density alarm and low-density lockout shall be set as 2-stage indication (i.e. stage 1 : Alarm, stage 2: Inhibit trip and close). The low-density lockout shall prevent operation (either trip or close) of the circuit breaker. Low density alarm shall be set at a level in excess of the low-density lockout.

4.2.1 Insulation level

Please refer to the document “HVDC-VAT-E-FD-0001 - Electrical of Basic Design.”

4.3 Testing

The circuit breakers shall be tested in accordance with relevant IEC standards. Test relevant to the dynamic performance shall be agreed upon with Employer, hence operating sequence for test purpose shall be presented to Employer. Test reports for grading capacitors shall be available if the circuit breakers are equipped with such equipment.

It shall be noted that tests, for example mechanical endurance test, which can reduce the life expectancy, shall be performed on identical types of equipment which shall not be part of the delivery to site for installation or spares quantity.

Point on Wave (POW) switching shall be tested in accordance with Technical Report IEC 62271-302. Capacitive and reactive switching duties of circuit breakers shall be proven according to IEC 62271 – 110 with the controlled switching circuitry disabled

5 Disconnectors

5.1 General

5.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in “Electrical Basis of Design - HVDC-VAT-E-FD-0001”.

5.1.2 Rated power

The rated power shall be defined by Contractor. The rated power of the Disconnector shall be compliant with all the operating ranges determined by the VSC converter designer.

5.1.3 Disconnector Requirements

The Disconnectors shall comply with:

- IEC 62271 HV Switchgear and Controlgear

All HV, MV and LV disconnectors shall be motor-operated for remote control and shall be capable of manual operation as well. Manual operation shall only be possible in selected manual operating mode on the equipment itself. The motor circuits shall then be opened on the + and - side. The AIS disconnectors shall be dimensioned for a dynamic stress at the HV terminal of at least 3000 N. It shall be possible to operate the disconnector with simultaneous ice or wind load from connected conductors in relevant ambient condition of the installation site. The disconnector must not be damaged, and the position indications must not be changed if the current mechanical operation is blocked. The disconnectors shall be lockable by padlock in both open and closed position. When locked, the control and motor circuits shall be opened on the + and - side. The motor shall be protected by a thermal relay.

Disconnectors shall be fitted with clear and reliable position indicators as per 62271-1, visible from ground level or permanent working platforms. Disconnectors intended for bus-transfer shall comply with the bus transfer requirements of IEC 62271-102 Annex B.

Circuit disconnectors should be interlocked with the associated circuit-breaker to prevent inadvertent opening or closing of the disconnector unless the associated circuit-breaker is open.

5.2 Design

Positions of all levers and switches for manual, local and remote operation in the motor drives for disconnectors shall be monitored. An alarm shall be raised in the HMI if the drive is not ready for remote operation. In the AIS Disconnector operating mechanism it shall be possible to set the control to local/remote. Furthermore when local control is chosen, no interlocking must interfere with the operation. The local/remote switch shall have a separate individual alarm. The light and heating shall be equipped with a separate power supply different from the main motor power supply. For AIS the light and heating power supply shall have a separate individual alarm apart from the main alarm. The disconnector shall have a visible ON-OFF position marking via mechanically coupled flag and necessary make/break free signal contact for local and remote signalling. For AIS it shall be switched on via two-pole commands and off via single pole commands. It shall also be provided with means to indicate the fully open and closed positions by positive direct drive at the disconnector, Aux contacts can be used", provided the indication shall verify the main circuit are in fully open and closed position, (i.e. mechanical moment is fully complete).

The disconnectors and earth switches provided by the Contractor are mechanically interlocked. . Electrical interlocking where technical not feasible can be used however Contractor shall present the relevant equipment to be designed with electrical interlocking for Employers approval. Position indicators shall be clearly visible standing on ground level without aid.

5.2.1 HVDC cable disconnectors

A high voltage disconnector shall be provided to allow the HVDC cable to be disconnected from the converter station, e.g. during maintenance of the cable. The disconnectors shall be remotely controlled and interlocked, such that they can be opened only when the converter is blocked, and no current is flowing in the converter valves.

5.2.2 Insulation level

Please refer to the document “HVDC-VAT-E-FD-0001 - Electrical of Basic Design.”

5.3 Testing

5.3.1 AC Switches

Type, Routine and design tests for AC switches shall be carried out as a minimum in accordance with IEC 62271-102. Dielectric tests shall be performed on a completely assembled, support structure mounted switch.

5.3.2 DC Switches

Routine tests for DC switches shall be carried out as required by IEC 62271-102. Dielectric type tests shall be performed on a completely assembled switch mounted on a supporting structure. Mechanical Operation for at least one switch of each type shall be subjected to a 2000 mechanical operation test to demonstrate that the switch is capable of 2000 operations without failure of any mechanical component part. A wet for outdoor and a dry for indoor DC withstand dielectric tests shall be carried out for each type and rating of the switches.

6 Earthing Switch

6.1 General

6.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in “Electrical Basis of Design - HVDC-VAT-E-FD-0001”.

6.1.2 Rated power

The rated power shall be defined by Contractor. The rated power of the Earth switch shall be compliant with all the operating ranges determined by the VSC converter designer.

