



Interoperability of the Power Electronics dominated grid by openness Inter-oPEn

Deliverable D5.1

Enabling interoperability from a legal and regulatory viewpoint

Dissemination			
Lead	Level	Type	Delivery Month
RUG	☒ PU (Public) ☐ SEN – Sensitive ☐ C-UE/EU-C - EU Classified	☒ R (Document, report) ☐ DEC (Websites, patent fillings, videos, etc.) ☐ DMP (Data Management Plan) ☐ OTHER	M30

Grant Agreement: 101119349
Project acronym: Inter-oPEn
Project title: Interoperability of the Power Electronics dominated grid by openness
Start of the project: 01.01.2024 (54 months)
Work package: WP5
Deliverable number: D5.1
Title of deliverable: Enabling interoperability from a legal and regulatory viewpoint
Deliverable due date: 31.05.2026
Date of submission: 02.06.2026
Authors: Donia Ayari (RUG), Mohammadtaher Azampour (RUG), Ceciel T. Nieuwenhout (RUG)
Contributors: n/a
Version: 1.2

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VERSION CONTROL

Version	Date	Author (Name, Institution)	Comments
1.0	28.05.2026	D. Ayari, M. Azampour, C.T. Nieuwenhout (RUG)	First draft
1.1	31.05.2026	Ali Sajjadi (RWTH ACS)	Internal Review
1.2	01.06.2026	D. Ayari, M. Azampour, C.T. Nieuwenhout (RUG)	Final draft

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1 About the project

The MSCA DN project titled Inter-oPEn started on January 1st, 2024 and will end on June 30th, 2028. Inter-oPEn is composed of 8 beneficiaries, 11 industrial associated partners and 10 doctoral candidates. The project offers a broad industry and transmission systems operator expertise for doctoral trainings, research, and secondments. In line with this, a unique doctoral training programme that integrates multi-sector knowledge, gathering electrical engineering and legal researchers, is implemented. The doctoral training programme is divided into three complementary parts: (1) Engineering components for swift interoperability; (2) Integration of a resilient and flexible power system and; (3) Enabling interoperability from a legal and regulatory view. Inter-oPEn follows an innovative approach by including two fundamental and new aspects: (1) The interplay of technical and legal perspectives is considered and; (2) Openness principles are heart of engineering and legal research, as well as training.

2 Introduction

The European Green Deal aims to transform the European Union (EU) into a modern, resource-efficient, and competitive economy.¹ In line with this objective, the European Climate Law makes the EU's commitment to reaching climate neutrality by 2050 legally binding.² In addition, the revised Renewable Energy Directive (RED II) sets a binding target of at least 42.5% renewable energy by 2030.³ Offshore renewable energy is expected to play a key role in achieving this ambitious renewable target, leading the European Commission to adopt the EU Strategy on Offshore Renewable Energy, which outlines concrete measures to increase offshore installed capacity to 300 GW by 2050.⁴

To integrate massive offshore wind power into the European grid, the Commission identified High-voltage Direct Current (HVDC) as a key enabling technology.⁵ However, as established in various reports, there are several legal barriers holding back HVDC development, especially where it concerns projects with multiple vendors and multiple terminals (MVMT).⁶ Within Inter-oPEn, WP5 is dedicated to addressing these barriers. Specifically, it aims to study IP protection, contractual relations, warranties, liability, and procurement, identified under the title of legal challenges of interoperability in MVMT HVDC systems,⁷ from a legal perspective, with a particular focus on openness as the solution.

¹ European Commission, 'The European Green Deal' COM(2019) 640 final, 11 December 2019.

² Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law') [2021] OJ L 243/1

³ Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) [2018] OJ L 328/82.

⁴ European Commission, 'An EU Strategy to Harness the Potential of Offshore Renewable Energy for a Climate Neutral Future' COM(2020) 741 final, 19 November 2020.

⁵ European Commission, *Implementation Plan on "High Voltage Direct Current (HVDC) & DC Technologies"* (SET Plan Secretariat 2022) https://setis.ec.europa.eu/system/files/2022-02/SETPlan_HVDC_DC_Tech_ImplementationPlan_Final.pdf accessed 13 May 2026.

⁶ PROMOTioN Deliverable 7.2, Ready4DC Deliverable 2.3 <https://ready4dc.eu/whitepaper-legal-and-regulatory-aspects-of-a-mvmt-hvdc-grid/> accessed 27 May 2026, V. Lakerink, C.T. Nieuwenhout, 'The challenges of competition and intellectual property law for HVDC grid development' *Utilities Law Review* [2024].

⁷ ENTSO-E, *Position on Offshore Development: Interoperability* (25 January 2021) <https://eepublicdownloads.entsoe.eu/clean->

The whitepaper is organised as follows. After a section explaining the definitions and background relevant to the legal framework for HVDC MVMT projects, this whitepaper will analyse two key parts of the legal framework. First, in section 3 the general legal framework for energy law, as well as the governance framework, are explained. In section 4, the intellectual property law regime relevant to MVMT HVDC systems is analysed. Section 5 focuses on the interaction between these two topics and how they are integrated in the Inter-oPEn project, after which section 6 concludes.

