PROTECTION & CONTROL FOR HVDC SYSTEMS

TABLE OF CONTENTS

PURPOSE AND SCOPE

This document describes the technical requirements for User's equipment directly connected to the England and Wales Transmission system within NGET's (National Grid Electricity Transmission) busbar protection zone. Nominal voltages of 400 kV, 275 kV, 132 kV and 66 kV apply unless otherwise agreed with the user as defined in the Bilateral agreement. This shall include all protection and control devices operating NGET Switchgear.The principles of this document also applies to the equipment connected at other voltages".

The functional and performance requirements for the protection and control of HVDC systems are covered. It is applicable for point to point HVDC links with both Current Sourced Converters (CSC) and Voltage Sourced Converters (VSC). An example of an HVDC system arrangement is shown in the Appendix B. It includes AC busbar(s), Harmonic filter(s), Converter Transformer(s), Pole(s), Converter(s), DC busbar(s)/link(s), DC filter(s) as well as DC Neutral.

PART 1 - FUNCTIONAL AND PERFORMANCE REQUIREMENTS

1 GENERAL REQUIREMENTS

Informative: This is a generic specification based on a bipole HVDC application. Each of the protection and control functions specified in this document may be called up and applied separately as appropriate and necessary to achieve the overall desired system for other application scenarios.

1.1 General

Each HVDC converter station shall be equipped with a control and protection system designed to operate satisfactorily under normal as well as abnormal conditions.

The control system shall be designed to permit transmission of power in both directions. The design shall assure that there are no harmful interactions between the HVDC transmission system and the AC network which may adversely affect either the HVDC converter protection system or the AC network protection system or other users of the transmission system. The HVDC transmission system shall be stable in all situations and the system shall be self-protecting with and without the inter-station telecommunication in service. The control and protection system for the two converter stations shall be identical as far as possible. The Contractor is responsible for finding an optimised control strategy to ensure a robust system.

Where a bipolar system is used for an HVDC system, each of the two poles shall be able to operate independent of the other pole in monopolar operation configuration for the case of an outage of one converter or scheduled maintenance and repair work on one of the converters. The same control functions as available for the whole bipolar system shall be available also in monopolar operation mode.

The control and protection system shall have full redundancy in all vital parts. The protection for a HVDC converter station shall comprise protection functions for AC busbar(s), Harmonic filter(s), Converter transformer(s), Pole(s)/Converter(s) as well as DC busbar(s)/line(s), DC Neutral, and DC filter(s). The protections shall detect and clear faults and faulty equipment within an HVDC system to protect stability of the GB transmission network as well as the HVDC system.

The control functions for an HVDC system shall include despatch control, operational control as well as Supervisory Control and Data Acquisition (SCADA) functions.

Informative: Despatch control concerns link transfer, ramping set points, control mode selection, Power Oscillation Damping (POD) and SSR control selection. Operational control concerns manual switching of individual AC or DC plant items at an HVDC converter station.

The HVDC facility shall be divided into a number of separately protected and overlapping zones as illustrated in Figure 1 of Appendix B. A protection function shall only act upon a specific type of fault within a designated zone and shall be stable to other types of disturbances or faults external to the relevant zone.

Every protective zone shall be protected by two main protection functions (preferably using a different protection principle) and one back-up protection function. Where different protection principles cannot be used, duplicated protections shall be used.

The protections shall be as independent as possible from the control system and, such that control failure shall not limit the functionality of these protections, and vice versa. Each of these protection systems shall always remain active and shall be powered by separate, independent power supplies.

Where protection and control functions are integrated within a same Intelligent Electronic Device (IED), the design shall satisfy the requirements for normal operations, maintenance as well as failure modes. Supplier(s) shall declare the integration arrangement in Table 1 of Appendix A (form TS 3.23.90.A).

All the protection and control functions for a HVDC system shall be co-ordinated with those ones for the interfacing feeder(s) and rest of connected AC network as appropriate, including but not limited to AC protection schemes, Tripping and Intertripping arrangement, Operational Tripping Schemes (OTS), Converter blocking sequence, Delay Auto Re-close (DAR) schemes, over-loading requirements etc.

The converter station design, CT characteristics and protection system shall be designed in such way that the AC protection of the converter and adjacent AC substations are not affected by the normal, transient and dynamic behaviour of the DC system.

The protection and control system for a HVDC converter station shall be designed to ensure that no single failure of equipment shall cause the total failure of an HVDC system.

It shall be possible to repair, maintain and test the pole on outage whilst maintaining unhindered normal operation of the remaining pole.

Isolation facilities shall be provided to allow on-line maintenance of the redundant control & protection equipment/system.

1.2 Engineering Interface

Engineering interface shall be provided with HVDC protection and control system for the setting configuration, commissioning, diagnostic and other engineering purposes. Software/Firmware version shall be clearly identifiable within the interface.

Auditoria shall be provided for version changes of configuration within the engineering interface.

1.3 Hardware and Accommodations

All the hardware, cubicles and other General Arrangements associated with the required functions in this specification shall comply with the relevant electrical, environmental and ancillary requirements in TS3.24.15 (RES), TS 2.19 (RES) as well as EATS48-4.

2 PROTECTION FUNCTIONS

2.1 AC Busbar Zone Protection

2.1.1 Double Busbar Arrangement

For HVDC systems connected to double busbar substations, the busbar protection shall be provided in accordance with TS 3.24.34 (RES).

On operation, busbar protection shall

a) Initiate converter blocking sequence

b) Trip the Main CB(s) at AC substation.

c) Initiate CBF protection where appropriate.

d) Be selectable to initiate DTT to the remote end(s) of the circuit.

Informative: The specific tripping scheme to clear busbar faults may vary depending upon the topology of converter stations.

2.1.2 Mesh Corner Arrangement-

For HVDC systems connected to mesh substations, Mesh Corner(MC) protection shall be provided. On operation, mesh corner protection shall

a) Initiate converter blocking sequence

b) Trip the associated CBs.

c) Initiate CBF protection where appropriate.

d) Lockout MCDAR where appropriate.

e) Be selectable to initiate DTT to the remote end(s) of the circuits connected to the same corner.

2.2 Converter Transformer Zone Protection

Where applicable, protection shall be provided to cover the connection between converter transformer(s) and converter(s).

2.2.1 Tapping Sequence Protection

Converter transformer tapping sequence shall be monitored to ensure correct operation of on load tap changers. When a fault is detected, the protection shall

a) Trip tap-changer MCB(s)

b) Generate an alarm

c) Block converter as necessary

2.3 DC Converter/Pole Zone Protection

DC Converter/Pole protection shall independently oversee the system and ensure equipment safety. For each converter/Pole there shall be two independent DC protection systems, Main1 and Main 2.

2.3.1 Asymmetry Protection

Asymmetry Protection shall be provided to detect persistent presence of fundamental and 2nd harmonic voltages or current between the DC terminals of the pole.

When the magnitude of the RMS voltage (fundamental and second harmonic frequencies) exceeds preset thresholds the protection shall operate with an inverse time characteristic in two stages:

a) Stage 1: As soon as a fault is detected an alarm shall be initiated.

b) Stage 2: If the fault persists, the pole shall be taken out of service.

2.3.2 Pole Differential Protection

Pole DC Differential Protection shall be provided to detect ground faults on the DC side of the converter.