6.1.3 ES Requirements

The reactors shall comply with:

- IEC 62271 HV Switchgear and Controlgear

All HV, MV and LV earthing switches shall be motor-operated for remote control and shall be capable of manual operation as well. Manual operation shall only be possible in selected manual operating mode on the equipment itself. The motor circuits shall then be opened on the + and - side. Motor-operated earthing switches shall also be installed for safe earthing inside the valve hall. On the DC side, earthing switches shall be installed to the extent required for reliable earthing in all relevant working situations. Earthing switches shall preferably be installed in combination with the disconnectors.

Where appropriate, Earth Switches shall be fully insulated and the connection to earth brought out through the enclosure by means of an insulated bushing in order that the earth switch may be used for various test purposes.

If operation of the disconnector when its earthing switch is closed causes damage to the disconnector, the motor operating of the disconnector shall be Interlocked by electrical interlocks controlled by the earthing switch. The main circuits of the earthing switches shall be provided along their entire length with warning marking. It shall be possible to equip earthing switches with auxiliary contacts and interlocking devices when required. The earthing switches shall be lockable by padlock in both open and closed position. When locked, the control and motor circuits shall be opened on the + and - side. The motor shall be protected by a thermal relay.

6.2 Design

Earth switches shall be provided for (or close to) all through wall bushings and cable terminations in valve halls and other enclosed high voltage areas.

Positions of all levers and switches for manual, local and remote operation in the motor drives for earthing switches shall be monitored. An alarm shall be raised in the HMI if the drive is not ready for remote operation.

In the AIS earthing switch operating mechanism it shall be possible to set the control to local/remote. Furthermore when local control is chosen, no remote interlocking must interfere with the operation, however all earth switches shall be mechanically interlocked with the contiguous upstream and downstream disconnectors. Electrical interlocking where technical not feasible can be used however Contractor shall present the relevant equipment to be designed with electrical interlocking for Employers approval The local/remote switch shall have a separate individual alarm. The light and heating shall be equipped with a separate power supply different from the main motor power supply. The light and heating power supply shall have a separate individual alarm apart from the main alarm. The disconnector shall have a visible ON-OFF position marking via mechanically coupled flag and necessary make/break free signal contact for local and remote signalling. For AIS it shall be switched on via two-pole commands and off via single pole commands status shall be made available to the SCADA system.

6.2.1 HVDC cable earth switches

Earth switches shall be provided on both sides of the HVDC cable disconnectors see section 5.2.1. The earth switches shall be capable of remote and manual operation. The earth switch on the cable side of each converter station is electrically interlocked also with the cable disconnector at the remote end.

6.2.2 Valve hall Earth Switches:

The Contractor shall provide remotely controlled motor operated earthing switches in the valve hall to protect maintenance personnel. All valve winding and dc power circuit connections shall be provided with earthing switches. The earth switches shall be interlocked to prevent energisation of the converter transformers unless they are all fully open and to prevent access to the valve hall unless they are all fully closed.

6.2.3 Insulation level

Please refer to the document “HVDC-VAT-E-FD-0001 - Electrical of Basic Design.”

6.3 Testing

6.3.1 AC Switches

Routine, type and design tests for AC switches shall be carried out as minimum in accordance with IEC 62271-102.

6.3.2 DC Switches

Routine tests for DC switches shall be carried out as required by IEC 62271-102

Dielectric type tests shall be performed on a completely assembled switch mounted on a supporting structure. Mechanical Operation for at least one switch of each type shall be subjected to a 2000 mechanical operation test to demonstrate that the switch is capable of 2000 operations without failure of any mechanical component part. A wet for outdoor and a dry for indoor DC withstand dielectric tests shall be carried out for each type and rating of the switches.

7 Reactors (incl. Phase, Smoothing and filter)

7.1 General

7.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in “Electrical Basis of Design - HVDC-VAT-E-FD-0001”.

7.1.2 Rated power

The rated power shall be defined by Contractor.

The rated power of the reactor shall be compliant with all the operating ranges determined by the VSC converter designer.

7.1.3 Reactor Requirements

The reactors shall comply with:

- IEC 60076-6 Power Transformers – Part 6: Reactors
- IEC 62001-4 High-voltage direct current (HVDC) systems – Guidance to the specification and design evaluation of AC filters

The smoothing reactor, filter and AC phase reactor shall be designed to ensure satisfactory operation according to the overall performance requirements for the total system seen in “HVDC-VAT-E-FD-0001 - Electrical Basis of Design”. Each individual harmonic current contribution through the reactor shall be assumed to have a size equal to its maximum continuous value. Any disturbances which may cause transient overvoltage or over currents in the design of the reactor shall be considered in order to prevent overstress of the converter equipment for both the DC side or the AC side of the converter.
Contractor shall ensure that the design of the reactor does not create unwanted resonances in the DC Cables. The Contractor shall outline the steps that will be taken to ensure that the inductance of the reactor remains linear throughout the operating current range
Furthermore on the AC side the design shall not permit the generation of excess overvoltage when disturbances occur in the receiving AC network.
All reactors shall be designed to minimize partial discharge on the surface of the reactor during operation, this shall be proven during testing and presented to Employer. Proof shall be provided by the Contractor that the reactor including support is kept well off the electrical forcing frequencies when considering the natural mechanical frequency of the reactor.

