European Network of
Transmission System Operators
for Electricity

NC HVDC - PRELIMINARY SCOPE

NETWORK CODE ON HVDC CONNECTIONS
AND DC CONNECTED POWER PARK MODULES

7 MAY 2013

TABLE OF CONTENT

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

1 CONTENT

On 29 April 2013 ENTSO-E received a mandate letter from the EC to develop a network code on HVDC connection rules, within ACER's framework guidelines on electricity grid connections (published 20 July 2011)[1]. This code will be covered by ENTSO-E in a Network Code on 'HVDC Connections and DC Connected Power Park Modules' (NC HVDC). In line with the mandate this network code is to be submitted to ACER within a time period of twelve months by 1 May 2014.

In the preparatory phase prior to receiving this mandate, ENTSO-E developed a preliminary scope, which serves as a basis for initial discussion with the wider industry and further drafting of the NC HVDC. One of the forums to conduct in-depth discussions with stakeholders throughout the development of the NC HVDC is a dedicated HVDC User Group which ENTSO-E initiated by means of an open call in January 2013[2]. With an extensive and well appreciated response of over 20 organizations, the first HVDC User Group meeting in which the ideas of the preliminary scope were discussed took place on 12 March 2013.

This document intends to enable stakeholders to already start assessing in full transparency the results of the preparatory work, following the policy option choices of ACER's framework guidelines. This publication also allows for stakeholders who have not yet been in contact with ENTSO-E on the topic of this code to raise their potential interest. Specific feedback on this response is pursued by means of questions raised in a "Call for Stakeholder Input", published jointly with this scope.

This preliminary scope is considered a working document and does not represent a firm, binding and definitive ENTSO-E position on the contents, the structure, or the prerogatives of the NC HVDC on which a formal public consultation will be organized by ENTSO-E according to Regulation (EC) 714/2009.

Further info on the development of the NC HVDC, now in the coming months, can be accessed on the ENTSO-E website[3].

2 NC HVDC GENERAL PRINCIPLES

Besides HVAC transmission, HVDC technology is used as well for the connection between synchronous zones, within synchronous zones or for the connection to Power Park Modules (PPMs).

HVDC technology can enable interconnections between different TSOs or synchronous zones where AC technology is either not practical and/or is less beneficial in terms of cost, environment, or technical performance. It will bring new market and control options, allowing the development of cross border exchanges of energy and ancillary services and will lead to a better RES integration with the consequent increase in consumer benefits.

However, these technologies always need to interact with the HVAC systems; the HVDC systems are essential facilities and their compliance to code specifications is of importance in order to ensure reliable operation of HVDC connections between synchronous zones, helping to maintain system security:

---

[1] http://www.acer.europa.eu/portal/page/portal/ACER_HOME/Communication/News/110720_FGC_2011E001_FG_Elec_GrConn_FINAL.pdf
[2] https://www.entsoe.eu/fileadmin/user_upload/_library/resources/HVDC/130130-HVDC_User_Group-Invitation_letter_and_ToR.pdf
[3] https://www.entsoe.eu/major-projects/network-code-development/high-voltage-direct-current/

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

- This code lays down specific technical requirements for the connection of HVDC transmission circuits and DC Connected Power Park Modules that have significant cross-border impact amongst TSOs within the ENTSO-E region.
- This code will provide common technical requirements that will assist effective competition and the efficient functioning of the internal electricity market to ensure system security and to minimise costs to consumers, within the provisions of ACER's framework guidelines on electricity grid connections.
- The NC HVDC is linked to the Network Code for "Requirements for Generators" (NC RfG), and operational Network Codes[4]. The NC HVDC will follow similar principles regarding the operational notification of new and existing HVDC systems and DC Connected PPMs, compliance procedures and derogations.
- The NC HVDC focuses on DC transmission grids' point to point and extension to multi-terminal radial connections. Meshed DC grids and DC collection grids are out of the scope of this network code.
- The NC HVDC strives for equitable treatment of all HVDC systems and DC Connected PPMs. It maintains a technology neutral approach.
- Several levels of detail will be given in code requirements
  - Exhaustive requirements, possibly with single European parameter values or thresholds;
  - Non-exhaustive requirements with ranges of parameters to be set at national level; and
  - Non-exhaustive requirements with specific details to be set at national level.

