Expert Group on Connection Requirements for Offshore Systems – Phase II (Proposal for the NC HVDC amendment)

Grid Connection European Stakeholder Committee

Approved on 01.12.2023

Contents

List of contributors

The work of this Expert Group has been supported by the kind contribution of the nominated grid connection European Stakeholder Committee (ESC) members and guest Experts as listed in Table 1. This Expert Group has been chaired by ENTSO-E and aims to provide inputs for the NC HVDC amendment process[1].

Table 1. List of members representing and associations

No	Full Name	Member Organisation of GC ESC	Affiliation
1	Karstein Brekke	IFIEC Europe	Hydro Energy AS
2	Frank Schettler	CENELEC	Siemens Energy
3	Gunnar KAESTLE	CENELEC	B.KWK
4	Mario Ndreko (**co-chair**)	ENTSO-E	TenneT TSO GmbH
5	Flemming Brinch Nielsen (**co-chair**)	ENTSO-E	Energinet
6	Pascal Winter	ENTSO-E	Amprion
7	Piotr Rzepka	ENTSO-E	PSE
8	Ranjan Sharma	WindEurope	Siemens Gamesa
9	Kamran Sharifabadi	WindEurope	Equinor
10	Tusitha Abeyasekera	WindEurope	Vestas
11	Vasiliki Klonari	WindEurope	WindEurope
12	Maria Kotofolou	WindEurope	WindEurope
13	Jörn Runge	VGBE	RWE
14	Mick Chowns	VGBE	RWE
15	Eric Dekinderen	VGBE	VGBE
16	Tarik Donlagic	Orgalim	Siemens AG
17	María López Gómez-Calcerrada	EASE	Iberdrola
18	Pedro Domingo González Guillén	EASE	Naturgy
19	Krzysztof Glik	COGEN Europe	PGE S.A
20	Adrian Gonzalez	ENTSO-E	ENTSO-E
21	Georgios Antonopoulos	ACER	ACER
22	Mario Carrero	Hydrogen Europe	H2Greem
23	Luis Sacristan	Hydrogen Europe	H2Greem
24	Adil Abdalrahman	T&D Europe	Hitachi Energy
25	Omar Jasim	T&D Europe	General Electric

[1] Note: Although T&D Europe and Hydrogen Europe are not a directly members in Grid Connection European Stakeholder Committee (GC ESC), the chair of this Expert Group following approval from ACER has invited these associations to contribute to this work.

Scope of this report

The objective of Phase I work of the Expert Group on Connection Requirements for Offshore Systems (EG CROS) was to identify and document in its report[2] the topics that are relevant in the domain of connection network code (CNC) requirements for grid connection and, consequently, fall within the interest of the Grid Connection European Stakeholder Committee (GC ESC). During the Phase II of this Expert Group (EG), the EG shall detail on content the recommendations stated in the Phase I report. The assessment shall consider the mapping of currently existing transmission topologies for the integration of demand and storage offshore technologies (see Terms of Reference (ToR) of EG CROS approved by GC ESC). In addition, it must be recalled that the Expert Group CROS does not aimed to provide a full revision of the existing HVDC code, but only to either amending, modernising existing codes (e.g. NC HVDC) or drafting (a) new dedicated NC(s), or by both approaches for the matters associated to the ToR.. During the Phase I, the EG has also collected all the relevant standards, which overlaps, and shortcomings shall be assessed in this Phase II. As main deliverable, this Phase II report should provide a paper which addresses the problem statement through the assessment included in Phase I report (Annex 1), developing specific recommendations (i.e. legal text proposals) for amending the current EU regulations in the scope of competence of Grid Connection European Stakeholder Committee (GC ESC).

Timing

- Started on June 2022 and aim for approval in GC ESC in December 2023

Target audience

- Grid Connection European Stakeholder Committee members;
- Relevant and/or interested stakeholders.

Expert Group history of online and physical meetings

The members of the Expert Group have discussed the various topics as given in the Expert Group Terms of Reference (ToR) from June 2022 till June 2023. Figure 1 collates the dates of the meetings (or webinars) as well as the dedicated physical workshops.

[2] GC ESC Expert Group on Connection Requirements for Offshore Systems – Phase I report. The report is available online at the link.

Figure 1. Timeline and meetings of this Expert Group during 2022-2023.

Chapter 1: Objectives of EG CROS Phase II

This Expert Group collates the common recommendations of the stakeholders on the topic of connection requirements for offshore systems.

The relevant regulation that concerns the content of this report is the COMMISSION REGULATION (EU) 2016/1447 of 26 August 2016, establishing a Network Code on requirements for grid connection of High Voltage Direct Current systems (NC HVDC)[3].

In its Phase I report, published as per April 2022, this Expert Group has detailed the relevant gaps for the NC HVDC, as summarised and presented in the table 2.

Table 2. List of the regulatory gaps regarding connection network codes that have been identified in the Phase I report of the EG CROS and they are exhausted in this Phase II report**.**

Topics which are not included in the current legislation (NC HVDC)	Relevant Regulation to be addressed
Lack of regulation for offshore Demand Facilities, power to gas (mainly electrolysis) facilities and Electricity Storage Modules connected to remote end HVDC converters stations. Currently the existing version of the NC HVDC defines requirements only for AC collected and HVDC connected to a synchronous area Power Park Modules.	NC HVDC
Lack of regulation for HVDC systems that are connecting isolated AC networks and at the same time those isolated AC networks are connected via HVDC systems to a synchronous area. This is commonly known as HVDC connection of isolated AC hubs.	NC HVDC
Lack of requirements for the topic of forced oscillations which is not covered in the existing NC HVDC (for the case of DC connected PPMs) neither NC RfG (for AC connected PPMs)[4].	NC HVDC, NC RfG

[3] Although the focus of this report is placed on the NC HVDC amendment proposals, the Expert Group would like to highlight and raise the attention that the Network Code HVDC was drafted together with the Network Code RfG (COMMISSION REGULATION (EU) 2016/631 of 14 April 2016) and the Demand Connection Code (Commission Regulation (EU) 2016/1388 of 17 August 2016), which interrelate to each other by using common terms and definitions, as well as common requirements referred through the codes. Therefore, the Expert Group recommends that all three grid connection codes are amended in one amendment package in order to avoid lack of consistency. This is not the opinion of ENTSO-E as coordinating a common amendment package of the three CNCs will delay urgent needed requirements and functionality the Network Code RfG (COMMISSION REGULATION (EU) 2016/631 of 14 April 2016) and the Demand Connection Code (Commission Regulation (EU) 2016/1388 of 17 August 2016)

[4] It should be noted that this Expert Group has discussed this very important topic but has not prepared any legal text proposal for active power forced oscillations. The topic is strongly related to the amendment of NC RfG and the discussions which are taking place at GC ESC during the period that this Expert Group work takes place. The position of the EG CROS members is

Moreover, next to the gaps of the Table 1, a set of technical requirements are scoped, as defined in the Table 3.

Table 3. List of the technical requirements to be scoped in the phase II of the EG CROS

Technical requirement to be scoped	Relevant Regulation
Evaluation of existing definitions of NC HVDC in order to support the development of amendment proposals.	NC HVDC
Definition/drafting of grid forming technical requirements for HVDC systems and DC connected Power Park Modules. The focus should be placed on the technical requirements as well as the control chain starting from the connection point of the HVDC station down to the remote-end HVDC station and the DC connected Power Park Modules. The control chain should be discussed and placed in the content of NC HVDC relevant articles.	NC HVDC
Develop grid forming technical requirements for DC connected Electricity Storage Modules[4]. This is a gap in the current regulation that need to be solved.	NC HVDC
Develop technical requirements for DC connected Power Park Modules, DC connected demand facilities and DC connected Electricity Storage Module in a shared/common interface point. This is a gap in the current regulation that need to be solved.	NC HVDC
Develop technical requirements for DC coupled HVDC interface points. Those are HVDC systems that connect isolated AC networks. It should be noted that here we refer to isolated AC network that has at least one connection via HVDC system to a synchronous area. Off-grid systems or isolated AC networks without AC or HVDC system connection to a synchronous area are not in scope.	NC HVDC
The interoperability of DC connected Power Park Modules 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	NC HVDC

that the requirements defined in NC RfG 2.0 (and specifically for Type D Power Plant Modules) should be applicable to the Power Park Modules connected via HVDC systems (DC connected PPMs).

[4] Please note that the term DC connected Power Park Modules is defined in the existing version of the NC HVDC.

the play in the way EMT models could be exchanged in the form of DLL based models[5].	
Black start capability is a technical requirement which is not mandatory and is imposed based on the generator type and the individual Member State need and philosophy of providing black start capabilities. The EG shall discuss the up-to-date requirements in the NC HVDC or NC RfG and provide any needed recommendations.	NC HVDC
Communication is also an important part for the coordination of the whole control chain from the onshore to the offshore converter and Power Park Modules. Limitations of communication should be defined and discussed in the EG. Technical requirements of communication links should be set. Coordinated operation of onshore and offshore (remote-end) HVDC converter stations with Power ParkModules without communication should be also explored.	NC HVDC

List of abbreviations

A-PPM	Asynchronously connected Power Park Module
A-PtG-DU	Asynchronously connected Power to Gas Demand Unit
A-ESM	Asynchronously connected Electricity Storage Module
A-DF	Asynchronously connected Demand Facility
RoCoF	Rate of Change of Frequency
HVDC	High Voltage Direct Current

[5] It should be noted that for this task and during the period of existence of this Expert Group an implementation guidance document has been provided by ENTSO-E supporting this task. This document can be found here. This Expert Group supports the simulation model requirements defined in this IGD and the relevant section about the model encryption approach. Concerning the topic of interoperability studies in the content of multi-vendor projects, it the view of the Expert Group this should be defined on national level, following the requirements of model encryption as defined by the relevant TSO.

Chapter 2: NC HVDC amendment proposals of the Expert Group

Motivation for initiating the amendment of the NC HVDC

Connection network codes (CNC) are the set of rules, initially drafted by ENTSO-E, with guidance from the Agency for the Cooperation of Energy Regulators (ACER), with purpose to facilitate the harmonisation, integration, and efficiency of the European electricity market. CNC is an integral part of the path towards completion of the internal energy market, crucial for ensuring the safety of system operation and the efficiency of the European Union's power grid, while achieving the European Union's energy objectives of:

- At least 55% cut in greenhouse gas emissions compared to 1990 levels.
- At least a 32% share of renewable energy consumption.
- At least 32.5% energy savings compared with the business-as-usual scenario.

The amendment of the CNC is a tool to modernise the regulation ensuring safe operation of the future power system, integration of novel technologies, harmonisation of requirements with aim to facilitate the energy transition in cost effective manner while preserving reliability and security of supply.

Among the most important drivers, but not limited to, for the amendment of the NC HVDC are the following:

- Modernisation of the connection network codes in order to safeguard system needs and to ensure that new capabilities of the European market are well defined and to a potential harmonised degree in EU.
- The grown in generation capacity of isolated offshore AC networks (AC hubs) that are expected in the near future to connect large scale (GW or tens of GW) offshore wind power generation and large-scale industrial demand (electrolysis).
- The high penetration of HVDC systems as well as converter interfaced Power Park Modules create new system needs and requires for different capabilities of the grid users in order to manage the power system stability. For example, low Inertia and, in some locations, low availability of short circuit power would affect system needs, hence requirements for Power Park Modules, Demand Facilities and HVDC systems.
- Maintain system security, reliability and cost-effective system design and system operation.

Amendments proposals consolidated in this Expert Group

Existing definitions cited from NC RfG, NC HVDC and NC DC

The following definitions have been adopted by the existing version of the network codes and used in this Expert Group report. It should be noted that these definitions may change as an outcome of the ongoing amendment process on NC RfG and NC DC (expected finalized by Q4 2023, EU parliament vote in 2024).

- **'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 not constitute a Demand Facility;

- **'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;

- **'synchronous area'** means an area covered by synchronously interconnected TSOs, such as the synchronous areas of Continental Europe, Great Britain, Ireland-Northern Ireland and Nordic and the power systems of Lithuania, Latvia and Estonia, together referred to as 'Baltic' which are part of a wider synchronous area;

- **'Power Park Module' or 'PPM'**[6] means a unit or ensemble of units generating electricity, which is either non-synchronously connected to the network or connected through power electronics, and that also has a single connection point to a transmission system, distribution system including closed distribution system[7] or HVDC system;

- **'HVDC converter unit'** means a unit comprising one or more converter bridges, together with one or more converter transformers, reactors, converter unit control equipment, essential protective and switching devices and auxiliaries, if any, used for the conversion.

New definitions to be integrated in NC HVDC

With the purpose to enhance the understanding of the CNCs and, at the same time, to introduce new capabilities, this section proposes a new set of definitions to be used in the amendment of the NC HVDC. Some of the definitions are transferred from other Expert Groups, such as EG storage. With blue colour the proposed amendments are highlighted. Current definition that are proposed to be replaced are shown as strikethrough test for the reader's understanding. Definitions used or introduced in other CNC's shall not be included in NC HVDC.

- **'connection point'**[8] means the AC interface at a synchronous area at which the Power-Generating Module, Demand Facility, distribution system or HVDC system is connected to a transmission system, offshore network, distribution system, including closed distribution systems, or HVDC system, as identified in the connection agreement;

- **'HVDC converter station'** ~~means part~~ is a part of an HVDC system which consists of one or more HVDC converter units (converting AC voltage to DC voltage, or vice versa) which are installed in a single location together with buildings, reactors, filters, reactive power devices, control, monitoring, protective, measuring and auxiliary equipment;

- **'Isolated AC network'** means an AC network which is not part of a synchronous area, which is connected to a synchronous area via one or more HVDC systems;

- **'Interface point'** means the AC interface of an isolated AC network at which technical specifications affecting the performance of the relevant equipment can be prescribed as specified by the RSO and as identified in the connection agreement;

[6] The definition may be subject to changes based on NC RfG amendment process.

[7] Definition Closed Distribution System; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.223.01.0010.01.ENG (Article 2, No 5)

[8] ENTSO-E do not agree in this proposal of definition change and do not support this.

- ~~'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;~~

- **'Remote-end HVDC Converter Station'** means an HVDC Converter Station which is not synchronously connected to any synchronous area;

- **'Electricity storage'**[9] means the conversion of electrical energy into a form of energy which can be stored, the storing of that energy, and the subsequent reconversion of that energy back into electrical energy;

- **'Electricity Storage Module (ESM)'** means a power generating module which can inject and consume active power to and from the network for electricity storage, excluding pump-storage Power Generating Modules;

- '**Power-to-Gas Demand Unit (PtGU)'** means a Demand Unit that converts electricity to gases (such as hydrogen or, with subsequent methanation, synthetic methane or other gases);

- **'Asynchronously connected Power Park Module (A-PPM)'**[10] means a Power Park Module that is connected via an interface point to one or more remote-end HVDC converter stations;

- ~~'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;~~

- **'Asynchronously connected Power-to-Gas Demand Unit (A-PtG-DU)'** means a Power-to-Gas Demand Unit that is connected via an interface point to one or more remote end HVDC converter stations;

- **'Asynchronously connected Electricity Storage Module (A-ESM)'** means an Electricity Storage Module that is connected via an interface point to one or more remote end HVDC converter stations;

- **'Asynchronously connected Demand Facility (A-DF)'** means a facility which consumes electrical energy and is connected via an interface point to one or more remote end HVDC converter stations.

Applicability of the NC HVDC

Figure 2 provides a graphical explanation of the applicability of the NC HVDC linked to key definitions proposed by this Expert Group. In this figure, light green areas comprise the various asset ownership schemes that are observed across Europe. The Expert Group would like also to highlight that the issue of co-location of A-ESM with A-PPM and A-PtG-DU shall be clarified in NC RfG and NC DC and be used as such in the NC HVDC. The same approach shall take place across the codes.