2.1 Definitions and Background

HVDC technology is formally defined under Commission Regulation (EU) 2016/1447 as “*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*”.⁸ HVDC systems provide greater transmission capacity, flexibility, system resilience, and long-term stability.⁹ At present, HVDC systems are designed as radial point-to-point transmission systems and are provided by a single vendor.¹⁰ Radial connections refer to offshore wind farms (OWFs) connected to a single State through dedicated export cables, with separate interconnectors linking two States.¹¹

The development of offshore grids is shifting away from radial connections and separate interconnectors towards meshed offshore grids, combining hybrid infrastructure and connecting multiple States in the North Sea.¹² The integration of offshore wind export and interconnection functions results in so-called ‘hybrid cable infrastructure’.¹³ Such meshed offshore grids require multi-terminal HVDC connections, defined as “HVDC transmission systems consisting of more than two separated HVDC substations and the interconnecting HVDC transmission lines”.¹⁴ In addition, multi-vendor configurations allow TSOs to procure technologies from different vendors.¹⁵

[documents/Publications/Position%20papers%20and%20reports/210125_Offshore%20Development_Interoperability.pdf](#) accessed 25 May 2026.

⁸ 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, art 2(1) [2016] OJ L 241/1.

⁹ ENTSO-E, T&D Europe and Wind Europe, (2021). Workstream for the development of multi-vendor HVDC systems and other power electronics interfaced devices, available at: <https://tdeurope.eu/wp-content/uploads/TDEurope-Multi-Vendor-HVDC-workstream.pdf> (accessed 31-5-2026).

¹⁰ READY4DC, *Deliverable D3.1: Multi-vendor Interoperability Process and Demonstration Definition* (31 March 2023) https://www.ready4dc.eu/wp-content/uploads/files/230331_D31_Draft_White_Paper_WG3.pdf accessed 13 May 2026.

¹¹ CT Nieuwenhout, *WP7.1 Deliverable 1 Intermediate Report for Stakeholder Review: Legal Framework and Legal Barriers to an Offshore HVDC Electricity Grid in the North Sea* (PROMOTioN Project) [https://www.promotion-offshore.net/fileadmin/PDFs/D7.1 -](https://www.promotion-offshore.net/fileadmin/PDFs/D7.1_-_Legal_framework_and_legal_barriers_to_an_offshore_HVDC_electricity_grid_in_the_North_Sea.pdf)

[Legal framework and legal barriers to an offshore HVDC electricity grid in the North Sea.pdf](https://www.promotion-offshore.net/fileadmin/PDFs/D7.1_-_Legal_framework_and_legal_barriers_to_an_offshore_HVDC_electricity_grid_in_the_North_Sea.pdf) accessed 13 May 2026.

¹² Ibid

¹³ CT Nieuwenhout, *Regulating Offshore Electricity Infrastructure in the North Sea: Towards a New Legal Framework* (PhD thesis, University of Groningen 2020) <https://doi.org/10.33612/diss.136543296> accessed 25 May 2026.

¹⁴ ‘IEC 62747:2014’ 62747 <<https://webstore.iec.ch/en/publication/7413>> accessed 4 November 2025.

¹⁵ ENTSO-E, *Position on Offshore Development: Interoperability* (25 January 2021) https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Position%20papers%20and%20reports/210125_Offshore%20Development_Interoperability.pdf accessed 25 May 2026.

The operation of cross-border MVMT systems requires both technical interoperability between technologies and legal interoperability across regulatory frameworks.¹⁶ In this context, interoperability can be defined as “the ability of a transmission system, its subsystems and components to function together, seamlessly allowing the transmission of electricity at the required power quality and level of security of supply”.¹⁷ This requires standardised interfaces jointly developed by relevant stakeholders, including TSOs, HVDC project owners, developers and operators, HVDC vendors, and the simulation industry.¹⁸ In addition, legal interoperability requires the alignment of contractual arrangements, regulatory frameworks, and intellectual property mechanisms.¹⁹

As such coordination depends on information exchange between stakeholders, this project focuses specifically on openness as a means of facilitating interoperability. In this context, openness, as a core principle under the European Interoperability Framework (EIF), can support interoperability through the use of open standards, open-source software, and open data.²⁰ According to the European Commission Open-Source Software Strategy 2020-2023, open-source software “combines copyright and a licence to grant users the freedom to run the software, to study and modify it, and share the code and modifications with others. It facilitates collaboration, innovation, and agility”.²¹ Open standards require that all stakeholders contribute to their development and participate in a public review, that the specification is publicly available, and that intellectual property rights are licensed on fair, reasonable, and non-discriminatory (FRAND) terms, allowing implementation in both proprietary and open-source software, preferably on a royalty-free basis.²²

Open-source software applied to MVMT HVDC projects may facilitate information exchange by allowing TSOs access to partially open HVDC control and protection systems where parts of the software, typically upper-level functions, are open for investigation and modification.²³ On the other hand, open standards further support interoperability by enabling the participation of different vendors in standard-setting processes and the development of common technical specifications.²⁴

3 Energy Law

The findings reveal regulatory tensions constraining openness in MVMT HVDC systems. Competition law, cybersecurity requirements, and intellectual property protection may limit the information exchange necessary to achieve interoperability. In addition, as offshore grid configurations evolve towards multi-terminal and multi-vendor systems, governance frameworks must adapt to facilitate coordination between stakeholders.

¹⁶ *Ibid*

¹⁷ *Ibid*

¹⁸ <https://tdeurope.eu/wp-content/uploads/TDEurope-Multi-Vendor-HVDC-workstream.pdf>

¹⁹ ENTSO-E, *Position on Offshore Development: Interoperability* (n 7)

²⁰ European Commission, *European Interoperability Framework – Implementation Strategy* COM(2017) 134 final.

