Expert Group on Connection Requirements for Offshore Systems / Phase I Report

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Contents

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1. Background

The European Green Deal defines the target for the European Union (EU) to become climate-neutral by 2050. To reach these goals, offshore renewable energy technologies as well as their effective integration at sea basin level becomes very important (for the North, Baltic, Mediterranean, Black seas, the Atlantic Ocean and the EU's outermost regions and overseas territories).

Targeting the effective integration of offshore renewables, a number of technical challenges still need to be considered and solved. These challenges include the development of planning standards for offshore high voltage direct current (HVDC) grids, the standardisation of assets and equipment, specification of HVDC systems, operation rules and connection network code requirements applied to offshore power generation modules and HVDC systems connecting to onshore transmission networks.

Whereas onshore transmission systems have seen an incremental development over the last decades, the offshore experience is much lower. At the same time a significant growth rate of offshore generation is planned. This requires offshore transmission systems and products which are even more reliable given that the accessibility of offshore sites is limited and the environment more demanding with often harsh weather conditions.

2. Objective of the EG CROS - Phase I

The objective of Phase I of the EG CROS is to identify the topics that are relevant in the domain of connection network code[1] (CNC) requirements for grid connection and consequently fall within the interest of the Grid Connection European Stakeholder Committee (GC ESC). On these boundary conditions, this EG shall report the identified issues and corresponding objectives for work on substance to be performed in a subsequent follow up phase (termed as Phase II) with more detailed discussions an proposals on how those issues could be supported by relevant EU CNC(s), either by amending existing connection network codes or by drafting (a) new dedicated CNC(s), or both.

When identifying the CNC issues from the experience of the stakeholders, a first assessment and guidance may already be given, whether amendments or new code(s) are deemed favourable for each issue. The Phase I work also includes identifying any relevant expert stakeholders, either as members or consulting parties for further engagement in the subsequent Phase II.

The expected deliverables are as followed:

- Provide a short paper with main discussion points and observations from Phase I.
- Provide a mapping of currently existing transmission topologies for the integration of offshore technologies.
- Provide a list of standards, including adoptable for offshore purpose (list to be completed in Phase II).

[1] e.g. network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules (NC HVDC), network code requirements for generators (NC RfG), network code for demand connection (NC DC).

- Provide the Terms of Reference[2] (ToR) for the subsequent Phase II of the follow up work to be done under the GC ESC.
- Identify relevant stakeholders for the identified issues.

3. Observations of EG CROS - Phase I key discussion points

Connection network codes (CNC) are the regulatory and binding legislation at European Union level of defining the minimum needed capabilities of:

- power generating modules (PGMs);
- transmission-connected demand facilities;
- transmission-connected distribution facilities;
- distribution systems, including closed distribution systems;
- demand units, used by a demand facility or a closed distribution system to provide demand response services to relevant system operators and relevant TSOs
- HVDC systems;
- DC connected PPMs[3];
- and remote-end HVDC converter stations;

CNCs accommodate a system supportive performance of all grid users with purpose of ensuring the system security especially during exceptional and out-of-range contingencies.

Recent work[4] published by the European Commission (EC) has highlighted that non-harmonised technical requirements and specification at the onshore and offshore connection point of HVDC systems[5] as well as DC connected power park modules (PPMs) may have an impact on the design and extendibility of offshore transmission systems. Such technical requirements refer, but are not limited to voltage ranges, frequency ranges, rate of change of frequency (RoCoF) withstand capability and fault ride-through capability at the onshore and the offshore connection point or multiple connection points.

A certain degree of harmonisation between TSOs already happens on project by project basis and the harmonisation of technical requirements has not been seen as a blocking point (for example on the technical requirement at the connection points of HVDC interconnectors).

Up to date the NC HVDC has been applicable to a given set of topologies, as given in the Article 3[6]. Future offshore AC systems connecting offshore wind power generation (DC

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[2] The Term of reference for the phase II, is presented in this report as “Proposal of the EG”in gray box throug the phase I report.

3 Based on the NC HVDC: ‘DC-connected power park module’ means a power park module that is connected via one or more HVDC interface points to one or more HVDC systems;

[4] EC Report on Technical Requirements for Connection to Offshore Hvdc Grids in the North Sea. Version online as of 16.02.2022: https://op.europa.eu/en/publication-detail/-/publication/52f264ac-255f-11eb-9d7e-01aa75ed71a1/language-en.

[5] According to NC HVDC, Article 2 (1): ‘HVDC system’ means an electrical power system which transfers energy in the form of high-voltage direct current between two or more alternating current (AC) buses and comprises at least two HVDC converter stations with DC transmission lines or cables between the HVDC converter stations;

[6] The requirements of the NC HVDC are applicable to: (a) HVDC systems connecting synchronous areas or control areas, including back-to-back schemes; (b) HVDC systems connecting power park modules to a transmission network or a distribution network, pursuant to paragraph 2; (c) embedded HVDC systems within one control area and connected to the

connected PPM) may in the near future be asked to facilitate the connection of a demand facility[7] and energy storage to one or multiple offshore HVDC interface points[8]. These demand facilities are expected to be basically power to gas facilities (including power to hydrogen electrolysis) which aim to support the decarbonisation of the energy system. On a ten-year network development horizon, offshore power to gas (PtG[9]) appears to be technically as well as economically feasible compared to the onshore electrolysis. Offshore electrical integration of PtG combined with wind power generation and energy storage, offers system integration advantages with a fraction of HVDC connections CAPEX while at the same time contribute to decarbonisation of the energy system while offering flexibility.

Large scale isolated AC offshore systems connected to a synchronous area via HVDC links may affect the global system stability of a synchronous area during contingencies. Robustness, resilience and reliability of such isolated power electronic dominated AC systems needs to be guaranteed by means of minimum technical capabilities (preferably mandatory) defined via connection network codes. A recent European Commission (EC) report[10] proposed the view that for such isolated offshore AC system, it is necessary to define minimum technical requirements for grid forming capabilities. These capabilities should be offered by power converters connected to such isolated AC offshore networks. The EG CROS supports this view and recommends in its Phase II to develop further this topic. In this task the involvement of the wind turbine and HVDC manufactures is beneficial.

Concerning the nominal AC frequency of such future isolated AC system for offshore wind integration which is combining demand, energy storage and generation, the EG CROS proposes to be kept at 50 Hz. CNCs are well established for 50 Hz nominal frequency and using non-standardized nominal frequency could lead to higher costs in equipment. Deviating from this nominal frequency could be conflictive with regulation, as those AC hubs would be connection points for demand facilities, energy storage and generation. Completelly isolated AC systems from synchronous areas which will not be in future subject to any grid expansion or would not have any connection option to any synchronous area may have the ability to develop non-standard frequency technical solutions. In principle, up to date such systems does not apply network codes.