[9] As EG, an alignment of this definition to the final version of NC RfG is recommended. In the current paper, ESM is understood as a standalone storage and not embedded or behind the connection point. This issue needs to be clarified in NC RfG and simply used as such in NC HVDC.

[10] It should be noted that the definition of Power Park Module is used as it is defined in the NC RfG. The EG CROS has not changed this definition as it was not part of its Terms of Reference.

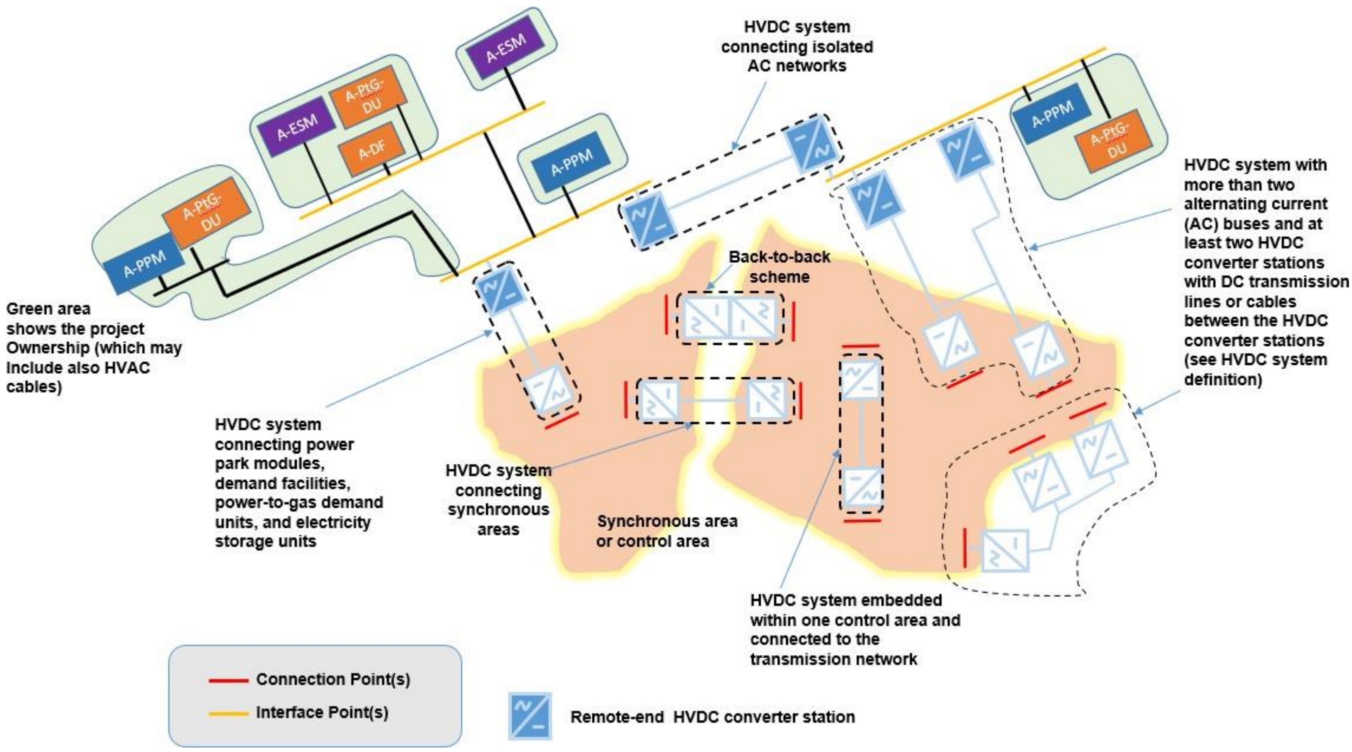

Figure 2. Explanation of NC HVDC applicability and the relation to the definitions of the connection point and the interface point as defined in this report. The reader is referred to amendment 1 for clarification.

Amendment 0: Whereas

With blue is the new legal text as proposed by the EG CROS.

Legal text:

(15) Beyond the technical capabilities defined by the requirements of this regulation, it is expected, unless specified otherwise, that the HVDC systems, asynchronously connected Power Park Module, asynchronously connected Electricity Storage Module, asynchronously connected Demand Facility and asynchronously connected Power-to-Gas Demand Units maintain providing a support to the system to the best of its ability and coherently with the HVDC system and asynchronously connected Power Park Modules, asynchronously connected Electricity Storage Module, asynchronously connected Demand Facility and asynchronously connected Power-to-Gas Demand Units design and protection schemes.

Amendment 1: Article 3 (scope of NC HVDC)

Legal Text:

1. The requirements of this Regulation shall apply at the AC side of HVDC systems:

   (a) ~~HVDC systems~~ connecting synchronous areas or control areas, including back-to-back schemes;

   (b) ~~HVDC systems~~ connecting Power Park Modules, Demand Facilities, Power-to-Gas Demand Units and Electricity Storage 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 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);

   (e) connecting isolated AC networks.

The relevant TSO shall consider the long-term development of the network in this assessment.

Amendment 2: Article 4 (Application to existing HVDC systems)

Disclaimer: it should be noted that the requirements of this article shall be coordinated with the relevant article of NC RfG and NC DC (which is under amendment process). With this proposal, the EG CROS would like to highlight points that should be considered. For the matters out of scope of the EG CROS, the outcome of the report of the EG Criteria for significant modernisation (CSM) shall prevail.

Article 4

Application to existing HVDC systems and asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module

1. Except for Articles 26, 31, 33 and 50, existing HVDC systems and existing asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module are not subject to the requirements of this Regulation, unless:

   (a) the HVDC system or asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module has been modified that its electrical and grid-dynamic characteristics, relating to paragraph 1.c, have significantly altered. In these cases, prior to carry out a modification:

      (i) the HVDC system or asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module owners who intend to undertake the modernisation of a plant or replacement of equipment affecting the electrical characteristics of the HVDC system or asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module shall notify their plans to the Relevant System Operator in advance; if the Relevant System Operator considers that the extent of the modernisation or replacement of equipment is significant, in respect of any of the criteria in paragraph 1.c below, the system operator shall notify the relevant regulatory authority or, where applicable, the Member State; and

      (ii) the relevant regulatory authority or, where applicable, the Member State shall decide which requirements of this Regulation shall apply and if the existing connection agreement needs to be revised or replaced; or

   (b) a regulatory authority or, where applicable, a Member State decides to make an existing HVDC system or existing asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module subject to all or some of the requirements of this Regulation, following a proposal from the relevant TSO in accordance with paragraphs 3, 4 and 5.

   (c) For the purposes of this article a significant alteration will be defined according to these parameters:

(i) A percentage increase above the existing maximum power transmission capability of the HVDC installation or asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module as defined by the Relevant System Operator in co-ordination with the relevant TSO;

(ii) A percentage deviation from the HVDC system or asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module short circuit contribution, to be defined by the Relevant System Operator in co-ordination with the relevant TSO; or

(iii) A percentage deviation from the existing required reactive power capability triggered by the HVDC system or asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module. The threshold is to be defined by the Relevant System Operator in co-ordination with the relevant TSO; or

(iv) A change of underlying technology of the HVDC system.

Amendment 3: Article 12 (RoCoF withstand capability)

Legal Text:

With regard to the Rate-of-Change-of-Frequency withstand capability at the connection point:

(i) an HVDC system shall be capable of staying connected to the network and operate at Rates-of-Change-of-Frequency up to the following values (non-consecutive):

- ±5,0 Hz/s over a period of 0,25 s
- ±2,5 Hz/s over a period of 0,5 s
- ±1,25 Hz/s over a period of 2 s

(ii) Without prejudice to the frequency ranges specified in Annex VI, an HVDC system shall be capable of staying connected to the network and operate at the sequence of Rates-of-Change-of-Frequencies which are defined considering the over frequency against time profiles given in Figure 3-a and the underfrequency against time profiles given in Figure 3-b;

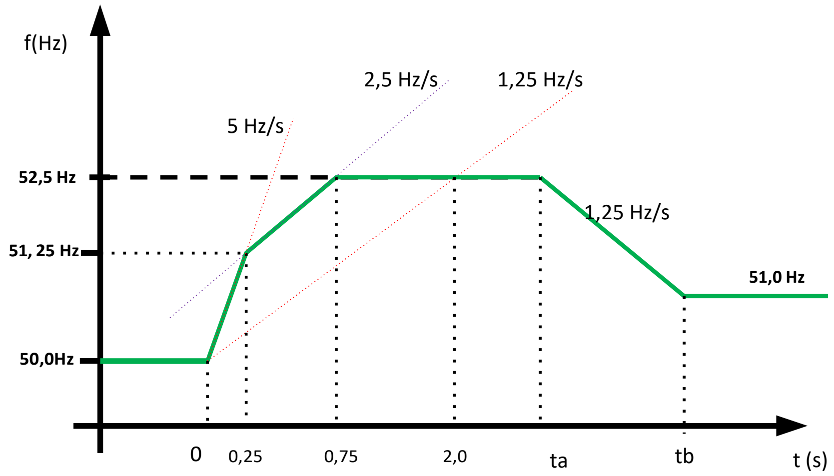

Figure 3-a. The frequency ride through profile that an HVDC system should remain connected to the network for the case of over-frequency. The value **ta** and **tb** shall be specified by the relevant TSO, but longer than for A-PPMs according to Article 39.

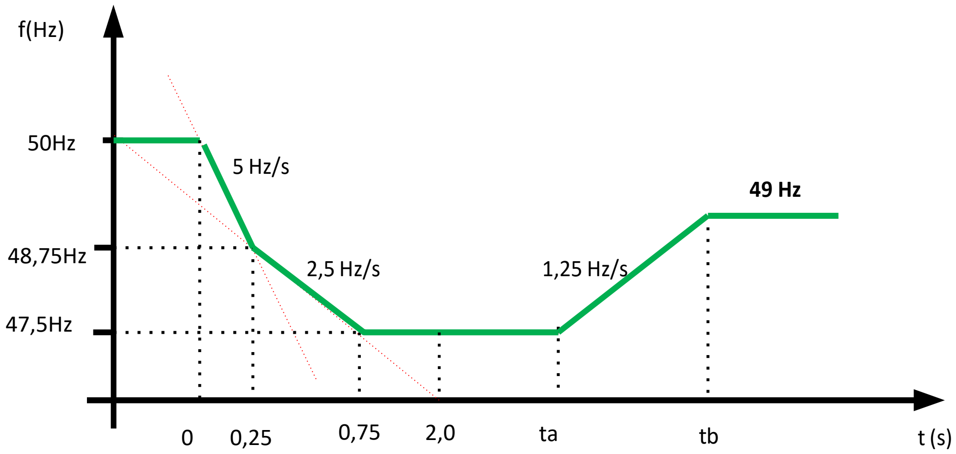

Figure 3-b. The frequency ride through profile than an HVDC system should remain connected to the network for the case of under-frequency. The value **ta** and **tb** shall be specified by each relevant TSO, but longer than for A- PPMs according to Article 39.

(iii) If the Rate-of-Change-of-Frequency is used for loss of mains protection of the HVDC system, the Rate-of-Change-of-Frequency threshold shall be set at higher values than the ones defined in point (i);

(iv) The HVDC system shall be capable of remaining connected to the network and continuing to operate stably when the network frequency remains within the frequency range specified in Annex I. The protection schemes shall not jeopardize frequency-ride-through performance.

Amendment 4: Article 14 (Grid forming capability)

Legal Text:

1. If specified by the Relevant System Operator, in coordination with the relevant TSOs, an HVDC system shall provide grid forming capability at its connection point as defined by the following paragraphs:

   (a) Within the HVDC system voltage, current and energy limits, the HVDC converter station shall be capable of behaving as a controllable voltage source behind an internal impedance (i.e. a Thevenin source) during both the normal operation and immediately after a grid disturbance. The Thevenin source is characterized by its voltage amplitude, voltage phase angle, frequency, and internal impedance all of which shall be adjustable in such a way as to ensure stability in the connected electrical power networks;

   (b) During the first instance following a grid disturbance:

      i. While the HVDC system voltage, current and energy limits are not exceeded, the instantaneous AC voltage characteristics of the Thevenin source of the HVDC converter station shall be capable of maintaining its amplitude and voltage phase angle while voltage phase angle steps or voltage magnitude steps (in positive and in negative sequence) are occurring at the connection point of HVDC converter station (grid side). The positive and the negative sequence current exchanged between the HVDC converter station (converter unit side), and AC grid shall flow naturally according to grid and converter impedances;

      ii. If the HVDC system and individual converter capabilities, voltage, current and energy limits are exceeded, the current, energy and voltage shall be kept within their admissible limit values. The relevant TSOs may specify additional requirements in the case that limitation is necessary. When a converter runs into current limitations and additional requirements are necessary, the relevant TSOs shall agree with the HVDC system owner on such requirements;[11]

      iii. Within the HVDC system voltage, current and energy limits, the TSO shall specify time dependent current envelopes with tolerance band for which the capability of the HVDC converter station is required. The time dependent current envelope shall be agreed between the HVDC system owner and the relevant TSO based on the HVDC system capabilities and overall optimization of the dynamic behavior.

   (c) During the disturbance period and after the first instants:

[11] During final review TSO is replaced with the relevant TSOs in Amendment 4, Article 14,1.b.ii

i. The voltage phase angle and the voltage magnitude shall be adapted according to a predefined dynamic performance;

ii. The HVDC converter station active and reactive power adjustment shall always respect the minimum and maximum HVDC transmission capability and current limits (in each direction);

iii. The TSO may specify additional requirements in the case that current limitation is necessary. When a converter runs into limitations and additional requirements are necessary, the TSO shall agree with the HVDC system owner on such requirements;

iv. The HVDC system shall be capable of stable and bumpless transition when reaching the HVDC system current or converter limits, without interruption, in a continuous manner and returning to the behavior described in paragraph 1.b as soon as the limitations are no more necessary.

2. Where an HVDC system is required to have the capability referred to in paragraph 1, the HVDC system shall be capable of supporting system survival by means of stable and bumpless transition towards and from island mode of system operation (islanding), without interruption, in a continuous manner while complying with paragraph 1.b and paragraph 1.c. The energy needed for this function shall be agreed between the HVDC system owner and the relevant TSO, in coordination with adjacent TSOs;

3. Where an HVDC system is required to have the capability referred to in paragraph 1, considering the voltage, current and energy limit as given 1.b to 1.c, the capability to provide the inherent usable energy shall be ensured throughout the whole active power operating range of the HVDC system;

4. Where an HVDC system is required to have the capability referred to in paragraph 1, the required dynamic performance of the HVDC system for the paragraphs 1.b and 1.c and its associated performance parameters shall be agreed between the relevant TSO and the HVDC system owner;

5. If grid forming capability as prescribed in paragraph 1 is requested and if specified by the Relevant System Operator, in coordination with the relevant TSO, the HVDC system shall be capable of contributing to limit the transient frequency deviation by providing an inertial response both in low and/or high frequency regimes. The inertial response shall be provided without delay. In that case the relevant TSO shall specify the contribution to inertia in the paragraph 14.4. The inertia shall be provided with a damped system response and the energy needed for this function shall be coordinated with sources external to the HVDC system and if applicable within the isolated AC network's design and operational limits;

6. If grid forming capability as prescribed in Article 14 is not requested and if specified by the

Relevant System Operator, in coordination with the relevant TSOs, an HVDC system shall be capable of contributing to limiting the transient frequency deviation as a function of HVDC system response proportional to rate of change of frequency both in low and/or high frequency regimes. The following shall apply:

(a) The HVDC system shall be capable without intentional delay of adjusting the active power injected to or withdrawn from AC grid within its rated power;

(b) This active power adjustment shall be performed based on the measured rate of change of frequency. The measurement method shall be agreed between the relevant TSOs and the HVDC system owner;

(c) When the frequency has recovered, the operating point of the HVDC system shall return to its pre-disturbance active power value or an operating point according to the power available for transmission through the HVDC system;

(d) The requirements regarding Rate-of-Change-of-Frequency measurement as well as the dynamic performance parameters of rapidly adjusted active power injected to or withdrawn from AC grid shall be agreed between the relevant TSOs and the HVDC system owner.