²¹ European Commission, *Open Source Strategy 2020–2023* COM(2020) 7149 final, 21 October 2020.

²² European Commission, *New European Interoperability Framework* (2017) https://ec.europa.eu/isa2/sites/default/files/eif_brochure_final.pdf accessed 25 May 2026.

²³ CIGRE, *Interoperability in HVDC Systems Based on Partially Open Software* (Technical Brochure, 2025) ISBN 978-2-85873-666-9.

²⁴ European Commission, *New European Interoperability Framework* (2017) https://ec.europa.eu/isa2/sites/default/files/eif_brochure_final.pdf accessed 25 May 2026.

3.1 Regulatory Framework

Article 194 TFEU establishes the legal foundation of EU energy policy and, in a spirit of solidarity between Member States, identifies the promotion of the *interconnection* of energy networks as one of the Union's core objectives.²⁵ In addition, directive 2019/944 requires transmission system operators to ensure the secure and efficient operation, coordinated development, and *interoperability* of the interconnected electricity system.²⁶ However, the information exchange required between HVDC stakeholders gives rise to regulatory tensions under competition law, cybersecurity law, and intellectual property law. The current legal framework does not sufficiently address these tensions, highlighting the need for regulatory intervention.

3.1.1 Regulatory Tensions

The adoption of openness facilitates information exchange between TSOs and vendors. For example, open-source software would allow TSOs to coordinate MVMT systems by accessing open upper-level functions of converters.²⁷ This, however, requires the exchange of information that may potentially expose commercially sensitive real-time data. Information sharing between competitors falls within the scope of Article 101 TFEU, which prohibits agreements, concerted practices, and decisions between undertakings that have as their object or effect the prevention, restriction, or distortion of competition within the internal market.²⁸ This is particularly relevant in the context of MVMT HVDC systems, where interoperability requires competing vendors to exchange models, operational data, and control specifications through interaction studies and EMT simulations in order to ensure system stability and avoid adverse effects resulting from vendor-specific implementations.²⁹

In particular, standardisation agreements and data-sharing arrangements between competitors may involve the exchange of commercially sensitive information and create risks of collusion and anti-competitive foreclosure.³⁰ At the same time, the Horizontal Cooperation Guidelines recognise that such cooperation generates efficiency gains and contributes to technical and economic progress and may qualify for an exemption under 101(3), provided that appropriate safeguards are implemented to mitigate competition law risks.³¹ For instance, the Guidelines identify mechanisms such as clean teams and trustees to facilitate information exchange while limiting access to commercially sensitive information.³² Open-source software arrangements may also fall within the scope of the Technology Transfer Block Exemption

²⁵ Consolidated Version of the Treaty on the Functioning of the European Union [2016] OJ C202/47, art 194.

²⁶ Regulation (EU) 2024/903 of the European Parliament and of the Council of 13 March 2024 laying down measures for a high level of public sector interoperability across the Union (Interoperable Europe Act) [2024] OJ L 903.

²⁷ CIGRE, Interoperability in HVDC Systems Based on Partially Open Software (Technical Brochure No 961, May 2025) <https://www.e-cigre.org/publications/detail/961-interoperability-in-hvdc-systems-based-on-partially-open-software.html> accessed 17 April 2026.

²⁸ Consolidated Version of the Treaty on the Functioning of the European Union [2016] OJ C202/47, art 101.

²⁹ Jaqueline Cabañas Ramos and others, 'Getting Ready for Multi-Vendor and Multi-Terminal HVDC Technology' (2024) 17(10) *Energies* 2388 <https://doi.org/10.3390/en17102388> accessed 15 May 2026.

³⁰ Commission Notice, 'Guidelines on the Applicability of Article 101 of the Treaty on the Functioning of the European Union to Horizontal Co-operation Agreements' [2023] OJ C 259/1.

³¹ TFEU (n 28) art 101(3).

³² European Commission, Guidelines on the applicability of Article 101 of the Treaty on the Functioning of the European Union to horizontal co-operation agreements, C(2023) 3445 final, para 407.

Regulation where they involve technology transfer agreements satisfying the conditions of Article 101(3) TFEU.³³

The Network Code on Cybersecurity requires that information provided, received, exchanged or transmitted be accessible only on a need-to-know basis and in accordance with relevant Union and national rules on security of information.³⁴ It also requires that the information exchanged be limited to that which is necessary and proportionate to the purpose of that exchange.³⁵ For instance, Article 46 requires entities to implement proportionate organisational and technical protection measures to safeguard the confidentiality, integrity, availability, and non-repudiation of information exchanged and these measures must take account of cybersecurity risks, follow recognised standards and best practices where possible, and be properly documented.³⁶

The Cyber Resilience Act further introduces cybersecurity, risk assessment, and compliance obligations for converter control and protection systems which qualify as products with digital elements.³⁷ This new regulation requires manufacturers to design, assess, and maintain products with digital elements in accordance with cybersecurity requirements, including conducting risk assessments and exercising due diligence when integrating third-party components, including open-source software.³⁸ In addition, it requires open-source software stewards to implement and document cybersecurity policies, ensure vulnerability handling, promote information sharing, and cooperate with authorities to mitigate risks.³⁹

Information exchange is constrained by competition law, intellectual property protection, and cybersecurity obligations, which respectively limit the sharing of commercially sensitive data, restrict disclosure to what is strictly necessary for secure operation, and curtail access to proprietary technologies, thereby requiring a model of regulated openness. Thus, these regulatory tensions reveal limitations in the existing legal framework and support the need for EU-level harmonisation to address interoperability failures in MVMT HVDC systems. In this context, achieving interoperability requires balancing common EU requirements with sufficient flexibility to accommodate technological innovation. For instance, new interoperability rules should be introduced under Directive (EU) 2019/944, Regulation (EU) 2019/943, and the HVDC Network Code.⁴⁰

³³ Commission Regulation (EU) No 316/2014 of 21 March 2014 on the application of Article 101(3) of the Treaty on the Functioning of the European Union to categories of technology transfer agreements [2014] OJ L 93/17.