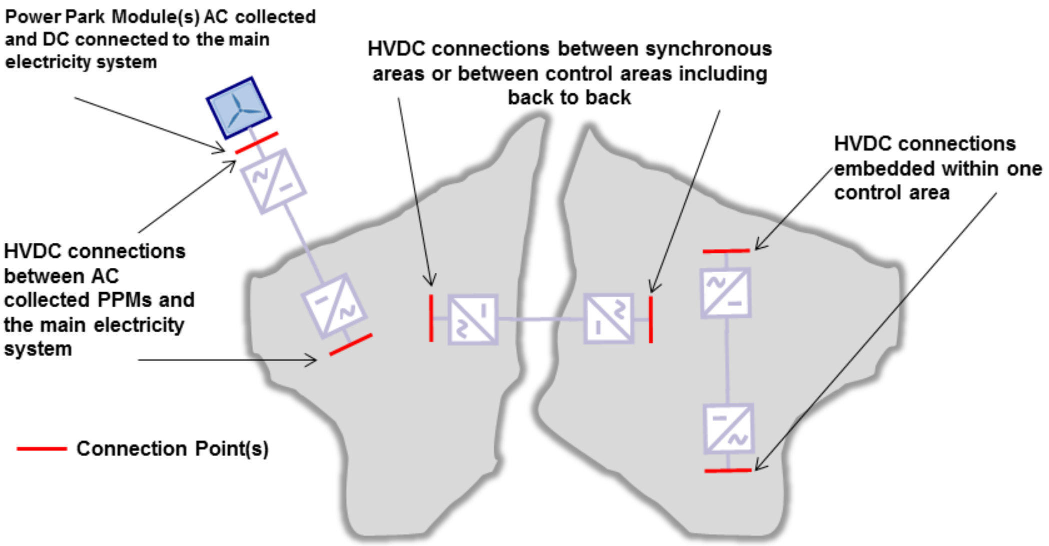
The NC HVDC will define the connection point(s) where the requirements shall apply.

The following configurations will be treated as Significant Grid Users to whom the requirements of the NC HVDC shall apply:

- HVDC connections between synchronous areas or between control areas, including back to back;
- HVDC connections to Power Park Modules;
- HVDC connections embedded within one control area and connected at transmission system voltage level. Connections at an AC voltage below transmission system voltage, as specified at national level, can be covered as Significant Grid Users if a cross-border impact is demonstrated by the relevant TSO and approved by the NRA;
- All Power Park Modules that are AC collected and DC connected to the main electricity system at any AC transmission voltage.

[4] https://www.entsoe.eu/major-projects/network-code-development/

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu



3 NC HVDC GENERAL REQUIREMENTS

3.1 REQUIREMENTS FOR HVDC CONNECTIONS

The requirements utilise the inherent capabilities of HVDC systems and DC connected PPMs to ensure or improve power system security and enhance market integration and renewable energy penetration.

For ensuring or improving power system security, HVDC systems and DC connected PPMs need to support frequency and voltage stability, robustness of transmission corridors, system recovery after a black-out and harmonized protection system.

In order to enhance market integration, they need to be capable of exchanging balancing and control energy. To that end, adequate power controllability is required, including frequency sensitivity and frequency control modes.

In order to enhance renewable energy sources penetration, they need to contribute to strengthen network operation conditions, in particular when conventional generation is far from the HVDC converter connection point or out of operation for economic reasons. Requirements such as synthetic inertia, priority to active or reactive contribution, post fault active power recovery enable HVDC converters to provide to the transmission system frequency and voltage stability.

Requirements for HVDC systems and DC connected PPMs have been distinguished in six categories:

- Requirements for active power control and frequency support;
- Requirements for reactive power control and voltage support;
- Requirements for fault-ride-through;
- Requirements for control stability;
- Requirements for protection devices and setting; and
- Requirements for power system restoration.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

This requirement classification is not exclusive. Some requirements related to fault-ride-through such as fault-ride-through capability, post-fault active recovery or auto-reclosure also contribute to frequency and voltage stability by maintaining or restoring rapidly pre-fault conditions for generation and load. These requirements shall apply when operating in either direction.