Amendment 5: Article 16: (Frequency control)

Legal Text:

Frequency control

1. If specified by the relevant TSO, utilizing the available power at the AC connection points of the HVDC system, an HVDC system shall be equipped with an independent control mode to modulate the active power output of the HVDC converter stations depending on the frequencies at all connection points of the HVDC system in order to contribute to the stabilisation of the system frequency;

2. The relevant TSO shall specify the operating principle, the associated performance parameters and the activation criteria of the frequency control referred to in paragraph 1.

Amendment 6: Article 19: (short circuit contribution during faults)

Legal Text:

Dynamic voltage support during faults

1. If grid forming capability as prescribed in Article 14 is not requested and if specified by the Relevant System Operator, in coordination with the relevant TSO, an HVDC system shall have the capability to provide fast fault current at a connection point in case of symmetrical (3-phase) faults;

2. Where an HVDC system is required to have the capability referred to in paragraph 1, the Relevant System Operator, in coordination with the relevant TSO, shall specify the following:

    (a) how and when a voltage deviation is to be determined, as well as the end of the voltage deviation;

    (b) the characteristics of the fast fault current;

    (c) the timing and accuracy of the converter response during fault, which may include several stages;

3. The Relevant System Operator, in coordination with the relevant TSO, may specify a requirement in the case of asymmetrical (1-phase or 2-phase) faults.

Amendment 7: Article 35 (Priority ranking of protection and control)

1. A control scheme, specified by the HVDC system owner consisting of different control modes, including the settings of the specific parameters, shall be coordinated and agreed between the relevant TSO, the Relevant System Operator and the HVDC system owner;

2. With regard to priority ranking of protection and control, the HVDC system owner shall organise its protections and control devices in compliance with the following priority ranking, listed in decreasing order of importance, unless otherwise specified by the relevant TSOs, in coordination with the Relevant System Operator:

    (a) network system and HVDC system protection;
    (b) grid forming capability as defined in Article 14.1 to Article 14.5, if applicable;
    (c) inertial response as in Article 14.6, if applicable;
    (d) active power control for emergency assistance;
    (e) automatic remedial actions as specified in Article 13(3);
    (f) FSM, LFSM O/U;
    (g) power gradient constraint.

Amendment 8: Article 36 (Changes to protection and control schemes and settings)

1. The parameters of the different control modes and the protection settings of the HVDC system shall be able to be changed ~~in the HVDC converter station~~, if required by the Relevant System Operator or the relevant TSO, and in accordance with paragraph 3;

2. Any change to the schemes or settings of parameters of the different control modes and protection of the HVDC system, shall be coordinated and agreed between the relevant TSO, the Relevant System Operator, and the HVDC system owner, in particular if the schemes and settings of the different control devices are necessary for transmission system stability and for taking emergency action;

3. The control modes and associated setpoints of the HVDC system shall be capable of being changed remotely, as specified by the Relevant System Operator, in coordination with the relevant TSO.

Amendment 9: Title III (increase of scope)

Proposal of the EG:

The title III of NC HVDC may be amended as follows:

"Requirements for asynchronously connected Power Park Modules, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module and remote-end HVDC converter stations".

Mapping of the offshore isolated network requirements to connected entities[12]

For the case of isolated AC network and the amendments proposed in Title III, Table 4 provides a map of the requirements and how they are linked to the grid users.

Table 4. Mapping of the relevant articles of NC HVDC Title III to the grid users.

Article	Requirement	A-PPM	A-PtG-DU	A-ESM	A-DF
A39	**Frequency stability requirement**	X	X	X	X
A39.1.a	**Frequency response**	X	X	X	
A39.1.b	**Coordinated frequency control**	X	X	X	
A39.2.a	**Frequency range and response**	X	X	X	
A39.2.c	**Automatic disconnection**	X		X	X
A39.3	**ROCOF**	X	X	X	X
A39.4	**LFSM-O**	X	X	X	
A39.5	**Maintain constant power**	X	X	X	
A39.6	**Active power controllability**	X	X	X	
A39.7	**LFSM-U**	X		X	
A39.8.a	**LFSM-UC**		X		
A39.9	**FSM**	X		X	
A39.10	**Frequency restoration**	X		X	
A39.11	**Frequency restoration**		X		
A40.	**Reactive power and voltage req.**	X		X	X
A40.1.a	**Voltage range**	X		X	X

[12] Review note: Article 39.2.b must be included in the table. A x in A39.2.b for A-DF must be included.

A40.1.b	**Wider voltage ranges**	x		x	x
A40.1.c	**Automatic disconnection**	X		X	X
A40.2	**Reactive power**	X		X	
A40.2.a.i	**Reactive power**	X		X	
A40.2.b.	**Voltage stability**	X		X	
A40.2.b.i	**Reactive power at HVDC/Pn**	X		X	
A40.2.b.ii	**Demonstrate q**				
A40.2.b.iii	**Supplementary reactive power**	X		X	
A40.3	**Priority of P or Q**	X		X	
A40.4	**Reactive power**				X
Amendment 13.a+b, + Title III	**FRT**	X	X	X	
Amendment 13.c + Title III	**Post fault active power recovery (PFAPR)**	X	X	X	
A41.	**Control requirements**	X	X	X	
A41.1	**During synchronization**	X		X	X
A41.2	**Provide output signals**	X		X	X
A42.	**Network characteristics**	X		X	X
A42.a	**RSO specify pre/post fault**				
A42.b	**Stable operation within range**	X	X	X	X
A42.c	**RSO provide AC network equivalent**	X	X	X	X
A43.	**Protection req.**	X		X	X
A43.1	**Protection scheme and setting**	X		X	X
A43.2	**Priority ranking**	X		X	X
A44	**Power quality**		X	X	
A44.1	**Not result in distortion**	X		X	X
A45	**General management requirements**	X	X	X	X

Amendment 10: Article 38 (scope)

Legal Text:

The requirements applicable to offshore Power Park Modules under Articles 13 to 22 of Regulation (EU) 2016/631 shall apply to asynchronously connected Power Park Modules and asynchronously connected Electricity Storage Modules subject to specific requirements provided for in Articles 41 to 45 of this Regulation.

The categorisation in Article 5 of Regulation (EU) 2016/631 shall apply to asynchronously connected Power Park Modules and the asynchronously connected Electricity Storage Modules.

The requirements applicable to transmission connected Demand Facilities, under Articles 14, 16, 17, 19, 41 and 43 of Regulation (EU) 2016/1388 shall apply to an asynchronously connected Demand Facility.

These requirements shall apply at the interface points of the asynchronously connected Power Park module, asynchronously connected Demand Facility, asynchronously connected Electricity Storage Module and the remote-end HVDC converter station.

Amendment 11: Article 39 (Frequency stability requirements)

Article 39 Legal Text:

1. **With regards to frequency response:** [13]

(a) asynchronously connected Power Park Module, asynchronously connected Power-to-Gas Demand Unit, asynchronously connected Electricity Storage Module and remote-end HVDC converter stations shall be capable of receiving a fast signal from a connection point in the synchronous area to which frequency response is being provided, and be able to process this signal ~~within~~ no later than 0,1 second from sending to completion of processing the signal for activation of the response. Frequency shall be measured at the connection point of the HVDC system or a predefined connection point in a synchronous area to which frequency response is being provided;

[13] Review note: an asynchronously connected Power-to-Gas Demand Unit must be included in article 39.2.a, 39.2.b, 39.3 and 39.4

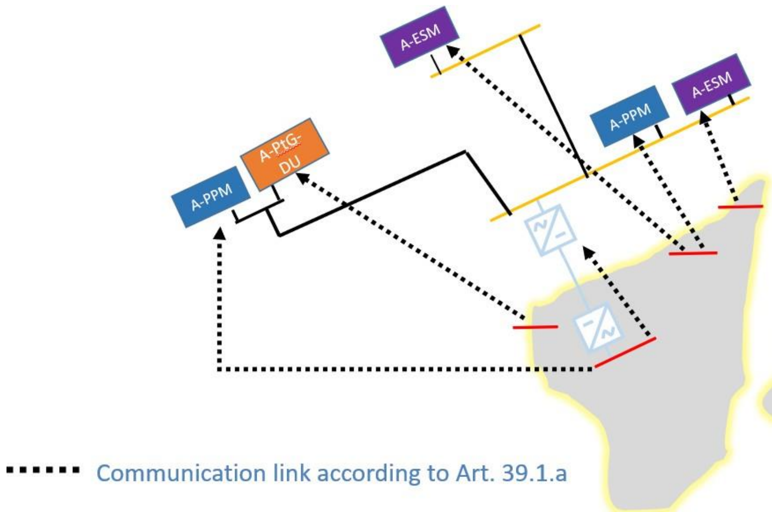

Figure 4. Explanatory graphical overview of the communication link according to article 39.

(b) An asynchronously connected Power Park Module, an asynchronously connected Power-to-Gas Demand Unit and an asynchronously connected Electricity Storage Module connected via HVDC systems to more than one control areas shall be capable of delivering coordinated frequency control as specified by the relevant TSO, in coordination with adjacent TSOs;

2. With regard to frequency ranges and response:

(a) Asynchronously connected Power Park Module, asynchronously connected Demand Facility and asynchronously connected Electricity Storage Module shall be capable of staying connected to the remote-end HVDC converter station isolated AC network and operating within the frequency ranges and time periods specified in Annex VI for the 50 Hz nominal system. Where a nominal frequency other than 50 Hz, or a frequency variable by design is used, subject to agreement with the relevant TSO, the applicable frequency ranges and time periods shall be specified by the relevant TSO, taking into account specificities of the system and the requirements set out in Annex VI;

(b) wider frequency ranges or longer minimum times for operation can be separately agreed between the relevant TSO and the asynchronously connected Power Park Module owner, the asynchronously connected Demand Facility owner and the asynchronously connected Electricity Storage Module owner in order to ensure the best use of the technical capabilities ~~if~~ needed to preserve or to restore system security. If wider frequency ranges or longer minimum times for operation are economically and technically feasible, the asynchronously connected Power Park Module owner, the asynchronously connected Demand Facility owner and the asynchronously connected Electricity Storage Module owner shall not unreasonably withhold consent;

(c) while respecting the provisions of point (a) of paragraph 2, an asynchronously connected Power Park Module, an asynchronously connected Demand Facility and an asynchronously connected Electricity Storage Module shall be capable of automatic disconnection at specified frequencies, if specified by the relevant TSO. Terms and settings for automatic disconnection can be agreed separately between the relevant TSO and the asynchronously connected Power Park Module owner, the asynchronously connected-Demand Facility owner and the asynchronously connected Electricity Storage Module owner;

3. With regards to Rate-of-Change-of-Frequency withstand capability, an asynchronously connected Power Park Module, an asynchronously connected Demand Facility, an asynchronously connected Power-to-Gas Demand Unit and an asynchronously connected Electricity Storage Module shall be capable of staying connected to the remote-end HVDC converter station isolated AC network and operable if the system frequency changes at a rate up to +/– 2 Hz/s (measured at any point in time as an average of the rate of change of frequency for the previous 1s) at the ~~HVDC~~ interface point of the asynchronously connected Power Park Module, asynchronously connected Demand Facility, and an asynchronously connected Electricity Storage Module for the 50 Hz nominal system;

4. Asynchronously connected Power Park Module, and asynchronously connected Electricity Storage Module shall have Limited Frequency Sensitive Mode — Overfrequency (LFSM-O) capability in accordance with Article 13(2) of Regulation (EU) 2016/631, subject to fast signal response as specified in paragraph 1 for the 50 Hz nominal system;

5. A capability of asynchronously connected Power Park Module, asynchronously connected Power-to-Gas Demand Unit and asynchronously connected Electricity Storage Module to maintain constant power shall be determined in accordance with Article 13(3) of Regulation (EU) 2016/631 for the 50 Hz nominal system;

6. A capability for active power controllability of asynchronously connected Power Park Module, asynchronously connected Power-to-Gas Demand Unit and asynchronously connected Electricity Storage Module shall be determined in accordance with Article 15(2)(a) of Regulation (EU) 2016/631 for the 50 Hz nominal system. Manual control shall be possible in the case that remote automatic control devices are out of service;

7. A capability for limited frequency sensitive mode — underfrequency (LFSM-U) for asynchronously connected Power Park Module and asynchronously connected Electricity Storage Module shall be determined in accordance with Article 15(2)(c) of Regulation (EU) 2016/631, subject to fast signal response as specified in paragraph 1 for the 50 Hz nominal system;

8. A capability for Limited Frequency Sensitive Mode — Underfrequency Consumption (LFSM-UC) for asynchronously connected Power-to-Gas Demand Unit based on the measured frequency at the Power-to-Gas Demand Unit interface point or based on a fast signal response as specified in paragraph 1 for the 50 Hz nominal system. More specifically, the following shall apply:

a. The Power-to-Gas Demand Unit shall be capable of reducing the consumption from the current active power input automatically down to the minimum technical operational level, according to the indicative **Figure 5** at a frequency threshold and with a droop setting specified by the relevant TSO:

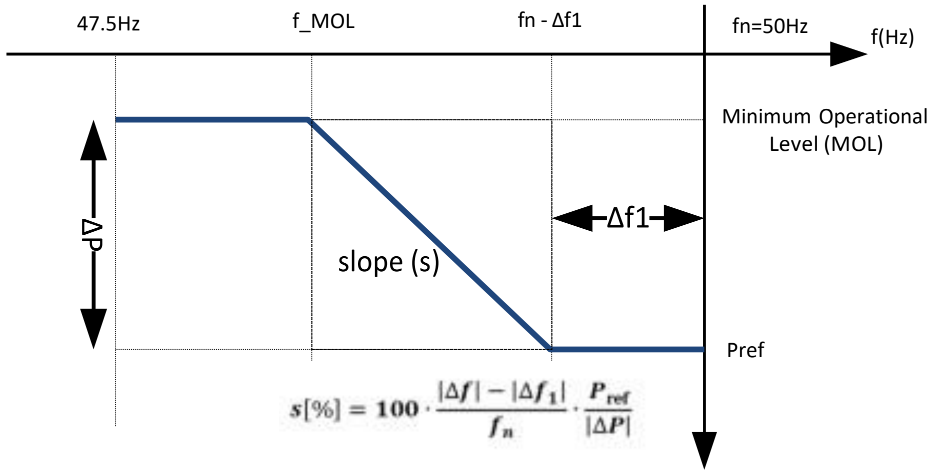

Figure 5. LFSM-UC curve for a Power-to-Gas Demand Unit

b. The default setting of the droop slope (%) shall be specified by the relevant TSO;

c. The frequency threshold shall be 49,8 Hz (inclusive), except for synchronous area IE and NI, where the frequency threshold shall be 49,5 Hz (inclusive);

d. The Power-to-Gas Demand Unit shall stay in this specific mode as long as the frequency is below the frequency threshold. If the frequency recovers, the electrical charging Demand Unit shall follow the same power-frequency characteristic until it is back to its prior state of active power input;

e. If the minimum technical operating level is larger than 20% of Pref, the Power-to-Gas Demand Unit should disconnect when reaching its minimum technical operating level;

f. If disconnection was performed according to the paragraph 8.e of this article, on return of frequency above the frequency threshold, a random time delay of up to 5 minutes shall be initiated before normal operation resumes;

g. Requirements for frequency measurement:
   i. Maximum measuring time window: 100 ms
   ii. Accuracy: ± 30 mHz

h. Stable operation of the Power-to-Gas Demand Unit during LFSM-UC operation shall be ensured;

i. The response time[14] for LFSM-UC shall be less or equal to 0,5 seconds. The Relevant System Operator has the right to request the demonstration of technical evidence of the response time.