³⁴ Commission Delegated Regulation (EU) 2024/1366 of 11 March 2024 supplementing Regulation (EU) 2019/943 of the European Parliament and of the Council by establishing a network code on sector-specific rules for cybersecurity aspects of cross-border electricity flows [2024] OJ L 2024/1366, Art 46(1)

³⁵ *Ibid*, Art 47(8)

³⁶ *Ibid*, Art 46.

³⁷ Regulation (EU) 2024/2847 of the European Parliament and of the Council of 23 October 2024 on horizontal cybersecurity requirements for products with digital elements and amending Regulations (EU) No 168/2013 and (EU) No 2019/1020 and Directive (EU) 2020/1828 (Cyber Resilience Act) [2024] OJ L 2024/2847.

³⁸ *Ibid*, Art 13.

³⁹ *Ibid*, Art 24.

⁴⁰ Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU [2019] OJ L 158/125; Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity [2019] OJ L 158/54; 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 [2016] OJ L 241/1.

3.1.2 Governance Framework

The development of cross-border MVMT HVDC grids is characterised by fragmented legal and regulatory frameworks across neighbouring States.⁴¹ At the same time, the transition towards MVMT systems increases coordination requirements between Member States, TSOs, vendors, and other stakeholders, requiring the allocation of new roles and responsibilities.⁴² Existing national governance models are insufficient on their own to coordinate a meshed grid and must therefore be complemented by a multi-level governance framework combining EU-level harmonisation, regional integration, and market-based coordination.

3.1.2.1 Grid Stages

i. Planning

The development of MVMT HVDC grids raises questions regarding the appropriate level of governance, namely whether greater EU centralisation is required or whether coordination should instead rely on regional integration mechanisms. In this context, three forms of regional cooperation in offshore grid planning are relevant: cooperation embedded within the EU governance framework through instruments such as the Ten-Year Network Development Plan (TYNDP) and Offshore Network Development Plans (ONDP); Member State-driven cooperation through frameworks such as the North Seas Energy Cooperation (NSEC); and multilateral pilot projects such as the Offshore TSO Collaboration (OTC).⁴³

Coordination between Member States in cross-border infrastructure planning may be strengthened through greater EU centralisation. Currently, cross-border planning at EU level takes place within the TYNDP under Regulation (EU) 2019/943, which builds on national and regional investment plans to identify cross-border infrastructure gaps while taking into account the long-term needs and commitments of system users and investors.⁴⁴ In addition, the ONDP is a regional-sea basin planning instrument that translates non-binding offshore objectives agreed by Member States into indicative transmission corridors, infrastructure needs, and associated costs, and is to be updated every two years.⁴⁵ The non-binding nature of these commitments limits the effectiveness of the ONDP, while enforcing binding obligations may exclude less mature projects and result in an incomplete or overly conservative planning outlook.⁴⁶

⁴¹ CT Nieuwenhout, 'Developing Offshore Wind Farms: A Comparison and Analysis of the Legal and Governance Frameworks of the North Sea Coastal States' (2023) 10(3–4) *European Journal of Comparative Law and Governance* 518.

⁴² CT Nieuwenhout, V. Lakerink and P. Ruffing, 'Whitepaper on the Preliminary Conclusions of Ready4DC WG2: Legal and Regulatory Aspects of a Multi-Vendor Multi-Terminal HVDC Grid' (Ready4DC, 2023).

⁴³ Leonardo Meeus, *Offshore Wind Energy in the North Seas: Crafting Collaboration and Navigating Governance* (Policy Brief No 2025/02, European University Institute, January 2025)

⁴⁴ Art 48.

⁴⁵ ENTSO-E. (2024). *Offshore network development plans: Paving the way towards an integrated onshore-offshore system planning* [Report/webpage]. European Network of Transmission System Operators for Electricity. <https://www.entsoe.eu/outlooks/offshore-hub/tyndp-ondp/>

⁴⁶ Nieuwenhout, C.T.; Lakerink, V., Ruffing, P., 'Whitepaper on the Conclusions of Ready4DC WG2: Legal and Regulatory Aspects of a Multi-Vendor Multi-Terminal HVDC Grid' (Ready4DC, 2023).