Besides the nominal frequency and frequency range, the frequency response requirements become important[11]. An open point for future work is the allocation of frequency response requirements in complex offshore HVDC topologies being shared between control and synchronous areas. Main concern in this case is the loss of power infeed in a particular control area and the allocation of obligations. On that basis, active power technical requirements need to be detailed for complex offshore topologies. This is a topic mainly touching upon operation requirements and agreement between TSOs or facilities. However,

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transmission network; and (d) embedded HVDC systems within one control area and connected to the distribution network when a cross-border impact is demonstrated by the relevant transmission system operator (TSO). The relevant TSO shall consider the long-term development of the network in this assessment.

[7] According to the network code on Demand Connection, a 'demand facility' means a facility which consumes electrical energy and is connected at one or more connection points to the transmission or distribution system. A distribution system and/or auxiliary supplies of a power generating module do no constitute a demand facility.

[8] According to NC HVDC, Article 2 (5): 'HVDC interface point' means a point at which HVDC equipment is connected to an AC network, at which technical specifications affecting the performance of the equipment can be prescribed;

9 PtG is not limited only to one technical solution or product.

[10] Technical Requirements for Connection to Offshore Hvdc Grids in the North Sea. Version online as of 16.02.2022: https://op.europa.eu/en/publication-detail/-/publication/52f264ac-255f-11eb-9d7e-01aa75ed71a1/language-en.

11 frequency sensitive mode (FSM), limit frequency sensitive mode – under/over frequency (LFSM-U/O).

it is worth mentioning that SOGL is not applicable to isolated AC systems. It is the view of the EG that CNCs should cover all the needed capabilities to meet system needs.

The expandability of future offshore topologies (AC and DC) is a key feature that future regulation should ensure. The uncoordinated and non-harmonised technical requirements and the uncoordinated selection of the HVDC system design may hinder if not block the expansion of HVDC systems. DC protection and DC switching station configurations should be designed to ensure the expandability of HVDC systems at the DC side in different time frames. This should be coordinated and planned in a holistic manner with TSOs having the role of coordinator. Multi-vendor and modular scalability is definitely an important condition for such networks to grow in different time scales.

Proposal of the EG:

Moving from the classical point-to-point HVDC system[12], towards complex HVDC topologies (including multi-terminal HVDC) would require a new set of technical requirements, capabilities and operation experience. Drafting strict requirements of complex multi-terminal HVDC structures without first gaining operation experience from industrial scale projects is not recommended. DC connection point technical requirements are not yet covered in the NC HVDC and would only be required if the same HVDC infrastructure is developed by different manufacturers in different timeframes (multi-vendor HVDC systems).

DC connection point requirements will be needed for the case of multi-vendor HVDC systems. DC connection point requirements should ensure that HVDC systems will be expanded in different project timeframes by different entities. Interoperability of assets forming meshed DC connections is very important and such interoperability requirements shall be the core part of such future DC side requirements. Electrical interfaces of converter stations, communication interfaces, signal exchange, control and protection systems need to be standardized as much as possible. Interfaces of control and protection systems are not yet harmonized today. Despite the efforts through the current standards, there is still a long way to go.

4. Main discussion points and observations

This chapter collates the most relevant inputs received from the stakeholders on connection network code implementation experience.

Within the Phase I of the EG CROS, WindEurope has proposed to relax frequency requirements (in the isolated AC system) for DC connected PPMs. The motivation is based on the argument that for DC connected PPMs, the frequency is set by the HVDC converter station (with small variations). The position of WindEurope is supported by the statement that such systems are isolated and requirements could be relaxed as such to reduce CAPEX. WindEurope elaborates the cases of the point-to-point DC connected PPMs, the NC HVDC requirements on frequency, RoCoF, fault-ride through and reactive power control could become much less strict compared to the ones that apply today. Moreover, in the offshore

[12] Based on NC HVDC, Article 2 (1): 'HVDC system' means an electrical power system which transfers energy in the form of high-voltage direct current between two or more alternating current (AC) buses and comprises at least two HVDC converter stations with DC transmission lines or cables between the HVDC converter stations;

case, a certain level of power oscillations at the wind turbine level or at the grid connection point may be allowed.

The view of ENTSO-E members in EG is that there should be no discrimination between AC and DC connected PPMs except for the regulatory allowed deviations in requirements. Moreover, taking into account the future expandability of DC connected PPMs to large isolated offshore islands facilitating also demand connections and energy storage, the deviation of technical requirements should be carefully limited between AC and DC connected PPMs.

WindEurope has requested to open up the discussions on forced power oscillations by wind turbines which are induced due to damping control of mechanical/tower vibrations and in specific to investigate how the damping energy from wind turbines affects the stability of the respective grid modes. These oscillations appear in the range of 0,1 Hz - 0,3 Hz and are caused by tower vibrations. For AC and DC connected PPMs in general i.e. DC and AC connected, it is up to the national implementation of the network codes to do not allow any such oscillations by PPM or in some cases to allow such power oscillations but with a very limited amplitude. The request of Wind Europe is to engage also the HVDC system (particularly the remote-End converter station) in this damping functionality.

From CENELEC perspective, all connected grid users should contribute to a stable operation of the power system. In this context, the damping to the mechanical/tower vibrations should be solved at the PPM level. Even if the HVDC system could absorb the oscillating energy by appropriate control algorithms and if such absorption would be effective to damp the oscillations under all system conditions, such measure would have an impact on the HVDC system design including the major power components. Moreover, the oscillating power would be transmitted by the HVDC system to other nodes in the transmission system and as a consequence, power oscillations could be excited at the onshore HVDC system's Points-of-Connection. Considering future HVDC grid scenarios, complex interactions between the different wind parks via the HVDC network can be expected.

<u>Proposal of the EG</u>:

The topic of forced oscillations in not covered in the existing NC HVDC (for the case of DC connected PPMs) neither NC RfG (for AC connected PPMs). Therefore, it is recommended to assess this topic in a follow up Phase II of this EGfor both for AC and DC connected PPMs. In addition, it should include a detailed assessment of the impact of such behaviour of PPMs to the power system and how requirements could be defined.