7.2 Design

The reactors shall be of the dry-air core type. The reactors shall have a maximum temperature class H. However, the maximum allowed temperature rises shall be chosen from one class lower, i.e. maximum class F In case the lower class F is not used Contractor shall point it out and present design for Employers approval. Special attention must be paid to minimisation of partial discharge on the surface of the reactor during operation for avoidance of the 'black spot' phenomenon.

When two or more coils are used in series, the Contractor shall demonstrate that the voltage sharing across coils is acceptable for fast transients resulting from faults and continuous operation.

The Contractor shall provide proof that the reactor mechanical natural frequency is kept well off the electrical forcing frequencies. Possible spacers between the layers shall be made of homogenous material without any joints. All reactors designed for outdoor use shall be treated with anti-tracking finish and preventative measures shall be provided to prevent deterioration or failure as a result of atmospheric pollution in order to achieve the specified lifetime. Non-metallic bird barrier mesh shall be used to prevent birds nesting inside the reactor windings or frame. Mylar shall not be used as an insulation material for outdoor reactors. The Contractor shall declare the following magnetic clearances, both axially and radially:

- Clearance to walls, roof and floor
- Clearance to other components
- Clearance to other reactors
- To small metallic objects
- To metallic objects forming closed loops

Calculations of the guaranteed maximum total sound power level for a single and three phase reactor set erected as for service shall be provided. The calculation shall take full account of the maximum continuous rated fundamental and harmonic currents specified in the reactors design.

The Contractor shall provide copies of the reports documenting the life time testing of previous reactors, which form the basis of the design of the reactor. The Contractor shall ensure that the insulation stress between winding turns and other highly stressed areas does not exceed the stress of any similar reactors that have been in service.

7.2.1 Insulation level of the windings

Please refer to the document “HVDC-VAT-E-FD-0001 - Electrical of Basic Design.”

7.3 Testing

The reactor shall be tested according to the applicable parts of IEC 62001-4,tests on support insulators, where applicable, may be performed in accordance with IEC 60168 and IEC 60076-6 with the following clarifications regarding the temperature rise type test.

1) The temperature rise type test shall be performed at maximum continuous rated current including all harmonics with full allowance made for the variation of reactor resistance with frequency. The Contractor shall submit calculations of the test current to be applied for Employer’s agreement prior to testing. The Contractor shall submit all calculations for the equivalent test current if:
    a. The test current is not equal to the maximum continuous rated current (but still above 0.9 of the equivalent current at power frequency, as allowed in the standard)
    b. The fundamental frequency of the supply at the test plant is not the same as the fundamental frequency of the reactor current when in service.
2) The test shall be performed with the reactor erected as for service including the installation of top hats or sound shields.
3) The manufacturer shall submit the details of the method of measuring the absolute temperature of each reactor and justification of the positioning of the temperature transducers.
4) The manufacturer shall submit all calculations used to determine the temperature rise and maximum hotspot when the test is not performed at the maximum specified ambient temperature.

The frequency dependence of the reactor resistance shall be measured and taken into consideration when calculating the total reactor losses. The Contractor shall provide detailed calculation of the power loss in the phase /limb reactor.

The harmonics are calculated by the Contractor using worst-case converter operating conditions such as converter harmonic voltages, HVDC cable parameters and reactor inductance. The harmonic resistance is determined by the Contractor by measurements on the manufactured converter reactor.

8 Resistors (incl. pre-insertion, Filter, grounding)

8.1 General

8.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in “Electrical Basis of Design - HVDC-VAT-E-FD-0001”.

8.1.2 Rated power

The rated power shall be defined by Contractor. The rated power of the Resistor shall be compliant with all the operating ranges determined by the VSC converter designer.

8.1.3 Resistor Requirements

The equipment shall comply with applicable IEC standards and take guidance from:

- IEC 62001 High-voltage direct current (HVDC) systems - Guidance to the specification and design evaluation of AC filters
    - Part 1: Overview
    - Part 2 Performance
    - Part 4 Equipment

IEC 60099-4 can be used for Pre-Insertion Resistors.

The resistors should be designed with negligible inductance and with low dependency of resistance versus harmonic frequencies.

8.2 Design

All resistors are expected to be of the dry-air type cooled by natural air, and the maximum temperature of any resistor element and any insulation shall not exceed the maximum safe working temperature of the material, under all rated operating conditions, both continuous and transient. In case other types are proposed by the Contractor, it shall be sent for Employers for approval. For HVDC Chopper resistors this shall be discussed with Employer to ensure grid code compliance. The current Rating of the resistor shall take harmonic current into considerations hence adding them to the fundamental frequency RMS current rating. The enclosures should be designed so as to prevent the ingress of birds or other animals. Further they should be designed so as to allow simple opening for maintenance. The resistors must be designed to minimize the corrosion risk on all part of the equipment, including resistor elements, internal and external connection points and housings. On request, the Contractor shall demonstrate documentation on the design criteria with respect to the temperature variations used in the design of the whole resistor construction, both for the cooling and electrical insulation capability and also for the electrical parameter change.