On operation, the protection shall take the pole out of service by

a) Initiate converter blocking sequence

b) Trip associated AC CBs necessary

c) Generate an alarm

d) Isolate Line and Neutral

Informative: This protection shall co-ordinate with DC line protection 0 as a ground fault on the HVDC bus may also operate the DC line protection. This protection shall block before the DC line protection initiate a restart.

Pole DC Differential Protection shall have two levels of sensitivity settings, at the lower level the delay time is longer (at typically 30ms). If the mismatch exceeds the higher level the protection shall act faster (the delay before operating is brought down to typically 3ms).

Informative: The delay is introduced to avoid spurious triggering if the protection detects mismatches during energisation caused by charging currents.

2.3.3 DC Overcurrent

DC Overcurrent shall be provided to detect overcurrent in the HVDC link and take the pole out of service if a fault is detected.

On operation, the protection shall;

a) Initiate converter blocking sequence

b) Generate an alarm

c) Trip Associated AC CBs necessary

d) Line and Neutral isolation as appropriate

The protection shall have an inverse definite minimum time (IDMT) characteristic

2.3.4 AC>DC Differential

AC>DC Differential protection shall be provided to detect a valve short circuit, other phase-to-phase short circuits which give rise to high AC currents and low DC currents and in response take the pole out of service.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Generate an alarm

c) trip Associated AC CBs necessary

2.3.5 DC>AC Differential

DC>AC Differential shall be detected to detect converter failures and if the fault persists take the pole out of service.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Generate an alarm

c) Trip Associated AC CBs necessary

Informative: This is the opposite of the AC > DC Differential above. In this case the sense of the difference indicates a converter failure where DC current flow bypasses the AC connections. This protection needs to be co-ordinated with AC system protections as well as the asymmetry protection.

2.3.6 AC Overcurrent

AC Overcurrent protection shall be provided to detect overcurrents in any of the valve winding connections which can result from phase to phase valve connection faults or control failure and initiate protective actions on detection. The protection shall contain both two stages and inverse characteristics selectable for an application.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Generate an alarm

c) Trip Associated AC CBs necessary

The protection shall have an inverse definite minimum time characteristic (IDMT).

2.3.7 AC Overvoltage Line Side

AC Overvoltage Line Side Protection shall be provided to detect overvoltage in the line winding side that could stress the equipment. It shall take the pole out of service if persistent AC overvoltage is detected.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Generate an alarm

c) Trip Associated AC CBs necessary

Informative: Overvoltage is tolerated for a certain time, depending on the voltage level, - if the overvoltage is removed within this time then the protection does not operate. If the overvoltage persists, or if the overvoltage is removed but recurs within the cooling period allowed, then the protection operates.

The equipment is required to be protected for AC system voltage excursions beyond the specified range resulting from a system disturbance. The overvoltage protection characteristic is defined here based on the equipment capability.

The line side overvoltage characteristic is based on the worst case of the converter transformer overfluxing in the event of overvoltage. The converter transformer overfluxing characteristic associated with the maximum tap at full frequency (50 Hz) is selected as it encompasses the requirement of all the equipment connected to the line terminal.

The operation of this protection shall be coordinated with the tap changer control and the tap limit protection to allow for normal operation. Provision shall also be made so that the settings do not give rise to unnecessary alarms and tripping due to permanent AC network voltage changes or switching actions.

2.3.8 AC Overvoltage Valve Side

AC Overvoltage Valve Side protection shall be provided to detect overvoltage in the valve winding side that could stress the equipment. It shall take the pole out of service if persistent AC overvoltage is detected.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Generate an alarm

c) Trip Associated AC CBs necessary

Informative: The voltage is measured on the line winding side of the converter transformer and calculated for the valve winding using the measured tap position.

Overvoltage is tolerated for a certain time, depending on the voltage level, - if the overvoltage is removed within this time then the protection does not operate. If the *overvoltage persists, or if the overvoltage is removed but recurs within the cooling period allowed, then the protection operates.*

The equipment is required to be protected for AC system voltage excursions beyond the specified range resulting from a system disturbance. The overvoltage protection characteristic is defined here based on the equipment capability.

For the transformer valve winding side overvoltage protection, the characteristic with respect to time is defined by the valve surge arrester capability, followed by the expected voltage on the eventual tripping of the AC filters and the consequent protective tap-changer lowering of the converter transformer.

The operation of this protection shall be coordinated with the tap changer control and the tap limit protection to allow for normal operation. Provision shall also be made so that the settings do not give raise to unnecessary alarms and tripping due to permanent AC network voltage changes and switching actions (such as Line and shunt reactor switching).

2.3.9 AC Undervoltage

AC Undervoltage protection shall be provided to monitor the line-to-line AC system voltage. If the AC undervoltage persists for a fixed period of time, the protection shall block and/or trip the pole.

On operation, the Protection shall produce

a) Inform relevant control functions such as Valve Base Electronics

b) Initiate converter blocking sequence

c) Trip associated AC CBs as necessary

d) Generate an alarm

Informative: The voltage is measured on the line winding side of the converter transformer and calculated for the valve winding using the measured tap position.

If any valve winding line voltage falls below the set level and remains below it for longer than a definite time, an indication to the control system that the AC voltages are too low to maintain the charge on the Valve unit power supplies is sent.

Following restoration of the voltage level, the control system shall be held for a predefined period to allow time for the gate unit to be fully charged. If the converter is de-blocked, it produces block and trip after a fixed delay when undervoltage is detected.

2.3.10 DC Undercurrent Protection

DC Undercurrent Protection shall be provided to prevent prolonged operation of either a rectifier or inverter operating into an open circuit, i.e., when one side fails to de-block.

When the DC current goes below a preset value for a preset time, then the DC current protection shall

a) Initiate converter blocking sequence

b) Generate an alarm

2.3.11 Tap Limits Protection

Tap Limits Protection shall be provided to prevent long-term voltage stress that may cause harm to the equipment, e.g. over-excitation of the converter transformer.

On operation, the Protection shall

a) Generate an alarm

b) Inhibit tapping to increase voltage

c) Force tapping to Lower voltage

Informative: Valve line side voltages are measured and compared with pre-set thresholds. For moderate voltage stress, the control is inhibited from raising the tapchanger position. For severe voltage stress the tapchanger is forced to tap down to acceptable levels. The overfluxing of the converter transformer is frequency dependent. The settings of this protection shall not interfere with normal tap changer control.

2.3.12 Thermal Protection

Protection shall be provided to prevent valve temperatures to exceed the thermal limits.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) trip associated AC CBs necessary

c) Apply Full Cooling as appropriate

d) Generate an alarm

2.4 Neutral Zone Protection

The following protections shall be used to detect and clear faults and faulty equipment on the DC neutral.

2.4.1 Common Neutral Area Protection

Common Neutral Area Protection shall be provided to detect a short circuit in common neutral area including the electrode line. The protection covers the common neutral bus between the poles and the electrode line area outside of the pole differential protection or filter protection zones.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Trip associated AC CBs necessary

c) Generate an alarm

d) Initiate NBGS sequence as appropriate

Informative: In the case of monopole operation, the protection will block the pole. In the case of bipole operation, the protection action is to introduce a pre-trip level which will close the Neutral Bus Grounding switch (NBGS) when a neutral area earth fault is detected. If the earth fault is caused by a flash over to ground, by providing a parallel low impedance path to *ground, the fault current can be diverted allowing the earth fault to extinguish. In doing so, the scheme may continue to operate without resorting to tripping both poles. Control action is used to balance the currents of the two poles to minimise the current to station ground. If the fault is cleared, the operator can then decide to open the NBGS to disconnect the temporary station ground. For persistent common neutral area faults, the protection shall initiate a converter blocking sequence to block both poles.*

2.4.2 Neutral Bus Overvoltage Protection

Neutral Bus Overvoltage Protection shall be provided to detect DC overvoltage on the neutral bus.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Trip associated AC CBs necessary

c) Alarm

d) Initiate Neutral Bus Grounding Switch sequence

The neutral voltage shall be compared against preset threshold levels to determine the integral operating time which has a logarithmic time characteristic, with definite minimum time (DMT), and IDMT sections.

