PROMOTioN
PROGRESS ON MESHED HVDC
OFFSHORE TRANSMISSION
NETWORKS

Deliverable 11.4
Report with justified recommendations to grid codes

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
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CONTENT

Document info sheet ..... **ii**
Distribution list ii
Approvals ii
List of Contributors ..... **iii**
1 Introduction **1**
2 Requirements for meshed offshore grids based on Commission Regulation for HVDC **3**
2.1 General Requirements for HVDC connections 3
2.2 General Requirements for DC connected offshore wind farms 4
2.3 General Requirements for remote-end HVDC converter stations 6
3 Gap analysis **8**
3.1 Gap analysis on requirements at the AC point of connection 8
3.2 Gap Analysis on requirements at the DC point of connection 9
4 Recommendations on grid code adaptions and extensions **11**
4.1 Re-evaluation of requirements based on results (PROMOTioN D1.7) 11
4.2 Requirements recommendations for grid connection of HVDC systems and DC connected power park modules (PROMOTioN D2.4) 11
4.3 Requirement recommendation for DRU connected wind power plants (PROMOTioN D3.8) 13
5 Summary **15**
Bibliography **16**

1 INTRODUCTION

The overall objective of WP11 is to support and establish harmonization of the industry's best practices, standards and requirements for HVDC grid systems and DC connected offshore wind power plants.
WP11 aims to ensure that the experience collected through the project – including research, engineering and demonstrations – is utilized in ongoing and future harmonization work.

WP11 aims to harmonize the work in existing and future working groups in IEC, CENELEC, CIGRE, and in national as well as the European grid codes proposed by ENTSO-E. Several of those working groups are covering overlapping topics, and there is a need to ensure that this work is aligned.

The more specific objectives of WP11 are:

- to provide a consistent and harmonized set of functional specifications to HVDC systems, wind power plants and other AC systems connected to the HVDC systems;
- to recommend test procedures for converters, protection systems, switchgear, wind turbines and plants in HVDC systems;
- to recommend requirements to models of HVDC systems and HVDC connected wind power plants;
- to recommend best practice for compliance validation of wind power plants connected to HVDC systems.

This deliverable reports the work in Task 11.4 regarding recommendation to grid codes, starting from the ENTSO-E Commission Regulation for HVDC.

The basic requirements on HVDC systems and on DC connected wind power plants are laid out in the European COMMISSION REGULATION CR 2016/1447 of 26 August 2016, establishing a network code on requirements for grid connection of HVDC systems and DC connected power park modules. These are binding pan-European rules originally drafted by ENTSO-E in consultation with stakeholders (i.e. transmission system operators), with guidance from ACER (Agency for the Cooperation of Energy Regulators). Within the framework of the European network codes, these requirements are implemented and supplemented by more specific requirements in national grid codes or application rules.

Within the CR 2016/1447 framework there are different levels of requirement, ranging from some which are precisely defined within the flexibility of tolerances available to each TSO area to set them (for example frequency response) to others which are highly flexible (for example the specification of the offshore AC power island into which a power park module interfaces). Thus, some requirements are qualitatively settled, well defined and harmonized while quantitatively there remains some flexibility in determining the final parameters applied in each member state as the harmonization is done to the maximal extent possible but still considers tuning with respect to national specificities.

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks

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Within the PROMOTioN project, gaps have been identified and recommendations to adapt and extend existing grid codes have been developed within various work packages. The results have been discussed and published in various deliverables:

- PROMOTioN D1.7 lists a qualitative and quantitative set of requirements for the meshed offshore grid based on the progress in the technical work packages during the first two years of the project.
- PROMOTioN D3.8 provides a list of requirement recommendations to adapt and extend existing grid codes with the focus on the recommendations to cover the diode rectifier unit (DRU) based concept
- Recommendations on grid code extensions on requirements for grid connection of HVDC systems and DC connected power park modules are specified in D2.4.
- PROMOTioN D11.5 relates findings of other research areas of the PROMOTioN project to the existing requirements on HVDC systems and DC connected wind power plants.