[14] Reference to IGD on LFSM / FSM

9. A capability for frequency sensitive mode for an asynchronously connected Power Park Module and an asynchronously connected Electricity Storage Module shall be determined in accordance with Article 15(2)(d) of Regulation (EU) 2016/631, subject to a fast signal response as specified in paragraph 1 for the 50 Hz nominal system;

10. A capability for frequency restoration for an asynchronously connected Power Park Module and an asynchronously connected Electricity Storage Module shall be determined in accordance with Article 15(2)(e) of Regulation (EU) 2016/631 for the 50 Hz nominal system;

11. A capability for frequency restoration for an asynchronously connected Power-to-Gas Demand Unit shall be determined in accordance with **Art. xx** of DCC[15];

12. Where a constant nominal frequency other than 50 Hz, a frequency variable by design or a DC system voltage is used, subject to the agreement of the relevant TSO, the capabilities listed in paragraphs 3 to 9 and the parameters associated with such capabilities shall be specified by the relevant TSO.

Amendment 12: Article 40 (Reactive power and voltage requirements)

Legal Text:

1. With respect to voltage ranges: [16]

(a) an asynchronously connected Power Park Module, an asynchronously connected Demand Facility and an asynchronously connected Electricity Storage Module shall be capable of staying connected to the remote-end HVDC converter station isolated AC network and operating within the voltage ranges (per unit), for the time periods specified in Tables 9 and 10, Annex VII. The applicable voltage range and time periods specified are selected based on the reference 1 pu voltage;

(b) wider voltage ranges or longer minimum times for operation can be agreed between the Relevant System Operator, the relevant TSO and the owners of the asynchronously connected Power Park Module, the asynchronously connected Demand Facility and the asynchronously connected Electricity Storage Module, to ensure the best use of the technical capabilities of the asynchronously connected Power Park Module, the asynchronously connected Demand Facility and the asynchronously connected Electricity Storage Module if needed to preserve or to restore system security. If wider voltage ranges or longer minimum times for operation are economically and technically feasible, the owners of the asynchronously connected Power Park Module, the asynchronously connected Demand Facility and the asynchronously connected Electricity Storage Module shall not unreasonably withhold consent;

[15] This should be linked to the new version of the DCC 2.0, after the Q4 of 2023.
[16] Review note: an asynchronously connected Power-to-Gas Demand Unit must be included in article 40. 1.a, 40.1.b and 40.1.c.

(c) for asynchronously connected Power Park Module, asynchronously connected Demand Facility and asynchronously connected Electricity Storage Module which have an interface point to the remote-end HVDC converter station isolated AC network, the Relevant System Operator, in coordination with the relevant TSO may specify voltages at the interface point at which an asynchronously connected Power Park Module, an asynchronously connected Demand Facility and a asynchronously connected Electricity Storage Module shall be capable of automatic disconnection.
The terms and settings for automatic disconnection shall be agreed between the Relevant System Operator, the relevant TSO and the owner of the asynchronously connected Power Park Module, the asynchronously connected Demand Facility and the asynchronously connected Electricity Storage Module;

(d) for HVDC interface points at AC voltages that are not included in the scope of Annex VII, the Relevant System Operator, in coordination with the relevant TSO shall specify applicable requirements at the connection point;

(e) where frequencies other than nominal 50 Hz are used, subject to relevant TSO agreement, the voltage ranges and time periods specified by the Relevant System Operator, in coordination with the relevant TSO, shall be proportional to those in Tables 9 and 10, Annex VII.

2. With respect to reactive power capability for asynchronously connected Power Park Module and asynchronously connected Electricity Storage Module:

(a) if the asynchronously connected Power Park Module owner, the asynchronously connected Electricity Storage Module owner can obtain a bilateral agreement with the owners of the HVDC systems connecting the asynchronously connected Power Park Module and the asynchronously connected Electricity Storage Module to a single interface point on an isolated AC network, it shall fulfil all of the following requirements:

(i) it shall have the ability with additional plant or equipment and/or software, to meet the reactive power capabilities prescribed by the Relevant System Operator, in coordination with the relevant TSO, according to point (b), and it shall either:

— have the reactive power capabilities for some or all of its equipment in accordance with point (b) already installed as part of the connection of the asynchronously connected Power Park Module and the asynchronously connected Electricity Storage Module to the isolated AC network at the time of initial connection and commissioning; or

— demonstrate to, and then reach agreement with, the Relevant System Operator and the relevant TSO on how the reactive power capability will be provided when the asynchronously connected Power Park Module and the asynchronously connected Electricity Storage Module is connected to more than a single interface points in the isolated AC network, or the isolated AC network at the remote-end HVDC converter station isolated AC network has either another asynchronously connected Power Park Module, asynchronously connected Electricity Storage Module or HVDC system with a different owner connected to it. This agreement shall include a contract by the owner of the asynchronously connected Power Park Module and the asynchronously connected Electricity Storage Module (or any subsequent owner), that it will install reactive power capabilities required by this Article for its asynchronously connected Power Park Module and asynchronously connected Electricity Storage Module at a point in time specified by the Relevant System Operator, in coordination with the relevant TSO. The Relevant System Operator, in coordination with the relevant TSO shall inform the owner of the asynchronously connected Power Park Module and the asynchronously connected Electricity Storage Module of the proposed completion date of any committed development which will require the owner of the asynchronously connected Power Park Module and the asynchronously connected Electricity Storage Module to install the full reactive power capability;

(b) Asynchronously connected Power Park Module and an asynchronously connected Electricity Storage Module shall fulfil the following requirements relating to voltage stability either at the time of connection or subsequently, according to the agreement as referred to in point (a):

(i) with regard to reactive power capability at maximum HVDC active power transmission capacity, asynchronously connected Power Park Module and asynchronously connected Electricity Storage Module shall meet the reactive power provision capability requirements specified by the Relevant System Operator, in coordination with the relevant TSO, in the context of varying voltage. The Relevant System Operator shall specify a U-Q/Pmax-profile that may take any shape with ranges in accordance with Table 11, Annex VII, within which the asynchronously connected Power Park Module and an asynchronously connected Electricity Storage Module shall be capable of providing reactive power at its maximum active power capacity. The Relevant System Operator, in coordination with the relevant TSO, shall consider the long-term development of the isolated AC network when determining these ranges, as well as the potential costs for asynchronously connected Power Park Module and asynchronously connected Electricity Storage Module of delivering the capability of providing reactive power production at high voltages and reactive power consumption at low voltages.

If the Ten-Year Network Development Plan developed in accordance with Article 8 of Regulation (EC) No 714/2009 or a national plan developed and approved in accordance with Article 22 of Directive 2009/72/EC specifies that a asynchronously connected Power Park Module and an asynchronously connected Electricity Storage Module will become AC-connected to the synchronous area, the relevant TSO may specify that either:

(i) the asynchronously connected Power Park Module, and the asynchronously connected Electricity Storage Module shall have the capabilities prescribed in Article 25(4) of Regulation (EU) 2016/631, for that synchronous area installed at the time of initial connection and commissioning of the asynchronously connected Power Park Module and the asynchronously connected Electricity Storage Module to the AC-network; or

(ii) the asynchronously connected Power Park Module owner and the asynchronously connected Electricity Storage Module owner shall demonstrate to, and then reach agreement with, the Relevant System Operator and the relevant TSO on how the reactive power capability prescribed in Article 25(4) of Regulation (EU) 2016/631 for that synchronous area will be provided in the event that the asynchronously connected Power Park Module and the asynchronously connected Electricity Storage Module becomes AC-connected to the synchronous area;

(iii) With regard to reactive power capability, the Relevant System Operator may specify supplementary reactive power to be provided if the connection point of a asynchronously connected Power Park Module and an asynchronously connected Electricity Storage Module is neither located at the high- voltage terminals of the step-up transformer to the voltage level of the connection point nor at the asset terminals, if no step-up transformer exists. This supplementary reactive power shall compensate the reactive power exchange of the high-voltage line or cable between the high-voltage terminals of the step-up transformer of the asynchronously connected Power Park Module and the asynchronously connected Electricity Storage Module or the assets terminals, if no step-up transformer exists, and the connection point and shall be provided by the responsible owner of that line or cable.

3. With regard to priority to active or reactive power contribution for asynchronously connected Power Park Module and asynchronously connected Electricity Storage Module, the Relevant System Operator, in coordination with the relevant TSO shall specify whether active power contribution or reactive power contribution has priority during faults for which fault-ride-through capability is required. If priority is given to active power contribution, its provision shall be established within a time from the fault inception as specified by the Relevant System Operator, in coordination with the relevant TSO;

4. With respect to reactive power capability for asynchronously connected Demand Facilities, the actual reactive power range at the interface point shall be specified by the relevant TSO for importing and exporting reactive power prescribed in article 15(1) of Regulation (EU) 2016/1388.

Amendment 13: FRT Capability of Power-to-Gas Demand Units

New Article YY

With regard to Fault-Ride-Through capability of asynchronously connected Power-to-Gas Demand Units:

a. The asynchronously connected Power-to-Gas Demand Unit shall, when operating above the minimum operating level, be capable of staying connected to the network and continuing to operate stably after the power system has been disturbed by faults in the isolated AC network according to a voltage-against-time-profile in line with Figure X.13 and Tables X.1.1 to X.1.2.

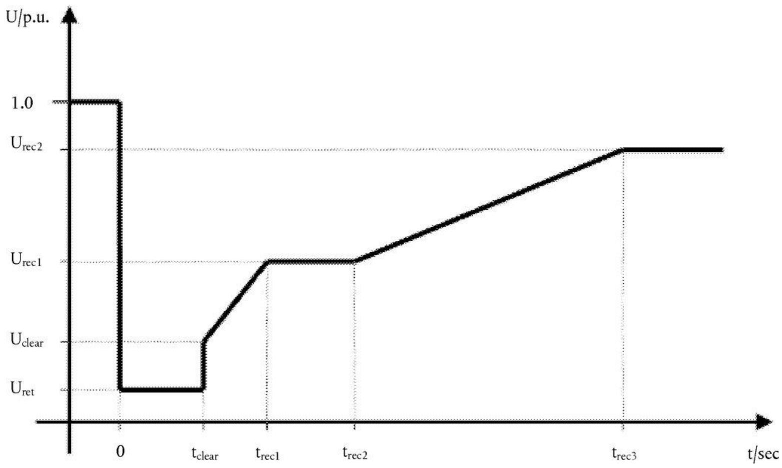

Figure X.13. Fault-ride-through profile of a Power-to-Gas Demand Unit.

Table x.1.1. Voltage parameters of a Power-to-Gas Demand Unit.

Voltage parameters (pu)	
U_{ret}:	0
U_{clear}:	0
U_{rec1}:	0
U_{rec2}:	0,85

Table .1.2 Time parameters for fault-ride-through capability of a Power-to-Gas Demand Unit.

Time parameters [seconds]	
tclear	**0,15**
trec1	**0,15**
trec2	**0,15**
trec3	3,0

b. The voltage-against-time-profile expresses a lower limit of the profile of the phase-to-phase voltages on the network voltage level during a symmetrical fault, as a function of time before, during and after the fault;

c. When the network voltage resumes, after the fault has been cleared, to a value within the voltage range of 0,85 pu – 1,1 pu, a Power-to-Gas Demand Unit shall recover its active power output level at the connection point. The relevant TSO shall specify the magnitude and time for post fault active power recovery;

d. Fault-ride-through capabilities in case of asymmetrical faults shall be specified by the Relevant System Operator, in coordination with the relevant TSO.

Amendment 14: Article 41 (Control requirements)

Proposal of the EG:

Article 41 of NC HVDC, shall also apply for asynchronously connected Power Park Module, asynchronously connected Power-to-Gas Demand Units and an asynchronously connected Electricity Storage Module.

Article 41 Legal Text:

1. During the synchronisation of an asynchronously connected Power Park Module, asynchronously connected Demand Facility and an asynchronously connected Electricity Storage Module to the isolated AC network, the asynchronously connected Power Park Module, the asynchronously Demand Facility and the asynchronously connected Electricity Storage Module shall have the capability to limit any voltage changes to a steady-state level specified by the Relevant System Operator, in coordination with the relevant TSO. The level specified shall not exceed 5 per cent of the pre-synchronisation voltage. The Relevant System Operator, in coordination with the relevant TSO, shall specify the maximum magnitude, duration and measurement window of the voltage transients;
2. The asynchronously connected Power Park Module owner, the asynchronously connected Demand Facility owner and the asynchronously connected Electricity Storage Module owner shall provide output signals as specified by the Relevant System Operator, in coordination with the relevant TSO.

Amendment 15: Article 42 (Network characteristics)

Proposal of the EG:

Article 42 of NC HVDC shall apply also for asynchronously connected Power Park Module, an asynchronously connected Demand Facility and an asynchronously connected Electricity Storage Module.

Article 42 Legal Text:

With regard to the isolated AC network characteristics, the following shall apply for an asynchronously connected Power Park Module, an asynchronously connected Demand Facility and an asynchronously connected Electricity Storage Module:

(a) each Relevant System Operator shall specify and make publicly available the method and the pre-fault and post-fault conditions for the calculation of minimum and maximum short circuit power at the HVDC interface point;

(b) the asynchronously connected Power Park Module, the asynchronously connected Power-to-Gas Demand Units, asynchronously connected Demand Facility and the asynchronously connected Electricity Storage Module shall be capable of stable operation within the minimum to maximum range of short circuit power and isolated AC network characteristics of the interface point specified by the Relevant System Operator, in coordination with the relevant TSO;

(c) each Relevant System Operator and HVDC system owner shall provide the asynchronously connected Power Park Module owner, the asynchronously connected Demand Facility owner, the asynchronously connected Electricity Storage Module owner with isolated AC network equivalents representing the system, enabling the asynchronously connected Power Park Module owner, the asynchronously connected Demand Facility owner and the asynchronously connected Electricity Storage Module owner to design their system with regard to harmonics.

Amendment 16: Article 43 (Protection requirements)

Proposal of the EG:

Article 43 of NC HVDC shall also apply for asynchronously connected Power Park Module, asynchronously connected Demand Facility and asynchronously connected Electricity Storage Module. For asynchronously connected Power-to-Gas Demand Facility, article 43.2 reference must be changed to article 16 (EU) 2016/1388.

Legal Text:

1. Electrical protection schemes and settings of asynchronously connected Power Park Module and an asynchronously connected Electricity Storage Module shall be determined in accordance with Article 14(5)(b) of Regulation (EU) 2016/631, ~~where the network refers to the synchronous area network~~.
   Electrical protection schemes and settings of asynchronously connected Demand Facility shall be determined in accordance with Article 16 of Regulation 2016/1388.

   The protection schemes have to be designed taking into account the system performance, grid specificities as well as technical specificities of the technology and agreed with the Relevant System Operator, in coordination with the relevant TSO;

2. Priority ranking of protection and control of asynchronously connected Power Park Module and asynchronously connected Electricity Storage Module, shall be determined in accordance with Article 14(5)(c) of Regulation (EU) 2016/631 and in accordance with article 16(3) of Regulation (EU) 2016/1388 for asynchronously connected Demand Facilities and agreed with the Relevant System Operator, in coordination with the relevant TSO.

Amendment 17: Article 44 (power quality)

Proposal of the EG:

Article 44 of NC HVDC shall also apply for an asynchronously connected Power-to-Gas Demand Facility and an asynchronously connected Electricity Storage Module.