3.1.1 REQUIREMENTS FOR ACTIVE POWER CONTROL AND FREQUENCY SUPPORT

The requirements for active power control and frequency support include:

i. **Frequency ranges** : the HVDC converters shall be capable of staying connected to the AC network and operating normally when frequency changes in accordance with normal and contingency operation of the network.

ii. **Rate of change of frequency withstand capability** : the HVDC converters shall be capable of staying connected to the AC network and operating when frequency is varying within the rate of change defined by the TSO.

iii. **Active power controllability; control range and ramp rates**: the HVDC converters shall be capable of transmitting active power in both directions by manual and automatic control in accordance with the TSO's operating and planning criteria.

iv. **Synthetic inertia capability** : the HVDC connection scheme shall be capable of providing synthetic inertia as a quantified response to frequency changes, activated both in low and high frequency regimes by rapidly adjusting the active power injected to or withdrawn from the AC network.

v. **Frequency sensitive mode**: is a mode in which HVDC converters shall be capable of responding to frequency deviations by adjusting the active power transmitted in a direction that assists in the recovery of target frequency.

vi. **Limited frequency sensitive mode (overfrequency)**: the HVDC converters shall be capable of operating in this mode which reduces active power output in response to a change in system frequency above a certain value.

vii. **Limited frequency sensitive mode (underfrequency)**: the HVDC converters shall be capable of operating in this mode which increases active power output in response to a change in system frequency below a certain value.

viii. **Frequency control** : is an HVDC operating mode which will be able to control the frequency by adjusting the active power output within normal operation.

ix. **Maximum loss of active power** : to maintain system stability, the maximum allowable loss of active power provided by an HVDC system to the wider system shall be specified at the connection point(s) by the TSO(s). This will ensure that loss of (an) HVDC system(s) at the connection point(s) does not lead to wide scale system instability.

3.1.2 REQUIREMENTS FOR REACTIVE POWER CONTROL AND VOLTAGE SUPPORT

The requirements for reactive power control and voltage support include:

i. **Voltage ranges** : an HVDC converter needs to be capable of staying connected to the AC network and operating within steady state and temporary operating voltage ranges for network security reasons, as defined by the TSO. The intention of this requirement is to specify voltage ranges in order to coordinate the performance of the overall system.

ii. **Short circuit contribution during faults**: is an essential factor for the network performance and to ensure adequate system security. The contribution shall be settable according to the system needs.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

iii. **Reactive power capability** : For HVDC converter stations, it is an essential requirement for safe operating conditions of the overall system. The intention of this requirement is to specify the reactive power capability as a function of the transferred active power and the AC operating voltage.

iv. **Reactive power exchange**: uncontrollable exchange of reactive power between the HVDC converter station and the AC network may cause adverse operating conditions in the system. The intention of this requirement is that the HVDC connection will consider and design its installation to limit unexpected reactive exchanges to acceptable values.

v. **Reactive power control mode**: The control of the reactive power of an HVDC converter station is of utmost importance for the steady state as well as the transient performance of the overall system. The intention of this requirement is to specify the control and utilisation of the reactive capability (as specified in iii). The specification may address:

- Control mode (e.g. voltage or reactive power control);
- Maximum reactive power exchange with the network as a function of transmitted power;
- Control resolution; and
- Control response, e.g. in steady state a slow control and a fast response to transients without exciting post-fault oscillations by providing maximum reactive power capability independently of the previous control state.

vi. **Priority to active or reactive power contribution**: The control of this balance can be of vital importance for the network security and voltage stability. The intention of this requirement is to ensure adequate balanced support from the HVDC converter station during AC network contingencies.

vii. **Power quality**: HVDC converters shall not introduce harmonics that would breach power quality rule compliance.

3.1.3 FAULT-RIDE-THROUGH

Fault-ride-through denotes the ability of a HVDC converter to remain transiently stable and connected to the system for a close fault or voltage dip at the AC onshore and/or AC offshore connection point. This capability is needed for riding through faults located in AC onshore, AC offshore or DC systems. This capability is important to ensure that HVDC systems do not reduce the system integrity and performance of the transmission system, thereby affecting the secure and economic operation across borders.