Wind Europe has requested the EG to discuss requirements for systems where wind turbines from different manufacturers are directly connected to the same substation[13] or remote-end HVDC station (wind farm interoperability). Performing detail interaction studies in multi-vendor environment is a challenge for designing such systems, especially when considering data and simulation models exchange (data and model exchange is an issue that affects intellectual property). The recent Expert group on interaction studies and simulation models

[13] CIGRE is currently preparing a brochure on such configurations, to be published in Q2, which should be considered by the EG.

(EG ISSM) provides a first set of technical requirement for simulation models for PPMs and HVDC systems but no work is available on how to solve data share and models for such studies.

Proposal of the EG:

The topic of interoperability of DC connected PPMs when different OEMs are connected to the HVDC interface point needs to be addressed. Today most TSOs or where applicable RSOs require the simulation models in the used software specific programming language (Fortran, DSL etc.). The Phase II of EG CROS should discuss the current state of the play in the way EMT models could be exchanged in the form of DLL based models. The expert group should pick up the recommendations made in the expert group interaction studies and simulation models, chapter 5.7.

Wind Europe has raised the concern that system operators place additional and non-harmonised requirements with regard to harmonics and power quality. Wind Europe recommends that system operators stay with the IEC 61000 standard and proposes to force it by means of regulation. The position of ENTSO-E members in the EG is that the topic is extremely hard to harmonize as different countries have different approaches based on national legislation with regard to power quality. In addition power quality is a local phenomenon which has origin in the individual national electricity system and it is influenced, power infrastructure, general penetration of power electronics in both generation and demand etc.

Proposal of the EG:

DC connected PPM requirements may deviate from the IEC harmonic standards or the onshore code requirements and specifications in the actual region. In such cases the details of the possible deviations from the requirements shall be agreed and documented between the involved parties.

CENELEC has raised the topic of Grid Forming capabilities and system recovery technical requirements. This is seen for the HVDC manufacturers as an issue of control chain and coordination between HVDC systems and DC connected PPMs. Additional frequency and voltage stability requirements for HVDC systems connecting DC connected PPMs are recognized and the request has been made for them to contribute to voltage, phase angle and frequency stability at their connection point more than before. The latter includes functionalities as grid forming capability[14], FSM and LFSM-O and LFSM-U. Since HVDC systems do not have significant energy storage, providing such grid forming capabilities to the connection point onshore requires for coordination between HVDC system and the DC connected PPM. Without such coordination, extra investments in alternative solutions (i.e.

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[14] Based on the definitions of the technical group HPoPEIPs report supported by ENTSO-E, Wind Europe and Solar Europe. Available online: https://eepublicdownloads.entsoe.eu/clean-documents/Publications/SOC/High_Penetration_of_Power_Electronic_Interfaced_Power_Sources_and_the_Potential_Contribution_of_Grid_Forming_Converters.pdf

energy storage in the HCDC circuit) may be needed to provide those capabilities and maintain system stability in the onshore grid.

Proposal of the EG:

It is the proposal by the EG to address all relevant technical aspects of the control chain coordination of a DC connected PPM and HVDC system with respect to the connection network code requirements. This should include:

- Grid forming capability[15];
- FSM, LFSM-U, LFSM-O;
- Synthetic inertia[16];
- Dynamic voltage control; and
- System Recovery;

Ideally, the HVDC system should be able to provide the above mentioned capabilities in coordination with the DC connected PPMs without communication. Communication is likely too slow to cope with such technical requirements. In order to comply without communication, the HVDC system should be allowed to control the power withdrawn from the DC connected PPMs by varying phase angle and frequency of the Remote-end HVDC converter station. The voltage and voltage phase angle variation of the remote-end HVDC station should enable the DC connected PPMs to adapt its power output in a defined range to meet the AC voltage and frequency limits in the isolated AC system accordingly. In principle the remote-end HVDC converter station connected to the offshore HVDC interface point should be capable to trigger the condition to meet the technical requirements at the onshore HVDC converter station. The DC connected PPMs should be able to operate with dedicated frequency control reserve, whenever DC connected PPMs and HVDC system are required to participate in frequency stabilisation in FSM and LFSM-O/U. If communication is required, the relevant communication times should be coordinated between DC connected PPMs and HVDC system. This would avoid or limit additional energy storage or dynamic braking devices (DC chopper) inside the HVDC system to fulfil the connection network code requirements in the onshore and offshore networks. The latter options should be discussed in the phase II and its feasibility should be shown.

HVDC systems will be used for PPMs connection as well as interconnectors[17]. The active power of PPMs should be required to support the operation of multi-purpose interconnectors. Since the HVDC system provides the connection between offshore HVDC interface point and the onshore grid connection point, the HVDC system should ideally control its power intake from the wind parks by varying phase angle and frequency of its generated AC voltage source in a respective DC connected PPM. That should enable the DC connected PPM to adapt its power output in a defined range to meet the AC voltage and

[15] The definition of grid forming capability should be also part of the Phase II work.

[16] Based on the understanding of EG members: Synthetic inertia in an electric power system means the capability of a grid connected converter to emulate the effect of inertia of a synchronous generator to a prescribed level of performance, whereas inertia in an electric power system means the property of a rotating rigid body according to which it maintains its angular velocity in an inertial frame in the absence of an external torque.

17 Based on the Clean Energy Package, and interconnector is defined as transmission capacity between two countries.

frequency limits in the respective offshore isolated AC system accordingly. Such coordination between HVDC systems, DC connected PPM and if applicable DC connected demand and energy storage facilities becomes necessary and could avoid additional investments, such as the need for DC choppers.

It is worth mentioning that the actual capabilities of the PPM depend on the energy source conditions (for example wind). The active power control of PPMs should be requested to support the operation of HVDC system, especially for multi-terminal cases (during DC or AC faults for example).

<u>Proposal of the EG</u>:

The following points should be addressed in the EG CROS, Phase II:

- The control chain starting from the onshore connection point of the HVDC station down to the remote-end HVDC station and the DC connected PPMs. The control chain should be assessed in the content of NC HVDC.
- The definition of grid forming technical requirements that should be given to PPMs and to HVDC system. It is still open where the energy should be stored, at the remote-end HVDC converter station, at HVDC link or at PPMs. All options should evaluated. The focus should be placed on the technical capabilities offered.
- Communication is also an important part for the coordination of the whole control chain from the onshore to the offshore converter and PPMs. Limitations of communication should be defined. Technical requirements of communication links should be set. Coordinated operation of onshore and offshore (remote-End) HVDC converter stations with PPMs without communication should be also explored.
- Phase II of the EG CROS should also discuss existing NCs definitions. One example could be synthetic inertia. Its definition is important for setting requirements on future functionalities and capabilities
- Black start capability is a technical requirement which is not mandatory and is imposed based on the .generator type and the and the individual member state need and philosophy of providing black start capabilities. The EG in Phase II will discuss the up to date requirements in the NC HVDC or NC RfG and provide recommendations.