This governance model may, however, evolve under the proposed revision of the TEN-E Regulation through the introduction of a common EU central scenario.⁴⁷ However, TSOs argue that reliance on a single central scenario is insufficient to capture long-term uncertainty in the European energy system.⁴⁸ Scenario diversity is essential to account for uncertainties in electrification rates, industrial transformation, and sector coupling, while a single centralised scenario risks embedding overly rigid assumptions into long-term infrastructure planning, thereby increasing the likelihood of misaligned investments.⁴⁹

The second coordination approach is Member State-driven, relying on intergovernmental cooperation such as NSEC which primarily operates as a facilitating platform for sharing best practices and supporting the development of non-binding NSOG offshore renewable energy targets under the TEN-E Regulation.⁵⁰ Its role in regional planning could nevertheless be strengthened through the adoption of binding commitments between participating Member States, potentially formalised through a regional agreement.⁵¹ For instance, a binding agreement between coastal states under international law or EU law could provide a common governance framework for offshore grids by establishing shared rules and objectives.⁵²

The third approach relies on multilateral pilot projects, such as the recent Offshore TSO Collaboration (OTC), which brings together TSOs in the North Seas, including the UK.⁵³ This approach strengthens coordination between TSOs through the adoption of a joint planning analysis of projects at sea-basin level.⁵⁴ The main added value lies in the joint identification of a portfolio of projects, while project approval remains with national authorities.⁵⁵

ii. Procurement

The transition from single-vendor HVDC projects towards MVMT systems significantly reshapes procurement of offshore HVDC systems.⁵⁶ In the procurement stage, coordination between TSOs becomes necessary to establish harmonised procurement strategies and contractual frameworks for multi-vendor projects.⁵⁷ In this context, solutions such as central

⁴⁷ European Commission, 'Proposal for a Regulation of the European Parliament and of the Council on Guidelines for Trans-European Energy Infrastructure' COM(2025) 1006 final.

⁴⁸ TransnetBW, TenneT, Amprion and 50Hertz, *Position on the European Grids Package* (9 March 2026) <https://www.transnetbw.de/Resources/Persistent/8/b/7/9/8b795b4efca3ff4f1195a746c060cf8c875b5f71/2603094%20German%20TSOs%20Position%20on%20Grids%20Package%20final.pdf> accessed 27 March 2026.

⁴⁹ Ibid.

⁵⁰ Kusters, J. E. H., van Kann, F. M. G., & Zuidema, C. (2026). *Developing transboundary marine spatial planning: Opportunities and barriers for the Greater North Sea Basin Initiative*. Marine Policy, 184, 106954. <https://doi.org/10.1016/j.marpol.2025.106954>

⁵¹ Ceciel T Nieuwenhout, *Regulating Offshore Electricity Infrastructure in the North Sea: Towards a New Legal Framework* (PhD thesis, University of Groningen 2020) <https://doi.org/10.33612/diss.136543296> accessed 14 May 2026.

⁵² Ibid.

⁵³ Elia. (2025, April 9). *12 offshore TSOs are striving for a robust offshore grid to strengthen European energy independence* [Press release]. Elia. https://www.elia.be/en/press/2025/04/20250409_expertpaperoffshore

⁵⁴ Offshore TSO Collaboration. (2025). *Offshore TSO collaboration: Expert paper III – Joint planning in Europe's Northern Seas: Supporting Europe's energy security and competitive growth through a regional approach to offshore grid development* (Report). <https://www.neso.energy/document/375676/download>

⁵⁵ Ibid.

⁵⁶ T&D Europe, *Workstream for the Development of Multi-Vendor HVDC Systems and Other Power Electronics Interfaced Devices* (T&D Europe, 2022) <https://tdeurope.eu/wp-content/uploads/TDEurope-Multi-Vendor-HVDC-workstream.pdf> accessed 14 May 2026.

⁵⁷ Ibid.

purchasing bodies and joint procurement mechanisms could facilitate coordinated procurement and the development of common technical specifications between TSOs.⁵⁸

Different contractual arrangements are possible in multi-vendor projects, where components such as converters, cables, grid controllers, and DC breakers are procured under separate contracts.⁵⁹ One approach is procurement through separate lots, allowing contracting entities to divide contracts according to the size and subject matter of specific components and technical functions.⁶⁰ At the same time, the transition from single-vendor turnkey projects to open-source multi-vendor configurations requires a new procurement governance framework in which responsibilities relating to system integration, information sharing, and fault allocation are redistributed between TSOs, system operators, and vendors.⁶¹

iii. Operation

The transition towards cross-border MVMT HVDC offshore grids increases operational coordination requirements, creating the need for EU-level harmonisation of operational rules. In this context, the HVDC Network Code should be amended to establish harmonised technical requirements regarding DC voltage levels, DC connection points, and system interoperability for system operation.⁶² For instance, Articles 51–53 of the HVDC Network Code, which govern information exchange and coordination between relevant system operators and HVDC system owners, should be amended to include interoperability obligations.⁶³

In order to strengthen regional operational coordination, Regional Coordination Centres (RCCs) could play a greater role in coordinating cross-border MVMT HVDC system operation. In particular, Article 37 of Regulation (EU) 2019/943 assigns RCCs coordination tasks relating to capacity calculation, security analysis, common grid models, outage planning, and post-operation analysis.⁶⁴ Cross-border MVMT HVDC grids could benefit from an integrated regional operational framework, such as a dedicated North Sea RCC or system integrator function, which may be necessary for future MVMT HVDC grids.⁶⁵

⁵⁸ Directive 2014/25/EU of the European Parliament and of the Council of 26 February 2014 on procurement by entities operating in the water, energy, transport and postal services sectors and repealing Directive 2004/17/EC [2014] OJ L94/243, arts 55–56.

⁵⁹ G Dawson and CT Nieuwenhout, *Multi-Party Cooperation Framework – Draft Version* (Deliverable 4.3, December 2024) <https://interopera.eu/wp-content/uploads/files/deliverables/20251002-Multi-party-cooperation-framework-draft.pdf> accessed 14 May 2026.

