European Network of
Transmission System Operators
for Electricity

Network Code for HVDC Connections and DC-connected Power Park Modules

Explanatory Note

7 November 2013

Disclaimer: This document is not legally binding. It only aims at clarifying the content of the Draft Network Code for HVDC Connections and DC-connected Power Park Modules. This document is not supplementing the final network code nor can be used as a substitute to it.

Content

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1. INTRODUCTION

1.1. Objective

The rapid increase of renewable energy sources (RES), the implementation of smart grids, and the efficient functioning of the internal electricity market while ensuring system security will all lead to massive changes to the electrical power system as we know it today. This will require a new framework to cope with these challenges and all participants of the energy market will have to face significant changes.

In this context, ENTSO-E elaborates the "Network Code for HVDC Connections and DC-Connected Power Park Modules. This Network Code is referred to as the "NC HVDC". The NC HVDC is based on ACER's Framework Guidelines on Electricity Grid Connections (FWGL) [1]. The NC HVDC responds to the EC's mandate to develop this Network Code [14].

Other Network Codes that are being developed by ENTSO-E are largely harmonizing existing procedures and requirements and are to a large extent based on existing rules and procedures. The NC HVDC implements a completely new approach for some requirements at European level which can be seen in the draft code **Error! Reference source not found.**, and was outlined during the consultation process "Call for Stakeholder Input" [5] in May 2013.

The aim of this Explanatory Note is to explain the challenges to be addressed by the NC HVDC and to put forward the main *new* topics that have to be addressed. With this document ENTSO-E is also sharing feedback received from stakeholders including the outcome of the consultation in the "Call for Stakeholder Input" [5]. The stakeholder involvement process is described in Chapter 3, while the specific technical feedback is covered in Chapter 4, dealing with the background of each requirement group.

The aim of this consultation on the proposed Articles of the NC HVDC is to obtain input to improve the code and to build consensus on the final code.

ENTSO-E welcomes input via the web consultation facility available at https://www.entsoe.eu/news-events/entso-e-consultations/ in the format described in the guidelines of the comment submission template by 7 January 2014. All feedback received by this date will be assessed by ENTSO-E and made publically available on the ENTSO-E website.

1.2. Background

1.2.1. European Network Code Development

The upcoming NC HVDC covers a specific area in a wider portfolio of network codes on electricity. The NC HVDC is the ninth code developed by ENTSO-E[1]. Key messages on the need for European wide network codes and an overview of how these interact, are linked with other European energy roadmaps, and benefit European energy consumers, are given in the ENTSO-E paper "European Network Code Development: The importance of network codes in delivering a secure, competitive and low carbon European electricity market" [6]. This section sketches some of the messages most relevant for the NC HVDC.

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

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What are the network codes?

Network Codes are sets of rules which apply to one or more part of the electricity sector. The need for them was identified during the course of developing the Third legislative package and Regulation (EC) 714/2009 sets out the areas in which network codes will be developed and a process for developing them.

Europe's energy policy objectives

Europe's trio of energy policy goals – ensuring security of supply, promoting the decarbonisation of the energy sector and creating competitive, liquid markets which benefit consumers – is well known.

More interconnected networks and markets: The electricity system is becoming increasingly interconnected and the electricity market is becoming much more pan-European. This provides opportunities for generators to sell into different markets, based on price signals, and gives consumers a greater choice over who they buy energy from.

Increases in cross-border flows: A natural consequence of bigger markets and the siting of fluctuating generation further away from the consumption centres are much greater levels of cross-border and long-distance power flows. These flows require careful management by TSOs and require greater coordination between grid operators in planning infrastructure developments, in designing markets and in operating the system – given the significant influence such flows can have on the operation of the system in real time.

A changing role for network users: The changes in generation portfolio and operational challenges discussed above are creating a change in the role of network users. It is becoming increasingly important that all types of users (i.e. generation, demand, distribution networks, and interconnections) play an active role in providing the capabilities and services which are needed to maintain the security of the pan European transmission system.

Creating stronger, more robust and smarter networks: Without a robust transmission system, none of the trio of energy policy objectives will be achieved. Europe's networks will need to change significantly in the coming years, with much greater levels of interconnection and the probable extension of networks offshore, using a greater proportion of HVDC technology. They will also need to adapt to much more active distribution networks and to greater customer participation.

Ensuring closer cooperation between TSOs: TSOs are working more and more closely together (building on a tradition of doing so for over 60 years) to make better use of existing assets and build on the very high levels of security of supply enjoyed to date. More advanced and coordinated operational planning procedures are being implemented by many TSOs through multi TSO coordination initiatives (and through regional market coupling initiatives). TSOs are also developing systems for coordinating balancing and remedial actions where system issues exist and enhancing real time data exchange (e.g. via the ENTSO-E Awareness System).

The network codes under development: Investment decisions taken now will affect the power system for the next decades. The European energy system of 2020 is being built today and the foundations of the European energy system of 2050 are being conceived. As such, there is a need to make sure that all users are aware of the capabilities which their facilities will be required to provide – recognising both the need for all parties to make a contribution to security of supply and the high cost of imposing requirements retrospectively. The grid connection codes therefore seek to set proportionate connection requirements for all parties connecting to transmission networks (including generators, demand customers and HVDC connections). A stable set of connection rules also provides a framework within which operational and market rules can be developed.

The system operation network codes will provide a solid basis for coordinated and secure real time system operation across Europe while market related network codes aim at creating a relatively simple set of market rules which can promote effective competition, minimise risk for all parties (particularly renewable generators who will benefit from markets close to real time) and give incentives for market players to act in a way which is supportive to the efficient operation of the system and minimise costs. All of them need to be developed in light of the connection requirements established in connection related network codes:

HVDC	Sets requirements for HVDC connections and DC connected generation.
Load Frequency Control & Reserves	Provides for the coordination and technical specification of load frequency control processes and specifies the levels of reserves (back-up) which TSOs need to hold and specifies where they need to be held.
Balancing	Sets rules to define the roles and responsibilities of TSOs and market parties to procure and exchange balancing products to balance the system from day ahead to real time in the most efficient way. It also includes financial principles for the payment of these services.
Requirements for Generators	Sets requirements which new generators connecting to the network (both distribution and transmission) – and existing generators (in very limited cases) - will need to meet, as well as responsibilities on TSOs and Distribution Network Operators.
Operational Security	Sets common rules for ensuring the operational security of the pan European power system.

The European electricity system is going through a period of unprecedented change. The generation mix is changing fundamentally, the potential for the demand side to become much more involved is vast and the market is becoming genuinely pan European. For Europe to achieve its trio of objectives of ensuring and enhancing security of supply; creating competitive markets; and facilitating the transition to a low carbon economy there will need to be a significant change in the role of network users, of Distribution System Operators and of Transmission System Operators.

With the growing share of electricity generation from intermittent renewable energy sources the difference between actual physical flows and the market exchanges can be very substantial. Remedial actions were identified by previous smart grid studies within European framework programs in operational risk assessment, flow control and operational flexibility measures for this area. At the same time an efficient and sustainable electricity system requires an efficient usage of existing and future transmission capacities to provide a maximum of transportation possibilities. New interconnections and devices for load flow control will be integrated in future transmission networks and will offer new operational options. Two major EC studies (iTesla [7] and Umbrella [8]) cover these aspects.