The EG CROS in Phase II should assess all above points and define proposals for amendments of the NC HVDC or NC RfG if applicable to cope with such issues.

Besides the tasks defined so far, the EG CROS should work on the definition of a glossary for the most important definitions as used in the network codes.

5. Offshore Topologies and applicability of Connection Network Codes

This section provides a first investigation of the possible offshore grid topologies expected in Europe. The aim of this section is to stress the variations of the connection options as well as to define the applicability as well as gaps of existing CNCs. The chapter concludes with actions and tasks to be completed in the Phase II of the EC CROS.

Case 1[18]: DC connected PPMs and Demand Facilities

The most common topology for HVDC systems and the DC connected PPMs up to date is the point-to-point connection as presented in Figure 1 (for the case that states A and B are in the same synchronous area). A realistic future variation of such connection case is shown in state B, where a (DC connected) demand facility and an (DC connected) energy storage module shares the HVDC interface point[19] with the DC connected PPM.

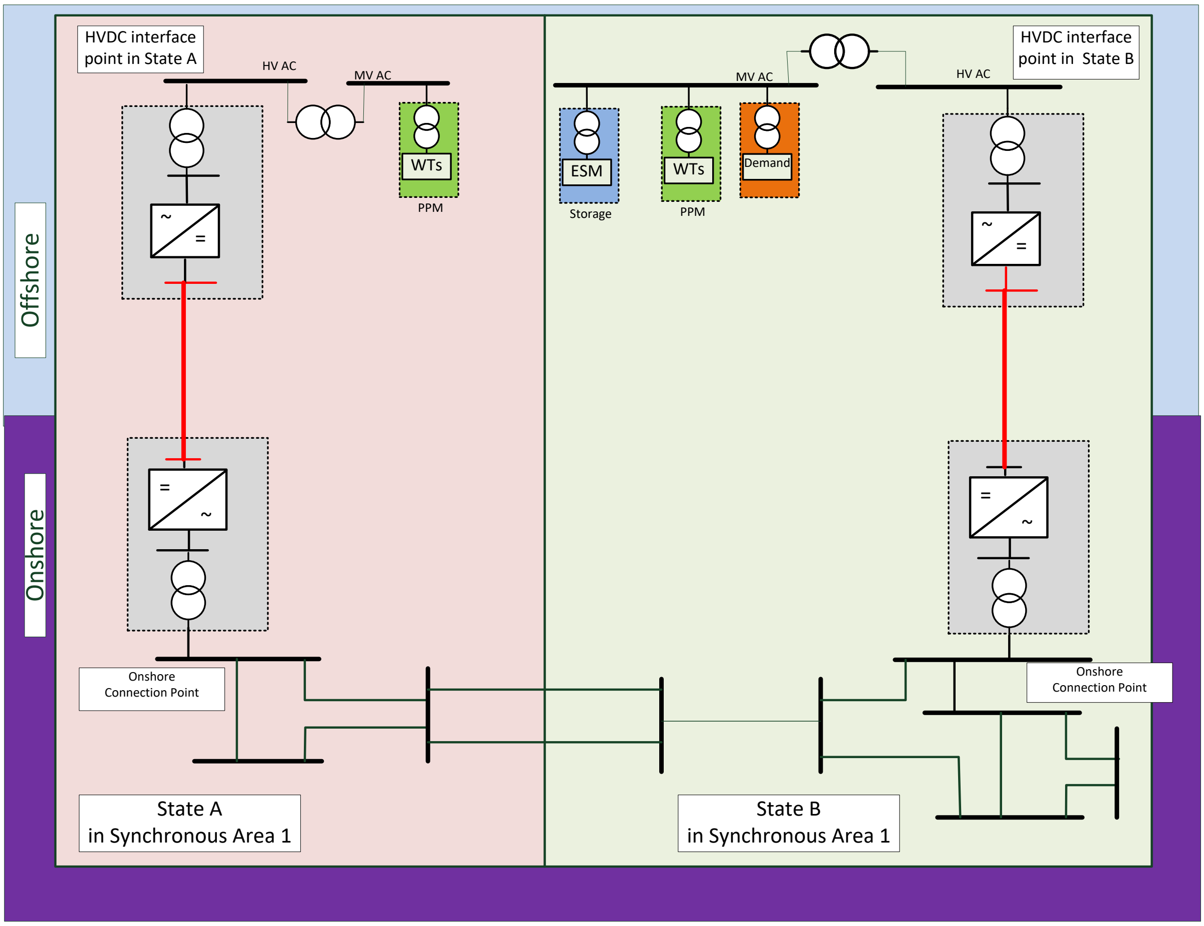

Figure 1. DC Connection of PPMs, energy storage and demand facilities (for monopolar HVDC system).

For the state A and its DC connected PPMs, the NC HVDC applies for the HVDC system as well as for the DC connected PPMs. However, for the case of state B, the presence of both a DC connected demand facility and energy storage which are connected at the same HVDC interface point is not covered within the frame of NC HVDC. Moreover, for this DC connected

18 The topology here is drawn as monopole HVDC system. For the case of bipolar HVDC, the same requirements shall apply for each pole converter at the offshore HVDC interface points as well as at the onshore AC connection points.
19 Based on NC HVDC, Article 2 (5), 'HVDC interface point' means a point at which HVDC equipment is connected to an AC network, at which technical specifications affecting the performance of the equipment can be prescribed.

demand facility, Network Code Demand Connection (NC DC) does not apply[20] (cf. NC DC article 3 (2) (a)).

In addition, up to date the remote-end HVDC converter station provides the voltage and frequency formation[21] at the offshore HVDC interface point. DC connected PPMs and if applicable DC connected storage facilities should be able in future to contribute to voltage/frequency formation of the HVDC interface point. The latter is commonly understood as a part of the capability of PPMs to provide grid forming[22] functionality.

As an additional variation of the topology in figure 1, figure 2 presents a case where two HVDC links are connected on the offshore AC and onshore DC side at the same time. This topology is considered as a multi-terminal HVDC grid case under the assumption that it is constructed by on HVDC supplier.

Proposal of the EG:

The NC HVDC should be extended to be applicable for DC connected demand facilities and DC connected electricity storage modules. The Phase II of the EG CROS should:

- propose such provisions and expand the applicability of the NC HVDC toward energy storage and demand facilities.
- elaborate potential harmonization of voltage and frequency ranges in combined DC connected- PPMs, demand facilities as well electricity storage units to allow for future expandability.
- propose and define minimum requirements for grid forming capabilities offered by DC connected PPMs and HVDC systems.