Article 44 Legal Text:

Asynchronously connected Power Park Module owners, asynchronously connected Demand Facility owners and asynchronously connected Electricity Storage Module owners shall ensure that their connection to the isolated AC network does not result in a level of distortion or fluctuation of the supply voltage on the isolated AC network, at the interface point, exceeding the level specified by the Relevant System Operator, in coordination with the relevant TSO. The necessary contribution from grid users to associated studies, including, but not limited to, existing asynchronously connected Power Park Module, an asynchronously connected Demand Facility and an asynchronously connected Electricity Storage Module and existing HVDC systems, shall not be unreasonably withheld. The process for necessary studies to be conducted and relevant data to be exchanged by all grid users involved, as well as mitigating actions identified and implemented, shall be in accordance with the process in Article 29.

Amendment 18: Article 45 (General system management requirements)

Proposal of the EG:

Article 45 of NC HVDC shall also apply for asynchronously connected Power Park Module, an asynchronously connected Power-to-Gas Demand Facility and an asynchronously connected Electricity Storage Module. For an Asynchronously connected Demand Facility, article 16(4) only applies if island operation is applicable.

General: Events caused by Energization of Demand Units or facility infrastructure must be included.

Legal Text of Article 45:

With regard to general system management requirements, Articles 14(5), 15(6) and 16(4) of Regulation (EU) 2016/631 shall apply to any asynchronously connected Power Park Module and asynchronously connected Electricity Storage Module.

With regard to general system management requirements, Articles 16(1), 17(1) and x(x)[17] of Regulation (EU) 2016/1388 shall apply to any asynchronously connected Demand Facilities.

[17] Review note: The reference x(x) will be the relevant article in NC DC 2.0 setting requirements for FRT and PFAPR

Amendment 19: NEW Article X (Grid forming capability)

Note: The legal text proposal of as it is defined by the Expert Group advanced capabilities for grids with a high share of Power Park Modules (ACPPM) and specifically for type D **shall** apply to asynchronously connected Power Park Module and asynchronously connected Electricity Storage Module. The report of the Expert Group AC PPM is available online on the link (retreated as per 14.7.2023). In addition to the legal text of the Expert Group ACPPM, the following provision **shall** be included for asynchronously connected Power Park Module and asynchronously connected Electricity Storage Modules.

Additional clause shall apply for the case of asynchronously connected Power Park Modules and Electricity Storage Modules:

- If grid forming capability as prescribed in Article 14.5 is requested and if it is specified by the Relevant System Operator, the asynchronously connected Power Park Modules and the asynchronously connected Electricity Storage Module shall be capable of contributing to the provision of paragraph 14 (e) by providing synthetic inertia within the Power Park Module's limits (including voltage, current, energy and mechanical limits)[18].

Amendment 20: Article 37 (black start)

Legal Text:

Black start

1. The relevant TSO may obtain a quote for black start capability from an HVDC system owner, asynchronously connected Power Park Modules and asynchronously connected Electricity Storage Module;

2. An HVDC system with black start capability shall be able, in case of one of the converter stations is energised, to energise the busbar of the AC-substation to which another converter station is connected, within a timeframe after shut down of the HVDC system determined by the relevant TSOs. The HVDC system shall be able to synchronise within the frequency limits set out in Article 11 and within the voltage limits specified by the relevant TSO or as provided for in Article 18, where applicable. Wider frequency and voltage ranges can be specified by the relevant TSO where needed in order to restore system security;

3. The relevant TSO and the HVDC system owner shall agree on the capacity and availability of the black start capability and the operational procedure.

[18] Wind Europe position is to have the following legal text instead: "[ ]..within the power park module's limits (**including but not limited** to current, energy and mechanical limits".WindEurope comments; Grid forming technology for wind turbine generators is still a "work in progress" topic.
In parallel understanding the impact from grid forming controls on the wind turbine generator design, lifetime, etc is still at an early stage and evolving.
Therefore, we are proposing some conservative language for addressing potential limits.
WindEurope strongly supports to revise such language in the future, once the technology is more mature and impact is better understood in the industry.

Amendment 21: Article 44 (power quality)[19]

Legal Text:

Asynchronously connected Power Park Module owners, asynchronously connected Electricity Storage Module owners and asynchronously connected Demand Facility owners shall ensure that their connection to the network does not result in a level of distortion or fluctuation of the supply voltage on the network, at the connection point, exceeding the level specified by the Relevant System Operator, in coordination with the relevant TSO. The necessary contribution from grid users to associated studies, including, but not limited to, existing asynchronously connected Power Park Module owners, asynchronously connected Electricity Storage Module owners and asynchronously connected Demand Facility owner and existing HVDC systems, shall not be unreasonably withheld.

Amendment 22: Article 47 (Frequency stability requirements for remote-end HVDC converter station)[20]

Frequency stability requirements (requirements for remote-end HVDC converter station)

1. Where a nominal frequency other than 50 Hz, or a frequency variable by design is used in the isolated AC network connecting asynchronously connected Power Park Module, asynchronously connected Demand Facility and asynchronously connected Electricity Storage Module, subject to relevant TSO agreement, Article 11 shall apply to the remote-end HVDC converter station with the applicable frequency ranges and time periods specified by the relevant TSO, taking into account specificities of the system and the requirements laid down in Annex I;

2. With regards to frequency response, the remote-end HVDC converter station owner, the asynchronously connected Power Park Module owner, the asynchronously connected Demand Facility owner and an asynchronously connected Electricity Storage Module owner shall agree with the Relevant System Operator in coordination with the relevant TSO on the technical modalities of the fast signal communication in accordance with Article 39 (1). Where the relevant TSO requires, the HVDC system shall be capable of providing the network frequency at the connection point as a signal to the remote end HVDC converter station;

3. For an HVDC system connecting asynchronously connected Power Park Module, asynchronously connected Demand Facility and asynchronously connected Electricity Storage Module the adjustment of active power frequency response shall be limited by the capability of the asynchronously connected Power Park Module;

4. If two or more remote-end HVDC converter stations are connected to one or more interface points of the same isolated AC network, the remote-end HVDC converter stations and their respective HVDC systems shall be capable to continuously operate stably over the full operating range between the maximum and the minimum HVDC

[19] Review note: this article must also include asynchronously connected Power-to-Gas Demand Facility

[20] Review note: Article 47(1), 47(2), 47(3), must also include asynchronously connected Power-to-Gas Demand Facility

system active power transmission capacity and contribute to the frequency control of the remote-end HVDC system isolated AC network they are connected to;

5. If paragraph 4 applies, the relevant TSO in coordination with adjacent TSOs, shall specify a study in order to define coordinated frequency droop slope parameters of the remote-end HVDC converter stations including power sharing ratio between the remote-end HVDC stations and their respective HVDC system. This study shall also include robustness against control interactions during frequency changes response and data provisions according to Article 29;

6. If grid forming capability as prescribed in Article 14.5 is requested and if it is specified by the relevant TSO, the remote end HVDC converter station shall be capable of adjusting at its interface point the isolated AC network frequency and voltage phase angle in order to use the synthetic inertia from asynchronously connected Power Park Modules and asynchronously connected Electricity Storage Modules.

Amendment 23: Article 48 (voltage ranges, remote end HVDC station)[21]

Legal Text Article 48:

1. With respect to voltage ranges:

(a) a remote-end HVDC converter station shall be capable of staying connected to the remote-end HVDC converter station isolated AC network and operating within the voltage ranges (per unit) and time periods specified in Tables 12 and 13, Annex VIII or, for voltage level below 110 kV as specified by the Relevant System Operator. The applicable voltage range and time periods specified are selected based on the reference 1 pu voltage;

(b) wider voltage ranges or longer minimum times for operation can be agreed between the Relevant System Operator, the relevant TSO and the asynchronously connected Power Park Module, the asynchronously connected Demand Facility and the asynchronously connected Electricity Storage Module owner to ensure the best use of the technical capabilities of a remote-end HVDC converter station if needed to preserve or to restore system security. If wider voltage ranges or longer minimum times for operation are economically and technically feasible, the remote-end HVDC converter station owner shall not unreasonably withhold consent;

(c) for ~~HVDC~~ interface points at AC voltages that are not included in the scope of Table 12 and Table 13, Annex VIII, the Relevant System Operator, in coordination with the relevant TSO shall specify applicable requirements at the connection points;

(d) where frequencies other than nominal 50 Hz are used, subject to agreement by the relevant TSO, the voltage ranges and time periods specified by the Relevant System

[21] Review note: Article 48(1)(b) must also include asynchronously connected Power-to-Gas Demand Facility

Operator, in coordination with the relevant TSO, shall be proportional to those in Annex VIII.

2. A remote-end HVDC converter station shall fulfil the following requirements referring to voltage stability, at the connection points with regard to reactive power capability:

(a) the Relevant System Operator, in coordination with the relevant TSO shall specify the reactive power provision capability requirements for various voltage levels. In doing so, the Relevant System Operator, in coordination with the relevant TSO shall specify a U-Q/Pmax-profile of any shape and within the boundaries of which the remote-end HVDC converter stations shall be capable of providing reactive power at its maximum HVDC active power transmission capacity;

(b) the U-Q/Pmax-profile shall be specified by each Relevant System Operator, in coordination with the relevant TSO. The U-Q/Pmax-profile shall be within the range of Q/Pmax and steady-state voltage specified in Table 14, Annex VIII, and the position of the U-Q/Pmax-profile envelope shall lie within the limits of the fixed outer envelope specified in Annex IV. The Relevant System Operator, in coordination with the relevant TSO, shall consider the long term development of the network when determining these ranges.

(c) If two or more remote-end HVDC converter stations are connected to one or more interface points of the same isolated AC network, the remote-end HVDC converter stations and their respective HVDC systems shall be capable to continuously operate stably over the full operating range between maximum and minimum HVDC system active power transmission capacity and contribute to the voltage stability of the remote-end HVDC system isolated AC network they are connected to.

(d) If paragraph c applies, the relevant TSO in coordination with adjacent TSOs, shall specify a study in order to define coordinated voltage stability control parameters of the remote-end HVDC converter stations including reactive power sharing ratio between the remote-end HVDC stations and their respective HVDC system. This study shall include robustness against control interactions during voltage disturbances and data provisions according to Article 29.

Amendment 24: Article 50 (power Quality)[22]

Legal Text:

Remote-end HVDC converter station owners shall ensure that their connection to the network does not result in a level of distortion or fluctuation of the supply voltage on the network, at the connection point, exceeding the level allocated to them by the Relevant System Operator, in coordination with the relevant TSO. The necessary contribution from grid users to the associated studies shall not be unreasonably withheld, including from, but not limited to, existing

[22] Review note: Article 50 must also include asynchronously connected Power-to-Gas Demand Facility

asynchronously connected Power Park Module, an asynchronously connected Demand Facility and an asynchronously connected Electricity Storage Module and existing HVDC systems. The process for necessary studies to be conducted and relevant data to be provided by all grid users involved, as well as mitigating actions identified and implemented shall be in accordance with the process provided for in Article 29.

Amendment 25: Article 52 (parameters and settings)

Legal Text

The parameters and settings of the main control functions of an HVDC system shall be agreed between the HVDC system owner and the Relevant System Operator, in coordination with the relevant TSO. The parameters and settings shall be implemented within such a control hierarchy that makes their modification possible if necessary.

Those main control functions are at least:

(a) grid forming capability, if applicable as referred to in Articles 14 and 35
(b) fast frequency control, if applicable as referred to in Articles 14 and 35;
(c) frequency sensitive modes (FSM, LFSM-O, LFSM-U) referred to in Article 15;
(d) frequency control, if applicable, referred to in Article 16;
(e) short circuit contribution during faults as referred to in Articles 19 and 35;
(f) reactive power control mode, if applicable as referred to in Article 22;
(g) power oscillation damping capability, referred to Article 30;
(h) subsynchronous torsional interaction damping capability, referred to Article 31.

Amendment 26: Annex I (Frequency ranges referred to in Article 11)

Change in the Table.

Frequency range	Duration
47,0 Hz-47,5 Hz	60 seconds
47,5 Hz-48,5 Hz	To be specified by each relevant TSO, but longer than established times for generation and demand according to Regulation (EU) 2016/631 and Regulation (EU) 2016/1388 respectively, and longer than for A-PPM, A-PtG-DU, A-ESM and A-DF, according to Article 39
48,5 Hz-49,0 Hz	To be specified by each relevant TSO, but longer than established times for generation and demand according to Regulation (EU) 2016/631 and Regulation (EU) 2016/1388 respectively, and longer than for A-PPM , A-PtG-DU, A-ESM and A-DF according to Article 39
49,0 Hz-51,0 Hz	unlimited
51,0 Hz-51,5 Hz	To be specified by each relevant TSO, but longer than established times for generation and demand according to Regulation (EU) 2016/631 and Regulation (EU) 2016/1388 respectively, and longer than for A- PPM, A-PtG-DU, A-ESM and A-DF according to Article 39
51,5 Hz-52,5 Hz	To be specified by each relevant TSO, but longer than for A-PPM, A-PtG-DU, A-ESM and A-DF, according to Article 39.

Amendment 27: Annex II (Requirements applying to frequency sensitive mode, limited frequency sensitive mode over frequency and limited frequency sensitive mode underfrequency)

ANNEX II

Requirements applying to frequency sensitive mode, limited frequency sensitive mode over-frequency and limited frequency sensitive mode under-frequency.

A. Frequency sensitive mode

1. When operating in frequency sensitive mode (FSM):

(a) the HVDC system shall be capable of responding to frequency deviations in each connected AC network by adjusting the active power transmission as indicated in Figure 1 and in accordance with the parameters specified by each TSO within the ranges shown in Table 2. This specification shall be subject to notification to the regulatory authority. The modalities of that notification shall be determined in accordance with the applicable national regulatory framework;

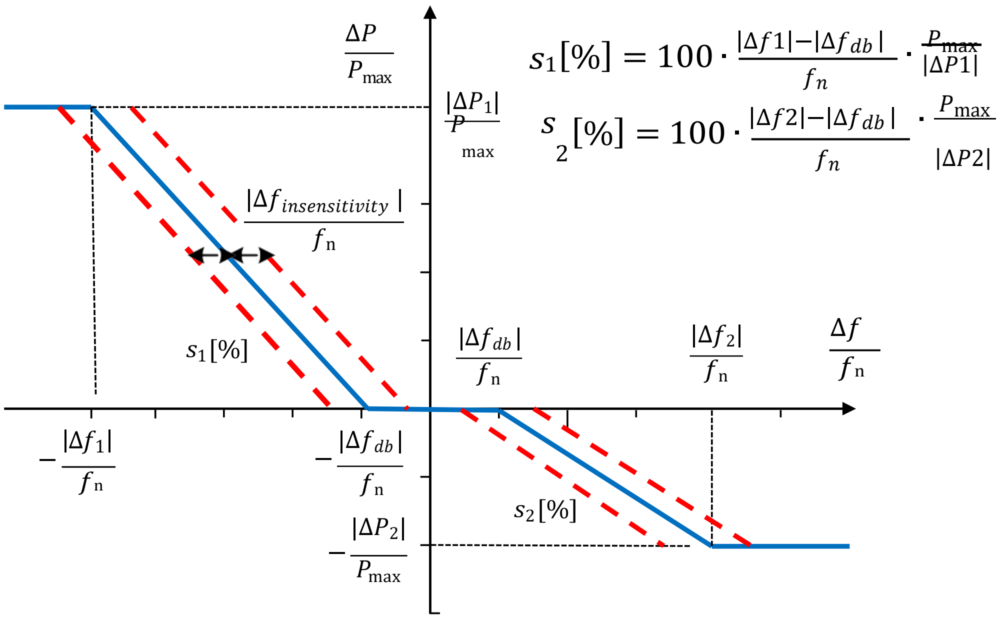

Figure 1: Active power frequency response capability of an HVDC system in FSM illustrating the case with deadband and insensitivity. In this figure, ΔP is the active power exchange by an HVDC system with the network at its connection point based on its actual operating point, Pmax is maximum transmission capacity of the HVCDC system, fn is the target frequency in the AC network where the FSM service is provided, Δf is the frequency deviation in the AC network where the FSM service is provided, ΔP1 is the agreed power change for the FSM at reaching the frequency threshold value Δf1, ΔP2 is the agreed power exchange at reaching the frequency threshold value Δf2, Δf_{db} is the deadband of the power frequency response, $\Delta f_{insensitivity}$ is the frequency response insensitivity (or else the permissible tolerance allowed), s1 is the droop value for the given ΔP1 and s2 is the droop for the given ΔP2.