Network codes will impact on all parties active in the energy sector and will lead to considerable change in existing practices. ENTSO-E recognises the importance of engaging with a wide range of stakeholders to ensure that these impacts are understood and that as broad a range of views as possible are reflected in the network code development and is seeking to structure processes to allow this to occur.

Through a transparent approach, collaborative method of working and shared objectives we are confident that the network codes can deliver real benefits in realising each of Europe's energy goals.

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1.2.2. NC HVDC Starting Point

This Network Code is referred to in full as the “Network Code on HVDC Connections and DC-connected Power Park Modules” (NC HVDC). The NC HVDC is being developed based on ACER’s Framework Guidelines on Electricity Grid Connections (FG) [1]. It forms part of the ENTSO-E work programmes 2012 [9] to 2014, and is subject to a mandate letter from the EC [3]. This planned NC HVDC will be the third connection code in line with the FG [1]. The two connection codes preceding the NC HVDC are the “Requirements for Grid Connection Applicable to all Generators” (RfG) and “Network Code on Demand Connection” (DCC). A fourth network code on Connection Procedures, also founded in the same FG [1], may follow at a later date still to be defined in the work programme.

The preliminary scope of this NC HVDC is set out in [10]. The draft code, as now consulted upon, largely reflects the scope with small changes, reflecting the assessment of stakeholder feedback.

The existing cover of HVDC requirements in national grid codes is varied. A few countries (including, but not limited to France, Great Britain and Italy) already have codes or equivalents in force or are in process of developing codes, whereas many countries have no HVDC installations and therefore had not had the need for developing connection requirements. The ENTSO-E TYNDP [11] shows that many other countries (including Germany) have extensive HVDC activities and/or future plans. These activities are pursued by a combination of TSOs and independent developers. This demonstrates the importance and urgency of this Code. The application of HVDC technology to compliment the hitherto dominant electricity transmission technology of High Voltage Alternating Current is expected to expand greatly in the years and decades ahead. The reasons for the expected rapid expansion in HVDC applications include the larger power transfers over longer distances and the connection to shore of very large offshore RES installations. This strengthens the view of ENTSO-E and the wider industry to pursue European-wide requirements which may be further specified at national level or based on the needs in specific projects.

1.3. Challenges Ahead relevant to HVDC Requirements

HVDC technology will increasingly be used in the coming years to develop interconnections between different synchronous areas and it is of the utmost importance for these new facilities to improve power system security. To supplement existing HVAC corridors, extensive developments of embedded HVDC systems (both within one or between several control areas) are also planned, in order to increase the flexibility and capacity of the entire system. The above contribute to market integration by supporting the development of cross-border exchange of energy and reserve. To that end, extensive active power controllability is needed. Automatic control modes are especially needed for exchanging balancing energy resulting from the activation of cross-border frequency containment and restoration reserve. The NC HVDC will define the minimum standards and requirements needed for achieving these goals related to market integration.

The conventional task for HVDC is bulk transfer of large volumes of energy over long distances. Additionally, HVDC has been used like a firewall in its back-to-back connection of large AC transmission systems. These tasks will remain a focus supplemented by the expected rapid growth of HVDC in the world of offshore power, so far predominantly associated with wind.

As the proportion of electrical power transmitted by HVDC to the vicinity of major load centres increases, the characteristics of HVDC including its responses to fast system changes under disturbed conditions increases in importance in two ways. In the first place this relates to its own robustness to disturbances, the ability to continue to deliver the power. This is particularly important considering the size of most of the HVDC schemes. Secondly, as HVDC displaces direct AC connection of generation, the ability of the HVDC system to “pass on” quickly and in a controlled manner the dynamic support from another system or from generation becomes increasingly important to deliver stable operation and hence security of supply.

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Security of the system cannot be ensured without considering the technical capabilities of all users. Historically large synchronous generation facilities have formed the backbone of providing technical capabilities. The energy system is changing rapidly especially with the massive integration of RES (wind generators, PV installations) in the European electricity network. At a European level this is illustrated in the Ten Year Network Development Plan (TYNDP 2012) issued by ENTSO-E [11]. In relation to the longer time horizon, on 8 March 2011 the European Commission issued “A Roadmap for moving to a competitive low carbon economy in 2050” [12]. Ireland is the first synchronous area to experience 50% of generation from non-synchronous sources (predominantly converter-based). Great Britain is expecting – under its “Gone Green” scenario – to exceed 75% and may even be close to 90% under the most challenging market conditions by 2030. The converter-domination of generation is further extended by HVDC converters.

The HVDC technology itself, in particular the branch of it called Voltage Sourced Converters (VSC), is developing rapidly. As illustrated at a December 2012 International HVDC Conference (IET’s ACDC2012) [13] with the statement in a workshop on VSC that since the first VSC installation there had been a fundamental change of configuration for every second VSC project. In contrast with the emerging HVDC VSC technology and the associated HVDC Grids, the alternative HVDC technology using Line Commutated Converters (LCC) is a mature technology, applied with large capacity in relative low numbers. It is important that the NC HVDC facilitates the development of both technologies.

In this context CIGRE issued in December 2012 a WG report (WG B4-52) [14] concluding that DC Grids are feasible. Another CIGRE group (WG B4-56) is working on connection requirements for meshed DC Grids whose report is expected end of 2013 or early 2014. This group is further considering recommending adoption of standard DC voltages, similar to how 400kV is a standard voltage in Europe for AC. In a DC Grid it will eventually become possible to have a Connection Point directly at HVDC (connection to a DC busbar).

Operating conditions with the highest RES injection (typically in windy / sunny conditions with moderate demand) present major system challenges, particularly where the high RES penetration extends to a total control area or even more if covering a total synchronous area. The main answer to this is to increase the controllability and the flexibility of all power system elements to deliver a power system which can react and cope better with the volatility of RES [15]. The three main new or expanded technical challenges ahead related to stable operation of the power systems are:

- Frequency management with reduced inertia in synchronous area or even in each control area;
- Voltage management in areas remote from main centres of RES installations during times of high RES production when conventional generation, which has traditionally provided this service, being displaced; and
- Fault level (system strength) management in context of rapid changes from high system strength during low RES production to extreme low system strength during high RES production, when synchronous generation is displaced (not operating).

1.4. Guiding principles

1.4.1. Why DC?

Efficient and reliable power transmission grids are one prerequisite to support EU energy targets and to achieve the political goals of a low-carbon energy system. The way the power system has to be designed and operated must be consistent with these paramount targets and poses new challenges for TSOs. The future power system must:

- Facilitate the integration of RES, partially located far away from load centres (e.g. offshore wind parks)
- Manage huge cross-border power flows caused by the pan-European electrical energy trade.
- Achieve both targets with minimal impact on environment and at least costs.

An efficient technology choice to achieve these targets is based on economics and technical performance. In general the choice is between AC and DC transmission. Thereby a comparison between these technologies leads to following areas of application for DC transmission:

- Distance: Long–distance, bulk power transmission is often more economic by HVDC
- Environmental constraints: The corridor needed to transmit a certain amount of power is considerably less for HVDC compared to AC.
- Overhead line versus cable: The charging current of AC cables requires well distributed reactive power compensation means. Therefore, for long cables (e.g. subsea cables) AC is usually not economic compared to a DC solution.
- Asynchronous interconnection: AC systems operating at different frequencies or using independent frequency control systems can only be coupled by HVDC.
- Control and stabilization of power flows: HVDC systems in an integrated power system may enhance the overall system performance and system security.