Section 2 of this document provides an overview of requirements for meshed offshore grids as specified in CR 2016/1447. It includes references to the relevant sections of both CR 2016/1447 and PROMOTioN D1.7 (Report on the re-evaluation of the requirements based on results by other WPs).

Section 3 provides a gap analysis on the requirements at the AC and DC point of connection.

Section 4 summarizes the recommendations on grid code adaptions and extensions that have been developed in various work packages of the PROMOTioN project.

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2 REQUIREMENTS FOR MESHED OFFSHORE GRIDS BASED ON COMMISSION REGULATION FOR HVDC

2.1 GENERAL REQUIREMENTS FOR HVDC CONNECTIONS

Commission Regulation (EU) 2016/1447 establishes a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules.
PROMOTioN D1.7 lists a qualitative and quantitative set of requirements for the meshed offshore grid based on the progress in the technical work packages during the first two years of the project.

The general requirements for HVDC connections in D1.7 refer to the AC side of the onshore HVDC converter station, which is also the case for the requirements to HVDC systems specified in CR 2016/1447. Those requirements are imposed by the onshore AC grid and connecters. The general requirements for HVDC connections are listed in Table 1 including references to relevant sections of D1.7 and CR 2016/1447.

Table 1. General requirements for HVDC connections.

Requirement	**PROMOTioN D1.7**	**CR 2016/1447**
Frequency ranges	3.2.1.1	II.1.11
Rate-of-change-of-frequency withstand capability	3.2.1.2	II.1.12
Frequency sensitivity modes	3.2.1.3	II.1.15
Active power controllability, control range and ramping rate	3.2.1.4	II.1.13
Synthetic inertia	3.2.1.5	II.1.14
Maximum loss of active power	3.2.1.6	II.1.17
Voltage ranges	3.2.2.1	II.2.18
Reactive power capability	3.2.2.2	II.2.20
Reactive power exchanged with the network	3.2.2.3	II.2.21
Reactive power control mode	3.2.2.4	II.2.22
Priority to active or reactive power contribution	3.2.2.5	II.2.23
Power quality	3.2.2.6	II.2.24
FRT capability	3.2.3.1	II.3.25
Short circuit contribution during faults	3.2.3.2	II.2.19
Post fault active power recovery	3.2.3.3	II.3.26
Fast recovery from DC faults	3.2.3.4	II.3.27
Energisation and synchronisation of HVDC converter stations	3.2.4.1	II.4.28

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks

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Interaction between HVDC systems or other plants and equipment	3.2.4.2	II.4.29
Power oscillation damping capability	3.2.4.3	II.4.30
Subsynchronous torsional interaction damping capability	3.2.4.4	II.4.31
Network characteristics	3.2.4.5	II.4.32
Priority ranking of protection and control	3.2.5.1	II.5.35
Changes to protection and control schemes and settings	3.2.5.2	II.5.36
Power system restoration – black start	3.2.6	II.6.37
Information exchange and coordination	3.2.7	IV

Requirements to offshore generation connected to meshed offshore grids in PROMOTioN D1.7 refer to the AC side of the onshore HVDC converter station. However, some of those requirements (frequency response, synthetic inertia and power oscillation damping) rely on energy sources and coordination with the converter station on the offshore side for their implementation ; from that perspective, the latter requirements will also need communication means to transmit specific onshore measurements such as the frequency to control the remote-end (offshore) converter and the wind farm power accordingly. This is also the case for the requirements to DC connected power park modules specified in CR 2016/1447.

2.2 GENERAL REQUIREMENTS FOR DC CONNECTED OFFSHORE WIND FARMS

The general requirements for DC connected offshore wind farms are listed in Table 2. Several of those requirements also refer to CR 2016/631 establishing a network code on requirements for grid connection of generators.