The requirements related to fault-ride-through include:

i. **Fault-ride-through capability**: the type of fault, fault duration, fault condition and voltage dip is dependent upon relevant TSO system security criteria. The capability to ride through is to be determined by the relevant TSO who can specify system conditions that include minimum fault infeed at the connection point. In the event of an AC fault or opening of the main breaker on one side, the active power reduction seen on the remote end system should be determined by the TSO. In some cases transient power reversal is not allowed. The reactive power capability of the interconnector on the 'healthy' side shall remain available according to performance defined by the TSO.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

ii. **Post fault active power recovery**: the HVDC converter must be able to recover active power output following fault clearance for AC and DC faults or recovery from voltage dips. This ability shall help to restore frequency and voltage stability and shall reduce any consequential thermal overload. The speed and magnitude of recovery is to be determined by the relevant TSO.

iii. **Auto-reclosures**: auto-reclosure of DC links post-fault shall improve the security of the transmission system by restoring system integrity quickly for transient faults. Where there is an overhead line connection, auto-reclosure capability shall apply.

3.1.4 REQUIREMENTS FOR CONTROL

The requirements for control include:

i. **Converter synchronization to and disconnection from the AC or DC-network**: A control sequence shall be agreed between the relevant TSO and the converter operator for synchronization the converters to and the disconnection from the AC or DC-network.

ii. **Control interaction between converter stations**: The presence of other links in close proximity could lead to adverse interaction between converter controllers during transient or steady state. The intention of this requirement is to satisfy that undesirable interaction of the HVDC control system with a wind farm controller or between nearby HVDC controllers are avoided by proper and robust control design and control coordination.

iii. **Power oscillation damping capability**: An HVDC system may enhance power system damping and contribute to the overall system stability. The intention of this requirement is to specify the performance of HVDC system controllers with the purpose of damping electromechanical oscillations.

iv. **Sub-synchronous torsional interaction damping capability**: HVDC systems electrically close to power generating modules may contribute to instability in the sub-synchronous frequency range (5 – 50 Hz).The intention of this requirement is to ensure that no torsional modes of oscillation in the sub-synchronous frequency range on a mechanical shaft of nearby power generating module(s) are negatively damped or destabilized due to control interaction with the HVDC converter.

v. **Short-circuit power**: The HVDC converter and associated link should operate within all operating characteristics at a minimum short-circuit power defined by the relevant TSO.

vi. **HVDC system robustness**: The converters within the HVDC system shall be capable of finding stable operation points after expected or unexpected changes in the configuration of the whole HVDC system. Changes in the system are (but are not limited to):

- loss of communication;
- reconfiguration of the system;
- changes in load flow (scheduled or not);
- changes in DC voltage (rise, fall); and
- trip of one converter;

vii. **Control robustness in multi-terminal and in multi-terminal tapped HVDC systems**: A grid controller has to be established, operated by the relevant TSO(s). The grid controller system shall cover among others:

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

- procedure to deal with scheduled power vs. real set points (losses or incompatible schedules);
- data exchange with station controllers, dispatch center (communication in a non-discriminating way);
- backup concept for grid controller in terms of complete outage of controller;
- The (N–1) criteria for a grid controller must be supported; and
- basic control functions (e.g. load dispatch, voltage control)

3.1.5 REQUIREMENTS FOR PROTECTION DEVICES AND SETTING

The requirements for protection devices and settings include:

i. **Re-connection**: The HVDC converter shall be able to reconnect after clearance of the transient fault or other disturbance causing the link to trip. The main goal is to re-establish system integrity as fast as possible. Reconnection times are in line with the TSO's strategy. It is important to emphasize that the chosen protection strategy should be agreed in such a manner that there is minimum interruption of the HVDC system which might jeopardize the system stability and that it can operate according to the agreed reconnection time.

ii. **Electrical protection schemes and settings**: This ensures that the HVDC systems are designed in a way that the protection devices are discriminative and stable so as to minimise malfunction operations.

iii. **Control schemes and settings**: The control schemes of the HVDC systems connected together have to be able to work together during operation. The control schemes and settings, both at AC and DC side, have to be compatible with other remaining requirements, because response times, tripping times, reconnection time etc. depend on the control settings.

iv. **Priority ranking of protection and control**: Due to the fact that there are plenty of control and protection functions, a priority list has to be manifested by the TSOs operating a HVDC system. This requirement is necessary because the different control modes might interfere with each other and could lead to different control targets if not ranked with clear priorities. Hence, a clear list indicating what control modes are active and dominating together with the values is essential. Moreover, all TSOs operating at the same HVDC system have to know all priority lists.

v. **Changes to the protection schemes and settings**: Any changes to the protection schemes relevant for the HVDC converters and the network and to the setting relevant for the HVDC shall be agreed between the relevant TSO and the HVDC converter owner and be concluded prior to the introduction of changes.