In the view of the above mentioned challenges and requirements for a future power system, DC transmission is expected to become increasingly important.

1.4.2. HVDC and its role for “smarter” transmission

Modern HVDC transmission offers advanced performance, as they can control active and reactive power independently. The first HVDC connected wind farms in the North Sea demonstrate that latest HVDC transmission is also able to control the frequency of islanded AC networks and to supply weak networks. If well planned and designed, these features offer remarkable flexibility:

- Future fast changes in power flows in situations resulting from the change in generation pattern could be handled more securely by the operator. Additional reactive power (particularly conveniently available inherently from VSC technology) would stabilize the voltage profile.
- The controllable active power flow can be used to minimize losses and to overcome bottlenecks by distributing the power flow in an optimal way, making the fullest use of all circuits.
- In emergency situations, e.g. partial black outs or islanding of networks, the HVDC scheme could increase stability margins or reenergize or stabilize an island.

2. General Approach to NC HVDC

2.1. Structure of NC HVDC

The Network Code contains General Provisions, including Subject matter and scope, Definitions, Regulatory Aspects, Recovery of costs and Confidentiality obligations, before introducing the technical requirements. The Chapter on requirements for HVDC connections is followed by the Chapter on requirements for DC-connected Power Park Modules. Other chapters cover Information exchange and coordination, operational notification procedure for connection, Compliance, Derogations and Final provisions. The main requirement chapters are organised into sections covering a group of requirements. Each technical requirement is covered by an Article.

2.2. Applications to HVDC Connections and DC-connected Power Park Modules

According to ACER's FG, "*the network code will apply to grid connections for all types of significant grid users already, or to be, connected to the transmission network and other grid user, not deemed to be a significant grid user will not fall under the requirements of the network code*".

A major challenge of the HVDC code is consequently to answer to the central question "Who are the Significant Grid Users?" in order to define unambiguously the field of application of the code.

The FG gives a general definition of the Significant Grid Users. They define them as "*pre-existing grid users and new grid users which are deemed significant on the basis of their impact on the cross border system performance via influence on the control area's security of supply, including provision of ancillary services*".

Based on that definition, ENTSO-E proposes that in the NC HVDC the following HVDC configurations are considered as Significant Grid Users:

- HVDC Systems connecting Synchronous Areas or Control Areas, including back to back schemes;
- HVDC Systems connecting Power Park Modules to the Network;
- HVDC Systems embedded within one Control Area and connected to the Transmission Network;
- HVDC Systems embedded within one Control Area and connected to the Distribution Network when a cross-border impact is demonstrated by the Relevant TSO and approved by the NRA; and
- All Power Park Modules that are AC collected and DC connected to a Synchronous Area at any AC transmission voltage.

The following picture illustrates the above mentioned different ways HVDC is envisaged to be used as well as the location of the connection points of the HVDC and the AC system. Motivation for this decision on Significant Users can be found in FAQ 15.These connection points form the physical interface between the systems thus the performance requirements are usually defined related to this connection points.

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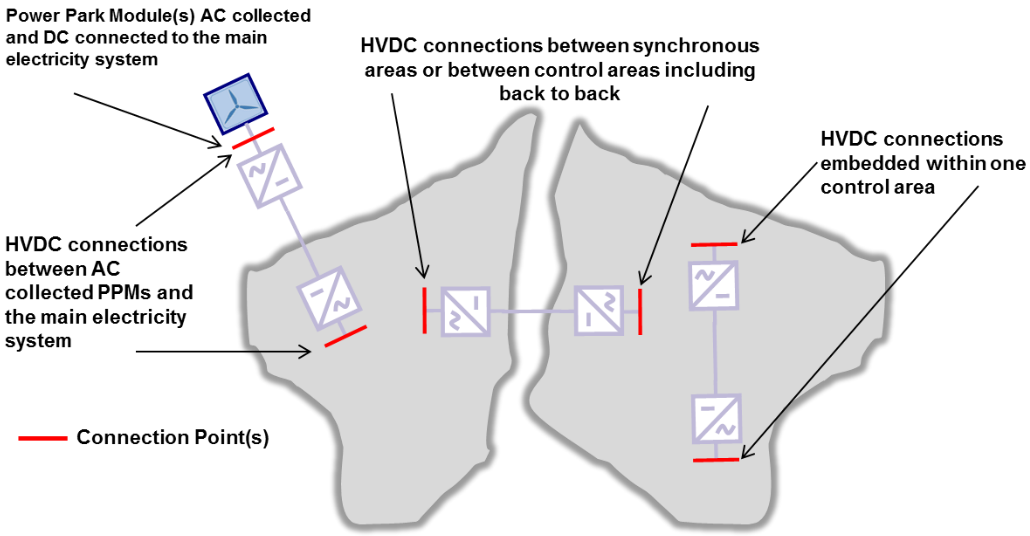
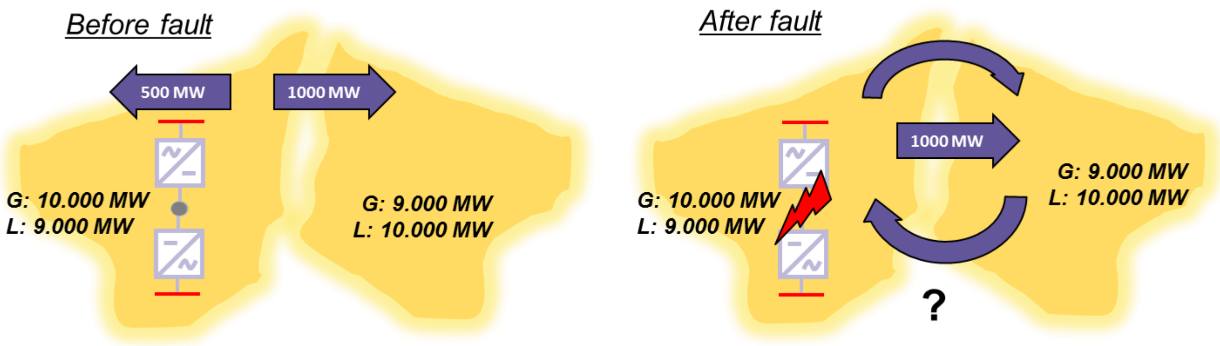


Example 1: HVDC transmission system across control areas

An HVDC transmission system with AC/DC terminals across multiple synchronous areas or control areas, has a cross border impact due to the fact that a fault on the HVDC system causes the change of flows between control areas. Therefore these schemes are deemed to be Significant Grid Users.



Example 2: Embedded HVDC transmission system within single control area

Large HVDC connections embedded within one control area can also have significant cross-border impact. For instance, the loss of an internal HVDC link can modify the distribution of cross-border flows and consequently have impact on the power flow in neighbouring control areas. All HVDC connections embedded in AC transmission systems have such a potential impact on cross-border flows.