Table 2. General requirements for DC connected offshore wind farms

Requirement	**PROMOTioN D1.7**	**CR 2016/1447**
Maximum power point tracking	4.1.1.1	
Operational frequency range	4.1.1.2	III.1.39
Operational rate of change of frequency	4.1.1.3	III.1.39
Active power independency of frequency	4.1.1.4	III.1.39
Active power control	4.1.1.5	III.1.39
Frequency response	4.1.1.6, 4.1.1.7, 4.1.1.8	III.1.39
Synthetic inertia	4.1.1.9	
DC voltage response	4.1.1.10	
Voltage range	4.1.3.1	III.1.40

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Reactive power control	4.1.3.2	III.1.40
Reactive power capability		III.1.40
Offshore AC FRT	4.1.2.1	
Post fault recovery	4.1.2.2	
Fast fault current during offshore faults	4.1.2.3	
DC FRT	4.1.2.4	
Onshore AC FRT	4.1.2.5	
Power oscillation damping	4.1.4	
Offshore AC energization	4.1.5	
Auto-synchronous (grid forming) operation	4.1.6	
Power quality	4.1.7	III.1.44

The table shows that in several aspects, PROMOTioN D1.7 specifies requirements going beyond CR 2016/1447:

- It is proposed that the Wind Turbine Generators (WTGs) that OWFs (Offshore Wind Farms) consist of must be capable of performing Maximum Power Point Tracking (PROMOTioN D1.7, 4.1.1.1).
- OWFs may be required to provide synthetic inertia. The operating principle of control systems installed to provide synthetic inertia and the associated performance parameters should be specified by the relevant system operator (PROMOTioN D1.7, 4.1.1.9).
- OWFs may be required to contribute to DC voltage response to support the HVDC grid (PROMOTioN D1.7, 4.1.1.10).
- OWF should be capable of staying connected to the network and continuing to operate after the network has been disturbed by securely cleared (symmetrical and asymmetrical) faults, which results in a voltage within a specified voltage-against-time-profile at the connection point (PROMOTioN D1.7, 4.1.2.1).
- The OWF should recover after faults while complying with
    - a voltage criterion when the post-fault active power recovery begins,
    - a minimum and maximum allowed time for active power recovery;
    - a magnitude and accuracy for active power recovery (PROMOTioN D1.7, 4.1.2.2).
- OWF should be capable of providing specified fault current at the connection point in case of symmetrical and asymmetrical faults (PROMOTioN D1.7, 4.1.2.3).
- OWF should be capable of coordinating with the DC grid control and protection systems in order to modify its output during faults, provided that the DC fault can be detected by the OWF (PROMOTioN D1.7, 4.1.2.4).
- OWF should be capable of modifying its output during onshore AC faults, provided that the onshore AC fault can be detected by the OWF (PROMOTioN D1.7, 4.1.2.5).
- OWF should be capable of contributing to damping of power oscillations. The voltage and reactive power control characteristics of OWF must not adversely affect the damping of power oscillations.

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OWF should be able to modulate its active power output as response to a signal for provision of damping via active power to the onshore AC grid (PROMOTioN D1.7, 4.1.4).

- OWFs should be able to perform necessary control actions, in coordination with Offshore HVDC Terminal, in order to start-up the offshore AC grid (PROMOTioN D1.7, 4.1.5).
- In case there is no reference available to be synchronized with, OWF should be able to perform auto-synchronous operation, where the OWF forms and controls AC grid voltage in its collector system. OWF should be able to switch between synchronous and auto-synchronous operation (PROMOTioN D1.7, 4.1.6).

Especially for requirements related to robustness and control during short circuit faults detailed quantifications are proposed in PROMOTioN D1.7.

2.3 GENERAL REQUIREMENTS FOR REMOTE-END HVDC CONVERTER STATIONS

Requirements for remote-end HVDC converter stations are listed in table 3. They refer to the offshore AC side of offshore HVDC terminals.

Table 3. General requirements for remote-end HVDC converter stations

Requirement	**PROMOTioN D1.7**	**CR 2016/1447**
Voltage range	4.2.1.1	III.2.48
Frequency range	4.2.1.2	III.2.47
Rate of change of frequency range	4.2.1.3	III.2.47
Offshore active power range		II.1.13
Reactive power control		III.2.48
Reactive power capability		III.2.48
Robustness and stability of offshore AC	4.2.2	
Offshore short circuit FRT	4.2.3	II.3.25
Offshore AC energization coordinated with DC connected PPMs	4.2.4.1	
Offshore AC voltage control	4.2.4.2	
Offshore AC power quality	4.2.4.3	III.2.50

Again, PROMOTioN D1.7 proposes requirements going beyond CR 2016/1447:

- Offshore HVDC Terminal should allow for necessary control actions to prevent or help damping electrical oscillations in the offshore AC grid (PROMOTioN D1.7, 4.2.2).
- Offshore HVDC Terminal should be able to perform necessary control actions, in coordination with OWFs, in order to start up the offshore AC grid (PROMOTioN D1.7, 4.2.4.1).

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- Offshore HVDC Terminal should be capable to control the offshore AC voltage by itself, by proper coordination with OWFs or by proper combination thereof (PROMOTioN D1.7, 4.2.4.2.)

For wind power plants connected to DRU terminals, a significant amount of the requirements to the remote-end converter are transferred to the offshore wind power plant. As a consequence, complexity in the offshore wind power plant regarding operation, control and communication will increase. Requirement recommendations to adapt and extend existing grid codes with the focus on the recommendations to cover the DRU concept are specified in PROMOTioN D3.8. An overview is given in section 4.3 of this document.

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3 GAP ANALYSIS

Section 3 provides a gap analysis of those areas where existing grid codes, standards and processes require complementing or adapting to respond to the findings of the earlier PROMOTioN work and to the emerging areas of best practice concern being identified. It is divided into a gap analysis at the AC points of connection on and offshore (section 3.1) and at the DC point of connection (section 3.2).

3.1 GAP ANALYSIS ON REQUIREMENTS AT THE AC POINT OF CONNECTION

An important source of information is a questionnaire survey that was carried out for PROMOTioN D11.5. Although its focus was on compliance evaluation, it also provides input from TSOs and developers concerning gaps in current grid codes and standards:

- There are no requirements available focusing on the interoperability of power electronics equipment in an AC grid
- Compliance evaluation processes are quite mature in EU markets where we operate. However, more focus in the future should be put on issues that are largely affected by generation being inverter-based rather than synchronous.
- Grid codes which combine practical usability with strict and clear requirements are most welcome.
- For an offshore synchronous area, the starting point may be to think about imposing the same frequency and frequency regulation requirements on the offshore system, but that may not be the most feasible and economic solution. Instead, the starting point should be that whatever the permitted frequency variation refers to the offshore frequency, this should not compromise frequency response or other capabilities such as resilience to faults of the whole HVDC system as it is observed onshore.
- Whilst limited standardisation exists to define the nature of the design of the offshore AC island, its control strategies and specification. The existing onshore requirements have consequences that for progressively larger and more complex offshore design lead unavoidably towards particular areas of requirement which may benefit from future standardisation.
- A further area of robustness consideration exists as future multi terminal HVDC links may form and support “loop flows” across an onshore network. In this role, the specification of the HVDC connections themselves may be required to be more robust than that of the generation they support, such that – in the condition of an extreme event – their collective loss at the point in time where generation may begin to disconnect does not further exacerbate the effect of the extreme event.
- The term synthetic inertia sits in CR2016/1447 (HVDC) and CR 2016/631 (RfG) and other grid codes. However, there is no agreed definition of this concept which also makes it challenging to verify compliance.

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3.2 GAP ANALYSIS ON REQUIREMENTS AT THE DC POINT OF CONNECTION

All previously stated regulations focus on the AC points of connection of HVDC systems. At the point of writing of the commission regulation, there were no multi-terminal HVDC systems in operation in Europe, which is still the case today. All existing links are point-to-point key-turn projects which are mainly designed to be an addition to the existing AC systems, which therefore dictate the requirements on the DC system. However, there are now several multi-terminal HVDC systems planned and to allow the development of larger multi-terminal offshore DC grids in Europe requirements at the DC point of connection need to be defined.

Setting up a grid code from scratch for the DC side is challenging:
In general any grid code should be discriminatory free toward the used technologies by specifying functional requirements, facilitate interoperability, e.g. between different vendors and components and ideally a DC grid code would develop to allow "plug-and-play" of the different components in future HVDC grids as it was in existing AC grids for the last decades. This was possible for the AC systems, because there are among other factors standardised voltage levels, components, grounding and fault clearings strategies. As indicated by the previous gap analysis, there are now also new challenges at the AC point of connection due to the increasing integration of HVDC systems into the AC systems.

Fulfilling the above named criteria for a new HVDC grid code is ambitious due to several aspects. Exemplary reasons are stated in the following.
Most generally, there are no standardised HVDC grid designs, yet. For example, there are different system configurations in use and under discussion for future HVDC with different associated grounding strategies and different resulting characteristic current and voltage profiles under fault conditions, to name the most commonly discussed: Symmetric monopole and bipole with metallic return. Furthermore, there are several voltage levels in use for existing and planned systems, e.g. ± 320 kV, ± 400 kV and ± 525 kV. While theoretically it is feasible to connect HVDC systems with different voltage levels and system configurations, the first would require further components and both make coordination between the different system components more challenging.
Moreover, the technology for HVDC systems is still under development. The commonly used voltage source converter technology envisaged for the set-up of future multi-terminal HVDC systems has been applied for the first time in 2010 and was only proposed in 2003. There are different variants of this converter type leading to different possible functionalities, e.g. with regard to voltage ranges and fault clearing. There are no standardised protection concepts for multi-terminal DC systems: Several fault detection and fault clearing concepts and components are being proposed and under development, e.g. protection IEDs and DC circuit breakers. PROMOTioN has contributed to developing these concepts and technologies further and bringing them to higher TRL levels. Moreover, it also initiated standardisation on several aspects, like DC circuit breaker fault current interruption tests, DC GIS systems and DC protection and control related aspects. For a complete overview of contribution to further standardisation in HVDC systems, please refer to D11.2, D11.3 and D11.5.
Apart from the system design and its components, another challenge is the specification of the wanted converter behaviour and the interaction between converters, e.g. for dynamic changes and transient events like faults. This entails two parts: knowing what a suitable behaviour from the components and system perspective

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would be and having the means to specify it appropriately. This is challenging because the time constants in DC systems are one order of magnitude smaller than in existing AC systems. While the AC system behaviour under transient events was determined by the passive behaviour of the components in the first milliseconds, the behaviour of the converters during this time frame has to be understood and defined in the controls, especially considering the limits of today's power electronic devices.

Another challenge in specifying requirements at the DC side point of connection for future systems, is that the overall system behaviour of the integrated AC and DC system has to be taken into account. Any changes related to active power in the DC system will have an impact on the connected AC systems and vice versa. For example to allow for ancillary services at the AC connection points related to AC system frequency, active power has to be exchanged, which has to have a corresponding source or sink and the required transmission capacity in the DC system has to be available. Thus, while there are no operational guidelines for the future HVDC grid specified, it will be difficult to translate different possibilities into requirements at the converter connection points.

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4 RECOMMENDATIONS ON GRID CODE ADAPTIONS AND EXTENSIONS

4.1 RE-EVALUATION OF REQUIREMENTS BASED ON RESULTS (PROMOTION D1.7)

PROMOTioN D1.7 lists the updated and evaluated qualitative and quantitative set of requirements for the Meshed Offshore Grid (MOG) that is used throughout the project. Table 1, table 2 and table 3 show that requirements are defined also where CR 2016/1447 does not provide specific requirements. The results of D1.7 can serve as basis for recommendations to grid codes.

4.2 REQUIREMENTS RECOMMENDATIONS FOR GRID CONNECTION OF HVDC SYSTEMS AND DC CONNECTED POWER PARK MODULES (PROMOTION D2.4)

Based on the work in WP2, PROMOTioN D2.4 compiles requirement recommendations to adapt and extend existing network codes (NCs) for high voltage direct current (HVDC) systems which are in interaction with HVAC transmission grids. The focus is on the converters' DC point of connection (PoC) and the onshore AC PoC, while both point-to-point HVDC links and meshed HVDC systems are addressed.

While the ENTSO-E commission regulation was the starting point, several national implementations were drafted and published on this basis. Within WP2 a comparison of the existing national HVDC NC in Denmark, Germany, Spain and the UK was carried out to check for harmonization potential and possibilities to specify certain aspects in more detail. The comparison shows that the NCs specify the requirements from the EU NC 2016/1447 which are usually similar but not identical. For instance, it can be noted that the FRT profiles go consistently down to 0 p.u. AC voltage and also that the fast fault current injection shall prioritize reactive current over active current for the AC voltage support. However, there exist also considerable differences when it comes to the comparison of definite values: Disparities are observed in the required converter operation times at specified frequency ranges while major inequalities are identified in the required response times for the frequency controls. Furthermore, it is noticed, that the UK grid code provides an FRT profile for single-phase faults, while the German NC clearly demands an uninterrupted grid connection as long as the fault is cleared by the AC grid protection.
Concerning the level of detail of the four national NCs, the German grid code appears to be the farthest in its specification. For example, the mitigation of the RoCoF is explicitly addressed and the provision of dynamic voltage support without a reactive current reference is introduced, pointing slightly towards future grid-forming capabilities. Both these aspects may be particularly related with the fast-rising number of grid-connected HVDC converters going into operation in Germany within the next decade, accompanied by the nuclear and coal phase-outs in 2022 and 2038, respectively.
A general difference in the specified timings and ranges can occur, if the specifications are written having in mind either the capabilities of the HVDC converter or the capabilities and/or needs of the connected AC systems. One distinctive example could be the power reversal capabilities: While the HVDC converter might be

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able to change the power contribution within several milliseconds, the impact on the connected systems importing or exporting the related energy should be taken into account as well.

Table 4 provides an overview of the requirements at the onshore AC point of connection for which adaptions or extensions are recommended.

Table 4: Overview of requirements at the onshore AC point of connection.

Requirement	**PROMOTioN D2.4**
AC fault ride through	2.2.1
AC voltage support	2.2.2
Frequency ranges	2.2.3
Synthetic inertia	2.2.3
Active power capability	2.2.3
Frequency control and control modes	2.2.3
Frequency support from offshore WWPs (OWPPs) and asynchronous AC grids	2.2.3

Although they are not fully aligned, the requirements imposed by the various national implementations of the grid code at the offshore connection point should not contradict each other and remain consistent one with another. It is therefore recommended to define common boundaries for the latter as minimal requirements common to all involved stakeholders. Within those boundaries, the exact values for each requirement (e.g. the FRT profiles for the AC voltage) can be decided on a project-specific basis.

In a separate section of PROMOTioN D2.4 grid code requirements at the DC point of connection are analysed. Existing grid codes typically consider HVDC converters and systems as separate grid components from the perspective of the AC network, i.e. not considering the DC side aspects. To facilitate the development of multi-terminal HVDC systems requirements on the DC side are needed.

Table 5 provides an overview of aspects which should be considered when drafting future grid codes based on the analysis in PROMOTioN. It is not a comprehensive list of all aspects that will likely be covered in future grid codes.

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Table 5: Overview of requirements at the DC point of connection.

Requirement	PROMOTioN D2.4
Voltage levels and ranges during normal conditions	3.1.1
Temporary overvoltages	3.1.2
Transient voltage profiles	3.1.3
Expected behavior of the converter during faults and recovery	3.2.1
Implications of DC FRT on the WPP	3.2.2
Specification of required control modes	3.3.1
Power ramp rates (normal conditions)	3.3.2
Requirements on power balancing capabilities at nodes	3.3.3
Integration of DRUs	3.4.1
Interaction between AC and DC side	3.4.2
Security criterion and reliability criteria	3.4.3
Maximum transfer capacity per cable / converter because of primary reserve	3.4.4

As discussed in section 3.2, specifying a lot of these aspects in a non-discriminatory way will be difficult due to the broad range of available technologies, their potential for further development and non-existing standards in grid design and protection among other factors.

4.3 REQUIREMENT RECOMMENDATION FOR DRU CONNECTED WIND POWER PLANTS (PROMOTION D3.8)

PROMOTioN D3.8 provides a list of requirement recommendations to adapt and extend existing grid codes with the focus on the recommendations to cover the DRU concept, which has been studied in detail in WP3 of PROMOTioN. The deliverable provides an overview of the considered and proposed requirements for DRU connection and indicates whether the requirements are equivalent to an existing grid code requirement, which can be fulfilled by DRU based systems, or if adaptions and/or extensions have been proposed to facilitate DRU integration (Table 5).

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Table 5: Overview of requirements considered for DRU connection in WP3 (Source: PROMOTioN D3.8)

Requirements for DRU connection	Existing	Adapted	Extended
2.1 Dynamic Active Power Control	X		
2.2 Island Support (No HVDC or AC Connection)			X
2.3 Minimum Production Limit (DR mode)			X
2.4 Steady State Frequency Control (DR mode)		X	X
2.5 Optimized (Narrow) Frequency Range		X	X
2.6 Dynamic Frequency Control		X	X
2.7 Rate of Change of Frequency (ROCOF) Limits		X	X
2.8 Steady State Voltage/Reactive Power Control		X	X
2.9 Dynamic Voltage Control		X	X
2.10 Offshore FRT		X	X
2.11 DC FRT Requirements		X	X
2.12 Onshore AC FRT		X	X
2.13 Onshore Frequency Support Requirements	X		
2.14 Synthetic Inertia	X		
2.15 Onshore Oscillation Damping Requirements	X		

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks

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5 SUMMARY

Within the PROMOTioN project, various work packages analyse grid code requirements to HVDC systems, to DC connected offshore wind farms and to remote-end HVDC converter stations in a very detailed way in order to

- identify gaps in current grid codes
- define requirements / specifications
- develop recommendations for the further development of grid codes

PROMOTioN D1.7 lists a qualitative and quantitative set of requirements for the meshed offshore grid based on the progress in the technical work packages during the first two years of the project.

PROMOTioN D2.4 compiles requirement recommendations to adapt and extend existing network codes (NCs) for high voltage direct current (HVDC) systems which are in interaction with HVAC transmission grids

PROMOTioN D3.8 provides a list of requirement recommendations to adapt and extend existing grid codes with the focus on the recommendations to cover the DRU concept.

PROMOTioN D 11.5 focuses on recommendations and best practice for compliance evaluation.

This document summarizes the findings of various work packages that have been published in different documents and deliverables and provides references to the relevant sections of Commission Regulation (EU) 2016/1447 on the one hand and of PROMOTioN deliverables on the other hand. It thereby provides a means of finding detailed information from all parts of the project.

In general, it is to note that countries specify requirements on HVDC systems in different levels of detail and that currently demanded values can considerably differ. Therefore, it is seen as one important recommendation for transmission system operators (TSOs) to agree on minimal requirements which shall ensure the compatibility of their national requirements and benefit in from homogeneity and a uniform behaviour throughout the ENTSO-E area. Further on, the analysis made clear, that the present NCs are not intended for (multi-terminal) HVDC grids but that, instead, HVDC converters are thought of as separate grid components affecting the AC network. Future grid code works should address the HVDC converters also from a DC system point of view to facilitate the development of multi-national multi-terminal systems in Europe. One first step forward could be the agreement on selected DC voltage levels and ranges. Furthermore, as the installed capacity of HVDC converters within the AC grids is expected to keep rising, the converters' interaction with the AC system, e.g. under fault conditions, should gain more attention in future HVDC grid codes.

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[4] PROMOTioN D3.8. List of requirement recommendations to adapt and extend existing grid codes.

[5] PROMOTioN D2.4. Requirement recommendations to adapt and extend existing grid codes.

[6] PROMOTioN D11.5 Best practice and recommendations for compliance evaluation.

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