In case of several modules in series, effects of non-linear transient voltage distribution must be taken into account for the insulation coordination of the construction. Resistors are to be protected against high resistance or open circuit faults and the circuit shall be designed in such a way to enable current differential protection to function properly. The Contractor shall provide overcurrent/time characteristics showing the thermal withstand capability of the installed resistor, for pre insertion resistors current vs time charactistics (I^2R)

8.2.1 Pre-Insertion Resistor

The pre-insertion resistor shall be rated for two consecutive energisations within 30mins interval and in accordance to grid code.. The Contractor shall provide energy vs time characteristics and state the cool down time period required for single and double energisation scenarios.

8.3 Test

The test shall be made in accordance to relevant standards however some test/requirements are added below. Generally the test levels and acceptance criteria are to be agreed between Contractor and Employer. Contractor shall propose special tests needed for the PIR.

8.3.1 Routine Testing

Resistors shall undergo routine tests as specified in IEC 62001-4, The routine tests for resistors include:

8.3.1.1 Resistance Measurements

Resistance measurements for the following components shall be measured with DC and to an accuracy of 0.5% or lower. This shall be compensated, where necessary, for an ambient temperature of 20^{o}C. Contractor shall as minimum provide the following.

- The resistance of each resistor within the unit enclosure
- The resistance of each resistor within the sub-assembly
- The resistance of each terminal of a sub-assembly to its frame.

8.3.2 Power frequency voltage withstand test

Shall be done in accordance to the standards.

8.3.2.1 Insulation Tests

Shall be done in accordance to the standards.

8.3.3 Type Testing

Resistors shall undergo the tests as specified in IEC 62001-4. Where PIR construction type is comparable to Surge arrester, then it shall be type tested according to IEC 60099-4.

The type tests for resistors include:

- Temperature rise test, For pre-insertion resistor the temperature rise test can be omitted however energy injection test reports shall be delivered to Employer.
- Lightning impulse test
- Measurement of inductance.
- Short circuit testing or verification by calculation in case agreed with Employer
- External corona, for resistors that are not designed for continues operation but only short term, corona can be omitted in case agreed and accepted by Employer
- Dynamic performance test

8.3.3.1 Temperature Rise Test

The frequency dependency of the resistance must be taken into account in the equivalent 50 Hz current to be used. Steady state conditions must be achieved and the loading shall be maintained for 30 more minutes. The temperature measured at the end of the test shall be corrected for maximum ambient temperature. The complete resistor bank shall be mounted in still air, ideally inside a building of suitable size that the ambient air does not rise. Otherwise, the test may be completed outside provided the outdoor wind speed does not exceed 2 metres/sec. The temperature of at least the following points shall be measured:

a) The highest temperature of the hottest element
b) The ambient temperature
c) The exit air temperature
d) The inlet air temperature

The resistor shall be deemed to have passed the temperature rise test run provided that:

a) The resistance of the resistor when corrected to 20^{o}C has not changed from its original measurement by more than 2%

b) A visual inspection of the resistor bank shows:
   a. The resistor elements are not distorted or sagging
   b. The colour of the resistor elements has not changed significantly
   c. The insulation is undamaged.

For pre-insertion resistor the temperature rise test can be omitted however energy injection test reports shall be delivered to Employer.

8.3.3.2 Measurement of Inductance

The inductance of the resistor shall be measured at both 50 Hz, 2500 Hz and tuning frequency whilst at the extremes of working temperatures.

8.3.3.3 Short Circuit Testing

The test must show that the design withstands the mechanical and thermal stresses caused by the transient currents that can occur. Verification by calculation can be accepted in case agreed with Employer

8.3.3.4 Dynamic performance test

The test shall be performed to ensure the correct operation of the pre-insertion resistor. The test to be defined by Contractor and approved by Employer.

9 Capacitors (incl. DC-side and filter)

9.1 General

9.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in “Electrical Basis of Design - HVDC-VAT-E-FD-0001”.

9.1.2 Rated power

The rated power shall be defined by Contractor.

The rated power of the Capacitor shall be compliant with all the operating ranges determined by the VSC converter designer.

9.1.3 Capacitor Requirements

The reactors shall comply with:

- IEC 60871, Shunt capacitors for AC power systems having a rated voltage above 1000V
- IEC 60358, Coupling capacitor and capacitor dividers.

9.2 Design

AC capacitors provided by the Contractor are internally fused. Un-fused capacitors may be accepted, if the Contractor proves that this design will provide the necessary reliability and security of the capacitor bank, and in accordance with project lifetime. The capacitor banks are designed by the Contractor in line with converter HV equipment maintenance interval. Furthermore capacitors used in a single rack or zone shall be of same type and subcontractor.

Each high-voltage filter capacitor banks or shunt capacitor banks shall contain at least two capacitor strings (P>2) for capacitor element failure protection obtained by unbalance measurement in the H configuration. The maximum and minimum capacitor unit capacitance value with/without spares shall be provided by the Contractor. The capacitor shall be divided into modular units, if this is not possible Contractor needs to present the solution for Employers approval. Each unit shall be easily replaceable when faulted without the need to remove other units. The units shall take into account changing temperature due to ambient conditions and electrical phenomenon. Furthermore the design shall also take into account that visual inspection and maintenance must be possible in an easy way taking HSE into consideration. Each capacitor rack shall be uniquely numbered and labelled, and each rack shall be labelled in such a way that the position of every capacitor unit within a rack can be identified. The labelling shall be designed such that is readable from the ground whilst the bank is energised. To ensure safe maintenance earthing of all parts, the rack shall be provided with facilities for electrical connection together of all structural members as well as facilities for earthing of all structure members of the rack. Safety shorting equipment shall be provided to ensure that any stored energy in capacitor units is discharged before performing maintenance work. Capacitors shall be provided with discharge resistors were possible for safety reasons, in case this requirement is not fulfilled Contractor shall present their solution for Employers approval.