Informative: For single pole operation NBGS is closed on detection of a fault. For bipole operation, it checks if the other pole has also found this fault and if so it will close the NBGS.

2.4.3 Neutral Bus Grounding Switch (NBGS) Protection

NBGS Protection shall be provided to protect the neutral bus grounding switch from failure to open.

The NBGS current shall be measured and compared with a preset threshold. The protection shall operate when its threshold is exceeded after a preset period of time.

On operation, the Protection shall

a) Generate an alarm

b) Issue close command to the NBGS

2.4.4 Neutral Bus Switch Protection

Neutral Bus Switch Protection shall be provided to protect the neutral bus switch from failure to open.

The neutral bus switch current shall be measured and compared with a preset threshold. The threshold is exceeded for a preset period of time, the Protection shall

a) Generate an alarm

b) Issue close command to the NBGS

2.4.5 Electrode Line Fault Detector

Electrode Line Fault Detector shall be provided to detect faults on Electrode line.

On operation, the Protection shall produce alarm “Electrode Line Fault”

2.4.6 Neutral Current Unbalance

Neutral Current Unbalance protection shall be provided to monitor the “spill” current from each pole, measured by DC CT and provide protection action on detection of the failure of the bipole current balancing or a main circuit fault.

On operation, the Protection shall produce Alarm “Neutral Current Unbalance”

The operating time shall be determined by an inverse response with a definite minimum time (IDMT) characteristics. There shall be an operating level below which the protection will not operate.

2.4.7 Metallic Return Earth Fault Protection

Where applicable, Metallic Return Earth Fault Protection shall be provided to detect faults in the DC metallic return.

The function may be achieved by monitoring the earth return or electrode line current in two stages:

a) Stage 1: generate alarm only if the current is above a preset threshold;

b) Stage 2: Initiate converter blocking sequence if the current is above a higher threshold.

2.4.8 Metallic Return Transfer Breaker (MRTB) Protection

Where applicable, the Metallic Return Transfer Breaker (MRTB) Protection shall be provided to protect against failure of the MRTB to commutate current from the ground return to the metallic return.

The metallic return transfer breaker current shall be measured and compared to a preset threshold. When the threshold is exceeded for a preset period of time, the Protection shall produce

a) Generate alarm

b) Re-close the MRTB

2.4.9 Ground Return Transfer Switch Protection

Where applicable, the Ground Return Transfer Switch (GRTS) Protection shall be provided to protect against failure of the GRTS to commutate current from the metallic return to the ground return.

The ground return transfer switch current shall be measured and compared with a preset threshold. When the threshold is exceeded for a preset period of time, the Protection shall

a) Generate an alarm

b) Issue close command to the GRTS.

2.4.10 NBGS Overcurrent

NBGS Overcurrent protection shall be provided with IDMT characteristic to detect overcurrent in NBGS.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Generate an alarm

2.4.11 Electrode Line Balance Protection

Electrode Line Balance Protection shall be used in a scheme where the electrode line has two conductors. This protection detects mismatch between the two electrode line conductors DC current signals measured by DC CTs.

On operation, the Protection shall produce Alarm "Electrode Line Unbalance".

2.4.12 Electrode Line Overload

Electrode Line Overload protection shall be provided IDMT characteristics with to detect overload in one of the electrode line conductors. Sudden trip of one of the parallel electrode lines may cause overload on the other line.

On operation, the Protection shall produce Alarm "Electrode Line Overload".

Informative: An integral timer is used so that a recurring overload has cumulative effect. In order to reset the integral when the current is below the operating threshold, a reset characteristic is defined.

2.4.13 Neutral/Earth Overcurrent

Neutral/Earth Overcurrent protection shall be provided IDMT characteristics with to detect overcurrents in the electrode line or earth current.

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Trip associated AC CBs as necessary

c) Generate an alarm

2.5 HVDC Transmission Link Zone Protection

The following protections shall be used for the HVDC Transmission link either Cables or Overhead lines.

2.5.1 DC Line Fault

DC Line Fault protection shall consist of two main protections capable of detecting ground faults on the DC link either overhead lines and/or submarine cables.

Informative: The fault current is brought to zero for a period of time to allow the arc to de-ionise. If the fault is between an overhead line and ground the Delay Automatic Re-close (DAR) scheme may in general be used to restart power transmission following de-ionization time. The protection of DC cables is similar to that for overhead lines. Since cable faults are *generally permanent no DAR schemes are used. If however, the line consists of both overhead and cable segments, then the DAR may be used for the overhead line faults.*

On operation, the Protection shall

a) Initiate converter blocking sequence

b) Generate alarm “DC Line Fault”

c) Line and Neutral isolation

Informative: DC Line protection is only active at the rectifier. To distinguish between faults in the DC system and at the inverter the telecommunication system may be needed to send to the rectifier, status signals indicating inverter failure or telecomm failure.

To prevent operation if a single phase, or more, fault occurs on the rectifier AC system, i.e. a fault outside the protection zone, the function is inhibited via AC Fault detection. The protection is also inhibited when the converter is blocked.

If the above inhibits are not active and the rectifier is de-blocked, DC line faults may be detected either by the presence of a negative rate of change of DC voltage (dVdc) below a threshold or, persistently low DC voltage and the presence of DC Current.

Following the protection operation, if the DC voltage has not recovered within a specified period of time, the DC line fault is assumed to be still present and the process shall be repeated. If the DC voltage and DC current does not recover after a preset number of retries the converter shall be blocked and the associated AC circuit breakers shall be tripped.

Informative: The pure undervoltage detector may also be needed to detect a DC Line Fault for cases when the differentiated DC voltage does not decrease below its threshold.

Due to the fast operation portion of DC Line Protection, the detection of DC Line Faults shall be co-ordinated so it does not operate for faults beyond the smoothing reactor on the inverter side.

2.5.2 Cable Pair Sharing Protection

Cable Pair Sharing Protection shall be used where a pair of DC cables is used to implement the transmission link. It detects mismatch between the same polarity of DC current signals measured by DC CTs indicating the faulty cable

Informative: The mismatch is derived by taking the absolute value of the difference between the DC current input signals.

The protection shall operate when the mismatch current exceed a preset threshold for a preset period of time. On operation, the Protection shall produce Alarm “Cable Pair Sharing Faulty”.

2.5.3 Cable Balance Protection

Cable Balance Protection shall be provided where DC cables of opposite polarity in a bipole scheme are crossed. It detects mismatch between the opposite polarity of DC current signals measured by DC CTs.

The protection will operate when the mismatch exceeds its pre-set threshold for a pre-defined period of time. On operation, the Protection shall produce Alarm “Cable Unbalance”

Informative: The mismatch is derived by taking the absolute value of the difference between the DC current input signals.

2.5.4 Cable Overcurrent

Cable overcurrent protection shall be provided where DC cables are used, to detect the cable current exceeding the normal continuous rating.