⁶⁰ Directive 2014/25/EU (n 58) art 65.

⁶¹ CIGRE, *Interoperability in HVDC Systems Based on Partially Open Software* (Technical Brochure No 961, May 2025) <https://www.e-cigre.org/publications/detail/961-interoperability-in-hvdc-systems-based-on-partially-open-software.html> accessed 14 May 2026.

⁶² 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 [2016] OJ L241/1.

⁶³ *Ibid.* Art 51-53.

⁶⁴ Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity [2019] OJ L158/54, art 37.

⁶⁵ CT Nieuwenhout, V Lakerink and P Ruffing (n 46).

4 Intellectual Property Law

Preliminary findings of the study are provided in two sections: first, the interaction between IP protection and interoperability in the MVMT HVDC field, and second, applicable IP protection methods.

4.1 Interaction of IP protection and Interoperability MVMT HVDC

Moving from conventional point-to-point HVDC projects to interconnected DC networks requires integrating a vendor-designed system. Achieving this objective requires substantial interoperability among independently developed technologies.⁶⁶ Among all interoperability issues within HVDC systems, control interoperability is particularly critical.⁶⁷

The reliability and robustness of MVMT HVDC systems, which constitute major sources of their complexity, depend significantly on the operation of control systems⁶⁸. To ensure reliable operation⁶⁹ and identify potential adverse control interactions, simulation and analytical studies are necessary.⁷⁰ These studies aim to simulate MVMT HVDC systems as realistically as possible by integrating converter models and control cubicle replicas from different vendors.⁷¹ The integration of models from different vendors, as well as the implementation of studies, would involve sensitive data. The risk of competitors accessing sensitive data includes exchanging models, specifications, measurements, analyses, mitigation strategies, and control-related information, which raises intellectual property and confidentiality concerns.⁷²

The converter control is recognised as the centre of Intellectual property protection for vendors of converters.⁷³ Most of the implemented control functions, structure, and designs, due to confidentiality and restrictive IP protection, are inaccessible.⁷⁴ However, access to a certain level of information is necessary for implementing the simulation and analytical studies. One approach to addressing this problem was to share black-box models with operators, enabling them to conduct system studies and de-risk the system.⁷⁵

Black-box models face some limitations; first, models cannot fully capture system behaviour under all conditions, leaving some risks unresolved,⁷⁶ and second, finding and understanding

⁶⁶ ENTSO-E, *Position on Offshore Development: Interoperability* (n 7); 'READY4DC, *Deliverable D3.1: Multi-vendor Interoperability Process and Demonstration Definition* (n 10).

⁶⁷ CIGRE WG B4.85, *Interoperability in HVDC systems based on partially open-source software*, 2019; P. Rault and others, 'BEST PATHS DEMO#2: Final Recommendations For Interoperability Of Multivendor HVDC Systems' (RTE 2018) D9.3.

⁶⁸ Filliot Louis and Leon Garcia William, 'Modelling, Simulation Framework and Data Sharing For Multi-Terminal Multi-Vendor HVDC Interaction Studies' <<https://ready4dc.eu/modelling-simulation-framework-and-data-sharing-for-multi-terminal-multi-vendor-hvdc-interaction-studies/>> accessed 4 March 2025.

⁶⁹ Mani Venkatasubramanian and Kevin Tomsovic, 'Power System Operation and Control' *The Electrical Engineering Handbook* (Elsevier 2005) <<https://doi.org/10.1016/B978-012170960-0/50057-8>> accessed 4 November 2025.

⁷⁰ Filliot Louis and Leon Garcia William (n 68).

⁷¹ *ibid.*

⁷² Filliot Louis and Leon Garcia William (n 68).

⁷³ Adil Abdalrahman and others, 'A Way Forward to Achieve Interoperability in Multi-Vendor HVDC Systems' 2022 24th European Conference on Power Electronics and Applications (EPE'22 ECCE Europe) (2022) <<https://ieeexplore.ieee.org/document/9907408/?arnumber=9907408>> accessed 3 March 2025.

⁷⁴ Ilka Jahn and others, 'An Architecture for a Multi-Vendor VSC-HVDC Station With Partially Open Control and Protection' (2022) 10 IEEE Access 13555 <<https://doi.org/10.1109/ACCESS.2022.3146782>>.

⁷⁵ CIGRE WG B4.85 (n 67).

⁷⁶ *ibid.*; Jahn and others (n 75).

the root cause of the problems is more challenging using black boxes.⁷⁷ Its applicability is more limited in an MVMT scenario, as vendors are highly conservative about disclosing relevant information to other vendors.⁷⁸ In this context, when an interaction issue between converters from different vendors is identified, the operator notifies the vendors. In this situation, the participating vendors are informed about the interaction problem, but do not have access to the internal details of the other vendors' converter control systems. As a result, they must assess the possible impact on their own systems and continue the interaction studies based largely on assumptions about the behaviour of the other systems.⁷⁹ In this situation, analysing the issue and addressing interoperability by tuning the control system are highly challenging.

The necessity of information sharing and the drawbacks of black boxing⁸⁰ underscore the importance of elaborating on applicable IP protection methods in the HVDC control context and of studying the enabling or disabling effects of each method on interoperability.

4.2 Applicable IP protection Methods

Given this cyber-physical nature,⁸¹ the subject matter of HVDC control systems includes hardware components, control methods, software, interfaces, communication protocols, data structures, and operational information. Consequently, multiple IP protection methods may apply, particularly IP rights such as patents and copyrights, as well as confidentiality arrangements (trade secrets).