The Contractor ensures that the dielectric fluid used within the capacitor unit is environmentally safe and biodegradable. PCB type fluid is not to be used by the Contractor.

For Filter capacitor Contractor shall provide protection which gives at least three stages of capacitor unit or element failure detection and designs the capacitor banks accordingly.

- The first stage generates an alarm and the filter continues in service. It may be assumed that the filter will be disconnected for maintenance within two weeks.
- The second stage generates a separate alarm and a delayed trip signal which will disconnect the filter after pre-defined time (i.e. 4 hours)
- The third stage causes an immediate disconnection of the filter.

9.2.1 Insulation level

Please refer to the document "HVDC-VAT-E-FD-0001 - Electrical of Basic Design."

9.3 Testing

The test shall be made in accordance to relevant standards however some test/requirements are added below. Type tests shall be performed on at least two units of each type of capacitor in accordance to IEC 60871-1, IEC 60168 were applicable and IEC 62001-4. In addition to the test stated in the applicable IEC standard a measurement of the capacitance versus frequency and temperature shall be performed as a type test.

9.3.1 Routine Testing

During routine test in case of failure of any element it shall be considered a failure of the entire unit. In other tests, any parameter falling outside the design limits to be specified by the Contractor and reviewed by the Employer shall constitute a failure of the unit to pass the test.

9.3.2 Type Testing

In the case of capacitors being manufactured at different plants, the two capacitor units from each plant shall be type-tested. If the design has been changed during the manufacture, the Employer reserves the right to have the type tests repeated on the new design.

10 Instrument transformers (CT's & VT's)

10.1 General

10.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in "Electrical Basis of Design - HVDC-VAT-E-FD-8901".

10.1.2 Rated power

The rated power shall be defined by Contractor. The rated power of the Instrument Transformers shall be compliant with all the operating ranges determined by the VSC converter designer.

10.1.3 Instrument Transformer Requirements

The transformers shall comply with:

- IEC 61869-1 Instrument Transformers – Part 1: General requirements
- IEC 61869-2 Instrument Transformers – Part 2: Additional requirements for current transformers
- IEC 61869-4 Instrument Transformers – Part 4: Additional requirements for combined transformers
- IEC 61869-5 Instrument Transformers – Part 5: Additional requirements for capacitor voltage transformers
- IEC 61869-14 Current transformers for DC applications
- IEC 61869-15 Voltage transformers for DC applications

Instrument transformers shall be airtight with the inner insulation shall be protected against penetrating moisture. The washer material shall be oil-resistant and resistant against climatic stress. The current transformers and its secondary cabling shall be rated to prevent saturation at maximum fault current including a possible DC component. The transformers/transducers used for metering must comply with accuracy class of 0.2S.

CT's and VT's shall be aligned with protection concept proposed by Contractor and "Control and Protection concept - HVDC-VAT-E-FD-8902". Spare cores shall be provided in each CT and VT; at least one metering and one protection class as applicable. If spare cores are not available for all CT/VT this shall be presented to Employer and agreed. The current transformers shall be installed in the current path so that the primary terminals, P1 and P2, are consequently oriented, while the voltage transformer shunt to the three phase voltage terminals. In case Oil-filled transformers they shall be equipped with an oil level indicator visible from ground level, preferably by indicating the position of the expansion chamber bellows, if applicable. In case SF6 gas-filled current transformers shall be equipped with a temperature-compensated gas pressure gauge with two contact outputs (1) alarm level 1 (2) alarm level 2. The settings shall be stated by the Contractor See also Section 3. The transformer shall be provided with valves for filling and sampling of oil or gas.

A voltage transformer is required for accurate measurement of harmonic voltage distortion at the Offshore grid entry point. This transformer should be able to able to accurately measure harmonic distortion over the frequency range from 50Hz to 5000Hz.

10.2 Design

For harmonic monitoring, special attention should be paid to the frequency characteristics of the transformer. The proposed detailed data for the transformers that measure AC wave forms shall be part of the detailed design phase. Each winding must be protected by a MCB. Each MCB must be provided with 2-make / 2-break free signal contacts, connected to the busbar protection relay. The transformers shall be designed to withstand the mechanical stress, which can arise as a result of all forces on the line terminal. DC current measuring units shall be of the zero flux current transformer type or based on DC shunt measuring. Conventional transducers will not be accepted. Optical instrument transformers are preferable for the DC side.

10.2.1 Insulation level

Please refer to the document “HVDC-VAT-E-FD-0001 - Electrical of Basic Design.”