The DC current shall be compared with a pre-set threshold, when its threshold is exceeded for a pre-defined period of time, the protection shall operate to generate Alarm “Cable Overcurrent”.

2.5.5 DC Under-Voltage

DC Under-voltage protection shall be provided to detect remote ground faults on DC overhead lines or submarine cables.

On operation, the protection shall

a) Initiate converter blocking sequence

b) Isolating Neutral as necessary

c) Trip associated AC CB(s) as necessary

d) Generate an alarm

2.5.6 DC Over-Voltage

DC Over-Voltage protection shall be provided to detect DC overvoltage on the HV bus.

Informative: Large overvoltage of considerable duration may occur due to peak rectification if a pole is started against an open DC line or if the rectifier is de-blocked against blocked inverter. At the same time the direct current may be very low due to the open circuit.

On operation, the protection shall

a) Initiate converter blocking sequence

b) Inhibit Raise Voltage

c) Forced lower voltage as necessary

d) Generate an alarm

2.5.7 DC Filter Overload

DC Filter Overload protection shall be provided to detect overload in the DC filters.

Informative: The filter overload capability is based on the filter element with the minimum overload capability. Cooling time applied to the integrator function may be related to the filter time constant, and allows for the cumulative effect of the filter current.

On operation, the protection shall generate Alarm “DC Filter Overload”.

2.6 Harmonic Filter Zone Protection

Informative: Harmonic filter may be of manufacturer dependent design. It usually comprises Capacitors, Reactors as well as Resistors and other equipments.

2.6.1 Overall Protection

An overall protection shall be provided for the Harmonic Filter. as per. The protection shall be responsive to both phase and earth faults. The protection shall be provided with self-supervision and CT supervision functions.

The setting range of the protection shall include 10 % - 50 % of the rated current of the filter.

If the overall protection is of high impedance type, a fully duplicated overall protection system driven from a common current transformer shall be provided for the filter.

2.6.2 Overcurrent Protection

Back-up protection having an overcurrent function capable of responding to both 50Hz and to up to 35th harmonics with both DTOC and IDMT characteristics shall be provided for the Harmonic filter.

The back-up protection function shall consist of three phase overcurrent and a residually connected earth fault protection.

The DTOC function shall be provided with a current setting range of 50 % - 200 % and 20-80% (based on 1 A secondary corresponding to approximately full load current of the filter) for overcurrent protection and earth fault protection respectively and a time setting range of 0.1s – 5 s in step of not greater than 0.1 s.

The back-up protection shall be stable for any inrush or outrush transients.

The back-up protection function shall on operation:

a) Trip the filter CBs.

b) Initiate CBF protection

2.6.3 Capacitor Protection

Capacitor protection functions shall be provided for each capacitor segment within the filter. Each shall comprise excessive RMS overcurrent protection, overvoltage protection and out-of-balance protection unless the Contractor can demonstrate that the capacitor bank is adequately protected by alternative protection functions.

The Contractor shall declare how the capacitor protections are applied to each capacitor bank.

Where the discharge current which occurs due to the short circuit of a capacitor unit is of sufficient magnitude to cause unacceptably high voltages on the secondary wiring of the out-of-balance protection, effective means of limiting this voltage shall be employed.

The operation of the above protections shall produce

a) Trip to the filter CBs

b) An alarm

2.6.4 Reactor Thermal Overload Protection

Where reactors are used for the Harmonic filter, and are of the dry type, two-stage thermal overload protection shall be provided. The first stage shall be for alarm purposes and the second stage for tripping. The current setting range of the protection shall include 50 % - 150 % of the rated current of the reactor.

2.6.5 Resistor Thermal Overload Protection

Where the Harmonic filter contains resistors, Two-stage thermal overload protection shall be provided for each resistor bank. The first stage shall be for alarm purposes and the second stage for tripping. The current setting range of the protection shall include 50 % - 150 % of the rated current of the resistor bank.

2.6.6 Resistor Open Circuit Protection

Resistor Open Circuit Protection shall be provided for each resistor bank. The protection shall be able to detect resistor open circuit and high resistance fault conditions.

The protection shall be stable for inrush or outrush transients and harmonics and shall not give an unwanted operation under any normal operating conditions or external fault conditions.

The supplier shall declare the method of measurement employed by the Resistor Open Circuit Protection.

The protection shall give a trip output after a time delay. The setting range for the time delay shall include 0.1 s – 5 s in steps of not greater than 0.1 s.

2.7 DC Smoothing Filter Zone protection

DC Smoothing Filter protection shall be provided to detect faults and faulty components within the filter.

Informative: DC Smoothing Filter protection may include a number of protection functions depending upon the HVDC technology and filter design.

On operation, the protection shall

a) Initiate converter blocking sequence

b) Trip associated AC CB(s) as necessary,

c) Generate Alarms (associated with operated protection functions)

2.8 Valve & Ancillary System Protection

Informative: The protective zone for these protections is normally within the Converter zone.

Valve & Ancillary system protections shall be provided to detect and clear faults associated with equipment failure that may cause the power transfer level to be compromised, harm the converter or compromise the integrity of the main components of the DC equipment, such as failure of the Converter Cooling Plant.

2.8.1 Valve Unit Protection

All the components in the converter valve units shall be monitored to ensure the number failed components do not exceed the redundancy level to affect normal performance of the converter.

If the number of failed components exceed certain preset numbers, the following actions shall be taken in stages as appropriate:

a) Generate alarms

b) Initiate converter block sequence

c) Trip associated AC CB(s)

d) Emergence shut-down of the converter

2.8.2 Converter Cooling Plant Protection

The converter cooling plant protection including but not limited to the following protective functions shall be provided to detect the faults or failure of the cooling plant. On operation, those protections shall block and/or trip a pole as appropriate and necessary.

a) Valve Cooling Water Flow Rate

b) Valve Cooling Expansion Vessel Water Level

c) Valve Cooling Water Conductivity

d) Valve Cooling Water Temperature

e) Valve Hall Dew Point

2.8.3 Valve Hall Fire Detection Protection

Each valve hall shall be equipped with a duplicated fire detection system to protect the Converters against fire hazards.

On operation, the fire detection system shall produce

a) Alarms,

b) Any other actions as specified in the Contract.

2.8.4 Valve Hall HVAC System

The Valve HVAC system shall be provided to ensure that the temperature in the valve hall does not go above preset values.

When excessive valve hall temperature is detected, the protection function shall take the pole out of service by

a) Initiating converter block sequence

b) Tripping Associated AC CBs necessary

c) Generating an alarm

2.9 Circuit Breaker Fail (CBF) Protection

Circuit Breaker Fail (CBF) protection shall be provided as per NGTS 3.24.39 (RES) for all AC system circuit breakers associated with the HVDC converter.

On operation CBF protection shall:

a) Trip other CBs connected to the same busbar or mesh corner.

b) Initiate the DTT send functions of each transformer and feeder connected to the same mesh corner where appropriate.

c) Lockout DAR where appropriate.

2.10 Converter Blocking Fail Protection

Converter Blocking Fail protection shall be provided to cater for the failure of blocking sequence for a HVDC converter.

On operation, the protection shall:

a) Trip associated AC CBs to electrically isolate the converter

b) Initiate the DTT send functions as appropriate

c) Lockout DAR where appropriate.

2.11 Voltage Transformer Gas and Oil Actuated Protection

Where a wound oil-filled voltage transformer is used, then it shall be provided with a gas and oil actuated relay to protect against gas accumulation, loss of oil and oil surge.