The EG should assess the applicability of the NC HVDC to the topology of and Figure 2.

20 NC Demand Connection shall not apply to: Demand facilities and distribution systems connected to the transmission system and distribution systems, or to parts of the transmission system or distribution systems, of islands of Member States of which the systems are not operated synchronously with either the Continental Europe, Great Britain, Nordic, Ireland and Northern Ireland or Baltic synchronous area;

21 This should be understood as the capability of the remote end HVDC converter station to provide a controllable in magnitude, phase angle and frequency instantaneous three phase voltage waveform without relying on any external voltage waveform.

22 Grid forming capabilities have been already defined in the connection network code of Great Britain (as non-mandatory requirements) as well as in Germany (for HVDC systems as a mandatory requirement).

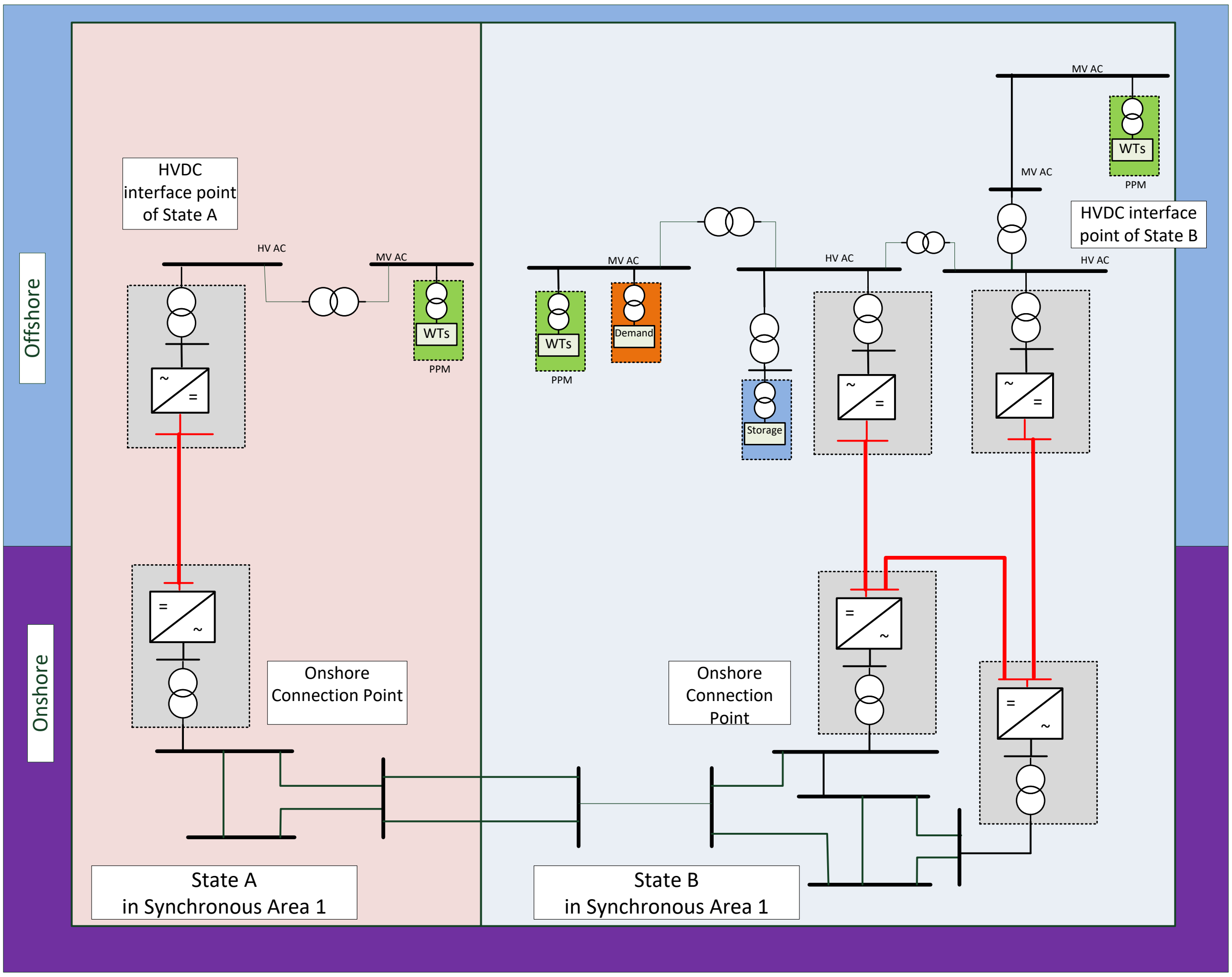

Figure 2. DC Connected PPM, energy storage and demand facilities with parallel HVDC links coupled on the AC and DC side.

Case 2a: AC connected HVDC interfaced points belonging to different synchronous areas

The architecture of Figure 3 presents a variation of a typical point-to-point topology of Figure 1, assuming that the offshore HVDC interface points are AC coupled. The presence of different technical specifications and CNC requirements in states A and B (being part of different synchronou area) at the HVDC interface points (NC HVDC requirement for DC connected PPMs and remote-End HVDC converter station) could be a blocking point of such architecture to grow in different timeframes and project phases. For example technical requirements are referred to voltage/frequency ranges, reactive power and voltage control capability. Irrelevant of who is operating such offshore transmission topology, the technical requirements imposed to DC connected PPMs, DC connected demand facilities and DC connected energy storage modules and HVDC stations (onhsore and offshore) shall be system supportive and shall ensure robust operation of the integrated system.

Proposal of the EG:

- The Phase II of the EG CROS should assess the applicability of the NC HVDC articles on the topologies of case 2a (Figure 3). This case shall be assessed both for the case that state A and B are connected to the same synchronous area, and for the case that state A and B are in different synchronous areas.
- Moreover, the EG should define the minimum technical requirements of the topology of figure 3 as well as the potential scope extension of the NC HVDC to cope with such case.