Table 2. Parameters for active power frequency response in FSM (range values of the figure 1)

Parameters	**Range**
$\Delta f1/f_n$, $\Delta f2/f_n$	0,02-0,06 %
Frequency response insensitivity, $\Delta f_{insensitivity}$	≤ 30 mHz
Deadband of the FSM, Δf_{db}	0 - ±500 mHz
$\Delta f_{db}/f_n$	0 – 0,01%
Range of the droop, s_1	≥ 0,1 %
Range of the droop, s_2	≥ 0,1 %

[...]

(b) as a result of a frequency step change, the HVDC system shall be capable of adjusting active power to the active power frequency response defined in Figure 1, in such a way that the response is:

(i) as fast as inherently technically feasible; and

(ii) at or above the solid line according to Figure 2 in accordance with the parameters specified by each relevant TSO within the ranges according to Table 3:

— the HVDC system shall be able to adjust active power output ΔP up to the limit of the active power range requested by the relevant TSO in accordance with the times t1 and t2 according to the ranges in Table 3, where t1 is the initial delay and t2 is the time for full activation. The values of ~~t1 and~~ t_2 shall be specified by the relevant TSO~~, subject to notification to the regulatory authority~~. ~~The modalities of that notification shall be determined in accordance with the applicable national regulatory framework;~~

— The initial activation of active power frequency response (the value of t_1) required shall be as short as possible. If the initial delay of activation is greater than 0,5 second, the HVDC system owner shall reasonably justify it to the relevant TSO.

B. Limited frequency sensitive mode — overfrequency

1. In addition to the requirements of Article 11 the following shall apply with regard to Limited Frequency Sensitive Mode — Overfrequency (LFSM-O):

(a) the HVDC system shall be capable of adjusting active power frequency response to the AC network or networks, during both import and export, according to Figure 3 at a frequency threshold f_1 adjustable between and including 50,2 Hz and 50,5 Hz with a droop *S3* adjustable from 0,1% upwards; The default frequency threshold f1 shall be 50 Hz + Δf1, where Δf1 is defined in Table X.

Table X

Definition of Δf1, Δf2 used for LFSM-O and LFSM-U

Synchronous area	Δf1 thresholds
Continental Europe	0,2 Hz
Nordic	0,5 Hz
Great Britain	0,5 Hz
Ireland	0,2 Hz (for LFSM-O and FSM), 0,5 Hz (LFSM-U)
Baltic	0,2 Hz

[...]

C. Limited frequency sensitive mode underfrequency

1. In addition to the requirements of Article 11, the following shall apply with regard to limited frequency sensitive mode — underfrequency (LFSM-U):

(a) the HVDC system shall be capable of adjusting active power frequency response to the AC network or networks, during both import and export, according to Figure 4 at a frequency threshold f2 adjustable between and including 49,8 Hz and 49,5 Hz with a droop S4 adjustable from 0,1% upwards; The default frequency threshold f2 shall be 50 Hz – Δf2, where Δf2 is defined in Table X.

Amendment 28: Annex III (Voltage ranges)

Annex III, voltage ranges referred to Article 18

Table 4: Minimum time periods an HVDC system shall be capable of operating for voltages deviating from the reference 1 pu value at the connection points without disconnecting from the network. This table applies in case of pu voltage base values at or above 110 kV and up to (not including) 300 kV.

Synchronous area	Rated Voltage	Voltage range	Time period for operation
Continental Europe	110 kV	0,85 pu-1,118 pu	Unlimited
		1,118 pu-1,15 pu	To be established by each relevant system opera•

			tor, in coordination with the relevant TSO but not less than 20 minutes
	132 kV	0,85 pu-1,098 pu	Unlimited
		1,098 pu-1,15 pu	To be established by each Relevant System Operator, in coordination with the relevant TSO but not less than 20 minutes
	150 kV	0,85 pu-1,118 pu	Unlimited
		1,118 pu-1,15 pu	To be established by each relevant system opera• tor, in coordination with the relevant TSO but not less than 20 minutes
	220 kV	0,85 pu-1,113 pu	Unlimited
		1,113 pu-1,15 pu	To be established by each relevant system opera• tor, in coordination with the relevant TSO but not less than 20 minutes
Nordic	110 kV	0,90 pu-1,05 pu	Unlimited
		1,05 pu-1,10 pu	60 minutes

	132 kV	0,90 pu-1,05 pu	Unlimited
		1,05 pu-1,10 pu	60 minutes
	220 kV	0,90 pu-1,05 pu	Unlimited
		1,05 pu-1,10 pu	60 minutes
Great Britain	132 kV	0,90 pu-1,098 pu	Unlimited
	275 kV	0,90 pu-1,09 pu	Unlimited
Ireland and Northern Ireland	110 kV	0,90 pu-1,118 pu	Unlimited
	220 kV	0,90 pu-1,113 pu	Unlimited
	275 kV	0,90 pu-1,09 pu	Unlimited
~~**Baltic**~~	~~110 kV~~	~~0,85 pu-1,118 pu~~	~~Unlimited~~
		~~1,118 pu-1,15 pu~~	~~20 minutes~~
	~~220 kV~~	~~0,85 pu-1,113 pu~~	~~Unlimited~~
		~~1,113 pu-1,15 pu~~	~~20 minutes~~

Table 5: Minimum time periods an HVDC system shall be capable of operating for voltages deviating from the reference 1 pu value at the connection points without disconnecting from the network. This table applies in case of pu voltage base values from 300 kV to 400 kV (included).

Synchronous area	Rated Voltage	Voltage range	Time period for operation
Continental Europe	330 kV	0,85 pu-1,05 pu	Unlimited
		1,05 pu-1,0875 pu	To be specified by each TSO, but not ~~more~~ less than 60 minutes
		1, 0875 pu-1,10 pu	60 minutes
	400 kV	0,85 pu-1,05 pu	Unlimited
		1,05 pu-1,0875 pu	To be specified by each TSO, but not ~~more~~ less than 60 minutes
		1, 0875 pu-1,10 pu	60 minutes
Nordic	330 kV	0,90 pu-1,05 pu	Unlimited
		1,05 pu-1,10 pu	To be specified by each TSO, but not more than 60 minutes
	400 kV	0,90 pu-1,05 pu	Unlimited
		1,05 pu-1,10 pu	To be specified by each TSO, but not more than 60 minutes
Great Britain	400 kV	0,90 pu-1,05 pu	Unlimited
		1,05 pu-1,10 pu	15 minutes

Ireland and Northern Ireland	400 kV	0,90 pu-1,05 pu	Unlimited
~~**Baltic**~~	~~330 kV~~	~~0,88 pu-1,097 pu~~	~~Unlimited~~
		~~1, 097 pu-1,15 pu~~	~~20 minutes~~
	~~400 kV~~	~~0,88 pu-1,05 pu~~	~~Unlimited~~
		~~1, 05 pu-1,15 pu~~	~~20 minutes~~

Amendment 29: Annex V (FRT profile referred to Article 25)

ANNEX V

Voltage ranges and time periods referred to in Article 25

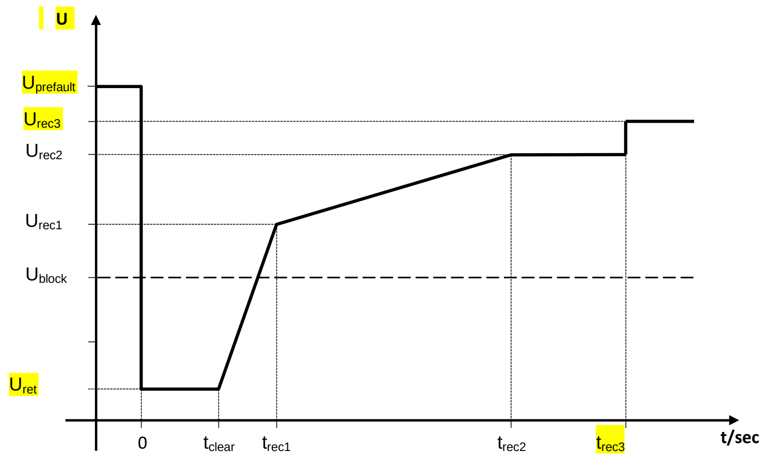

Figure 6: Fault-ride-through profile of an HVDC converter station. The diagram represents the lower limit of a voltage- against-time profile atthe connection point, ~~expressed by the ratio of its actualvalue and its reference 1 pu value in per unit~~ before, during and after a fault. $U_{prefault}$ is the prefault voltage, Uret is the retained voltage at the connection point during a fault, tclear is the instant when the fault has been cleared, Urec1 and trec1 specify a point of lower limits of voltage recovery following fault clearance. U_{block} is the blocking voltage at the connection point. The time values referred to are measured from the fault.

Table 7: Parameters for Figure 6 for the fault-ride-through capability of an HVDC converter station.

Voltage parameters [pu]		~~***Time parameters [seconds]***~~	
Uret	***0,00-0,30***	~~***tclear***~~	~~***0,14-0,25***~~
Urec1	***0,25-0,85***	~~***trec1***~~	~~***1,5-2,5***~~
Urec2	***0,85 – 0,9***	~~***trec2***~~	~~***trec1-10,0***~~
Urec3	***Minimum voltage specified in article 40***		

Table 7.2: Time parameters for Figure 6 for the fault-ride-through capability of an HVDC converter station.

Time parameters [seconds]	
tclear	*0,14-0,25*
trec1	*1,5-2,5*
trec2	*trec1-10,0*
trec3	*To be specified by each TSO and ≥ trec2*

Amendment 30: Annex VII (Voltage ranges and time periods referred to in Article 40)[23]

Expert Group members would like to raise the attention/question to GC ESC for the time period for operation of 0,85 – 0,9 p.u which is today 60 minutes (from 110 kV – 400 kV). It is the view of some stakeholders that the duration time for this range may be further optimized as part of a general approach for optimum design of future isolated AC networks.

Table 9: Minimum time periods for which asynchronously connected Power Park Module, asynchronously connected Electricity Storage Module and asynchronously connected Demand Facility shall be capable of operating for different voltages deviating from a reference 1 pu value without disconnecting from the network ~~where the voltage base for pu values is from 110 kV to (not including) 300 kV.~~

Rated voltage	**Voltage range**	**Time period for operation**
110 kV	0,85 p.u – 0,9 p.u	60 minutes
	0,9 p.u – 1,10 p.u	Unlimited
	1,10 p.u – 1,118 p.u	Unlimited, unless specified otherwise by the Relevant System Operator, in coordination with the relevant TSO.
	1,118 p.u – 1,15p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO.
132 kV	0,85 p.u – 0,9 p.u	60 minutes
	0,9 p.u – 1,10 p.u	Unlimited
	1,10 p.u – 1,118 p.u	Unlimited, unless specified otherwise by the Relevant System Operator, in coordination with the relevant TSO.

[23] Review note: this article must also include asynchronously connected Power-to-Gas Demand Facility

	1,118 p.u – 1,15p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO.
150 kV	0,85 p.u – 0,9 p.u	60 minutes
	0,9 p.u – 1,10 p.u	Unlimited
	1,10 p.u – 1,118 p.u	Unlimited, unless specified otherwise by the Relevant System Operator, in coordination with the relevant TSO.
	1,118 p.u – 1,15p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO.
220 kV	0,85 p.u – 0,9 p.u	60 minutes
	0,9 p.u – 1,10 p.u	Unlimited
	1,10 p.u – 1,118 p.u	Unlimited, unless specified otherwise by the Relevant System Operator, in coordination with the relevant TSO.
	1,118 p.u – 1,15p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO.

Table 10: Minimum time periods for which asynchronously connected Power Park Module, asynchronously connected Electricity Storage Module and asynchronously connected Demand Facility shall be capable of operating for different voltages deviating from a reference 1 pu value without disconnecting from the network ~~where the voltage base for pu values is from 300 kV to 400 kV (included).~~

Rated voltage	Voltage range	Time period for operation
330 kV	0.85 p.u – 0.9 p.u	60 minutes
	0,9 p.u – 1,05 p.u	Unlimited
	1,05 p.u -1,15 p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO. Various sub-ranges of voltage withstand capability can be specified.
400 kV	0.85 p.u – 0.9 p.u	60 minutes
	0,9 p.u – 1,05 p.u	Unlimited
	1,05 p.u -1,15 p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO. Various sub-ranges of voltage withstand capability can be specified.

Amendment 31: Annex VIII (Reactive power and voltage requirements referred to in Article 48)

Reactive power and voltage requirements referred to in Article 48

Table 12: Minimum time periods for which a remote-end HVDC converter station shall be capable of operating for different voltages deviating from a reference 1 pu value without disconnecting from the network ~~where the voltage base for pu values is from 110 kV to (not including) 300 kV~~.

Rated voltage	Voltage range	Time period for operation
110 kV	0.85 p.u – 0.9 p.u	60 minutes
	0,90 p.u – 1,10 p.u	Unlimited
	1,10 p.u -1,12 p.u	Unlimited, unless specified otherwise by the Relevant System Operator, in coordination with the relevant TSO.
	1,12 p.u – 1,15 p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO.
132 kV	0.85 p.u – 0.9 p.u	60 minutes
	0,90 p.u – 1,10 p.u	Unlimited
	1,10 p.u -1,12 p.u	Unlimited, unless specified otherwise by the Relevant System Operator, in coordination with the relevant TSO.
	1,12 p.u – 1,15 p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO.
150 kV	0.85 p.u – 0.9 p.u	60 minutes
	0,90 p.u – 1,10 p.u	Unlimited
	1,10 p.u -1,12 p.u	Unlimited, unless specified otherwise by the Relevant System Operator, in coordination with the relevant TSO.
	1,12 p.u – 1,15 p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO.
220 kV	0.85 p.u – 0.9 p.u	60 minutes
	0,90 p.u – 1,10 p.u	Unlimited
	1,10 p.u -1,12 p.u	Unlimited, unless specified otherwise by the Relevant System Operator, in coordination with the relevant TSO.
	1,12 p.u – 1,15 p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO.

Table 13: Minimum time periods for which a remote-end HVDC converter station shall be capable of operating for different voltages deviating from a reference 1 pu value without disconnecting from the network ~~where the voltage base for pu values is from 300 kV to 400 kV (included).~~

Rated voltage	Voltage range	Time period for operation
330 kV	0.85 p.u – 0.9 p.u	60 minutes
	0,90 p.u – 1,05 p.u	Unlimited
	1,05 p.u -1,15 p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO. Various sub-ranges of voltage withstand capability can be specified.
400 kV	0.85 p.u – 0.9 p.u	60 minutes
	0,90 p.u – 1,05 p.u	Unlimited
	1,05 p.u -1,15 p.u	To be specified by the Relevant System Operator, in coordination with the relevant TSO. Various sub-ranges of voltage withstand capability can be specified.

Amendment 32: Article 54 (Simulation model requirements for HVDC systems)

This Expert Group would like to raise the attention to ACER and GC ESC members that the simulation model requirements for HVDC systems as given in the EG ISSM report should be also taken into account for the future NC HVDC amendments.

Chapter 3: Analysis of the offshore topologies defined in phase I

The aim of this chapter is to assess the applicability of NC HVDC to given topologies, as identified in the phase I report of this Expert Group.