10.3 Testing

10.3.1 AC Transformers

The Contractor shall ensure that the Inductive voltage transformers (IVT’s) shall be tested in accordance with IEC 61869-3 and Capacitor voltage transformers shall be tested in accordance with IEC 61869-5. Furthermore the main insulation tan δ shall be measured at ambient temperature and different voltages; at 10 kV rms. and also around 0.5, 1.0 and 1.5*Um/√3 and if possible up to full power frequency voltage.

For No-load curves, winding resistance a sufficient number of points of the no-load curve shall be plotted in order to determine constant Fs = instrument security factor and n = accuracy limiting factor.

The secondary winding resistances shall be measured and the constant, RCT = secondary resistance of current transformer, shall be specified at 75°C winding temperature. Test at 1VA shall be included in the routine test report. Furthermore, the Instrument transformer windings at Grid Entry points shall fulfil TSO requirements (for UK, as specified in BCA)

10.3.2 DC transformers

DC current transformer tests shall be performed according to IEC 61869-14. DC Voltage transformer tests shall be performed according to IEC 61869-15.

11 Surge Arrestors

11.1 General

11.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in “Electrical Basis of Design - HVDC-VAT-E-FD-8901”.

11.1.2 Surge Arrestor Requirements

The Surge arrestors shall comply with:

- IEC 60099-4 Surge Arresters – Part 4: Metal-oxide arresters without gaps for AC systems
- IEC 60099-5 Surge Arresters – Part 5: Selection and Application recommendations

- IEC 60099-9 Surge Arresters – Part 9: Metal-oxide arresters without gaps for HVDC Converter Stations

Only gapless arresters of the metal oxide type shall be used. The arresters shall have sufficient pressure relief capability in order to make them explosion free and to ensure that personnel and equipment safety is guaranteed. The housing should be sealed to prevent moisture ingress. Each arrester shall have a single surge counter for recording the number of surges which have passed through the arrester. The counter shall be weather-proof and provided with means to enable the removal of the counter without disconnecting the surge arrester. It shall be possible to read the counter when the plant is in operation and for DC SA's it shall also be available in the HMI.

11.2 Design

The arrester across the valves or valve group shall be capable of discharging the maximum credible overvoltage in dc cables and associated terminal equipment charged. AC system arresters shall be capable of discharging without damage the energy associated with operation of the system with all ac filters & shunt capacitors connected, including the duty resulting from fault clearance and re-closure onto a permanent fault and subsequent fault clearance.

The surge arresters shall be designed to withstand the mechanical stress, which can arise as a result of all forces on the line terminal. The protective characteristics of the arresters shall be selected by the Contractor based on the Insulation Coordination Study to coordinate the overall system protection. In the event that surge arresters with parallel connected housings are used then matching sets of spare surge arresters shall be provided to permit replacement of the surge arrester. Surge arresters located indoors shall have polymer housings.

11.2.1 Insulation level

Please refer to the document "HVDC-VAT-E-FD-0001 - Electrical of Basic Design."

11.3 Testing

AC and DC arresters shall be tested in accordance with relevant parts of IEC 60099-4 and IEC 60099-9. DC arresters shall also be tested with relevant sections of CIGRE Brochure 034. For multi column arresters the current sharing between columns in a single housing and/or between parallel-connected arrester units shall be demonstrated in design as well as routine tests.

12 Bushings and Insulators

12.1 General

12.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in “Electrical Basis of Design - HVDC-VAT-E-FD-8901”.

12.1.2 Rated power

The rated power shall be defined by Contractor. The rated power of the bushing shall be compliant with all the operating ranges determined by the VSC converter designer.

12.1.3 Bushing and Insulator Requirements

The equipment shall comply with the following standards:

- BS EN 50180 Bushings above 1 kV up to 52 kV and from 250 A to 3,15 kA for liquid filled transformers
- BS EN 50181 Plug-in type bushings above 1 kV up to 52 kV and from 250 A to 2,50 kA for equipment other than liquid filled transformer
- EN 50299 : Oil-immersed cable connection assemblies for transformers and reactors having highest voltage for equipment Um from 72,5 kV to 550 kV
- IEC 60137 Insulated bushings for alternating voltages above 1000 V
- IEC 60168 Tests on indoor and outdoor post insulators of ceramic material or glass for systems with nominal voltages greater than 1000 V
- IEC 60815 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions
- IEC 61462 Composite hollow insulators - Pressurized and unpressurized insulators for use in electrical equipment with rated voltage greater than 1 000 V - Definitions, test methods, acceptance criteria and design recommendations
- IEC 65700 Bushings for DC application

All insulators and bushings shall be of the polymer type in case another solution is chosen Contractor to present for Employers approval. Any bushing penetrating into the valve hall must be GIS or of the dry-air type and not oil-filled in order to reduce the fire risk.

12.2 Design

As far as possible the insulators and Bushing shall be of the type that Contractor expects to use as standard to improve availability of the components. The post insulators and bushings should preferably be made up so far as possible by identical interchangeable units so as to simplify maintenance and spare part holding.

12.2.1 Insulation level

Please refer to the document "HVDC-VAT-E-FD-0001 - Electrical of Basic Design."

12.3 Testing

Insulators and bushings shall be tested to applicable standards, Insulators and bushings subjected to DC voltage shall be of a type which by tests or otherwise have proven to be suitable for DC voltage application.

13 Busbars and Connections

The Contractor shall supply all strain and rigid bus required for AC and DC switchyards. Buses shall be designed with adequate margins of safety with respect to the current-carrying capacity and mechanical strength to withstand electrical and mechanical stress. The buswork and connectors shall be designed to prevent corona discharge. Corona rings shall be applied where required.

14 Marshalling Kiosks.

All switches, handles and locking points are fitted by the Contractor with facilities for the application of a padlock. All outdoor kiosks, boxes and cubicles provided by the Contractor are of galvanised steel, stainless steel or aluminium construction and should be weather proof, light and contain anti-condensation heaters.

15 Multicore / Multi-pair Cabling

The Contractor shall supply, install and test all multicore/multi-pair cabling required for the Plant connections. The Contractor ensures that all cabling from outdoor Plant is suitability armoured, steel wire armour is preferred. The Contractor ensures that cabling within all buildings is of a low smoke and fume construction. The Contractor ensures that AC and DC signals are not to be present on the same cable. The Contractor ensures that all cores are ferruled.

If there is any cabling above ground level it shall be fixed to/supported by heavy duty galvanised cable tray. All cables are numbered, labelled appropriately and recorded by the Contractor on a cable schedule.

16 Enclosure, structures and surface treatment

16.1 General

16.1.1 Rated voltages

The rated voltage should be determined by Contractor to ensure optimal operation and optimized cost or to relevant grid voltages provided in “Electrical Basis of Design - HVDC-VAT-E-FD-8901”.

16.1.2 Requirements

- EN 50341-1 European Standard for Overhead electrical lines exceeding AC 45 kV
- European Code 3, EN 1993 Design of Steel Structures
- European Standard ENV 1090-1 'Execution of Steel Structures - Requirements for conformity assessment of structural components'.
- European Standard ENV 1090-2 'Execution of Steel Structures – Technical Requirements for Steel Structures'.

In general, enclosures shall be insensitive to aggressive ambient conditions such as air humidity (containing salt), dust, temperature, etc. The primary enclosure shall be hermetically sealed to ingress of foreign bodies such as dust, dirt, moisture, etc. Enclosures, Operating mechanism, etc. shall be made of corrosion-resistant material. The Contractor shall describe his metal enclosure, and his surface treatment, for instance by referring to paint instructions and by guaranteeing that the surface treatment is durable for the lifetime of the substation. The paint instructions shall contain repair instructions.

Structures, supporting structures and eventual rails shall be included. Apart from the fixed structures, any scaffold or movable platform, required for service and maintenance, shall also be supplied. Structures and rails as well as on cut edge shall be protected against corrosion by electro-galvanizing. Bolts, washers and nuts shall be of stainless steel or hot galvanized. The use of stainless steel must be at least quality A2, and must be electrical separated from normal carbon steel.

Enclosure of a panel shall have the following characteristics:

- Clear, manageable mechanical layout.
- Short and easily accessible drive linkage.
- Few crossovers of mechanically moved parts in the gas compartments (In GIS).

The enclosures shall have the lowest resistance path and be electrically continuous to a maximum degree possible for 50 Hz induced currents and for high frequency currents. Metal oxide varistors shall be installed at enclosure discontinuities.

Enclosures shall be EMC tight and prepared for EMC transits for screened cables.

If needed, the enclosures shall be equipped with expansion joints for compensation of misalignment, with vibration absorbers and if required with compensation equipment in case of thermal expansion. The structures shall be of the (bolted or welded) beam, tube or lattice type. All steel shall be hot-dip galvanized. All structures shall be bolted to concrete foundations above ground. In case non-magnetic structures are needed, they shall be manufactured of suitable aluminium alloys.

17 Nameplates

Nameplates of the parts of the switchgear and individual components shall be mounted in an accessible location to provide required information for operation and maintenance. All nameplates shall include but not limited to the following information (In conduction to IEC 62271-1):

- Manufacturer’s name and address
- Date of manufacturing
- type and designation
- Serial number
- Maximum ambient temperature
- System frequency
- Rated and maximum operating voltage,
- Rated and maximum continuous current at ambient temperature
- Lightning-Impulse withstand voltage
- Power Frequency withstand voltage

- Short circuit current (rms)
- Short time withstand current and duration
- Peak value of short circuit current
- Total weight of gas at rated density (if GIS applies)
- Total weight of the equipment
- Rated gas pressure at 20 °C (if GIS applies)
- Opening pressure of the bursting disc (if GIS applies)
- Recommended moisture limits of insulation gas (if GIS applies)
- Auxiliary voltages
- Purchase Order number

For outdoor switchgear and control gear, the nameplates and their methods of attachment shall be weather-proof, non-fading and corrosion-proof If the switchgear and control gear consist of several poles with independent operating mechanisms, each pole shall be provided with a name-plate. Labels are in English and are suitable for the Project life in the intended environment.

All main electrical equipment and functions shall be RDS-PP tagged both in documentation and at equipment.

For UK projects HV equipment naming shall follow STCP 10-1, OFTO asset needs to follow the National Grid TP109 . please refer to OC11 (Numbering and nomenclature of High voltage apparatus at certain sites).

18 Testing and Commissioning

Before the switchgear can be approved for dispatch from the factory, a collection of type test certificates shall be made covering the parts of the switchgear.