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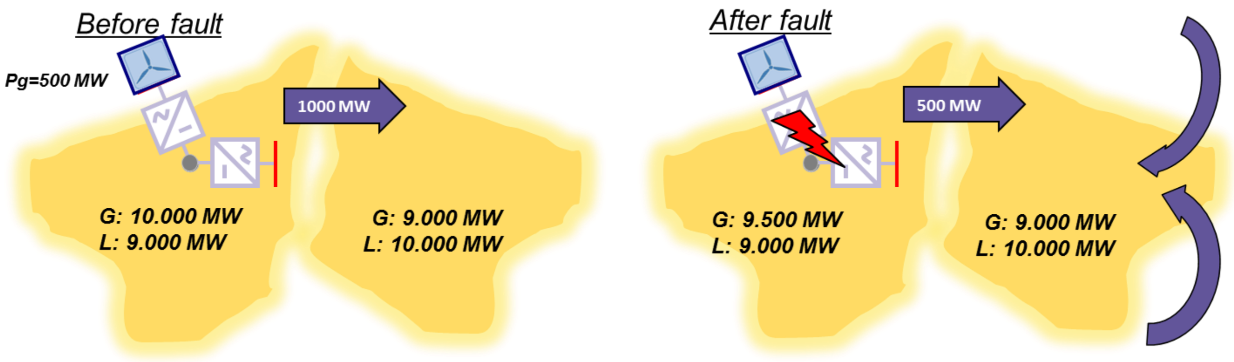

Example 3: HVDC generation collection system within one control area

An HVDC generation collection system, in which all the AC/DC terminals are connected within a single control area, has a cross border impact due to the fact that a fault on the HVDC system causes the change of flows between control areas. However it is important to recall that cross-border issues are not only based on active power exchange in tie lines but are also related to the technical capabilities of all the users playing a critical part in system security. Therefore the requirements will improve robustness to face disturbances, to help to prevent any large disturbance and to facilitate restoration of the system after a collapse. Moreover, harmonization of requirements and standards at a pan-European level (although not an objective in itself) is an important factor that contributes to supply-chain cost benefits and efficient markets for equipment, placing downwards pressure on the cost of the overall system.

Therefore, all requirements that contribute to maintaining, preserving and restoring system security in order to facilitate proper functioning of the internal electricity market within and between synchronous areas and to achieving cost efficiencies through technical standardisation shall be regarded as “cross-border network issues and market integration issues”.

The option to apply the NC HVDC to most, if not all, HVDC links has the following advantages:

– The scenario that a TSO owned HVDC link could be transferred to another party during its lifetime is realistic. The application of the code enables to guarantee that these links comply with appropriate minimum standards and requirements.
– TSOs are expected to apply the same technical requirements for TSO-owned by HVDC links as described in Article 3(5) of the Code. Application of the NC HVDC to TSO assets ensures non-discrimination across Europe compared to third party projects.
– In case the HVDC link to AC collected and DC connected Power Park Modules (e.g. offshore wind farms connected by HVDC) is owned by the TSO, application with the NC HVDC ensures a non-discriminatory approach towards these generating units in which the HVDC link is owned either by the Power Generating Facility Owner or by a third party.

In addition to point-to-point connections, multi-terminal schemes are also foreseen in future. In this regard the requirements shall ensure that multi-terminal schemes work together in a robust and safe way. For future connection points at DC substations, requirements are not provided in this issue of NC HVDC, but are expected to be added at a later revision when the HVDC switching technology has emerged.

Mixture of AC and DC transmission of power from offshore PPMs is also relevant. At present HVDC systems provide predominantly point to point power transfers. It is envisaged that DC grids (meshed DC systems) will gradually emerge for some applications, initially as a new emerging technology and eventually as a proven technology. One important step needed in this context for the TSO to further develop future HVDC systems is the interoperability of different vendors and the ability to integrate individual projects into the existing system. In this respect, the NC HVDC is expected in the future to play an important role [16]. Future revisions of the NC HVDC are expected to bring these aspects forward as the DC grid technology moves into implementation.

For existing users, previous connection codes (Requirement for Generators (RfG), Demand Connection Code (DCC)) provide an extensive but transparent and non-discriminatory process before the requirements could be considered applicable. A Cost-Benefit Analysis showing the socio-economic benefits and cost of the proposal has to be carried out and the report will be subject to a public consultation. Finally the TSO sends the proposal on the applicability of the requirement, including the outcome of the consultation, to the relevant National Regulatory Authority for approval. ENTSO-E considers that this approach is also relevant for the NC HVDC. This is expected in particular for HVDC to have relevance for low-cost software (control) changes with potentially large security benefits.

2.3. Classification of the requirements

For each requirement, the NC HVDC provides a classification into exhaustive or non–exhaustive, and mandatory or non-mandatory requirements:

- **Non-mandatory** requirements leave a choice at national/regional level about including the specific requirements. This typically covers aspects which may not be essential everywhere.
- **Mandatory** requirements are to be implemented throughout Europe.
- **Non-exhaustive** requirements leave certain details of a requirement to be further specified at a national level. This is often focused on parameters. The national choice may be limited by a parameter range defined at European level within which the national parameter must be set.
- **Exhaustive** requirements define all details of a requirement.

These classifications are introduced to give an optimal balance of cross-border relevant functionalities that should be fully specified at European level and those where further specifications are best made locally to be fit for purpose at the lowest cost. The proposed classifications follow the same principle used in the preceding network codes RfG and DCC.

Furthermore, network codes as referred to in Regulation (EC) 714/2009 only cover aspects with cross-border relevance and supporting market integration. Other capabilities needed for efficient and cost-effective operation of the national power system shall be defined in national regulation.

Finally, when a requirement is defined as non-mandatory, its application will need to be judged in each national context. Where it can be demonstrated as justified and cost-effective, it will be included as a requirement. This justification may imply Cost Benefit Analysis (CBA), particularly if the requirement is both significant and new. For this quantitative information from grid users is needed, in particular with respect to the cost of capabilities, preferably as percentage of total cost. Although this information was called for by ENTSO-E in the “Call for Stakeholder input”, this was not forthcoming. Such information would still be welcome, as discussed in the User Group meetings [17] as this information would also be essential for the national implementation at a later stage.

Further information on the classification and implementation of individual requirements is given in the document “NC HVDC - Requirement Outlines” [18], published alongside the draft code during this public consultation.

2.4. Reference point for Requirements

Following consultation and following agreement with Stakeholder representatives at the 2nd User Group meeting ENTSO-E confirms that wherever possible, the performance requirements are defined for the HVDC system at the AC connection point. Motivation for this decision can be found in the document “NC HVDC – Frequently Asked Questions” (FAQ 14).

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2.5. Development of additional Services for Weak Systems

With increasing capacities of RES, the likelihood for operation of a synchronous area or at least a control area with at times very high percentage Non-Synchronous Generation (NSG) increases. This was described for varies countries in the Appendix (Section 7) of the NC HVDC Call for Stakeholder Input [5]. In the extreme case the total demand may be covered by supply from converter based technology (PPM and HVDC connections). In general NSG results in both lower total system inertia as well as lower fault levels / short circuit ratios (or system strength). A family of challenges are related to operation with less system inertia and less system strength:

System inertia related challenges revolve around frequency management, which becomes an increasing problem as the total system inertia reduces. This is due to lack of time available to deliver primary response. This results in the system experiencing higher rates of change of frequency df/dt with even higher risk of further loss of generation in countries where embedded generators are loss-of-mains by RoCoF (Rate of Change of Frequency) protections, e.g. in GB (at 0.125Hz/s) and Ireland (at 0.5Hz/s). System strength related challenges are varied. Some challenges are only expected during operation at very low level of Synchronous Generation (SG) e.g. as low as 25-35%. For smaller synchronous area (e.g. Ireland and GB) this can initially be looked at on a synchronous area basis, but as system strength is a local problem it can also affect a relatively weakly connected part of a very large synchronous area, such as Western Denmark connected to Continental Europe. Such extreme low system strength is expected to become frequent as described in [19] for Ireland and in [20] for GB, the latter focused on a 2030 scenario (Gone Green). Challenges includes

- Inadequate synchronising torque to retain stability.
- Potential commutation failures of LCC, the conventional type of HVDC. Traditionally LCC schemes required a fault level in MVA of at least 3 times the MVA rating of the HVDC link.
- High harmonics. If minimum fault level (or SCR) in operation is much lower than the fault level used in the design, then unexpected high harmonics may appear. As a rough measure if the fault level is halved, the harmonic voltage distortion will double. High Negative Phase Sequence (NPS or 3 phase unbalance) voltages. The synchronous generators as major sink for NPS are being displaced by NSG which do not perform similarly as a sink, unless explicitly designed to do so.
- Larger voltage steps, e.g. when switching capacitors or reactors on the network in order to control the system voltage.
- New challenges for Transmission Protection Systems in which the protection systems have to distinguish between fault currents and load current of similar magnitude.