4.2.1 Patent

The applicability of patents and their importance for interoperability in the HVDC field have already been emphasised in prior HVDC-relevant works, including projects such as Ready4DC⁸² and InterOPERA.⁸³ However, the question of openness within patent protection, as well as the theoretical and empirical analysis of the enabling or restrictive effects of patents on interoperability in this field, remains largely unexplored.

A patent grants exclusive rights over the use of an invention. Within the European framework, patents are granted under the European Patent Convention (EPC)⁸⁴ for inventions that satisfy the requirements set out in Article 52 EPC. In the context of HVDC technologies, patents may cover converter technologies, control methods, communication solutions, and software-related implementations. Patent protection, therefore, plays an important role in protecting innovation and encouraging investment in the development of HVDC systems.

⁷⁷ Filliot Louis and Leon Garcia William (n 68).

⁷⁸ P. Rault and others (n 67).

⁷⁹ CIGRE WG B4.85 (n 67); Filliot Louis and Leon Garcia William (n 68).

⁸⁰ CIGRE WG B4.85 (n 67).

⁸¹ Siddhartha Kumar Khaitan and James D McCalley, 'Cyber Physical System Approach for Design of Power Grids: A Survey' 2013 IEEE Power & Energy Society General Meeting (2013) <<https://doi.org/10.1109/PESMG.2013.6672537>> accessed 16th conditions for interoperability January 2026Patent.

⁸² CT Nieuwenhout, V Lakerink and P Ruffing (n 46).

⁸³ P Torwelle and others, InterOpera Deliverable 2.1, Functional Requirements for HVDC Grid Systems and Subsystems, 2024, <https://interopera.eu/wp-content/uploads/files/deliverables/20250417-D2.1-Functional-requirements-for-HVDC-grid-systems-and-subsystems.pdf> (accessed on 31-5-2026).

⁸⁴ 'The European Patent Convention – Contents' <<https://www.epo.org/en/legal/epc/2020/index.html>> accessed 19 May 2025.

Patent protection is based on public disclosure of the invention in exchange for exclusive rights. Such disclosure may support interoperability by making technical information publicly accessible. However, patent holders retain the right to control the use of patented technologies through licensing arrangements. Since interoperability in MVMT HVDC systems may depend on access to patented technologies, interfaces, or control-related methods, licensing conditions and patenting strategies may directly affect coordination and compatibility between vendors.⁸⁵

In this context, the dual nature of patent protection may both facilitate and restrict interoperability. The interoperability impact of patents depends not only on the patented subject matter itself, including hardware of the controller, and control-related methods, but also on patenting strategies, patent pools, standardisation processes, and the potential emergence of standard-essential patents (SEPs)⁸⁶ protect technologies considered essential for implementing a technical standard.

The patent landscape in HVDC technologies shows that patents constitute a major form of intellectual property protection in the field, particularly at the European Patent Office (EPO), where major global industrial actors are highly active. The findings demonstrate an increasing focus on protecting control-related innovations, especially through patents directed at core control methods, devices, and computer-implemented inventions. While earlier patents often treated control as a peripheral element, more recent patents increasingly position control as the central contribution of the invention on system-level power transmission and network control technologies, rather than converter-specific technologies. Consequently, the growing role of patents in control-related innovations calls for a deeper legal analysis of their enabling and restrictive effects on interoperability under EU regulatory frameworks.

4.2.2 Trade Secret

Trade secrets protect commercially valuable information that remains secret and is subject to reasonable measures to maintain confidentiality under Directive (EU) 2016/943.⁸⁷ In HVDC systems, trade secret protection is particularly relevant for software architectures, control functions, algorithms, operational knowledge, and engineering know-how. Vendors frequently rely on secrecy, black-boxing approaches, confidentiality agreements, and restricted-access environments to protect such information. Compared with patents, trade secrets provide stronger control over access to information because disclosure is not required for protection. However, this secrecy creates significant interoperability challenges.

Studies on interoperability in HVDC systems have identified secrecy and confidentiality as hindrances. They discussed how secrecy impedes communication and cooperation in MTMV HVDC in various ways.⁸⁸ First, it restricts the sharing of models, analyses, and relevant interaction measurements.⁸⁹ Second, vendors will be hesitant to integrate models and control-cubicle replicas into a single simulation environment for software- or hardware-in-the-loop

⁸⁵ CT Nieuwenhout, V Lakerink and P Ruffing (n 46); Lakerink V and Nieuwenhout CT, 'The Challenges of Competition and Intellectual Property Law for HVDC Grid Development' (2024) 24(4) *Utilities Law Review*.

⁸⁶ CT Nieuwenhout, V Lakerink and P Ruffing (n 46).

⁸⁷ Directive (EU) 2016/943 on the protection of undisclosed know-how and business information (trade secrets) against their unlawful acquisition, use and disclosure, OJ L 157, 15.6.2016.

⁸⁸ P. Rault and others (n 67); Filliot Louis and Leon Garcia William (n 67).