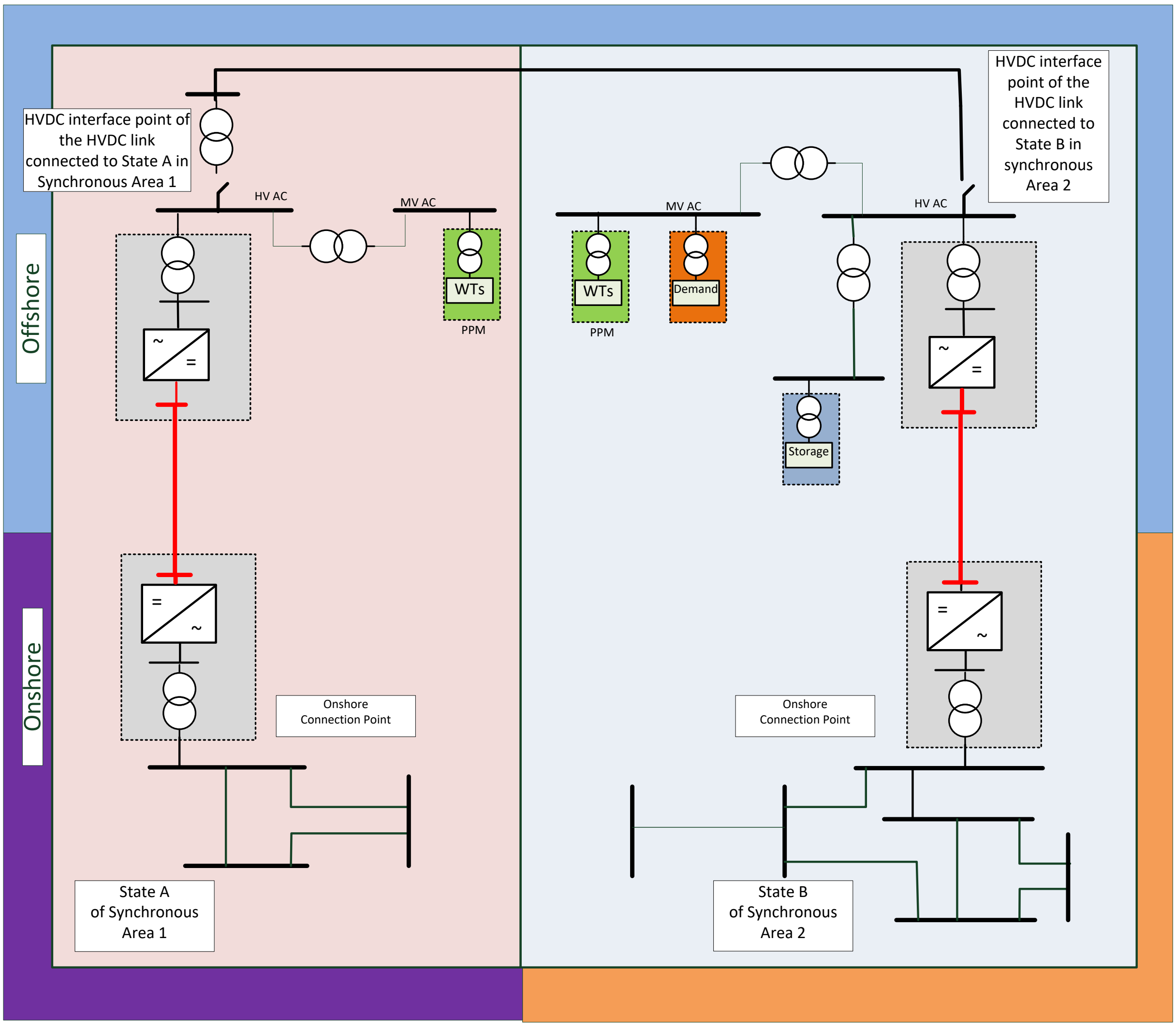

Figure 3. A case that the offshore HVDC interface points of different synchronous areas are AC connected.

Case 2b: DC coupled HVDC interface points belonging to different synchronous areas

Case 2b illustrates a situation where an HVDC interconnector is built between two offshore HVDC interface points (one belonging to the state A and the second to the state B, regardless of whether state A and B are part of the same synchronous area).

Unlike typical interconnectors which are operating connected to the onshore system, this specific offshore configuration would require a completely different set of technical requirements and parameters. Moreover, next to the technical capabilities the share of data and models for planning and design studies is a significant issue for the case when the owners as well as the original equipment manufacturers of PPMs, HVDC and demand facilities and energy storage modules are different entities. An illustration of this topology is shown in figure 4.

Next to the topology of Figure 4, the connection of the two HVDC interface points (isolated AC systems) belonging to different states could be substituted by a common DC connection between the two HVDC stations, as shown in Figure 5.