On operation, the Mechanical protection shall

a) Initiate converter blocking sequence as necessary

b) Trip the associated AC CB(s).

c) Initiate CBF protection

d) Lockout DAR as appropriate.

2.12 Tripping Arrangements

2.12.1 Tripping systems

Two separately energised independent tripping systems shall be provided for all the protection functions specified in this TS.

The tripping systems shall be designed to operate from 110V DC battery systems specified in TS 3.12.4 (RES).

Each tripping system shall be provided with a separately protected supply fed from different battery systems.

High burden self resetting trip relay(s) shall be provided for each tripping system.

The outputs of all protections shall operate in to both tripping systems.

Operation of the tripping systems from the protections shall be conditioned by auxiliary switches on the appropriate primary disconnectors to inhibit tripping when the protected AC and/or HVDC system are disconnected from the transmission network.

2.12.2 Trip Outputs

The trip relays of each tripping system shall provide output contacts for initiation into the following;

a) Tripping of the associated circuit breaker(s).

b) Intertripping to associated remote circuit breaker(s) where appropriate.

c) Circuit Breaker Fail protection.

The protection system shall provide outputs for initiation of

a) Disconnector sequential isolation where required.

b) Trip relay resetting where required.

2.12.3 Direct Transfer Trip (Intertripping)

Receipt of a Direct Transfer Trip (DTT) shall

a) Initiate converter blocking sequence,

b) Trip the Main CB(s).

c) Initiate CBF protection where appropriate.

d) Lockout DAR where appropriate.

3 CONTROL FUNCTIONS

3.1 Control Systems

3.1.1 Architecture

The control system shall be structured in an hierarchical manner. The following levels (ref. IEC 60633) shall be identified in the software and if applicable in the hardware for each converter:

a) System control

b) Master control

c) Station control

d) Pole control

e) Converter unit control

f) Valve unit control

Only one converter station shall have the active control of the HVDC transmission system at the same time (this station is called the MASTER station, and the other corresponding converter station is called the SLAVE station). The HVDC transmission system shall normally be controlled from the MASTER station or associated control points. Switching of the MASTER function between the converter stations shall not result in an unintentional jump in the power transmission nor in any electrical disturbances or unintended control actions.

Switching of the MASTER function shall be done in the SLAVE station (from LOCAL or REMOTE control) by taking over the active control from the MASTER station.

3.1.2 Control Points

An HVDC link shall be equipped for remote control from the control centres. The control system shall automatically prepare all signals and changes in analogue values from the converter control system for transmission to the control centres without delay.

The response time shall comply with the following requirements: Maximum time from a command is received from the control centre until the breaker is operated: 1 sec.

a) Maximum time from a digital channel is changed until the value is transmitted to the control centre: 1 sec.

b) Maximum time from an analogue value of a high priority channel is changed until the value is transmitted to the control centre: 1,5 sec.

There shall be no limitations in the transmission capacity to the control centre other than the limitations given by the available communication speed and the communication protocol.

There shall be selectable three level control points for an HVDC system:

a) Local Control Points (LCP) where a specific plant item and associated functions within a HVDC converter station e.g. converter transformer bay, can be operated;

b) Station Control Points (SCP) where all the plant items and their associated functions within an HVDC converter station can be centrally operated;

c) Remote Control Points (RCP) where all the plant items and associated functions for a HVDC system can be remotely operated.

It shall be possible to have multiple Remote Control Points, each with two independent communication routes (“A” and “B”) to each converter station. The ‘A’ routes shall normally be in service, reverting to the ‘B’ route on loss of functionality of the ‘A’ route or hardware.

It shall be possible to split control functions for a converter station into dispatch controls and operational controls, and assign only one type of controls to a specific Remote Control Point.

An HVDC system shall have control arbitration mechanism to ensure that only one control point has control authority (active) to operate a plant item or function at a time. Selected control points shall be clearly annunciated at the HMIs of all the control points.

HVDC systems shall normally be unmanned and operated from remote control points. The HVDC link shall also be suitable for manned operation.

3.1.3 Control Point Selections

The system shall be designed to permit a free choice for the control and monitoring of the link from either the station control room (SCP) at one of the converter stations or from one of the remote control centres (RCPs). Switching between station and remote control shall only be possible at the SCP of converter stations. Further details shall be determined in the detailed engineering of the control system design.

3.1.4 Test and Operation mode for Remote Control

It shall be possible to switch the remote control between the two states OPERATION and TEST,

On OPERATION:

a) All indications, alarms and measured values from the HVDC station to the remote control equipment shall be in an updated state.

b) All commands and set-point values from remote control equipment shall be active in the HVDC station

On TEST:

a) All indications and alarms to the remote control equipment shall be frozen by the remote control interface when position is changed to TEST. A marking shall be used to clearly indicate that the indications and alarms as presented in the control centre are not reflecting the actual status of the HVDC-link.

b) All measured values to remote control equipment shall be in an updated state.

c) All commands and set-point values from remote control equipment shall be inactive, i.e. blocked in the remote control interface.

3.2 Dispatch Controls

The control system shall contain automatic control features that enable the HVDC-link to function under steady state, transient, dynamic operating conditions. Where Line Commutation Converter (LCC) is used, the HVDC systems shall comply with IEC 60919 Part 1, 2 and 3 as appropriate.

For dispatch control, at least the automatic functions described in Clauses 01 – 0 shall be available.

3.2.1 Converter Control Modes

The converter stations shall have three control modes:

a) PV where constant Active Power (P) and Voltage (V) are controlled as pre-defined targets;

b) PQ where constant Active Power(P) and Reactive Power (Q) are controlled

c) Frequency (f) is controlled as predefined targets.

Each converter station shall be capable of operating in PQ and PV independently. The selection of control mode shall be available from the Local and Remote despatch controls. The supplier shall declare control strategy priorities for the control design.

It shall be possible to apply a schedule of settings for a rolling preset period of time. Within this period, it shall be possible to adjust the scheduled despatch or to over-ride the schedule by manual adjustment of the setting parameters.

3.2.2 Start-Up and Shut-Down of HVDC transmission

It shall be possible to automatically start up or shut down the DC-link transmission by setting a power order in the range between minimum and maximum power.

An automatic start against an open end at the other converter station shall not be possible.

3.2.3 PV Control

In PV mode, it shall be possible, from all despatch control points, to select the active power set point from -200% to +200% of the link nominal rated active power in a preset step ranged from 5 to 100 MW. There shall be a minimum operating point of the converter stations to be defined in the Contract in the percentage of rated current.

It shall be possible to select the target AC system voltage from 80% to 120 % of nominal system voltage with preset increment ranged from 0.5 kV to 5 KV steps. The deadband for AC system voltage control shall be no more than ± preset threshold from the target voltage.

3.2.4 PQ Control

In PQ mode, it shall be possible, from all despatch control points, to select the active power set point -200% to +200% of the link nominal rated active power in a preset step ranged from 5 to 100 MW. There shall be a minimum operating point of the converter stations to be defined in the Contract in the percentage of rated active power.

It shall be possible to select the target reactive power in the range of -200% to +100% of rated active power in MVar with a preset increment ranged from 1 to 50MVAr. The deadband for the reactive power control (actual MVAr exchanged between the converter station and AC system) shall be no more than a preset value ranged from ± 1 – 200 MVar from the target.

3.2.5 Frequency Control

Frequency control shall be provided from the HVDC converter to support re-synchronising in the event of a system split. The control shall have manual and automatic operating modes.