⁸⁹ Ibid.

simulations with other vendors' models and replicas.⁹⁰ Third, although non-disclosure agreements (NDAs) are a common legal mechanism for protecting trade secrets in this context, the involvement of multiple vendors, TSOs, and other stakeholders within a single HVDC project can result in multiple, potentially incompatible, NDAs. This lack of compatibility may hinder communication and information sharing, particularly when interoperability issues arise.⁹¹

Effective interoperability in MVMT HVDC systems often depends on information exchange, interaction studies, simulation activities, and coordination between vendors.⁹² The need to preserve secrecy may therefore restrict communication, cooperation, and access to interoperability-relevant information. Consequently, trade secrets and confidentiality mechanisms appear particularly influential in shaping the practical conditions for interoperability within HVDC control systems. This highlights the need for a deeper analysis of the interaction between interoperability and trade secret protection, particularly in the context of standardisation processes⁹³ within the EU regulatory framework as applied to the HVDC context.

4.2.3 Copyright

Given the software-centred nature of modern HVDC control systems, the relevance of copyright becomes increasingly important because communication interfaces, control logic, monitoring functions, and data-processing mechanisms are largely implemented through software.⁹⁴ In this context, copyright protection may affect access to software interfaces, modification possibilities, reverse engineering, and software interoperability.

Under the European Union legal framework, computer programs are primarily protected by copyright law under Directive 2009/24/EC.⁹⁵ Copyright protection arises automatically upon creation of the software and protects the expression of the program rather than its underlying ideas, principles, or technical functions. From an interoperability perspective, the computer program directive permits certain forms of reverse engineering and decompilation where necessary to achieve interoperability between independently developed software systems. Despite the growing software dependence of HVDC systems, the role of copyright in shaping interoperability has received relatively limited attention in the existing HVDC literature.⁹⁶

Accordingly, a deeper legal analysis is required to assess how copyright protection may both facilitate and restrict interoperability in software-dependent, multi-vendor HVDC environments under the EU legal framework.

5 Interactions: Energy and Intellectual Property Law

The development and operation of cross-border MVMT HVDC systems require coordination between Member States, TSOs, vendors, and other stakeholders operating under different

⁹⁰ Filliot Louis and Leon Garcia William (n 67).

⁹¹ *Ibid.*

⁹² Lakerink and Nieuwenhout (n 84); Ceciel Nieuwenhout, Vincent Lakerink and Philipp Ruffing (n 64).

⁹³ Lakerink and Nieuwenhout (n 84)

⁹⁴ *Ibid*

⁹⁵ Directive 2009/24/EC on the legal protection of computer programs, OJ L 111, 5.5.2009

⁹⁶ Lakerink and Nieuwenhout (n 84).

legal and commercial interests. Focusing on the legal dimensions of interoperability in the context of MVMT HVDC systems, the concept of legal interoperability becomes relevant, referring to the ability of organisations operating under different legal frameworks, policies, and strategies to cooperate effectively without legal barriers⁹⁷. In this context, both energy law and intellectual property law play an important role in shaping interoperability conditions in HVDC systems.

While interoperability in MVMT HVDC systems is often approached as a technical objective, the legal issues surrounding interoperability arise from different but interconnected legal frameworks. Energy law primarily governs roles and responsibilities of actors in the electricity sector under EU energy legislation, and HVDC system operation through sector-specific regulation, including the HVDC Network Code.⁹⁸ Intellectual property law regulates ownership, access, disclosure, and control over technologies and information.

Despite their different regulatory purposes, both frameworks directly shape the conditions for information exchange between stakeholders, influencing interoperability of MVMT HVDC systems. For instance, energy law can establish regulatory frameworks for cooperation among Member States in the North Sea and support coordination among TSOs in system operations. From an intellectual property perspective, interoperability is affected by the application of patent, copyright, and trade secret protection to control systems, software, interfaces, and technical information. Depending on the scope of protection, licensing arrangements, confidentiality obligations, and the degree of openness adopted by stakeholders, such protection may either facilitate or constrain interoperability. Achieving interoperability in MVMT HVDC systems requires a coordinated legal approach combining regulatory frameworks and intellectual property arrangements.

6 Conclusion

The findings demonstrate that interoperability in MVMT HVDC systems is not merely a technical matter but a multidimensional legal challenge shaped by the interplay of multiple applicable legal frameworks, contractual arrangements, and regulatory obligations within a single HVDC project. In this context, interoperability is directly influenced by both regulatory frameworks and contractual relationships governing information exchange, access to technologies, allocation of responsibilities, confidentiality obligations, and coordination mechanisms.

From an energy law perspective, interoperability requirements must comply with competition law and cybersecurity obligations which limit the exchange of information by restricting the sharing of commercially sensitive data and requiring that information exchanges be limited to what is necessary and proportionate to their purpose. From an intellectual property law

⁹⁷ European Commission, *New European Interoperability Framework: Promoting Seamless Services and Data Flows for European Public Administrations* (2017) https://ec.europa.eu/isa2/sites/default/files/eif_brochure_final.pdf accessed 25 May 2026.

⁹⁸ See, Directive (EU) 2019/944 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast) [2019] OJ L 158/125; Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity [2019] OJ L 158/54; 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 [2016] OJ L 241/1.

perspective, interoperability depends on legal and contractual arrangements capable of structuring relationships between vendors and TSOs, including mechanisms governing information sharing, licensing practices, confidentiality obligations, and access to protected technologies. Patent, copyright, and trade secret protection may facilitate or restrict interoperability depending on how protection methods are applied, how IP is managed, and how innovations are shared in practice. Consequently, relying on proprietary technologies in MVMT HVDC systems underscores the need for further legal analysis of the interaction among intellectual property protection, openness strategies, and interoperability within the EU legal framework.