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PROTECTION & CONTROL FOR HVDC SYSTEMS

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PURPOSE AND SCOPE

This specification defines the functional and performance requirements for the protection and control of HVDC systems within National Grid. 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. This document shall be read in conjunction with the Technical Specification for HVDC converters as defined in TS 2.31.

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. 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 Quality Assurance

All the software/firmware version control and configuration parameter settings shall be managed as per TP107.

1.4 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 TS3.24.4, TS3.24.15, TS 2.19 as well as EATS48-4.

1.5 Type Registration

HVDC protection and control systems shall be type registered in accordance with National Grid Transmission Procedure TP183 – Type Registration.

1.6 Spares, Maintenance and Refurbishment

Unless separately specified in the Contract, spares, maintenance and refurbishment requirements for HVDC protection and control systems shall comply with National Grid existing policies, particularly PS(T)12.08, PS(T)12.09, PS(T)12.10, PS(T) 024, PS(T) 035 and PS(T) 066.

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.

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 in accordance with TS 3.24.6.

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

Transformer protections shall be provided for the converter transformers as per TS 3.24.8.

If the HVDC system is connected to a Mesh Corner substation, TS 3.24.6 shall also be complied for the transformer protections.

Where applicable, protection shall be provided to cover the connection between converter transformer(s) and converter(s) as per TS 3.24.65 Overall protection.

2.2.1 Tapping Sequence Protection

Converter transformer tapping sequence shall be monitored to ensure correct operation of on load tap changers in accordance with relevant clauses in TS 3.3.4 and TS 3.24.61. 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:

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