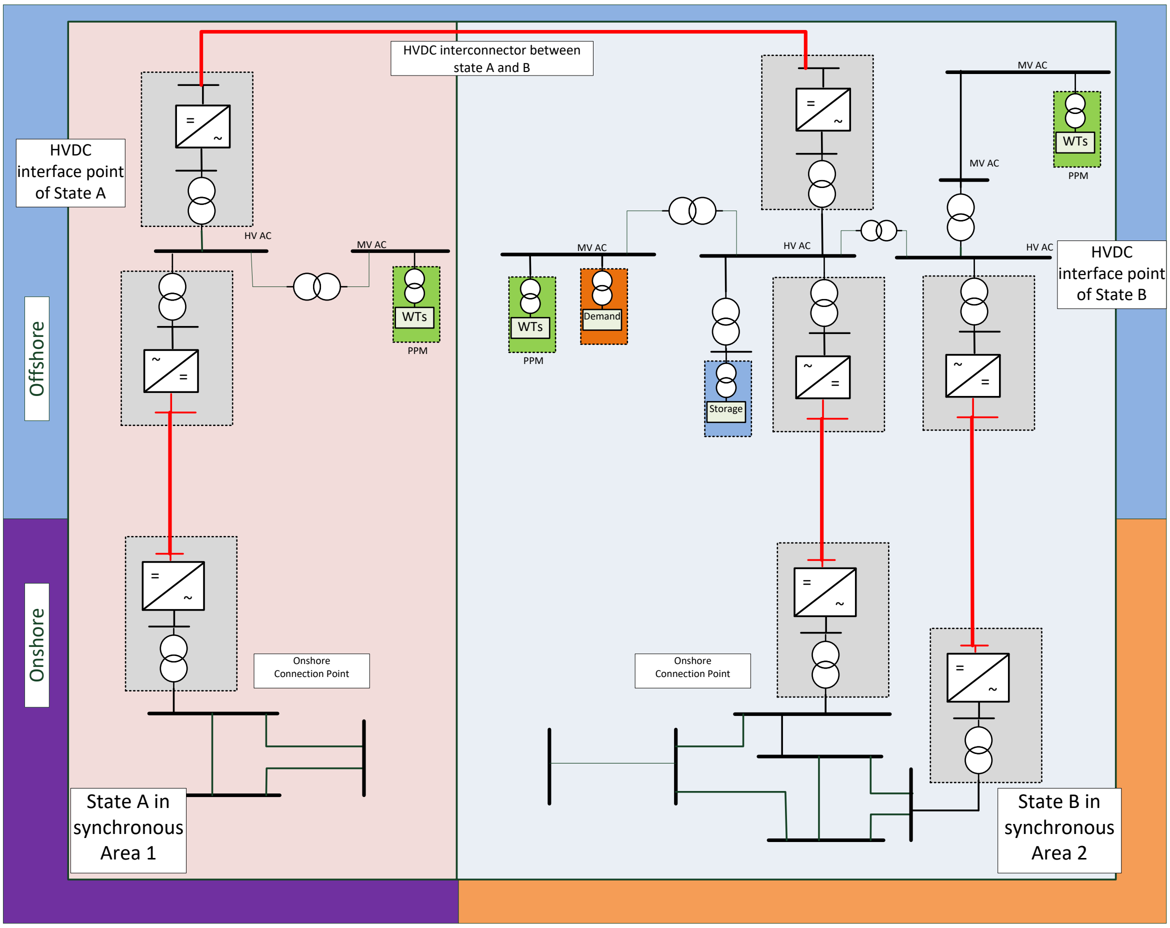

Figure 4. Topology showing DC connected HVDC interface point that belond to different synchronous areas.

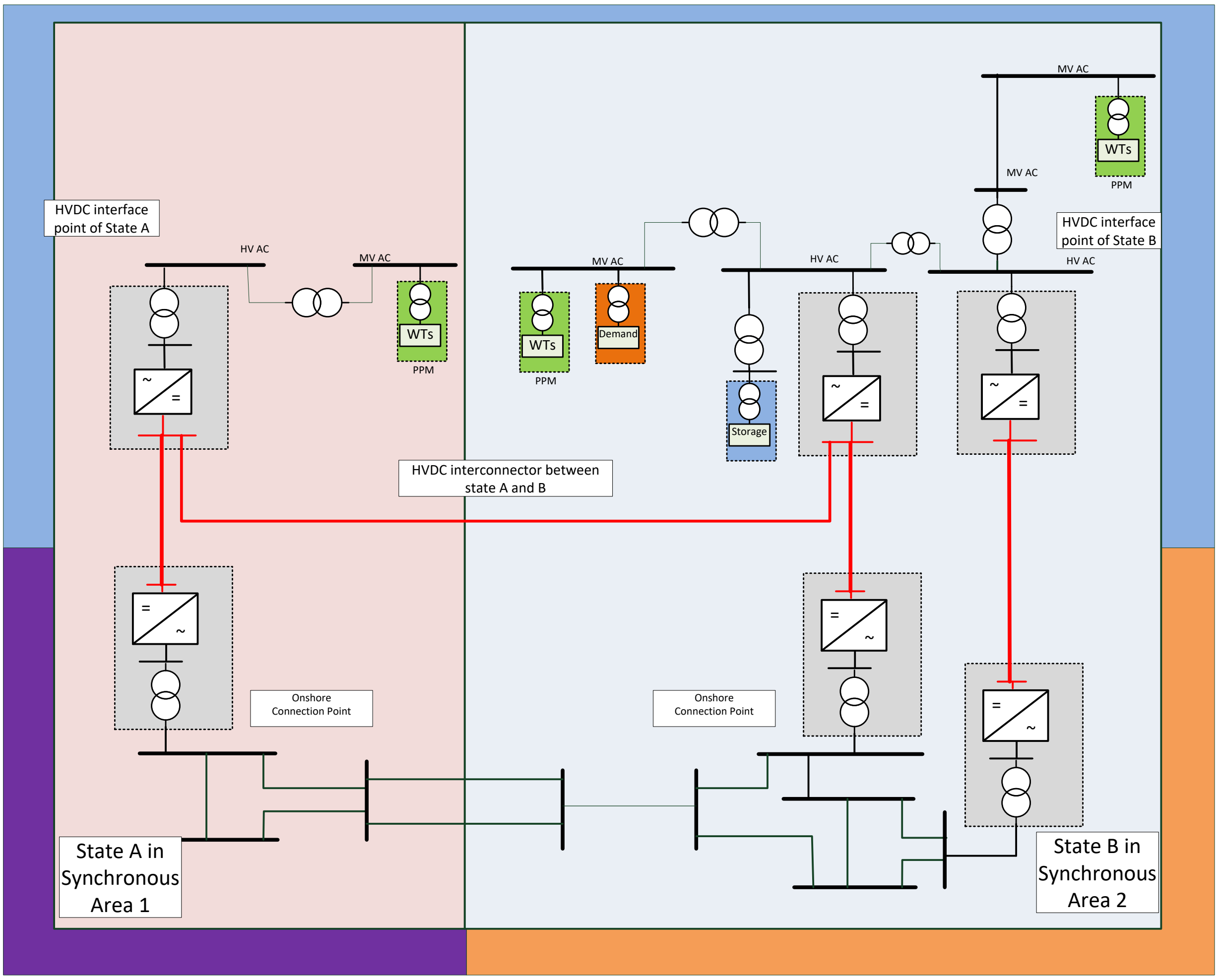

Figure 5. Topology showing DC coupled HVDC stations, i.e. a connection between the converter stations DC side forming a DC grid (including the case that the onshore HVDC converter stations are also at different SAs).

<u>Proposal of the EG</u>:

- The Phase II of the EG CROS should assess the applicability of the NC HVDC articles on the topologies of case 2b (Figure 4 and Figure 5). The assessment should be done for both the case that the states are in the same as well as in different synchronous areas.
- Moreover, the EG should define the minimum technical capabilties of such interconnectors, connecting offshore HVDC interface points (regardless if the onshore HVDC converter stations are at different synchronous areas).

Case 2c: Hybrid AC/DC connected PPMs shared between different states and synchronous areas

The case 2c shown in Figure 6 illustrates a case where a PPM could at the same time have an AC as well as DC connection (could be depending on the operational regime) however as long as the HVDC interface point is synchronously connected to state A it overrules the DC connection. What is special for this case is that the timeframes of development of the AC and the DC connection could be different. Depending on the connection or not of the AC line in state A, the HVDC converter stations will fall to different provision of NC HVDC.