Case 1[24]: DC connected PPMs and Demand Facilities

For the topology of figure 4, the NC HVDC applies for the HVDC system, the Power Park Module, the Demand Facility and Electricity Storage Module. In this case it can be seen that the interface point could be defined accordingly by the relevant TSO and defined at the connection agreement. For the example, for the case of State A, the interface point is defined at the remote-end HVDC system terminal assuming that the offshore AC cable is owned by the asynchronously connected Power Park Module owner. It should be noted, that for the case of state A, the requirements for the asynchronously connected Power Park Module apply at the interface point, under the assumption that the AC cables are owned by the Power Park Module.

For the state B, three interface points are defined respectively by the relevant TSO, for the remote end HVDC system, the PPM, Electricity Storage Module and the Demand Facility. It should be noted that the respective requirements of Title II shall apply at the interface point for each interface point.

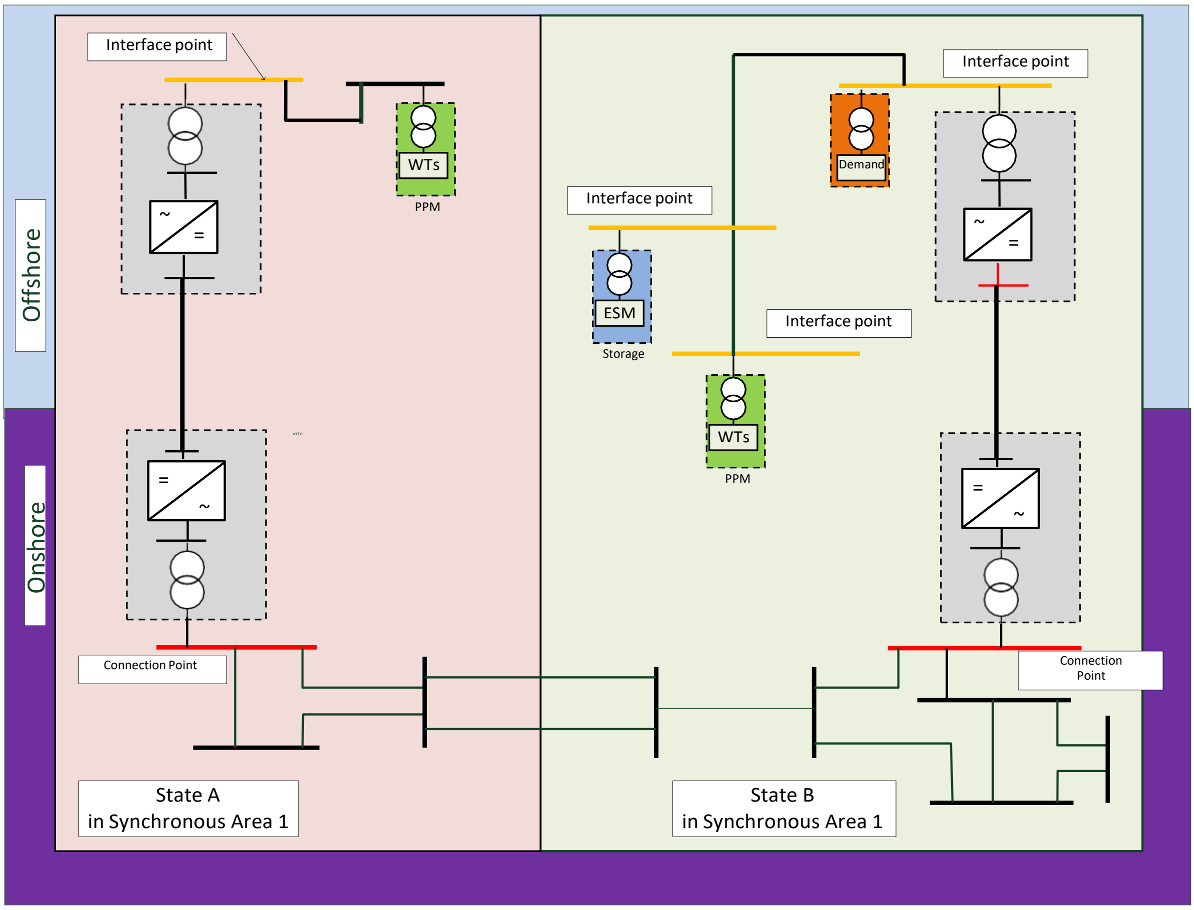

Figure 3. HVDC Connection of PPMs, energy storage and Demand Facilities (for monopolar HVDC system). With red is a connection point and with orange and interface point, as termed also in figure 1. Please note that a red

[24] 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 interface points as well as at the onshore AC connection points.

bus indicates a connection point and an orange bus an interface point, as in figure 2 and the relevant definitions of chapter 2.

For the topology of figure 5, NC HVDC applies for the HVDC system (which is including the multi-terminal case) both at the interface points and the connection point. It should be noted that the requirements at the interface point of the HVDC system as well as its connection point apply irrelevant if it is a single or multi-vendor HVDC project[25].

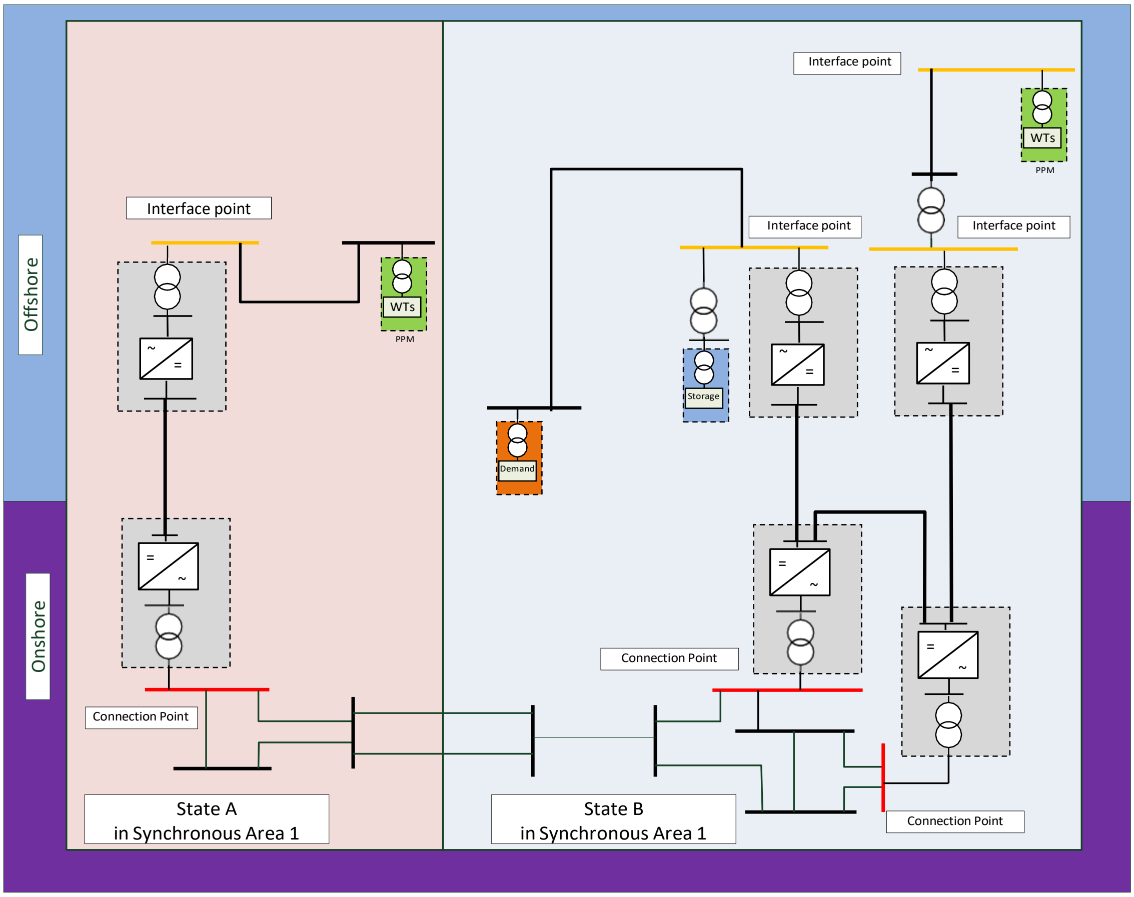

Figure 4. HVDC Connected PPM, energy storage and Demand Facilities with parallel HVDC links coupled on the AC and DC side. Please note that a red bus indicates a connection point and an orange bus an interface point, as in figure 2 and the relevant definitions of chapter 2.

[25] A multi-vendor HVDC system is a system that at least two vendors provide the HVDC converters stations or other equipment of the HVDC system.

Case 2a: Isolated AC network connected via HVDC systems to different synchronous areas

The topology of figure 6 presents a case of an extended isolated AC network (including wind power generation, Demand Facility and Electricity Storage Module), connected to the synchronous areas via two HVDC systems.

The definition of interface points as proposed in this report allows for the development of technical requirements to be set at the different locations in the isolated AC network, depending on the ownership of the assets.

Moreover, the definition of the interface point and the common requirements as defined in the Title III for Power Park Modules, Electricity Storage Modules and Demand Facility including Demand Units for Power-to-Gas enables a certain level of harmonization in the development and growth in capacity of such offshore AC networks, irrelevant if they are shared or not between different control zones and synchronous areas.

With regard to the selection of the FSM parameters, the range defined provide the common basis to design and coordinate the exchange of frequency response reserves. It should be also noted that the NC HVDC provides the legal basis to define the ranges where choices of those ranges can be coordinated by the relevant systems operators, relevant TSOs or adjacent TSOs.

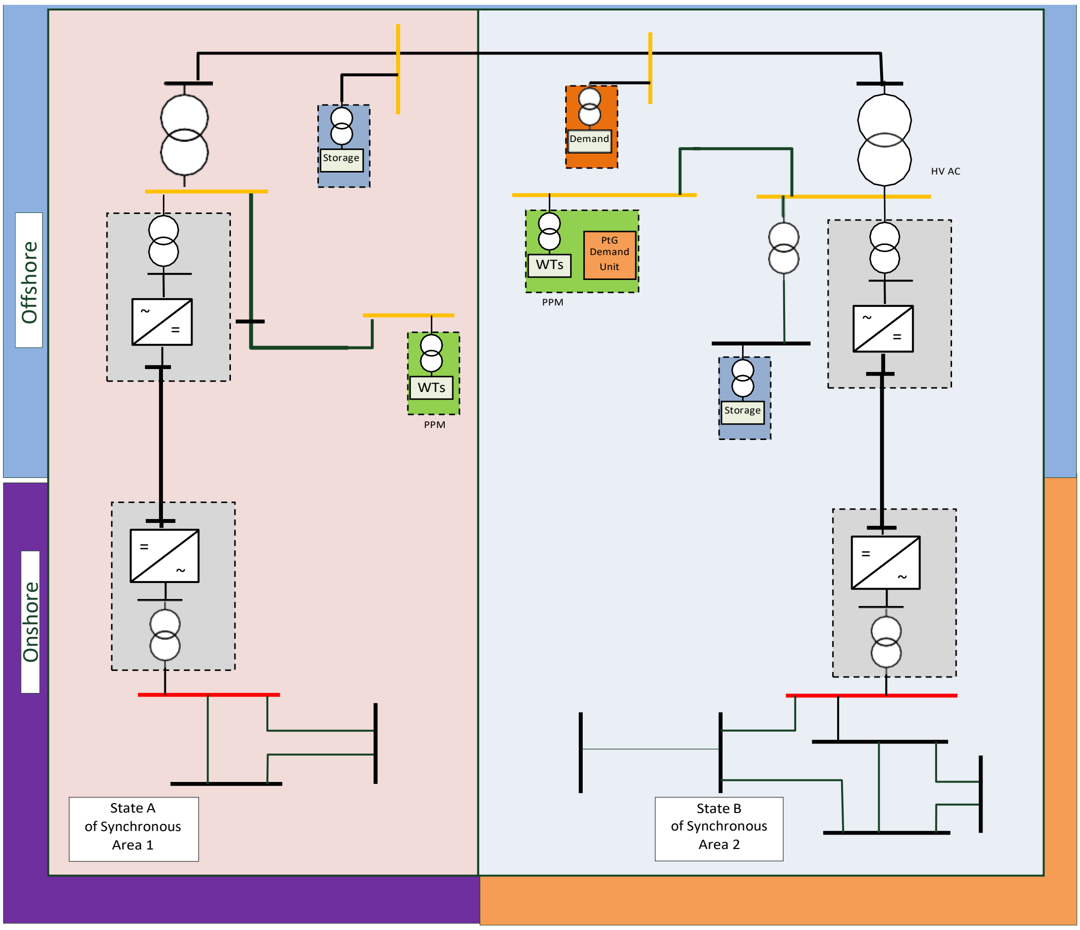

Figure 5. A case that the interface points of different synchronous areas are AC connected. Please note that a red bus indicates a connection point and an orange bus an interface point, as in figure 2 and the relevant definitions of chapter 2.

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

For the topology of figure 7, NC HVDC applies for the HVDC system, the PPMs, the Demand Facility and Electricity Storage Module.

For the HVDC interconnection between the two interface points, the requirements for remote end HVDC converter stations would apply, as defined in the proposed amendments 23.

The planning and grid integration studies as well as the design of such offshore network could be coordinated by the relevant TSOs or Relevant System Operators under the given NC HVDC regulation.

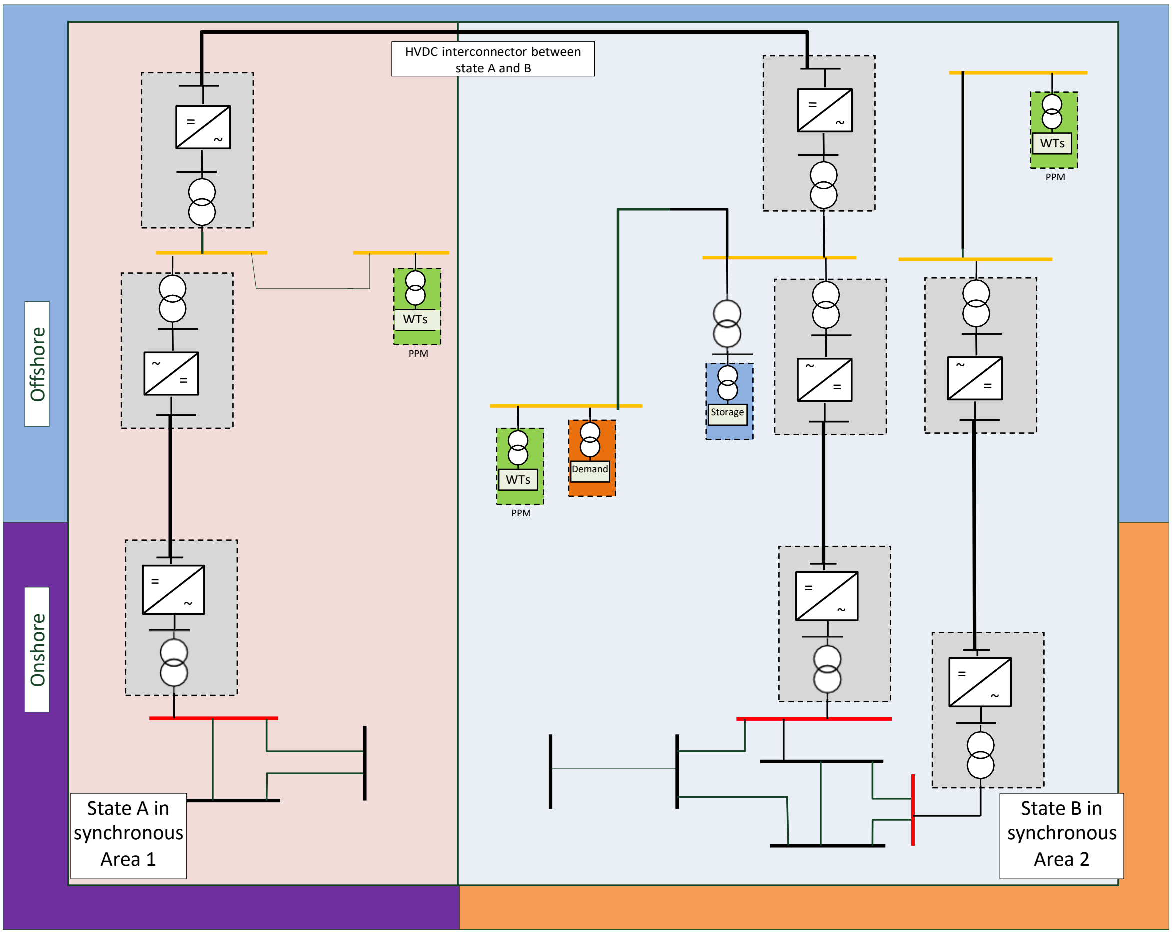

Figure 6. Topology showing DC connected HVDC interface point that belong to different synchronous areas. Please note that a red bus indicates a connection point and an orange bus an interface point, as in figure 2 and the relevant definitions of chapter 2.