The technical requirements of the HVDC systems can contribute to an extent to ameliorate in part many of the above problems by delivering a number of services, including:

- Synthetic Inertia (SI) to aid frequency management, [21]
- SMART use of SI contribution to deliver synchronising torque [20], [22]
- Very fast fault current contributions up to their current ratings. [23] This is still 2-3 times less than the initial fault current (sub-transient) contribution from the displaced synchronous generation would have been.

The NC HVDC recognises that for the above three services both the TSO need cases and the ability of the technologies have only emerged recently. The draft NC HVDC therefore bring out the requirements in a cautious manner, aimed at enabling these services to be brought in where the need is clear and at a time when the technology is ready to move from demonstration to full scale implementation. The motivation for these services is to avoid or at least reduce in the most socio-economic manner the impact of one or more of the following alternatives:

- An upper limit on development of RES;

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- Large scale constraint of RES production (modest constraint for the most extreme conditions is still expected to be appropriate); or
- Jeopardising system security by no longer being able to maintain current system performance, having to accept a higher level of consumer interruptions.

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3. Stakeholder Interactions

3.1. Call for Stakeholder Input

ENTSO-E has published the Preliminary Scope of the NC HVDC [10] together with a ‘Call for Stakeholder Input’ [5] document on 7 May 2013, asking stakeholders to provide feedback until the 7th June. On 11 June, during the 2nd user group meeting, ENTSO-E gave participants the opportunity to elaborate on their responses. The valuable feedback received here has been taken into account in the drafting phase. The details of the stakeholder input and all User Group meetings are publicly available on the ENTSO-E website [17].

ENTSO-E received a total of 16 responses from various organisations, industrial companies and academia. The full feedback is publicly available via the ENTSO-E website.

Stakeholders pointed out that many requirements affect only software and therefore have low cost implications. A request was made to make such requirements mandatory even if it is not yet clear that such requirements are needed everywhere, as overall, the standardisation will result in a lower cost.

In relation to the proposed requirements, set out in the “Preliminary Scope” document for the NC HVDC, ENTSO-E sought in the “Call for Stakeholder Input” support from Stakeholders (particularly from HVDC converter manufacturers) regarding both the feasibility of the capabilities proposed (if not immediately, from when) as well as the per unit cost sensitivity in relation to the total cost of the facility. Valuable feedback was received as to the feasibility of requirements as well as statements on cost being significant or not. Nevertheless, more detailed cost information was not forthcoming making it impractical to deliver quantitative CBAs of new capabilities, particularly those not yet in widespread use.

3.2. User Group Meetings

The User Group meetings held so far concluded the following key principles.

- NC RfG / DCC are to be used as reference point for HVDC System and DC-connected PPM requirements
    - The NC HVDC will also be cognisant of inherent additional capabilities
    - Possible deviations will be discussed and explained
- The suggested ‘Significant User’ classification
    - The NC HVDC has a dual objective of being forward looking and avoiding obstacles for future grid investments. Covering all HVDC Systems within the scope of the NC HVDC, with appropriate care for flexibility in national implementation, addresses both objectives.
- Focus on AC-side requirements for all configurations
    - The NC HVDC strengthens present best practices, reflects power system scenarios and enables grid development plans.
    - The NC HVDC is complimentary with ongoing work in CIGRE/CENELEC on DC side requirements.
    - Future amendments of the NC HVDC could cover more specific DC connection point requirements.
- Technology-neutral approach of the code
    - The NC HVDC does not provide a set of requirements per technology or configuration.

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- Due care is taken in the development of all individual requirements so as not to discriminate technologies are impose barriers for the further use of a specific technology. The ongoing consultation is deemed crucial to confirm this.

3.3. DT HVDC Response to Stakeholder Feedback

The feedback received in the Call for Stakeholder Input and User Group meetings provided crucial support in developing the code and its supporting documents. Some examples:

- Many requests for clarification have been covered in the supporting documents or have been explicitly provided for in the requirements of the code where possible.
- The requirements on Rate-of-Change-of-Frequency withstand capability and Fault-Ride-Through have been made more exhaustive.
- In context of offshore, the requirements in NC HVDC have recognised that the possible largest cost component of reactive power should be selected from a defined range reflecting the relevant network development plans, as well as the option of optimization of DC link and offshore plant design.

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4. Requirements of NC HVDC in Light of Future Challenges

4.1. Requirements for Active Power Control and Frequency Support – Articles 7 to 15

For a proper operation of the power system, frequency shall be statically and dynamically stable across a synchronous area and across all its voltage levels. Deviations of frequency from its nominal value indicate generation-load imbalances which have to be eliminated in order to guarantee a stable frequency across the electric system. The European TSOs are responsible for this frequency control and for maintaining frequency quality within pre-defined quality criteria. The Network Code on Load Frequency Control & Reserves will provide the coordination and technical specification of load-frequency control processes and specifies the levels for different classes of reserves which TSOs need to hold. The generating units, with their ability to vary their active power output when a frequency deviation occurs, as well as the other users connected to power system are required to contribute to frequency control or at least to frequency stabilisation. To that end, the connection codes set requirements for new facilities connected to the power systems.

The following paragraphs give some examples of exhaustive and non-exhaustive frequency requirements.

Frequency ranges

HVDC converters should at least match the same capability as defined in the Network Code for Requirement for Generators in article 8(1)a). This requirement is intended to be mandatory and exhaustive.

Following consultation based on a significantly wider range of 45 – 55 Hz, the ENTSO-E has settled on a narrower range of 47 – 52 Hz. This secures that the HVDC converters withstand slightly wider frequency ranges than generating units (no interaction with rotating masses). In case of network splitting, in which some isolated parts can experience large frequency deviations, system operation will be easier if TSOs can rely on HVDC connections even though generation has partly or totally tripped.

Rate of change of frequency withstand capability

HVDC converters are expected to have wider capability than that defined for generators (via Network Code for Requirement for Generators, Article 8(1)b) and for DC-connected PPMs). This is needed to maintain coordination of generators and HVDC systems and avoid sub-sequent unwanted tripping.