When operating in automatic mode, the frequency control shall be initiated if the frequencies measured at the converter stations differ by a predefined frequency with a pre-defined time delay. The frequency range shall be 0 to 1Hz in 0.1Hz steps. The time delay range shall be 0 to 120s in 1s steps.

The droop setting shall be adjustable between 1% and 10% with 1% increment step of the nominal frequency.

3.2.6 Power Ramping

It shall be possible to increase or decrease the transmitted DC-power with a constant predefined rate-of-rise or rate-of-fall.

The ramp rate shall be selectable, from all despatch control points, in the range of 1 to 500MW/min with a preset increment between 1 to 50 MW.

3.2.7 Power Reversal

It shall be possible to reverse the direction of power flow with a changeover period between blocking and de-blocking not exceeding a specified time, in the range of 0 – 600 seconds.

3.2.8 Pole Balance Control

The control system shall act to balance the loads of each pole of the bi-pole to minimise earth currents. The maximum permitted continuous earth current shall not exceed 5 amps. This limit shall only be exceeded for the duration of converter or cable earth faults.

3.2.9 Reactive Compensation and Harmonic Filter Control

Harmonic filter control shall be provided to achieve compliance with the specified harmonic performance requirements by switching harmonic filters. The function shall also provide Reactive Compensation and/or AC Voltage support including Temporary Over Voltage (TOV) control by switching the same filter banks. Supplier shall declare the control strategy and design to achieve those requirements.

Three control modes shall be provided for the switching of reactive compensation and harmonic filters:

a) MW Mode where the filters are switched at pre-determined MW transfer levels,

b) Target Voltage mode where the filters are switched when preset high and low voltage threshold limits are exceeded

c) MVAR mode where filters are switched when threshold MVAR transfer levels are exceeded.

The specified harmonic performance requirements shall not be comprised under any circumstance during operation of all above control modes.

The control system shall have mechanism to ensure the equal switching duty among the harmonic filters.

Where applicable, the Reactive Compensation and Harmonic Filter control shall co-ordinate with the Dynamic Var Compensation Equipment for the purpose of Reactive Compensation and/or Voltage control. Supplier shall declare the control strategy to be agreed by National Grid.

3.2.10 Emergency Power Control/Power Demand Override

Where required, functions for helping either one of the two AC grids during special system conditions (e.g. extreme AC frequency, extreme AC voltage or defined circuit breaker operations) shall be available. Additional entries shall be available for future use.

Informative: as an example, the over and under frequency protection functions settable using the HVDC control interfaces may be required within HVDC control systems.

3.2.11 Power Oscillation Damping

Where specified, a Power Oscillation Damping (POD) function shall be provided as part of the HVDC control system to enhance the damping of electromechanical oscillations on the transmission system.

It shall be possible to tune the POD to accommodate a range of system conditions.

Facilities shall be provided at all designated control points to modify the characteristics of the POD manually or automatically should system conditions require.

Where an HVDC system operates with the Dynamic Reactive Compensation e.g. Static Var Compensators (SVCs) and where both with POD functions, co-ordination between the two controllers shall be provided to ensure optimum damping for all expected operational combinations of these equipments. The supplier shall be responsible for all aspects of this co-ordination, including the provision of all communication equipment and cabling if necessary.

POD performance shall be demonstrated by means of studies and tests according to the criteria and principles specified in the Contract.

3.2.12 Sub Synchronous Resonance (SSR) Damping

All protection and control functions/devices shall have sufficient immunity to potential SSR and shall not either de-function or mal-function under any foreseeable SSR conditions.

Where specified, the converters shall be equipped with a control function for damping of sub-synchronous resonance between converter and generators in the vicinity of the converter stations.

3.2.13 Change Over Mechanism

Where protection and control equipment is duplicated, a dedicated changeover mechanism shall be installed at each level of the controls i.e. station, bipole and pole level to monitor the availability and health of the equipment.

If one protection or control is failed, it shall automatically change over to the redundant one. In the event of the redundant control being unavailable due to for example maintenance or faulty, the associated pole shall be blocked and/or tripped.

When both station controls become unavailable, an alarm shall be raised to alert the operator and the bipole and pole controls shall maintain the prevailing power transfer until the operator intervenes. Provision shall be made to allow a ramp to minimum power and controlled shut down.

For a bipole design, the control system shall freeze the previous orders from the station controls until the operator intervenes. In the same manner, failure of both duplicated controls at the bipole level shall cause an alarm to be raised and the previous orders from the bipole controls shall be latched at pole level until operator intervention. Provision shall be made to allow a ramp to minimum power and controlled shut down.

3.2.14 Automatic Pole Switching

Where a bipole design is used, the Automatic Pole Switching function shall be provided to re-configure bipole operation into Monopole operation when one of the poles is tripped.

3.3 Manual Operation

Informative: the manual operation is mainly intended for test purposes and emergency operation.

3.3.1 Starting, Stopping and Regulation of the DC Transmission

It shall be possible manually to start up and shut down the whole DC-power transmission. The manual control mode is mainly intended for tests and maintenance but shall also permit operation of the link in case of loss of the telecommunication between the converters. For this purpose a tracking function shall allow slow ramping of power on the HVDC link.

A manual start against an open end at the other converter station shall as far as possible be avoided through interlocks.

3.3.2 Open Converter/Line Test Modes

An open-line test arrangement shall be provided in the converter control system to enable voltage testing of the HVDC line/cable. From each of the two HVDC converters it shall be possible to make a controlled increase of the DC voltage from zero to 1.05 times the rated DC cable voltage against an open inverter.

This shall be done without risk for reflection in the open end, resulting in unacceptable cable voltage levels. The open-line test shall also be possible without the HVDC cable connected. This Function shall only be available in the local control room.

Informative: the following protections will need to be sensitised or desensitised as no current should flow through the converter during this test:

a) *AC>DC Differential*

The DC signal input need to be set to zero to sensitise the protection during Open Circuit Test Mode.

b) *AC Over-Current Protection*

As no current flow through the converter during the test this protection will need to be sensitised by shifting IDMT characteristic down to a new pick-up level.

c) *DC Over-Current Protection*

As no current flow through the converter during the test, this protection will need to be sensitised by shifting IDMT characteristic down to a new pick-up level.

d) *DC Differential protection*

This protection needs to be sensitised when Open Circuit Test Mode is selected to protect against flashovers.

e) *DC Line Fault protection*

This protection needs to be sensitised to enable persistent DC line faults to be detected during open circuit test mode

f) *DC Under-Voltage Protection*

-Inhibited.

g) *DC Under-Current Protection*

-Inhibited.

3.4 SCADA Functions

A SCADA system shall be provided for the HVDC converter station as per TS 2.7 (RES), Manual Control

All the CBs and disconnectors shall be provided with open and close controls that can be initiated from any control points.

It shall be possible to manually tap converter transformers at all the control points

3.4.1 Controls, Indications and Alarms

All the specified manual control and automatic functions shall be provided with IN/OUT selection facilities at LCPs, SCPs and pre-defined RCPs via the converter Station SCADA System.

All CBs and disconnectors within a HVDC converter station shall have double point indications as per TS3.24.4 (RES) to show “Open”, “Close” and “D.B.I” status which shall be alarmed.