T&D Europe (HVDC manufacturers) perspective for the case 2b

Background / Basic Considerations

- The figure 7 shows an HVDC interconnector linking two islanded AC networks;
- The interface points can have asynchronously connected Power Park Modules, demand or Electricity Storage Module;
- It should be noted that for the isolated AC network, all connectees are assumed to be Power Electronic Interfaced Devices (PEID). Hence this case consists of a 100% PEID system;

- The Network Code (NC) requirements for these islanded AC systems must be such that the system operator can assure operating conditions which allow stable operation of the complete system under all relevant conditions;
- What conditions are relevant will be defined by the corresponding use cases and cannot be prescribed or limited in a NC.

Technical Requirements

- All power electronic interface devices should behave in a "Grid Forming" technical requirement. This is addressed by the amendment 19 which defines this minimum technical requirement for asynchronously connected Power Park Modules and asynchronously connected Electricity Storage Modules;
- The grid forming behavior is characterized by, among others, dynamic frequency/active power behavior and dynamic voltage control;
- A device contributing to frequency/active power control requires a source of energy, which is independent from the network receiving the frequency support. Ideally, the source used for this energy compensation is independent of the AC system for which the functions of dynamic frequency/active power behavior and dynamic voltage control are to be provided. Such an independent source may be, for example, another synchronous area connected via the DC circuit of the HVDC system. Other options can be dedicated energy storages or using the capabilities of Power-to-Gas facilities or units;
- The capabilities of the individual connectees needs to be coordinated to assure system stability covering all relevant network configurations and operating conditions;
- The capabilities of the individual connectees should be defined and specified in the following categories
    - synthetic inertia, addressing the initial response to changes in the AC system frequency or voltage;
    - primary frequency control, using frequency-power droop characteristics;
    - secondary frequency control, covering frequency restoration and re-balancing the relevant energy reserves;
  - The resulting dynamic system behavior should be studied to demonstrate compliance with the defined requirements and avoid adverse system interactions;
- Practical considerations of specific system configurations/conditions:
  1. The energy needed to provide stable operating conditions in the islanded offshore systems can be balanced by the HVDC connected onshore systems if they have the necessary capabilities;
  2. Within their capabilities, DC Dynamic Braking systems can help to absorb energy surplus, when an onshore system is temporarily not available;
  3. The overall system concept should cover aspects of system startup and system restoration;
  4. The capabilities needed are not related to any individual connectee but rather depend on the set-up of the overall system;
  5. It is important that there is a source for balancing the energy in all time frames as described above;
  6. An HVDC system as designed today is a transmission system and thus must continuously balance the power import into and export from its DC circuit all time;
  7. Thus, there is no room for compensating surplus or deficit in a connected AC system, unless the power can be taken from another connected (independent) power source;

8. A DC Dynamic Braking Device is an exception here having a defined energy absorption capability;
9. The NC HVDC addresses synthetic inertia, but the requirements are recommended to be defined in more detail allowing for a coordinated overall system design.

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

For the topology of figure 8, NC HVDC applies for the HVDC system, the PPMs, the Demand Facility and Electricity Storage Module. With regard to the multi-terminal HVDC system, DC planning standards apply as agreed between the relevant TSOs and the owners of the HVDC system.

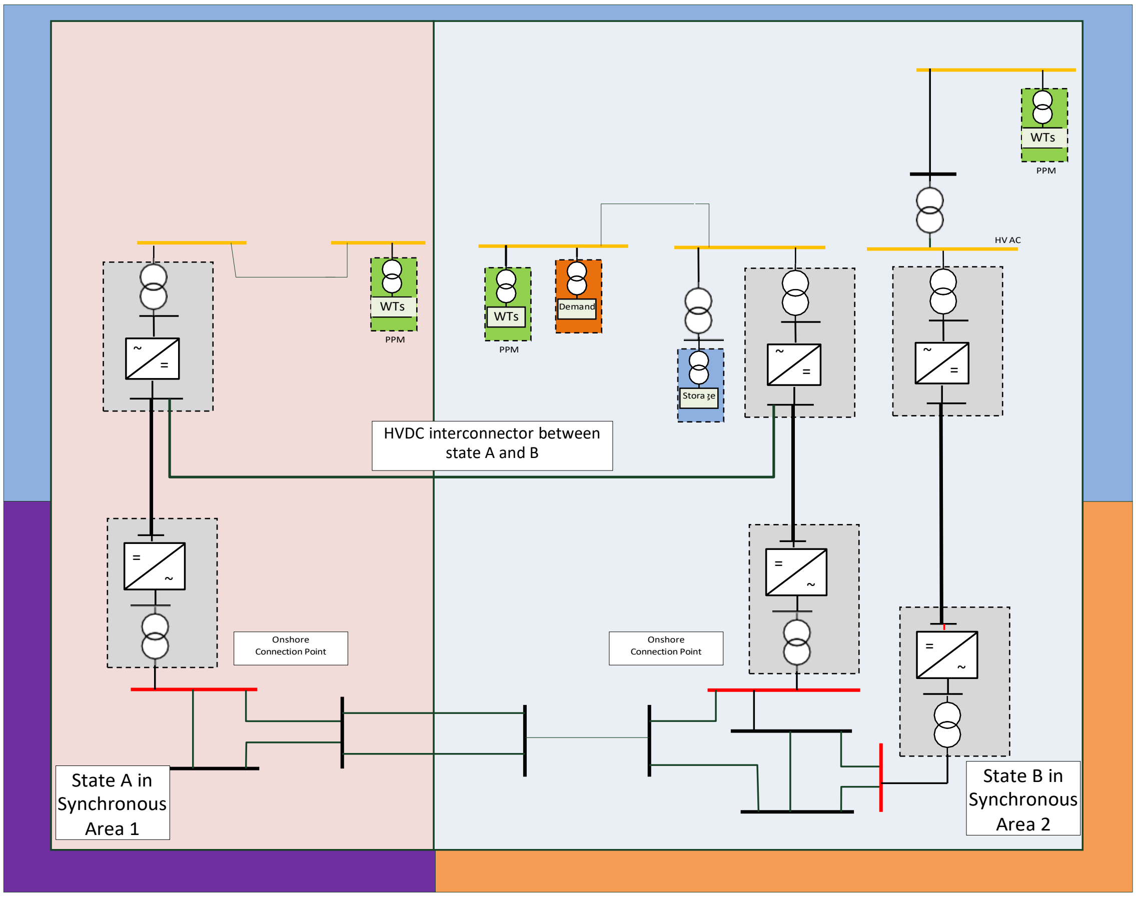

Figure 7. Topology showing DC grid coupled interface points including the case that the onshore HVDC converter stations are also at different SAs.

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

For the topology of figure 9, the Power Park Module in state B has an AC connection to State A and a DC connection to state B.

In that case, the Power Park Module and the Electricity Storage Module in state B have a connection point and not an interface point, hence NC RfG shall apply. Please note, that for the Electricity Storage Modules which are AC connected, NC RfG shall apply as well, according to the relevant Expert Group recommendations.

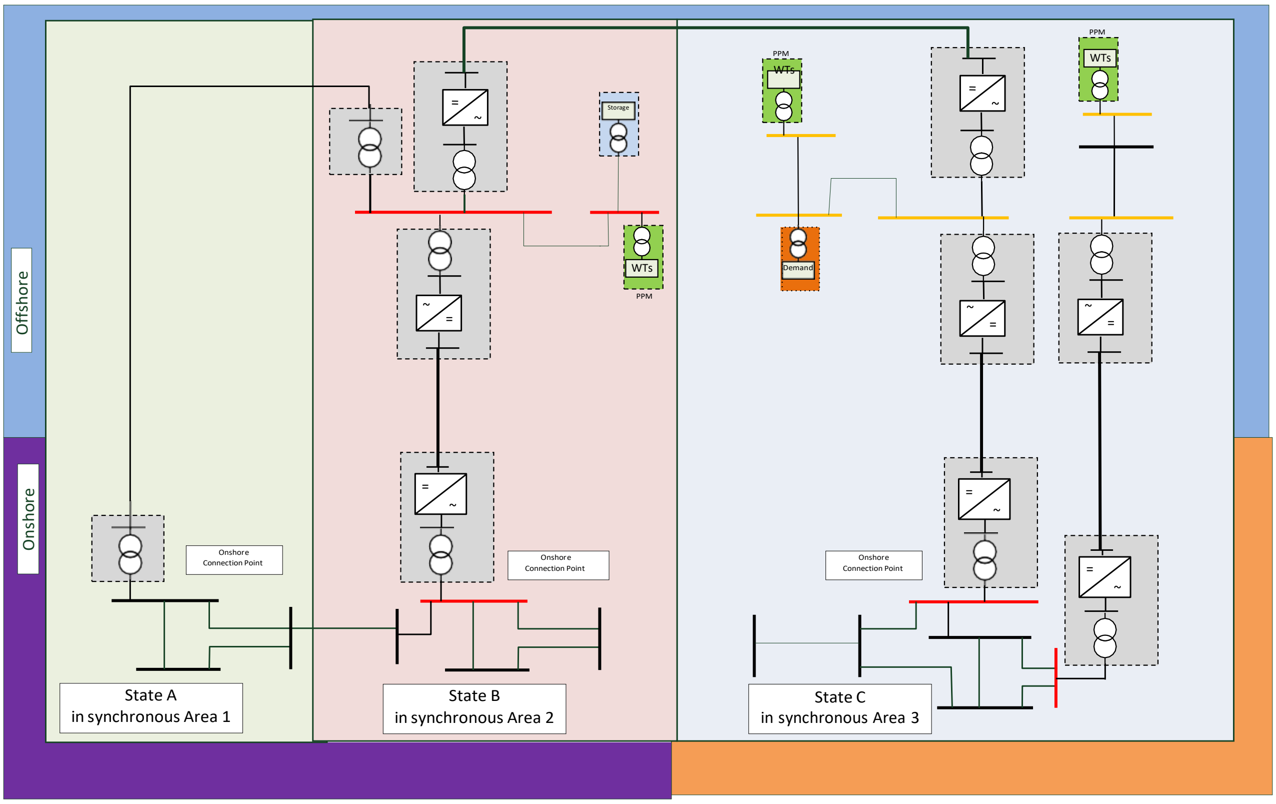

Figure 8. Simultaneous AC and DC connected PPMs (including the case that the onshore HVDC converter stations are also at different SAs).

Alternatively, if the AC connection is not in operation, like the case of figure 10, the Power Park Module and the Electricity Storage Module in state B will have an interface point, hence NC HVDC applies and its title II requirements.

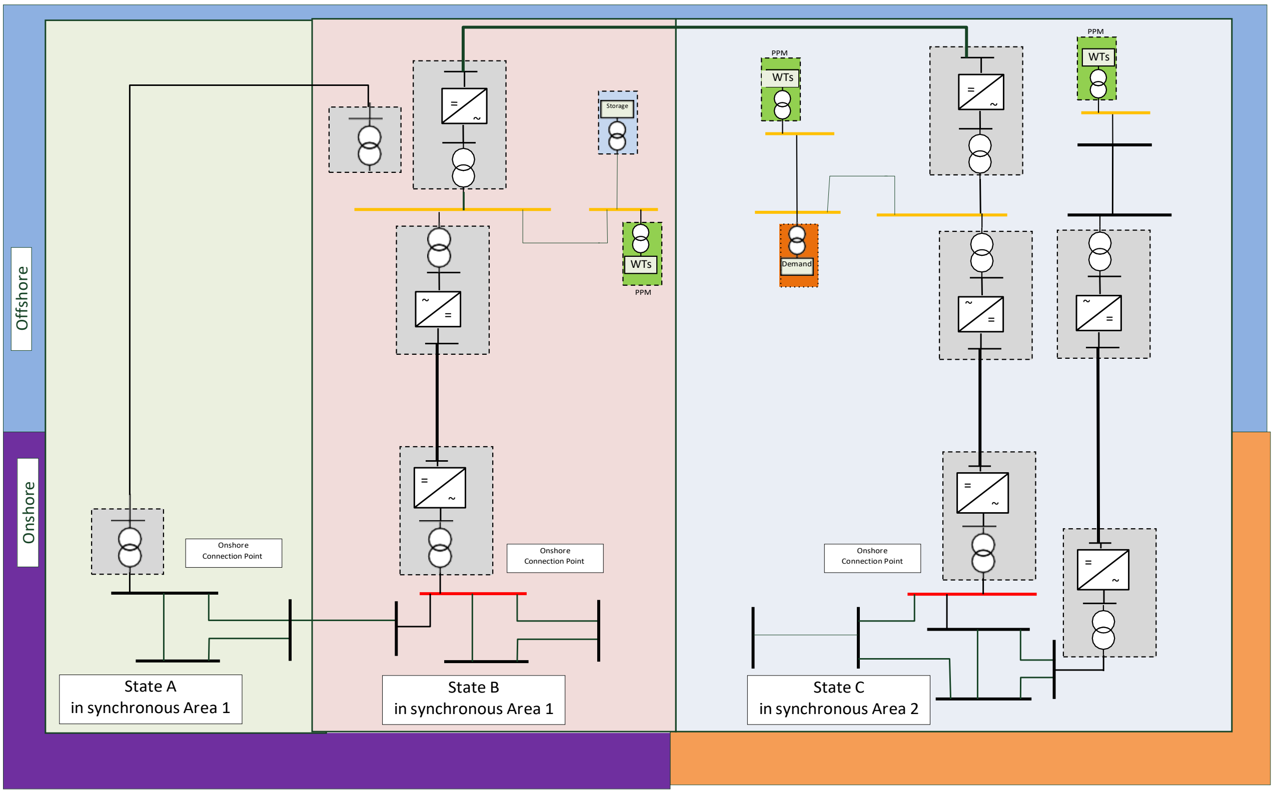

Figure 9. Simultaneous AC and DC connected PPMs (including the case that the onshore HVDC converter stations are also at different SAs).

Conclusions

This Expert Group proposes amendments of the NC HVDC in order to facilitate the development of offshore grids in Europe, which is seen as a key enabler for the energy transition.

It is the view of the Expert Group that the amended new version of the NC HVDC including the proposals made in this report can facilitate the future developments in multi-terminal, multi-vendor HVDC grids and does not consist of any barrier.

It is the view of the Expert Group members that the amendment of the NC HVDC shall not be performed independently from the NC RfG and the NC DC as there are various interdependencies highlighted in the frame of this report (connection point definition, FRT requirements, grid forming requirements, storage and HVDC connected Demand Facility requirements).

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End of the document,

1st of December 2023

Brussels.