3.1.6 REQUIREMENTS FOR POWER SYSTEM RESTORATION

The requirements for system recovery after a black-out include:

i. **Black start**: The relevant TSOs decide if black start capability of a HVDC system is needed. Moreover a procedure and a sequence for a black start of the system have to be agreed, including those of HVDC systems.

ii. **Capability to take part in isolated network operation**: In the case where the HVDC system is connected to a weak grid, the HVDC system has to be designed to be able to take part in isolated network operations.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

3.2 REQUIREMENTS FOR DC CONNECTED POWER PARK MODULES

The connection point for the DC Connected PPM is the AC interface to the Power Park Module. Connection points for the HVDC system are the AC interface points to the HVDC converters.

As a general principle, the PPM connected through HVDC has to be designed, coordinated and set up to fulfill the requirements for AC connected offshore and onshore PPMs as prescribed in the Network Code for “Requirements for Generators”, with possible modifications.

However, due to the specific situation of these isolated converter-based AC systems, technical and/or economic benefits may derive from new, not yet fully developed control and protection methods. In such cases the PPM performance and HVDC performance for the PPM side shall be mutually coordinated, without impairing the fulfillment of the main system AC side requirements as defined in the Network Code for “Requirements for Generators”. In addition to these requirements, the HVDC connection on the main system side has also to meet the requirements in Section 3.1 in order to ensure the overall system security.

3.3 INFORMATION EXCHANGE AND COORDINATION

Adequate and coordinated information exchange between network operators, HVDC system owners/operators and DC connected offshore PPM owners is a prerequisite for network operators to fulfill multiple objectives:

i. **Operation:** The management of the HVDC system must be done within the operational strategy of the rest of the grid, which means that the TSO must be able to manage the relevant parameters in the power system's operation and has continuously an overview of the state of the system.

ii. **Parameter setting:** Future network changes might require adjustment of specific parameters settings in the control of an HVDC system. Therefore it shall be coordinated that these parameters are accessible.

iii. **Recording fault and dynamic behaviour:** Recordings of the system stability and security enable the network operators to analyse the system behaviour in critical states, e.g. for risk assessments, and to draw conclusions for possible improvements, if applicable.

iv. **Analysis of faults and disturbances:** In order to be able to cooperate on fault or disturbance analysis the parties shall agree on appropriate fault triggering and measuring signals to be recorded, and the data exchange format.

v. **Simulation models:** System stability and security need to be adequately modeled for corresponding simulations, which are performed regularly by the relevant TSOs. Depending on the scope of the simulations, the owner of an HVDC connection or DC connected PPM shall make an appropriate simulation model available.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

3.4 COMPLIANCE & DEROGATION

3.4.1 COMPLIANCE

Compliance with the NC HVDC shall be demonstrated for the HVDC converters and DC connected PPMs as applicable. In order for this process to take place, prior submission of relevant data as required under “Information Exchange” is necessary, including validated models of the plant. Compliance is demonstrated to the relevant TSO upon successful completion of the Operational Notification Procedure for connection of the relevant plant. This procedure may also include compliance with the local requirements, set between the owner and the TSO. Where it is not possible to demonstrate compliance under this procedure, equipment certificates, and/or simulation study results may be used as substitute for (part of) the compliance tests. Where there are different owners with respect to PPMs, single and multi-terminal HVDC connections, there shall be co-ordination and co-operation between owners to facilitate compliance testing. If the HVDC system is owned by the TSO, compliance testing is still carried out by the TSO but the National Regulatory Authority may have insight in the test results. Full test reports shall be available to the NRA with due regard to confidentiality of data.

The owner shall ensure that compliance shall be maintained throughout the lifetime of the plant. Any modification to the plant, including controls, that could impact its compliance shall be notified to the TSO beforehand and is subject to compliance re-testing as applicable.

For PPMs, the compliance process shall be in line as that specified in the Network Code for “Requirements for Generators”.

3.4.2 DEROGATION

The derogation procedure for non-applicability of (part of) the NC HVDC shall be transparent, non-discriminatory and based on cost benefit analysis. It is applicable to both existing and new connections, and shall be requested by the owner(s). The criteria for assessing the request for derogation shall be set and published by the National Regulatory Authority; it shall be objective and non-discriminatory, and take into account the recommendation of the TSO provided the TSO does not own the HVDC system. The decision on derogation shall be taken by the NRA.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu