ENTSO-E Position on Offshore Development

Interoperability

25 January 2021

About ENTSO-E

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the pan-European association of 42 electricity transmission system operators (TSOs) in 35 countries. In 2009, ENTSO-E was registered in the EU legislation and has since then been given a series of legal mandates.

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Executive Summary

This paper outlines the perspectives of ENTSO-E and Transmission System Operators (TSOs) regarding solving the technical challenges related to the interoperability of the main components of offshore high-voltage direct current (HVDC) systems. The need for interoperability originates from the integration of a high number of converters delivered by various manufacturers and consequently based on a diversity of technologies. This document focuses on enabling the development of multi-terminal, multi-vendor[1] offshore HVDC systems. The proposals and recommendations for achieving interoperability are also applicable to onshore HVDC grids and all multi-vendor power electronic interfaced device (PEID) systems.

This position paper considers the current state of technology and research and explains which practical issues remain to be solved to achieve the multi-terminal, multi-vendor, offshore HVDC systems interoperability. The identified needs for action are compared against the "do nothing" option by impact assessments. The following key issues are considered essential for resolving the present shortcomings and barriers to a reliable and cost-efficient interconnected offshore grid infrastructure.

1 The term "multi-vendor" refers to technologies from different manufacturers, not to their sales departments

Mutual development effort

TSOs[2] and manufacturers must acknowledge that a mutual effort is required to achieve fit-for-purpose specifications of system components in the design phase. TSOs cannot draft detailed specifications without knowing the specific characteristics and behavior of potential assets and without performing de-risking studies already in the planning and design phase of the projects. A consensus between TSOs and manufacturers regarding the adequate level of specifications is requested in this early phase.

Simulation models

TSOs must evaluate the expected dynamic performance of the system by using appropriate simulation models which properly reflect the assets' electrical behaviour. These models need to be already available for TSOs in the planning and design phase of the projects, during which TSOs have to rely on the manufacturers' support. Both parties should acknowledge that the models need to evolve during the development stages of a project. Models provided by manufacturers must be interoperable so they can be integrated and tested in independent simulation environments available for TSOs on multiple platforms. These simulation models must be accessible to all relevant parties for system engineering studies in a multi-vendor environment. Commitment by manufacturers to a level playing field in transparency is essential while still respecting intellectual properties.

High voltage industrial full-scale demonstrator project

The operational interoperability of HVDC grids optimally requires demonstration in a full-scale industrial high-voltage project for de-risking. In addition, for de-risking multi-vendor controls, down-scaled test environments can be used in parallel. However, to de-risk an entire HVDC project, a full-scale demonstration is the ultimate target. A TSO-led initiative in cooperation with manufacturers is considered the best approach. This initiative must include clear implementation processes, which need to be accompanied by studies involving all relevant stakeholders to prepare such a demonstrator. Such a project will increase the technology-readiness of HVDC multi-terminal, multi-vendor, multi-purpose systems for later commercial application.

Scalability and replicability

To achieve economies of scales and synergies, the replication of new methods/approaches and learning effects from pilot and demonstration projects need to be ensured. Therefore, the upcoming activities must involve all relevant parties and facilitate knowledge sharing and standardisation efforts.

2 "TSOs" refers to the grid operator. The ownership models may vary across some countries.

1. Motivation

A major part of the integration of large-scale offshore renewables into the European energy systems will be realised by applying HVDC technology. As described in the ENTSO-E's first position paper on offshore development, a stepwise and modular development of technology and designs is expected (Figure 1). In particular, the multi-purpose design concepts building on HVDC technology must evolve and develop progressively.

Although current point-to-point HVDC connections have reached the highest technology readiness level (TRL 9), multi-terminal HVDC offshore grids connected from the DC side are still at a preliminary development level and mainly a topic of research activities. No full-scale, multi-terminal, multi-vendor demonstrator project currently exists in Europe[3] – neither offshore nor onshore. Considering the huge amount of expected offshore renewable energy sources (RES), it is clear that offshore infrastructure must be ready to evolve from one design concept into another (Figure 1).

3 Multi-terminal multi-vendor projects such as Zhoushan and Zhangbei are already completed or under implementation in China.

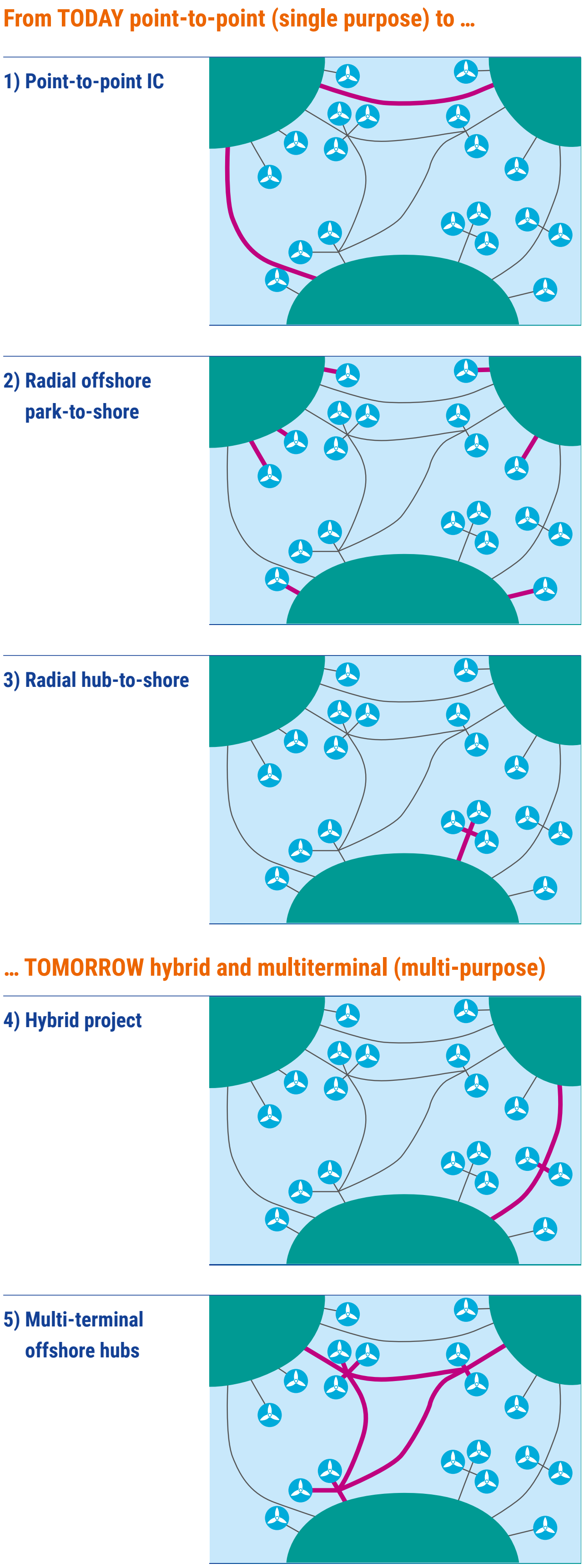


Figure 1: Various offshore design concepts with 1) – 3) being single purpose and 4), 5) being multi-purpose (connecting offshore RES and connecting markets)

For the cost-efficient and scalable development of the HVDC grid infrastructure, the single-vendor approach, as currently applied in point-to-point projects, must evolve towards multi-vendor and multi-purpose capabilities for HVDC converter stations, HVDC switching stations and Power Park Modules (PPMs). It should be possible to purchase such assets from various manufacturers, similar to the manner in which AC grids have evolved. Plug and play[4] approaches are required to facilitate the necessary acceleration accommodate the Green Deal targets. Multi-purpose, multi-terminal, multi-vendor characteristics are key for the future HVDC infrastructure. To facilitate this, interoperability between technologies and between different vendors must be ensured:

- **TSOs, HVDC suppliers and offshore developers require a technical and regulatory collaboration framework to be able to develop such schemes. This enables a smooth performance of all the steps: from the basic design to the bidding process and construction phase, as well as the extension of such projects at a later stage.**

- **The extendibility of such HVDC grids in the design phase must be ensured, i.e. the capability of HVDC grids to connect further converters and DC cables from various manufacturers during their lifecycle.**

Solving the above issues will contribute to integrating offshore RES and European energy markets without jeopardising the security of supply and risking stranded investments.

Therefore, it is of utmost importance that HVDC equipment and control schemes from different manufacturers are interoperable. Hence, the proposals and recommendations for achieving HVDC interoperability are also applicable to onshore HVDC grids.

Definition

Interoperability of a transmission system, its subsystems and components is defined as their ability to function together, seamlessly allowing the transmission of electricity at the required power quality and level of security of supply.

4 With site-specific settings and configurations.

1.1 Purpose of the Position Paper – Breaking the Vicious Circle

Recently finalised research initiatives such as the European H2020 projects "BestPaths[5]" and "PROMOTioN[6]" have addressed the topic of interoperability, identifying present gaps on how to approach the challenges it raises and concluding that from a pure technical perspective, no "showstopper" could be identified. However, TSOs still see considerable uncertainty regarding the practical implementation of HVDC multi-terminal, multi-vendor projects, due to limited field experience in this context. Moreover, HVDC manufacturers do not guarantee interoperability by contract. The current situation is characterised by a closed loop, according to Figure 2.

A. To offer technological solutions, manufacturers require specifications which cover the required asset capabilities and performance in compliance with system needs.

B. However, up to this point, TSOs cannot yet draft detailed specifications for HVDC multi-terminal, multi-vendor multi-purpose systems due to limited operational experience with these technologies, especially under inter-operating conditions.

C. Finally, manufacturers cannot develop products without specifications at a sufficient level of detail. As a consequence, position A appears again.

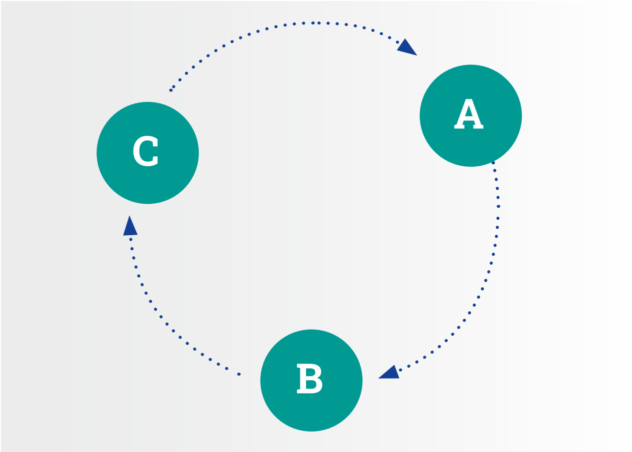


Figure 2: Schematic impact of the current situation regarding solving interoperability.

To break this loop, a joint first-of-a-kind full-scale demonstration project is required before exploiting the technology in a market-driven environment. This would result in an enhanced common understanding between TSOs and manufacturers and would mitigate the associated risks of implementing an interconnected HVDC grid infrastructure.

In the following, the further definitions of "interoperability" and its implications are elaborated. Furthermore, the roles and responsibilities that arise within the different stakeholder groups are analysed so that interoperability can be ensured.

5 Best Paths, H2020 EU Research project, http://www.bestpaths-project.eu/

6 PROMOTioN - Progress on Meshed HVDC Offshore Transmission Networks, H2020 EU Research project, https://www.promotion-offshore.net/

1.2 Definitions: Interoperability between Manufacturers and Technologies

By ensuring the interoperability of systems, technical implementation risks and failures of hardware, software and control systems are reduced as technical solutions are harmonised. A common understanding is created between stakeholders, which finally leads to the standardisation of assets. Harmonising the technical solutions which become commercially available facilitates the integration of new technologies and solutions in a "plug and play" manner. Some re-tuning of controls might, however, be necessary during project implementation. In addition, interoperability enhances the competition and cost-efficiency of the overall system when designing and extending HVDC multi-terminal systems.

Interoperability includes **"technological interoperability"** and **"manufacturer interoperability".**

Technological interoperability covers the operational compatibility of different technologies, e.g. interoperability between 3-level voltage source converters (VSCs) and modular multi-level converters (MMCs). In this case, different technologies might also come from the same manufacturer.

Manufacturer interoperability describes the necessity of compatibility of the same technologies but from different manufacturers. Figure 3 illustrates these differences. Moreover, both types of interoperability can appear simultaneously, i.e. the compatibility of different technologies from different manufacturers.

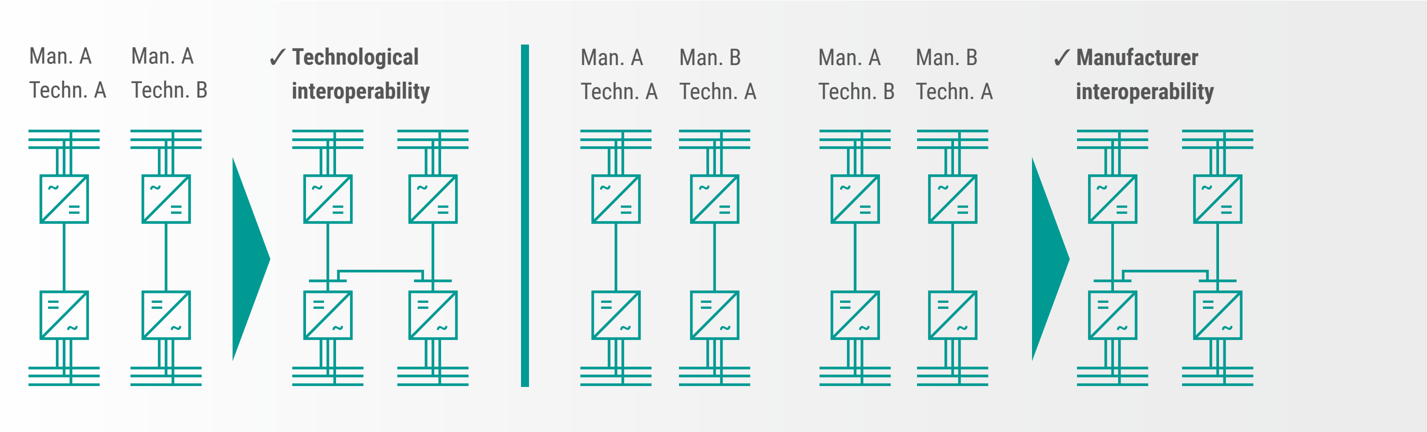


Figure 3: Exemplary illustration of technological interoperability vs. manufacturer interoperability

1.3 Roles and Responsibilities of the Relevant Stakeholders

To successfully establish an interconnected HVDC transmission system, the roles and responsibilities of all involved parties need to be clearly assigned and mutually respected. However, closer cooperation between TSOs and manufacturers, starting from their respective domains of responsibilities and expertise as well as intellectual property rights, is required.

Today's principles for application to system design do not vary from the relevant pillars of onshore transmission system design and include:

- solid system planning criteria and connection rules to achieve
  - an adequate level of security of supply,
  - sustainability and robustness, and
  - non-discriminatory access to system users / market players.
- harmonised and standardised functional specification of system and equipment to achieve
  - seamless interoperability of system components, and
  - cost-efficiency.

The most relevant competences that stem from these principles are the application of

i) holistic engineering expertise for power systems and

ii) dedicated expertise for developing and specifying assets.

As stated in the first ENTSO-E position paper on offshore development, holistic system engineering competence is a typical TSO strength, whereas dedicated expertise for specifying assets lies with the respective manufacturers. Closer cooperation between TSOs and manufacturers should be envisaged, with the TSOs[7] taking a leading role as infrastructure owners and operators backed by a legal mandate for system security.

Power system engineering determines the system characteristics and performance criteria for power transmission and supply at a level of security, sustainability and robustness adequate to achieve the EU energy policy objectives. All system components must be specified and designed to match these system needs while considering reasonably technical opportunities but also possible limitations or restrictions.

7 "TSOs" refers to the grid operator. The ownership models may vary across some countries.

2. ENTSO-E's key messages for interoperability

Interoperability remains the enabler for the development of multi-terminal, multi-vendor HVDC projects. Research projects such as "BestPaths" and "PROMOTioN" have already outlined the necessities and formulated innovation steps for interoperability, but a number of practical issues regarding the implementation of multi-terminal, multi-vendor HVDC solutions in full-scale projects remain unsolved. TSOs are motivated to lead relevant studies and participate in the appropriate initiatives to develop processes and methods for practical application.

To address the development needs, the relevant aspects of interoperability can be distinguished by technical and legal issues, which are listed in Table 1.

Technical issues	Legal issues
› Functional and operational requirements	› Intellectual property rights
› Demonstration in target environment	› Contractual relations and warranties
› Power system engineering and planning	› Regulation and Legal Framework
› Standardisation of systems and equipment	

Table 1: Classification of interoperability aspects by technical and legal issues.

Within the following sections, the above issues are further explained. ENTSO-E's key messages on open issues are provided, including suggestions on how to approach them.

The importance of finding solutions for each issue is underlined by a short impact analysis in the event these issues continue to remain unsolved – the "do-nothing" situation.

2.1 Technical issues

2.1.1 Functional and Operational Requirements

Current HVDC Connection Requirements

The European Network Code HVDC (Commission regulation (EU) 2016/1447) defines the required capabilities of an HVDC system, including parameter ranges and characteristics at the AC grid connection point. It provides a minimum set of requirements for the functionality of HVDC systems at the AC-interface but does not cover DC grid functional requirements at potential DC-side connection points, which will become relevant in the context of multi-terminal systems.

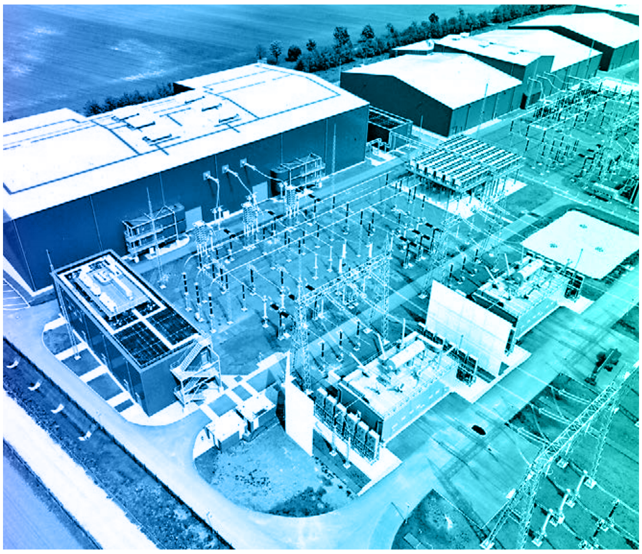
Need for DC Grids' Functional and Operational Requirements

The definition of DC grids' functional requirements is considered necessary as network codes and guidelines for DC systems are currently not available. Similar to AC transmission systems, such codes and guidelines are essential elements for implementing energy policy objectives and facilitating the electricity market at an adequate level of security of supply. Such DC grid functional requirements must consider all DC subsystems and DC grid elements, and define connection requirements in terms of capabilities of systems and equipment at DC-side connection points. These requirements must address a minimum set of functionalities and capabilities for securing grid stability and power quality, hence enhancing the NC HVDC or developing a new network code for DC grids. In addition, an operational guideline, similar to the system operation guideline, is deemed necessary to define the operational requirements and rules for DC grid systems, also complementing the Network Code on Electricity Emergency and Restoration (NC ER). Finally, market rules also have to be defined.

The DC grids' functional and operational requirements must be drafted in cooperation with the relevant technical stakeholders. Stakeholder interaction should include the exchange of reports, studies and possible technical solutions to demonstrate cooperation and make efficient use of the work already done. Functional requirements and industrial standards (IEC, CENELEC etc.), either existing or under development, should be aligned to achieve the cost efficiency of system implementation.

Impact (if issues are not solved)

If DC grids' functional and operational requirements are not available, interoperability will be significantly impaired or may not be achieved at all, with an adverse impact on market facilitation and security of supply. The lack of clear requirements would result in an increase of implementation costs and reduced scalability as tailored and proprietary solutions would be implemented for each separate project. Finally, the absence of an interoperable grid infrastructure would impede the achievement of the energy policy targets.



2.1.2 Demonstration in Target Environment

A real full-scale industrial demonstration project[8] is deemed necessary in a steps-wise approach to confirm and prove the technology readiness of HVDC grid solutions and reduce the risks for investments in subsequent projects. The high voltage multi-terminal, multi-vendor demonstration should be a cross-border project[9] and ensure replicability. This means that the developments must not be applicable to the demonstration project only but serve as a pilot facilitating the stepwise development of further multi terminal, multi-vendor HVDC grids. Interoperability must be ensured for the successful realisation of this. In parallel, additional de-risking efforts using down-scaled test environments can be applied, focusing on the interoperability of control systems.

The development of the requirements/specifications and demonstrator needs to be aligned and defined together with the relevant stakeholders. This cooperation could include, but is not limited to, studies for assessing the impact of the HVDC system on onshore systems.

Projects and related locations assessed in the Ten-Year Network Development Plan (TYNDP) and projects potentially investigated by the H2020-Project "PROMOTioN" could be considered as potential demonstration projects. Proving the suitability of defined requirements/specifications while preparing a real implementation in a step-wise approach is considered necessary to decrease the associated risks by facilitating standardisation activities in parallel.

Impact (if issues are not solved)

If the mitigation and reduction of risks of a multi-vendor HVDC project cannot be demonstrated by a real full-size project, no multi-vendor projects will be initiated. If interoperability is not demonstrated and de-risked, also proven during lifetime, then single-vendor projects will prevail. Proprietary systems will most likely not be able to function when linked together to a larger multi-terminal system.

TSOs and stakeholders would remain at the level of rather academic R&D-based demonstration. R&D efforts are useful and necessary but not sufficient to safeguard the practical and flexible industrial solutions that are replicable to other projects.

2.1.3 Power System Engineering and Planning

To solve the open engineering and planning issues with regard to interconnected HVDC systems, TSOs must define the technical requirements and operational guidelines on both the AC and DC side, considering the impacts on the interconnected power system as a whole. TSOs are one of few entities who can take responsibility for the development, construction, operation and maintenance of the HVDC transmission infrastructure comprehensively; therefore, they should already be taking a leading role when technical requirements and operational guidelines are defined.

TSOs and HVDC system manufacturers must collaborate in defining functional requirements to adequately consider opportunities and expansion potential but also the limitations of existing and future technologies. A common planning approach for multi-terminal HVDC systems is a prerequisite for an efficient and aligned infrastructure and the minimising of divergent national implementations.

Impact (if issues are not solved)

TSOs must identify and limit the risks when integrating additional DC components in the existing system. If today's planning approaches evolve further, with adequate consideration of the new technologies and (sub-)systems, then AC- and DC-system characteristics and performance may be incompatible with each other. This may impair system interoperability and efficiency and reduce the overall reliability and thus security of supply, especially if multiple manufacturers are included in a project. In the event that technical and/or vendor interoperability is not achieved, this may lead to stranded investments, thus reducing social welfare.

8 Such a project will be based on a cost–benefit analysis and will be a "first of a kind" project, which will continue operation until the end of its lifetime

9 Cross border ensures a multi-TSO collaboration

2.1.4 Standardisation related to multi-terminal, multi-vendor HVDC Grids

Standardised models, interfaces and processes in the design phase will support the required studies for de-risking of the projects before their practical implementation; whether it be the requested demonstrator or, subsequently, commercial projects. The scope and objectives of relevant engineering studies as well as the roles and responsibilities of involved parties must be defined in order to be comparable and transparent (e.g. interaction studies, modelling methods). Standardisation of models, tools and design processes must be based on the open participation, consultation and consensus of relevant parties.

Contrary to current common practice, it is necessary to consistently adapt converter models to reflect changes in the installations during the lifetime of the converter, e.g. due to adaptations of the control system. To enable this, models of control schemes and of physical characteristics and behavior of systems and equipment[10] should be separated, requiring standardised interfaces between model parts. It is important that converter control models and interfaces are agreed upon between manufacturers and other parties involved in simulation studies. This is important to facilitate the appropriate modelling of performance and interaction of systems and equipment during the planning and functional specification phases, in order to adequately estimate the behavior of the real implementation. This should include offline Electro Magnetic Transient as well as real-time Hardware In the Loop and Software In the Loop studies.

Furthermore, manufacturer interoperability especially calls for the standardised functional specification and design of systems and equipment. Such industrial standards must be developed or – if already existing – eventually enhanced based on system needs, but considering the opportunities and limitations of certain technologies. TSO and manufacturers should collaborate closely in their respective domains of expertise to align legitimate interests.

Impact (if issues are not solved)

The lack of standardisation of the above-mentioned models, interfaces, processes and the functional specification for the design of systems and equipment can lead to the incompatibility of simulations models used by different parties, or a mismatch between the expected and real performance of system components. For example, TSOs might conclude specifications from system needs which may not be reasonably feasible for certain technologies, or manufacturers may specify systems and equipment which are not fit-for-purpose with regard to specific system needs. Another risk is that interoperability studies may be defined differently by different manufacturers and the outcomes cannot be compared between each other.

Eventually, TSOs would take over full responsibility without knowledge of the full operational performance risks of new assets or multi-terminal, multi-vendor structures. In a worst-case scenario, assets cannot be used, or may be damaged or even destroyed, if not responding correctly under real multi-terminal, multi-vendor system conditions. This reduces cost-efficiency (e.g. in the event of stranded investments), reliability and security of supply.

In a different scenario, HVDC connections may not be extended to multi-terminal, multi-vendor systems. Competition between manufacturers may be compromised, with the risk of remaining in the current status quo in which TSOs will be locked into one manufacturer for each project. Potentially, the number of manufacturers may be reduced and market entry barriers for new ones will be created.

10 E.g. HVDC converter stations, HVDC switching stations and PPMs.

2.2 Legal Issues

In addition to the technical perspective explored in the previous chapter, the completed European H2020 projects "BestPaths" and "PROMOTioN" have underlined the presence of a number of additional legal barriers such as existing regulation. Related messages are summarised below.

2.2.1 Intellectual Property Rights, Contractual Relations, Warranties and Legal Framework.

Currently, HVDC assets for offshore wind power connections are typically contracted and purchased via engineering, procurement and construction contracts from a single manufacturer for complete point-to-point systems. The technical functionalities and the operation of these systems do not consider connection and interaction with other manufacturers' equipment. Such a contractual framework does not cater to multi-terminal, multi-vendor extensions and would not allow mutual interaction studies and compliance simulation and testing. Consequently, to establish a multi-vendor cooperation framework the existing contractual relations would have to be revised. A multi-vendor framework has to enable model sharing, ensure proper conditions for interaction studies in particular with regard to control and protection systems to detect interoperability issues, and define liabilities and warranties in the event of malfunctioning. It is also important to safeguard intellectual properties when exchanging know-how between manufacturers, TSOs and other stakeholders.

In addition, moving from point-to-point offshore wind connection to more complex interconnected structures will also "link" different national legal and regulatory regimes to each other. All related questions regarding asset ownership, the allocation of costs and benefits, and operational and market rules will have to be solved prior to the commercial operation of these systems. Hence, planning, developing and implementing a complex (offshore) HVDC grid requires substantial efforts by European and national policy makers to create a sound legal and regulatory governance for developing and operating these systems. The longer this takes, the higher the risk that investors will reduce their commitment to invest.

3. The way forward – unlocking multi-terminal, multi-vendor HVDC systems

Offshore wind energy is expected to be an important part of the European energy transition and a key contributor to reaching the climate targets of the EU Green Deal. ENTSO-E and the TSO community are committed to promoting and developing a full-scale multi-terminal, multi-vendor HVDC system demonstrator in order to investigate and solve interoperability issues and enable the development of such assets towards a higher technological readiness level for competitive solutions. It is essential to mitigate the associated risks in cooperation with offshore RES developers, manufacturers and other stakeholders via such a demonstration project before exploitation in a market-driven environment.

3.1 Tasks for TSOs

To de-risk future projects regarding multi-terminal, multi-vendor HVDC systems, TSOs will start adapting their planning approaches. One necessary step is to assess the possible interactions early in the planning phase by performing interaction studies. The aim is to detect interoperability issues as early as possible and to establish more precise and fit-for-purpose functional specifications for new DC assets to reduce associated risks. Coordinating and performing engineering and interaction studies in a multi-vendor environment becomes more relevant compared to today's point-to-point HVDC planning.

The development of rules and requirements is also a major task for TSOs, which need to be adapted when developing multi-terminal multi-vendor HVDC systems. This includes the adaption of existing network codes (e.g. NC HVDC, NC ER) as well as the formulation of new guidelines operating multi-terminal, multi-vendor HVDC systems.

Furthermore, TSOs must drive the development towards a full-scale demonstrator project to reach a higher level of technology readiness and facilitate the standardisation of systems and equipment in a "plug and play" manner.

3.2 Tasks for Manufacturers

Manufactures must support TSOs in defining the coverage, level of detail and clear interfaces of models to be used for interaction studies and further pre-studies in a multi-vendor environment. This could include, but is not limited to, the definition of electrical as well as control signal interfaces.

Current shortcomings in the exchange of expertise while still respecting intellectual properties must be overcome.

The manufacturers, in cooperation with other stakeholders, should take the lead in defining the contractual and legal relations necessary to establish a multi-vendor cooperation framework.

The manufacturers should also take the opportunity to standardise the components of their systems and equipment when the technology readiness level is reasonable.

3.3 Tasks for Policy Makers

European and national policy makers must create a sound legal and regulatory governance for developing a full-scale, multi-vendor multi-terminal, multi-purpose demonstration. Such a project should define and execute the implementation in a harmonised manner and facilitate the dissemination of findings to subsequent projects under a market-driven environment.

Policy makers are requested to initiate funding to facilitate the relevant research and development and demonstration activities before a commercially viable infrastructure can be implemented.

Abbreviations

Acronym	Meaning
ENTSO-E	European Network of Transmission System Operators for Electricity
HVDC	High-Voltage Direct Current
IC	Interconnector
MMC	Modular Multi-level Converter
MT	Multi-terminal
MV	Multi-vendor
NC ER	'Network Code on Electricity Emergency and Restoration': COMMISSION REGULATION (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration
NC HVDC	'Network Code on High Voltage Direct Current': COMMISSION REGULATION (EU) 2016/1447 of 26 August 2016 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules
PEID	Power Electronic Interfaced Device
PPMs	Power Park Modules
RES	Renewable Energy Sources
TRL	Technology Readiness Level
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
VSC	Voltage Source Converter

Way forward

ENTSO-E is prepared to contribute to offshore development and to be involved in upcoming debates about how this can best be organised. This position paper, which contains the ENTSO-E position on offshore development interoperability issues, will be followed in the upcoming months by further publications.

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