Each specified function shall provide alarms and indications as appropriate, to the associated LCPs, all the SCPs and RCPs, including but not limited to:

a) All the control selections & indications

b) Controls and indications of all circuit breakers, disconnectors and earth switches

c) Circuit breaker, transformer, disconnector, filter, fixed reactive compensation, Dynamic Reactive Compensation and instrument transformer plant alarms & condition monitoring data.

d) Control mode status

e) Pole status

f) Valve cooling system status

g) Converter transformer tapchanger position indications.

h) AC current, voltage, power and reactive power per pole

i) AC system overall power and reactive power and frequency

j) AC filter & Dynamic Reactive Compensation reactive power

k) DC current, voltage magnitude and polarity

l) Earth current

m) Rectifier delay angle

n) Inverter extinction angle

o) Station auxiliary systems e.g. fire, environmental, security as well as other domestic services.

Informative: The alarms and indications that are to be provided as per this TS and other relevant functional specifications.

For alarm handling (local, remote and grouping information), refer to the Generic Equipment Model (GEM).

Protection operation or failure shall annunciate through the substation alarm & event logging system. The following protection output alarms shall be provided;

a) Protection operated alarm for each electrical and mechanical protection.

b) Trip relay operated indication (where required).

c) Protection supply supervision alarm for each fused supply.

If the protection equipment is of the static (analogue or digital) type, an alarm output of equipment inoperative shall be provided for the loss of DC auxiliary energising supply and internal relay failures.

All MCB operations shall be correctly alarmed, and shall not trip the system unnecessarily.

Each function shall provide information that can be accessed via a communications port (Informative interface).

3.4.2 Time Synchronisation

Each function shall be provided with a substation time reference which shall be based on GPS.

All events and alarms generated by the control system and external input signals (events and alarms) to the control system shall be stored in the control and protection system. All recordings and messages shall be given with a real time stamp. Correct time tagging shall be ensured.

The accuracy and resolution of the time tagging shall at least be 1 ms. The station master clocks of both HVDC converters shall be synchronised. In case of loss of synchronisation, the station master clocks shall continue operation with the internal crystal with an accuracy of 1 ppm.

3.4.3 Interlocking

An Interlocking function shall be provided to ensure safe operation of the AC and DC switchgears within a converter station.

3.4.4 Sequential Isolation

HVDC system shall be provided with disconnector sequential isolation where required. The contract will state if this is required.

3.4.5 Synchronising

The AC system of an HVDC converter station shall be provided with check synchronising and system synchronising functions as necessary.

The AC VT shall provide a voltage input (incoming voltage) to the Synchronising functions mentioned.

3.4.6 Voltage Selection

The AC VT shall provide inputs to the substation voltage selection function.

The converter substation AC voltage selection function shall provide a voltage reference input (running voltage) that represents the voltage of the busbar to which the HVDC is selected to for the Synchronising functions.

3.4.7 Ferro-resonance Detection and Quenching

Ferro-resonance detection and quenching facilities shall be provided. Where required, an F4 ferro-resonance scheme shall be provided unless otherwise specified.

3.4.8 Phases Unbalanced Detector

A phase unbalanced detector function shall be provided to the AC system to initiate an alarm for a sustained unbalanced load current.

3.4.9 AC CB Pole Discrepancy Tripping

AC CB pole discrepancy tripping function shall be provided for the AC CBs.

Informative: Pole discrepancy has traditionally been known as ‘phases not together’ within the UK electricity supply industry.

3.4.10 Instrument Transformers supervision

Functions which use signals from VTs shall be provided with a VT supervision function.

The VT supervision function shall initiate an alarm on VT failure.

3.4.11 Interfacing with Special Protection and Operational Tripping Schemes

The converter station control systems shall provide interfaces to AC network special protection and operational tripping schemes (SPS/OTS).

On receipt of commands from the SPS/OTS, an HVDC control system shall be capable of taking the actions including but not limited to (subject to the Contract):

a) Converter block

b) Converter De-block

c) Converter ramp up/down at a pre-defined rate to a pre-defined set point

d) Enable/disable/modify POD control

e) Enable/disable/modify SSR control

3.5 Communications

Where communication is required for an HVDC control, duplicated channels shall be provided to ensure no single failure shall result the loss of communication between two converters.

Standard IEC communication protocols such as the IEC 60870-5-101, the IEC60870-5-104 and IEC61850 shall be used for the local and remote communications for an HVDC system.

All the communication channels for protection and control systems shall be supervised and alarm if they become faulty.

3.6 Metering

Operational metering functions shall be provided to give indications to the SCADA of:

a) AC system Voltage

b) AC active and reactive power

c) Harmonics as appropriate

If required, Settlement metering functions shall be provided. ~~as per TS 3.9.XX~~

3.7 Recording & Monitoring

3.7.1 Fault Recording

Fault recording shall be provided for both AC and DC system within a HVDC converter station. Quality of Supply Monitoring

Quality of supply monitoring function shall be provided as appropriate.

3.7.2 Cable Monitoring

The control system shall integrate measurement and status signals from the cable condition monitoring function.

3.8 Test Facilities

3.8.1 Test / Normal Facility

A Test / Normal facility shall be provided by means of a ‘lockable’ selector switch for each IED. When in the “Test” position the following shall apply;

a) Isolate the initiation of converter blocking sequence

b) Isolate the Tripping functions

c) Disable the DTT Send function (if applicable)

d) Generate alarm(s) when in the “Test” position for each affected protection function

Informative: ‘Lockable’ shall be by means of a unique key or padlock facilities to accept a 5mm diameter and 30mm hasp.

3.8.2 Routine Protection Operation Test Facility

A secure Routine Protection Operation test facility shall be provided to initiate the tripping of the main CB(s) from the all the main protection by simulating internal faults. The facility shall initiate tripping, I/T, DAR (if applicable), Auto-Switching (if applicable), CBF, fault recorders, blocking converter sequence etc.

3.9 Auxiliary Supply

Two independent 110V DC battery systems shall be provided. Power Supply Supervision

All the control and protection cubicles shall be provided with power supply supervision.

4 PERFORMANCE REQUIREMENTS

4.1 General

All the HVDC protection and control functions shall perform correctly in accordance with the requirements of this specification, and appropriate level 3 National Grid RES Technical Specifications, for the range of power system conditions specified in TS1 (RES) and the range of environmental conditions specified in TS 3.24.15 (RES).

The performance of the protection shall not be adversely affected by the worst conditions of magnetising inrush, current transformer saturation or harmonics.

4.1.1 Minimisation of Non-Characteristic Harmonics

The control system shall be designed to minimise the generation of non-characteristic harmonic currents.

4.1.2 Failure of Telecommunications

All the communications facilities for automatic control of the HVDC system shall be duplicated and functionally independent. The channels shall be continually supervised providing annunciation of degradation or failure to all control points.

Any telecommunication failure shall not cause any unintentional operation of the control system. If the telecommunication link between the MASTER converter control system and corresponding remote control centre breaks down during remote operation, the initiated orders shall be completed. The operators shall have the possibility to switch MASTER converter station to the other one for normal operation during such failure on the telecommunication link.

When the telecommunication link is re-established, the normal control of the power transmission shall automatically be re-established. All alarms and indications issued in the HVDC converter during the failure shall be transmitted in chronological order to the control centre.

An HVDC link operation shall not deviate from its operating point in the event of total failure of the communications channels.

The supplier shall declare the limitations of the operation of the HVDC link and loss of functionality in the event of total communications system failure. The supplier shall also detail the required manual actions to maintain normal operation, effect start-up and shutdown sequences, change control modes, modify set-points and operating parameters under this circumstance.