Active power controllability; control range and ramp rates

The management of variability and uncertainty is critical for the secure operation of a power system with high levels of variable generation and HVDC schemes. HVDC converters have the inherent capability to control within a few hundred milliseconds active power. In some cases, TSOs need fast active power control. For instance, in case of a nearby contingency that results in limited power transmission, the HVDC system shall be capable of decreasing its power output in order to solve overloads on the nearby network (‘fast run back’). On the other hand, in case of tripping of another parallel HVDC or AC circuit, the HVDC system shall be capable of increasing its power flow up to the nominal operation power in order to overtake the net flow (‘fast run up’). This requirement is defined as non-exhaustive, giving the opportunity to add certain detailed requirements at a national level or project base.

TSOs require HVDC links to be capable to contribute to market integration by supporting the development of cross-border exchange of energy and reserve. To that end, extensive active power controllability is needed. Automatic control modes are especially needed for exchanging balancing energy resulting from the activation of cross-border frequency containment and restoration reserve. This requirement is defined as non-exhaustive, giving the opportunity to add certain detailed requirements at a national level.

Ramp values for the active power control may be different and fixed or adjustable depending on power system needs, protection settings and topology, so as this value or a range of the values, when adjustable,

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should be agreed between TSO / facility owner and manufacturer. This requirement is proposed to be mandatory and non-exhaustive.

Frequency sensitivity and frequency control requirements

HVDC systems are required to be flexible to modify their active power flow during frequency excursions to maintain system frequency stability. Frequency deviations of a synchronous area can be reduced by a smooth reduction of the active power output of HVDC converters in case of high frequencies and by a smooth increase in case of low frequencies.

This requirement is included as mandatory and non-exhaustive to allow provisions for different ramp rates, gains, droop values, deadbands, static and dynamic reserve during operational time frames. Different values could be envisaged at national level depending on reserve requirement, generation, control structure and system characteristics at both ends of the HVDC connector. Schemes and settings of the different control devices of the HVDC system shall be coordinated and agreed between the relevant TSOs at both ends of the HVDC connector. In some cases those could be disabled to operate the HVDC system at fixed power.

The capability is mandatory. The capability is required by the TSO during normal or contingency situation such as system separation between two control areas or power restoration.

Synthetic inertia capability

System synchronous inertia fundamentally affects how fast and how far the frequency drops or increases during an energy imbalance, being the rate of change of frequency and the frequency turning point (lowest or highest). With high penetration of non-synchronous generation, power electronic devices and HVDC links connected to the grid, system inertia tends to reduce, favouring frequency excursions and higher rate of change of frequency. This might trigger rate-of-change-of-frequency-type of loss of mains protection and some consider risks of transient stability issues (lack of synchronising torque). This will result in a fundamental change under both steady state and transient condition of the power system.

Fast-acting response from HVDC converters can provide synthetic inertial capability if required by implementing the necessary controls. Reliable and useful measurement of rate of change of frequency is a substantial challenge, due to angular movement between generators when disturbed. Inertia emulation could therefore work against its intended purpose when not designed with great care. One method of implementing this capability (as well as other synchronous generator type capabilities) is given in [22], see also Section 2.5.

This requirement capability is power system dependent and will change with the needs of each system and synchronous area as well as with the system development over time, i.e. substituting conventional, synchronous generation with non-synchronous generation. Therefore, this requirement is defined as non-mandatory and non-exhaustive.

Maximum loss of Active Power

Given the technology potential for large capacity single DC links, the NC HVDC explicitly addresses the need for TSOs to give further specifications for the configuration of an HVDC System such that it does not result in unreasonable sizing of operational reserves with costs to be covered by all grid users.

4.2. Requirements for Power Control and Voltage Support – Articles 16 to 22

As part of the transmission system, the HVDC connections shall ensure the reliability of the power system, and in terms of voltage withstand capabilities shall have at least the same capability as generation and demand. This coordinated approach avoids subsequent undesired trips. The power system needs a stable and healthy voltage for its proper operation. As generation connected through power electronics is progressively displacing traditional synchronous generators, which are the traditional voltage control sources, voltage profiles are changing. For this reason voltage control must be required for new generation technologies as well as for the new equipment connected to the AC network, including HVDC technology.

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Current injection profiles during faults are changing progressively in the AC network, while they are critical to both recover the voltage during faults and to inject enough current quickly enough for system protection schemes to operate reliably. For these reasons it is important that HVDC systems have extensive capabilities to support voltage and to provide voltage control to the AC network. While considering this family of requirements, the differences in capabilities and behaviour of the HVDC converter technologies arise. Some HVDC converter technologies are very flexible in terms of reactive power management as they can be managed independently from active power in such a way that the HVDC converter can provide voltage control during normal operation and voltage support during contingencies. Other HVDC converter technologies do not allow independent management of the reactive power, or they scarcely can do it, so that they can provide neither support nor control, unless shunt reactive compensation is added. To ensure that the full potential of all technologies can be used while no barriers should be created for future use of any of them, a balance in level of detail is pursued in requirements for reactive power and voltage support in the NC HVDC.

In this category and based on the above principles, the NC HVDC establishes requirements on voltage ranges, short circuit contribution during faults, reactive power capability, reactive power exchanged with the network, reactive power control mode, priority to active or reactive power contribution and power quality.

Voltage ranges

HVDC converters should at least match the same capability as defined in the Network Code for Requirement for Generators, article 11(2). This is needed to maintain coordination among generators and HVDC systems and avoid subsequent unwanted trip. This requirement is intended to be mandatory and exhaustive otherwise voltage thresholds within a synchronous area may be applied in an inconsistent manner and potentially affect system security. Voltage range values may differ for each synchronous area.

Short-circuit contribution during faults

A certain minimum level of short circuit current during faults needs to be injected by HVDC converters in order to maintain the local short circuit current so that the voltage could recover properly. It is important here the time constant of reaction of the converter immediately after the short circuit to provide short circuit current. It is not the SCR or short circuit power level at which the HVDC connection must be able to operate because this is dealt with separately. In addition to support to voltage recovery, very fast short circuit contribution is needed to aid selective operation of transmission protection, particularly under high RES production [20].

Reactive power capability

In order to maintain voltage stability, reactive power capability is required, independently from the technology of the converter. To ensure technology-neutrality and allow for local system specificities, this requirement is non-exhaustive, allowing TSOs to adapt the specific requirements to local system needs.

Reactive power exchange with network

The idea of this article is to allow a limited reactive power exchange with the grid, but it is only dealing with steady state and non-transient conditions.

Reactive power control mode

Proper reactive power management is important for preserving system voltage stability. The most important source for voltage control and reactive power control were synchronous generators. However, increasing penetration of renewable energy sources will displace synchronous generators and reactive power control capability of HVDC converters in the power system needs to be utilized for the benefit of the power system.

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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.

Power quality

HVDC converters shall not introduce harmonics that would breach power quality compliance and affect the optimum operability of the TSO(s). The idea is to require HVDC converters to filter their own (at least) possible perturbations to the power quality.

4.3. Requirements for Fault-Ride-Through– Articles 23 to 25

Due to their importance for the future power transmission system HVDC systems must have a high availability in terms of active and reactive power exchange with the AC side. Fault ride through capability starts with the ability of a HVDC converter to remain transiently stable and connected to the system for a nearby fault or voltage dip

In case of DC side faults the admissible interruption times in particular depends on the realization of the DC transmission path connecting the converter stations. To interconnect adjacent synchronous systems often either a back to back HVDC station or underwater cables are utilized. For long distance onshore bulk power transmission the choice is between overhead lines, underground cables or a mixture of the two. Underground cables are considered the favoured alternative for environmentally sensitive areas. The increased difficulty in obtaining permits for new transmission overhead lines and routes leads to solutions attempting to enhance the transmission capability of existing lines. To this aim either a full or a partial conversion of AC lines to DC might be considered as an attractive approach.