The Contractor shall:

- Inform the Employer well in advance to enable him to be present for the routine tests.
- Provide the Employer with Test procedures for FAT and SAT minimum 4 weeks before start of FAT. The test procedures must be approved by the Employer before the tests can be carried out.

The Contractor shall be responsible for working in liaison with the Employer and other associated works contractors, etc. for planning, coordinating and resolving all commissioning activities. For the avoidance of doubt, the commissioning process shall encompass all activities and deliverables required in order to transition from a completed Installation to 'in service' components and equipment.

The Contractor shall be responsible for developing a Commissioning Program, in agreement with the Employer, which shall detail key commissioning phases including, but not necessarily limited to:

1. Factory Acceptance Test (FAT)
2. Completed Installation
3. Site Acceptance Test (SAT)
4. Pre-energization test
5. Complete energization
6. Substation operational test
7. Compliance demonstration with connection requirements (including documentary evidence)
8. Completion of commissioning documentation

The Employer have all rights to participate in FAT/SAT test and to receive any relevant FAT/SAT test document

During Commissioning activities, the Contractor shall ensure that suitably experienced, competent and qualified personnel are employed, and that responsibilities are clearly allocated and understood.

Key responsibilities shall include, but not be limited to:

- Switching sequence implementation
- Liaison with Vattenfall, TSO, associated works contractors, etc.
- Management of HSEQ
- Recording/documenting all procedures, tests, results and rectifications

18.1 Type Tests

The switchgear shall have passed all relevant type tests for all components in conformity with applicable EN/IEC Standards, especially IEC 62271 Including its normative references. Documented type tests which have already been made, shall be repeated if older than 10 year unless agreed with Employer. The Contractor shall submit all type test reports to the Employer. In case any type tests are older than 10 years this shall be presented for Employer for approval.

18.2 Factory Acceptance Test (FAT)

The FAT in compliance with applicable IEC standards, especially IEC 62271 Including its normative references covers but not limited to:

- Power-frequency voltage tests on main circuit
- Impulse voltage withstand test
- Partial discharge test (PD test)
- Test on auxiliary and control circuits
- Measurement of the resistance of the main circuit
- Tightness test
- Design and visual checks
- Mechanical function tests
- Pressure test of enclosure and partitions.
- Test of auxiliary equipment and interlocks devices.
- Test of relays (e.g. Omicron test) [2]

For instrument transformers, surge arresters, etc. routine tests shall be carried out in conformity with the applicable EN/IEC Standards.

The Contractor must submit all test reports to the Employer shortly after tests have been performed. The test report shall after successful testing be approved by the Employer.

18.2.1 Site Acceptance Test (SAT)

After the installation process being completed, SAT has to be performed by the Contractor.

The SAT covers but not limited to:

- On site power-frequency voltage withstand test on main circuit
- Measurement of the resistance of the main circuits
- Partial discharge test (PD test)
- Gas leakage and gas quality verification, if applicable
- Gas quality verifications, if applicable
- Visual inspection and verification
- Mechanical, operational and interlock test for all relevant items.
- Complete function test of control system
- Test of protective circuits and functions
- Test of interface to wind farm and substation control system.

The Contractor shall supply the necessary test equipment.

The Contractor must submit all test reports to the Employer shortly after tests have been performed. The test report will after successful testing be approved by the Employer

19 Spare parts

The Contractor shall supply all spare parts and maintenance accessories required to meet the guarantees for availability and reliability requirement as stated in the Contract. Further, the Contractor shall provide recommended Spare parts list for Employer's review and approval. Spare parts may be stored at either Converter Station (onshore or offshore), but it must be possible to replace the failed equipment as per the availability and reliability requirement. The Contractor shall replace at no cost all spares consumed or damaged during installation, commissioning, and trail operation, unless otherwise stated in the Contract.

Spare parts requiring indoor and if necessary, climate-controlled storage shall be stored within the Converter Station buildings and provision for this storage shall be made in the building design.

All special tools, testing equipment, handling equipment, etc. which are required by the maintenance staff to maintain the stations shall be supplied. All necessary software licences for software shall be provided.

20 Documentation

Prior to manufacturing and erection, the Contractor shall submit the relevant drawings (in DWG format) and time schedules to the Employer. The drawings shall be prepared and submitted according to Employer Requirements Volume 2 – Documentation. Manufacturing and erection shall be carried out in accordance with the drawings which have been reviewed by the Employer.

The drawings shall as a minimum include:

- Drawings of control panels
- Data sheets
- Switchgear layout including cross-sections and gas scheme drawings
- Component drawings, including rating plates
- Single line
- Plan of force impacts on the floor
- Earthing system
- Gas diagram (if applicable)
- Shipping units
- Equipment location drawings
- Full manuals for all equipment

Prior to Taking-Over, the Contractor shall submit required documents, detailed operating and maintenance instructions, including:

- Repair instructions with parts lists and specification of materials with numbers facilitating the identification of spare parts.
- Test reports
- A coloured general layout plan for wall-hanging showing the gas compartments, isolators, components, sensors, gas connection points, filters, bursting plates, etc. (if applicable)

Complete as-built documentation shall be submitted according to Master Document Register.