All the equipment shall be resilient to the partial and/or total failure of hardware. Appropriate alarms shall be generated when the failure(s) detected.

5 FORMS AND RECORDS

TS 3.24.90.A Function Integration Table

PART 2 - DEFINITIONS AND DOCUMENT HISTORY

6 DEFINITIONS

The definitions in BSEN 60633: 1999 apply to this specification.

CB	Circuit Breaker
CBF	Circuit Breaker Fail
CT	Current Transformer
CTS	CT Supervision
DAR	Delayed Auto-Reclose
DTT	Direct Transfer Trip
EIDMT	Extremely Inverse Definite Minimum Time
ENCC	Electricity Network Control Centre
IED	Intelligent Electronic Device
HV	High Voltage
IDMT	Inverse Definite Minimum Time
I/T	Inter-Trip
LV	Low Voltage
MC	Mesh Corner
POD	Power Oscillation Damping
OC	Over Current
SCS	Substation Control System
TS	Technical Specification
CSC	Current Sourced Converter
VSC	Voltage Sources Converter

7 AMENDMENTS RECORD

Issue	Date	Summary of Changes / Reasons	Author(s)	Approved By (Inc. Job Title)
1	October 2014	First issue	Richard Poole/Ray Zhang	GCRP

7.1 Procedure Review Date

5 years from publication date.

PART 3 - GUIDANCE NOTES AND APPENDICES

8 REFERENCES

TS 1 (RES)	Ratings and General Requirements for Plant, Equipment and Apparatus for the NGT System and Connection Points To It
TS 3.24.15 (RES)	Environmental and Test Requirements for Electronic Equipment
TS 3.24.34 (RES)	Busbar Protection
BS EN 50328:2003	Semiconductor converters. General requirements and line commutated converters. Specification of basic requirements
IEC 60146-1-2	Semiconductor converters – General requirements and line commutated converters - Part 2: Application guide
BS EN 50329:2003	Semiconductor converters. General requirements and line commutated converters. Transformers and reactors
BS EN 60146-2:2000	Semiconductor converters – Part 2: Self commutated semiconductor converters including direct d.c. converters
BS EN 60700-1:1998 + A2: 2008	Thyristor valves for high-voltage direct current (HVDC) power transmission. Electrical testing
BS EN 60633:1999	Terminology for high-voltage direct current (HVDC) transmission
IEC/TR 60919-1	Performance of HVDC systems with line commutated converters – Part 1: Steady state conditions
PD/IEC/TR 60919-2	Performance of HVDC systems with line commutated converters – Part 2: Faults and switching
IEC/TR 60919-3	Performance of HVDC systems with line commutated converters – Part 3: Dynamic conditions
BS EN 62501: 2009	Voltage Sourced Converter (VSC) valves for high-voltage direct current HVDC power transmission – Electrical testing
IEC/PAS 61975	System tests for HVDC installations
DD/IEC/PAS 62001:2004	Guide to the specification and design evaluation of a.c. filters for HVDC systems
DD/IEC/PAS 62543:2008	DC transmission using Voltage Sourced Converters (VSC)
DD/IEC/PAS 62544:2008	Active filters in HVDC applications
BS EN 61378-2:2001	Converter transformers. Transformers for HVDC applications
BS EN 60076-10:2001	Power transformers. Determination of sound levels
BS IEC 60747-6:2000	Discrete semiconductor devices and integrated circuits. Thyristors

Engineering Recommendation (Er) G5/4 Levels Of Harmonic Distortion.

APPENDIX A - FUNCTION INTEGRATION TABLE

FUNCTION DESCRIPTION	BOX 1	BOX2	BOX3	BOX4	BOX5	BOX6
PROTECTION FUNCTIONS						
AC Busbar Zone Protection						
Double Busbar arrangement						
Mesh Corner Arrangement						
Converter Transformer Zone Protection						
Converter Transformer Protection						
Tapping Sequence Protection						
DC Converter/Pole Zone Protection						
Asymmetry Protection						
Pole Differential Protection						
DC Overcurrent						
AC>DC Differential						
DC>AC Differential						
AC Overcurrent						
AC Overvoltage Line Side						
AC Overvoltage Valve Side						
AC Undervoltage						
DC Undercurrent Protection						
Tap Limits Protection						
Thermal Protection						
Neutral Zone Protection						
Common Neutral Area Protection						
Neutral Bus Overvoltage Protection						
Neutral Bus Grounding Switch (NBGS) Protection						
Neutral Bus Switch Protection						
Electrode Line Fault Detector						
Neutral Current Unbalance						

FUNCTION DESCRIPTION	BOX 1	BOX2	BOX3	BOX4	BOX5	BOX6
Metallic Return Earth Fault Protection						
Metallic Return Transfer Breaker (MRTB) Protection						
Ground Return Transfer Switch Protection						
NBGS Overcurrent						
Electrode Line Balance Protection						
Electrode Line Overload						
Neutral/Earth Overcurrent						
HVDC Transmission Link Zone Protection						
DC Line Fault						
Cable Pair Sharing Protection						
Cable Balance Protection						
Cable Overcurrent						
DC Under-Voltage						
DC Over-Voltage						
DC Filter Overload						
Harmonic Filter Zone Protection						
Overall Protection						
Overcurrent Protection						
Capacitor Protection						
Reactor Thermal Overload Protection						
Resistor Thermal Overload Protection						
Resistor Open Circuit Protection						
DC Smoothing Filter Zone protection						
Valve & Ancillary System Protection						
Valve Unit Protection						
Converter Cooling Plant Protection						
Valve Hall Fire Detection Protection						
Valve Hall HVAC System						

FUNCTION DESCRIPTION	BOX 1	BOX2	BOX3	BOX4	BOX5	BOX6
Circuit Breaker (CBF) Fail Protection						
Converter Blocking Fail Protection						
Voltage Transformer Gas and Oil Actuated Protection						
CONTROL FUNCTIONS						
Control Systems						
Control Points						
Control Point Selections						
Test and Operation mode for Remote Control						
Dispatch Controls						
Converter Control Modes						
Start-Up and Shut-Down of HVDC transmission						
PV Control						
PQ Control						
Frequency Control						
Power Ramping						
Power Reversal						
Pole Balance Control						
Reactive Compensation and Harmonic Filter Control						
Emergency Power Control/Power Demand Override						
Power Oscillation Damping						
Sub Synchronous Resonance (SSR) Damping						
Change Over Mechanism						
Automatic Pole Switching						
Manual Operation						
Starting, Stopping and Regulation of the DC Transmission						
Open Converter/Line Test Modes						
SCADA Functions						
Manual Control						

FUNCTION DESCRIPTION	**BOX 1**	**BOX2**	**BOX3**	**BOX4**	**BOX5**	**BOX6**
Controls, Indications and Alarms						
Time Synchronisation						
Interlocking						
Sequential Isolation						
Synchronising						
Voltage Selection						
Ferro-resonance Detection and Quenching						
Phases Unbalanced Detector						
AC CB Pole Discrepancy Tripping						
Instrument Transformers supervision						
Interfacing with Special Protection and Operational Tripping Schemes						
Communication Supervision						
Metering						
Operational Metering						
Settlement Metering						
Recording & Monitoring						
Fault Recording						
Quality of Supply Monitoring						
Cable Monitoring						
Test Facilities						
Routine Protection Operation Test Facility						
Test / Normal Facility						
Power Supply Supervision						

APPENDIX B - AN EXAMPLE OF AN HVDC SYSTEM ARRANGEMENT