The requirements that will be demanded from the HVDC system depend on the foreseen type of transmission path. Overhead lines are subject to atmospheric disturbances (lightning strikes; line swinging during windy weather conditions etc.) posing high requirements on the frequency and admissible duration of automatic reclosing sequences in case of DC link short circuits. To maintain the security of supply a high reliability and robustness comparable to today’s AC system performance must be ensured in this regard. In the case of parallel operation of AC and DC lines running on the same tower even higher requirements on the HVDC system result due to the probability of intersystem failures. On the other hand, if the transmission path is realized as underground cable, limited requirements to mitigate DC link short circuits might apply. In general a cable failure leads to time consuming repair times and fast recovery times for active power are not possible at all. Nevertheless there might be high demands with respect to reactive power support. Independent of system performance requirements the protection of the HVDC system against any kind of overloading must be assured for all specified fault scenarios.

Fault-ride-through capability

The type of fault, fault duration, fault condition and voltage dip is dependent upon local TSO system security criteria. The capability to ride through is to be determined by the local TSO who can specify system conditions that include minimum fault power/current at the connection point. Further considerations related to fault-ride-through are given in [20].

Post fault active power recovery

The HVDC converter must be able to recover active power output following fault clearance for AC and transient 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 local TSO.

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Autoreclosure

Auto-reclose 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-reclose capability shall apply.

4.4. Requirements for Control– Articles 26 to 31

HVDC transmission can be fitted more readily than AC to a gradual expansion plan for transfer of power. AC transmission often has to be built from the start with a high capacity to maintain stability, but DC can be tailored to discrete stages. Expansion of existing HVDC systems will naturally result in a more complex network with an increase in the number of multi-vendor converters in the same area. Therefore, requirements for cooperation and coordination of control systems designed and built by different vendors should be set up to allow expandability of network in the future.

HVDC systems provide great controllability and flexibility. Depending on the HVDC system technology, these devices can provide innumerable control functions to contribute to the overall system security and quality of supply. It is essential that this is made in a safe and coordinated manner. The NC HVDC establishes requirements to ensure the following:

- the control system is robust in case of a unexpected changes;
- the HVDC system does not interfere with other equipment connected to the AC network;
- the correct coordination between the protection systems of the HVDC system and the AC network; and
- the correct coordination of all the different control functions implemented within the HVDC system.

Also the NC HVDC will set the base for control functions that may be implemented if needed according to the AC network characteristics, e.g. power oscillations damping controller, sub synchronous torsional interaction damping controller and black start capability.

The interactions between AC and DC systems are quite complex and variable in nature. Taking the short circuit ratio value on the AC system is a simplified approach to evaluate these interactions. However, as non-synchronous generation becomes dominant, this concept may no longer hold entirely true, due to dominance of design based choices rather than machine characteristics [20]. The minimum short-circuit ratio at AC connection points is an important aspect for the functioning of the HVDC schemes. This is well established for LCC based HVDC schemes, but at the ACDC2012 international conference in December 2012 (VSC workshop) [13] this was shown to be a major issue also for the performance of VSC type HVDC schemes.

The requirements related to the converter control could be classified into the following categories:

Converter energisation and synchronisation

The HVDC links shall be capable of connecting and disconnecting without disturbances to the existing grid.

Interaction with the AC system / Control performance to enhance AC system performance

The requirements shall ensure that at first any adverse effect on the AC system or on any grid user is avoided (e.g. excitation of torsional stress on nearby generators). Further on the capabilities of HVDC converters to enhance the overall AC system performance and to contribute to its security shall be utilized, e.g. through Power Oscillation Damping contribution to the AC system dynamic stability (small signal). This will become more and more important in the future power system (e.g. due to reduction of conventional generation units otherwise providing ancillary services). The intention of this requirement is to satisfy that undesirable interaction of HVDC control system with offshore wind farm control or between nearby HVDC controls are avoided by proper and robust control design and control coordination.

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Interaction between Power Electronic Equipment

The requirements shall ensure that there is no adverse interaction between different power electronic equipment (e.g. between HVDC converters, between Power Park Modules and HVDC converters etc). This aspect is especially important if the grid is dominated by power electronic equipment and therefore likely to operate with low short circuit levels (e.g. connection of (offshore) wind parks via HVDC).

Power oscillation damping capability

HVDC may enhance power system damping and contribute to the overall system stability. The intention of this requirement is to specify the performance of HVDC controllers with the purpose of damping low frequency oscillations, typically in the range from 0.1 – 2.0 Hz, in power systems caused by generator swing. The method of damping could be by active and/or reactive power modulating of the HVDC link or by active power modulation of the offshore PPMs or a combination of both.

Sub-synchronous torsional interaction damping capability

HVDC electrically close to power generating modules may contribute to instability in the sub-synchronous frequency range. The intention of this requirement is to ensure that under no conditions should one or more torsional modes of oscillation in the SSR range on a mechanical shaft of nearby power generating module(s) be negatively damped and destabilized by control interaction with the HVDC.

HVDC system robustness

The HVDC system has to be resilient for a prescribed list of system changes. Also tripping of the HVDC System itself should not result in unreasonable transients at the connection points based on further specifications given by the TSO.

4.5. Requirements for Protection Devices and Settings – Articles 32 to 35

It needs to be ensured that the HVDC links are designed in a way that the protection devices are discriminative and stable so as to minimise malfunction operations.

HVDC converters requirements should be in line with the capability as defined in the Network Code for Requirement for Generators, Article 9(5) b)

Due to the fact, that there are plenty of control and protection functions, a priority list has to be manifested by the TSOs operating an 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 priority ranked. Hence, a clear list, 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.

The control schemes of the HVDC links 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.

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 Network Operator and the HVDC converter owner and be concluded prior to the introduction of changes, as well as the procedure to carry out these changes, that sometimes will be motivated by the HVDC owner and other will be the TSO who will request them.

Additionally, the detailed internal set of parameters of the different control modes (such as gains, time constants, slopes, deadbands, references, etc…) as well as the protection settings that do not need to be operated remotely must be available so as to be modified if necessary (due to new network conditions, new more detailed studies, etc…) and not fixed in the control system. For example, a POD control could, with a set of parameters could be inefficient or even unstable if AC network conditions changes; in this case, the parameters must be settable and the TSO and the HVDC owner must arrive to an agreement in order to change them.

And finally, some control modes and their setpoint must be operable remotely if required by the Relevant TSO, and this should be specified in order to have the necessary communication system implemented.

4.6. Requirements for Power System Restoration – Articles 36 to 37

Both black start capability and the capability to operate in isolated, weak networks might be required from the HVDC system. For instance in case of a regional blackout the HVDC system could support the affected area via the converter station that is connected to the healthy part of the system. In this regard HVDC can play an important role to minimize down times and to energise the system as quickly as possible. Coordination is needed with other equipment in the affected area (protection, dispersed generation etc.), thus the necessary communication equipment has to be available even under disturbed conditions.