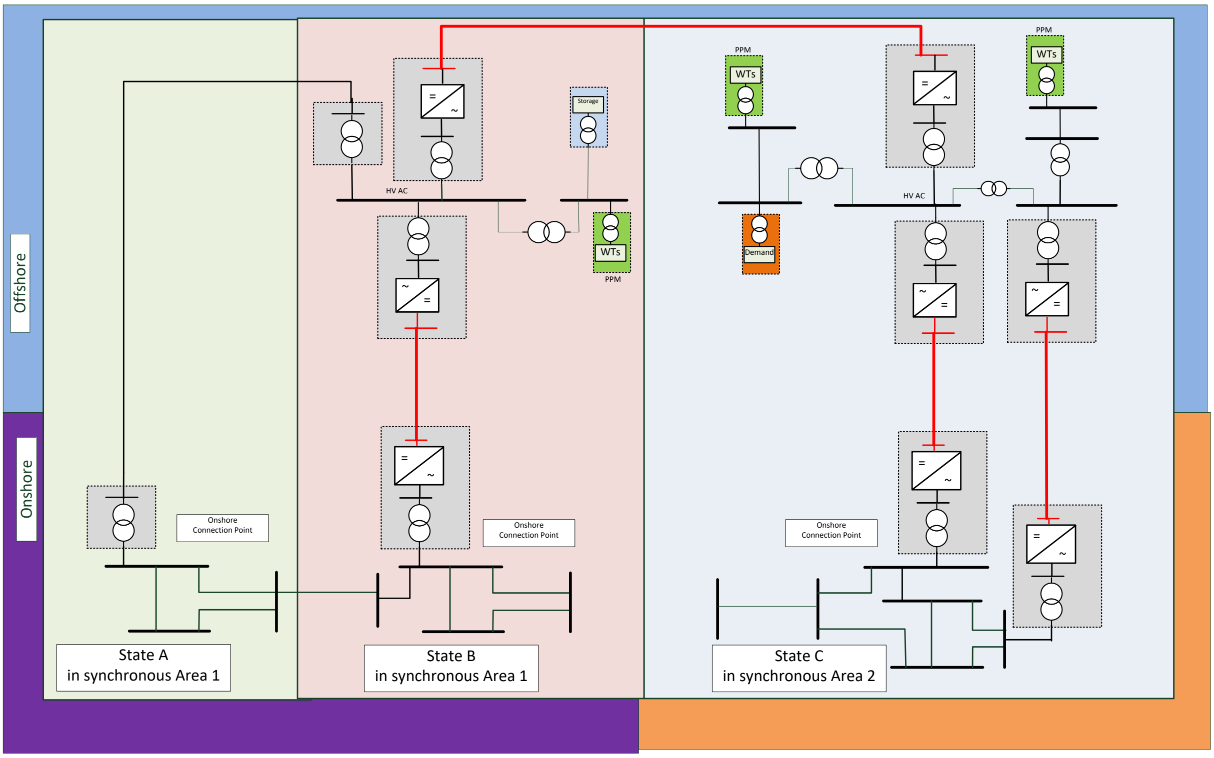

Figure 6. Simultaneous AC and DC connected PPMs (including the case that the onshore HVDC converter stations are also at different SAs).

<u>Proposal of the EG</u>:

- The Phase II of the EG CROS should assess the applicability of the NC HVDC articles on the topology of case 2c.
- Moreover, the EG should define the minimum technical requirement or such interconnectors.

6. Collection of standards for connecting offshore wind Power Park Modules with HVDC

- IEC 60038, IEC standard voltages
- IEC 60059, IEC standard current ratings
- IEC 60071-1, Insulation co-ordination - Part 1: Definitions, principles and rules
- IEC 60071-2, Insulation co-ordination - Part 2: Application guidelines (Proposed horizontal standard)
- IEC 60076-7, Power transformers - Part 7: Loading guide for mineral-oil-immersed power transformers
- IEC 60196, IEC standard frequencies
- IEC 61000, Electromagnetic compatibility (EMC)
- IEC 61936, CMV Power installations exceeding 1 kV AC and 1,5 kV DC
- 50654-1, HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 1: Guidelines
- CLC/TS 50654-2, HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 2: Parameter Lists
- CISPR 18, Radio Interference Characteristics of Overhead Power Lines and High Voltage Equipment
- 2006/42/EC, Machinery Directive of the European Parliament and of the Council of 17 May 2006 is a European Union directive concerning machinery and certain parts of machinery.
- DNVGL-ST-0145, Offshore Substations
- ISO 12100, Safety of machinery –General principles for design – Risk assessment and risk reduction.,
- DIN VDE 0105-100 VDE 0105-100:2015-10, Operation of electrical installations, Part 100: General requirements
- EN 50160:2010 "Voltage characteristics of electricity supplied by public distribution networks".
- IEEE P2800 “IEEE Approved Draft Standard for Interconnection and Interoperability of Inverter-Based Resources (IBR) Interconnecting with Associated Transmission Electric Power Systems”
- Cigre TB 391, Guide For Measurement Of Radio Frequency Interference From HV And MV Substations
- Cigre TB 568, Transformer Energization in Power Systems: A Study Guide, Februar 2014.
- Cigre TB 590, Protocol for reporting the operational performance of HVDC transmission systems
- Cigre TB 697, Testing and commissioning of VSC HVDC systems

7. Terms of Reference for the Phase II

Based on the points highlighted and discussed in the section 4 and section 5, the tables 1-2, provide the most relevant points to be detailed in the EG CROS Phase II.

Table 1. Gaps to be detailed in the phase II.

Topic not included in the current legislation	Relevant Regulation
DC connected Demand Facilities	NC HVDC
General applicability of Demand Facilities (article 3(2)(a))	NC DC
DC connected ESM (Energy Storage Module)	NC HVDC
General applicability of ESM	EU Regulation (NC RfG)
AC interconnection between several HVDC interface points	NC HVDC
DC connected HVDC systems (article 3(7)(b)	NC HVDC
DC interconnection between several HVDC stations with individual HVDC interface point	NC HVDC

Table 2. Technical requirements to be scopped in Phase II

Technical requirement to be scoped	Relevant Regulation
Remote-end HVDC and converter station to provide voltage and frequency formation.	NC HVDC
DC connected PPM to provide voltage and frequency formation	NC HVDC
DC connected ESM to provide voltage and frequency formation	NC HVDC
Technical minimum requirements for AC interconnectors between HVDC interface points	Initial set of minimum technical requirements.
Technical minimum requirements for DC connected PPM, DC connected Demand Facilities and DC connected ESM in a shared/common HVDC interface point	NC RfG, NC DC, EU regulation (NC RfG)
Technical minimum requirements for DC connected HVDC systems	NC HVDC
Technical minimum requirements for DC coupled HVDC stations	NC HVDC