4.7. Requirements for DC-connected Power Park Modules and associated HVDC Converter Stations – Articles 38 to 45

These requirements mostly apply to offshore generation. Consideration is needed to match the requirement of the PPM and the offshore AC system with the requirements of the HVDC link. The requirements for the offshore PPM need to recognise the different characteristics of the offshore AC island system, having no system strength from synchronous generation. Thus, additional requirements become more relevant (e.g. harmonics…) whereas others (e.g. frequency ranges) have to be adapted in order to enable a safe and secure operation. Moreover, the definition of the requirements is aimed to enable the future enlargement of the islands. The communication from the main interconnected system to the offshore facility needs to be ensured. Communication within the installed equipment in the AC islands can be provided via system state variables, for example frequency, or via a separate communication channel.

More and more components in the European grid are connected by power electronic interfaces. Large offshore PPM clusters are developed and DC connected to the main (onshore) electricity system. In future these projects connected to one synchronous area may become DC or AC connected to another synchronous area. The grid behaviour is expected to be different from today. Bearing in mind that the PPMs and HVDC converter units installed today are built to operate for the coming 30 - 40 years, the requirements for designing this equipment needs to be specified now in order to allow a future stable, reliable and economically efficient operation of the system, even when operational or market rules would evolve further:

- AC connections may become DC and vice versa.
- A cluster of DC connected PPMs may become a node in the interconnection between synchronous areas.
- AC and DC circuits should be interchangeable.
- DC connected PPMs will have low inertia and be more volatile which impacts system operation.
- DC connected PPMs will be required to contribute system services into the network which they are providing power to.

Therefore, as a general principle the requirements for DC connected PPMs are closely aligned with the NC RfG, with possible variation in ranges and settings where needed. Similarly, remote end HVDC converters have to fulfil the requirements of the NC HVDC with possible variation in ranges and settings. DC connected PPMs and remote end HVDC converters together need to have economically efficient, consistent, coordinated requirements so as not to impair requirements at the AC onshore transmission connection point.

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Further development of RES connections with non-synchronous generators as well as HVDC is gradually making the power system behaviour becoming dominated by converters. Converter interaction becomes a critical element in the system. Emulating several synchronous generation behaviours needs to be considered, leading to further requirements being defined in later versions of the NC HVDC.

Frequency and Active Power Control

The NC HVDC will establish economically efficient, consistent and coordinated requirements with regards to frequency and active power control for DC connected PPMs and remote end HVDC converter. With regards to frequency, PPMs and convertors must be resilient to reasonable frequency variations. DC connected PPMs shall be capable of staying connected to the network and operating within pre-defined frequency ranges and time periods compatible with AC connected. Given the nature of DC-connected PPMs, no split between Synchronous Areas is deemed reasonable for this requirements, resulting in a single frequency withstand capability for all of Europe. HVDC convertors as part of the network must be last to disconnect in case of severe system events, proposed consistent with any other convertor requirements, and do have as such longer duration times for this withstand capability.

Reactive Power Control and Voltage Support

The NC HVDC will establish requirements for reactive power control and voltage support capability in order to allow a future stable, reliable and economic operation of the system.

Fault ride Through

The NC HVDC will establish requirements for FRT for all grid users within a DC connected AC collection grid in order to prevent large outages in case of failures within the AC collection grid. The entire DC connected AC collection system must be able to withstand disturbances in the AC transmission systems connected to.

4.8. Information exchange and coordination – Articles 46 to 49

The objective is to provide an adequate and coordinated information exchange between network operators and HVDC system and DC connected offshore PPM owners. These requirements enable the TSOs to operate the power system in an efficient and minimum cost manner.

The ENTSO-E NC HVDC drafting the requirements on information exchange and coordination reflect application of similar principles to those used in the other connection codes (generation, demand).

4.9. Compliance & derogation – Articles 63 to 73

The question whether the code is applied to existing HVDC link is a major one. In the previous connection codes (generation, demand), ENTSO-E has proposed an approach where a national TSO could initiate and carry out to its end a procedure of applicability. In that case, a Cost-Benefit Analysis showing the socio-economic benefits and cost of the proposal has to be carried out and the report will be subject to a public consultation. Finally, the TSO sends the proposal on the applicability of the requirement, including the outcome of the consultation, to the relevant national regulatory authority for approval.

ENTSO-E following initial consultation has incorporated this same approach to the NC HVDC.

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5. Conclusions and Next Steps

The energy system is changing rapidly especially with the massive integration of RES. This requires a new framework to cope with the challenges ahead. All participants of the energy market are faced with significant changes and the implementation of new processes and technologies. The NC HVDC is proposing to break new ground to help to accomplish this task on a European level. ENTSO-E acknowledges that significant changes to the existing framework are necessary. To find out the best solutions for the development ENTSO-E conducted a "Call for Stakeholder Input" [5] on the most challenging new topics. The questions raised in the survey, the feedback received and the modified or confirmed approach to each topic is stated in this document. This has been used as guidance for developing NC HVDC.

The goal of the NC HVDC is therefore to ensure secure system operation, enhance market integration and to support the integration of RES into the system now and in the years to come. As a consequence, not only today's situation that reflects the historical development was taken into account, but future development as given in European and national scenarios as well. As a result the requirements for the 3 main HVDC types of application are described, covering

– Interconnections of synchronous areas.
– Embedded HVDC links providing power corridors in parallel with HVAC.
– HVDC linking Power Park Modules to the larger Synchronous Areas.

ENTSO-E believes that the NC HVDC is in line with ACER's FWGL, meets the needs for system operation for the European network for the foreseeable years and aligns with the key messages and opinions provided by stakeholders.

The "European Network Code Development: The importance of network codes in delivering a secure, competitive and low carbon European electricity market" [6] suggests that capabilities should be established suitable for the lifetime of the assets. In NC HVDC it has been necessary to compromise with lesser requirements in areas where the technology is not ready to deliver to the expected needs. This should facilitate freedom for the technology to deliver optimal solutions. These aspects are expected to be covered in later issues of this Code.

Careful classification of requirements into mandatory/non-mandatory, exhaustive/non-exhaustive have been undertaken in order to minimise costs. This, while covering basic needs in appropriate locations, avoids or defers unnecessary investments elsewhere.

ENTSO-E conducts this NC HVDC consultation, requesting in depth feedback Article by Article to collect further opinions and suggestions to improve the code. Stating clearly the motivation behind each comment is important as well as clearly stating proposed change. This is needed to give the appropriate weight to the comments in the post consultation review as part of the overall effort to identify the final most economic and efficient solutions.

The consultation on the questions stated in this document will be open for two month until 7 January 2014. ENTSO-E will use the answers received as guidance to further develop the NC HVDC and continue the valuable dialogue with stakeholders.

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7. Abbreviations

AC	Alternating Current
ACER	Agency for the Cooperation of Energy Regulators
CA	Control Area
CBA	cost-benefit analysis
CIGRE	International Council on Large Energy Systems
CP	Connection Point
DC	Direct Current
DCC	Demand Connection Code
EC	European Commission
ENTSO-E	European Network of Transmission System Operators for Electricity
FACTS	Flexible AC Transmission Systems
FG	Framework Guidelines
H	system inertia constant
HVDC	High Voltage Direct Current
IEEE	Institute of Electrical and Electronic Engineers
IET	Institution of Engineering & Technology
LCC	Line-commutated converter
NC	Network Code
NPS	Negative Phase Sequence
NSG	non-synchronous generation
PCC	power control characteristics
PPM	Power Park Module
PV	photovoltaic
RES	Renewable Energy Sources
RfG	Requirements for Generators (network code)
SA	Synchronous Area
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
VSC	Voltage-sourced converter
WG	Working Group

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