

D5.1

Multi-Terminal

Multi-Vendor

HVDC

**Risk Assessment
and Procurement
Strategy**

PUBLIC



ABOUT INTEROPERA:

The InterOPERA project will define technical frameworks and standards for electricity transmission and accelerate the integration of renewable energy. Ensuring that HVDC systems, HVDC transmission systems or HVDC components from different suppliers can work together – making them “interoperable”- is a top priority to accelerate Europe’s energy transition.



**Co-funded by
the European Union**

DISCLAIMER:

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

PROJECT DETAILS:

Duration: 1 January 2023 – 30 April 2027

Grant agreement: 101095874

Multi Terminal Multi-Vendor HVDC Risk Assessment and Procurement Strategy

D5.1

DECEMBER

AUTHORS:

Laurens Busschaert	Elia Group
Poul-Jacob Vilhelmsen	Energinet
Johannes Klindworth	Amprion GmbH
John Moore	SuperGrid Institute
Sebastien Silvant	SuperGrid Institute
Charlotte Brønserud Jespersen	Energinet

REVIEWERS:

TBD

OTHER CONTRIBUTORS:

Nicolas De Narp	GE Vernova
Tim Schacht	Siemens Energy
Christoph Gringmuth	GE Vernova
Dr. Oliver Pohl	Amprion
Thomas Vanhoye	Elia
Arman Derviskadic	Hitachi Energy
Staffan Norrga	SciBreak
Emanuela Caminiti	Terna
Stephan Poehler	TenneT
Fabian Laugner	TenneT
Fitim Kryezi	Energinet
Thorrolf Wadepohl	Siemens Energy
Jan Stensrud	Statnett
Carlo Degli Esposti	Teradec
Remco Ververs	TenneT
Christian Sarchese	Terna
Marco Schudel	RTE

Nils Charels	Elia
Adedotun Agbemuko	Elia
Xavier Bourgeat	RTE
Nicolas De Narp	GE Vernova

VERSION CONTROL

Version number	Vo
Created by	Laurens Busschaert
Date created	24/11/2025
Status	Release
Data Classification	Public

Executive summary

Until today HVDC Point-to-Point systems (PtP) are sourced through Engineering, Procurement, Installation, Commissioning (EPIC) contracts. Owners determine the interfaces between the AC grid(s) and the DC system, the design of which remains entirely the ownership and competence of the respective Original Equipment Manufacturer (OEM). For such complex projects clear advantages of this procurement strategy is the execution speed and limited risk it offered to the owners when constructing and operating the system. In return for the owner's low risk profile, a premium is paid and no further knowhow of the control of the system was required to serve the business cases behind PtP connections. During operation, for the OEMs this approach also serves as a "low risk" solution commercially/contractually, as potential challenges within the full DC-system can be solved by the respective OEM, utilizing in-house knowledge, enabling safe operational functionality of the entire DC-system without compromising the connecting AC-systems and related protection zone, for which the owner carries the full responsibility for its stability.

At the dawn of multi-terminal HVDC system technology, a model where owners being locked in with a single vendor to develop a meshed DC grid step by step is not economically, and in many cases technically or practically not viable for connecting two different single-vendor DC systems. InterOPERA aims to unlock an economically viable model with operational flexibility and a modular approach where owners can source newly defined functional components/sub-systems from competitive supplier markets. To achieve this, the HVDC system needs to be broken down into smaller functional components/sub-systems (e.g. Converter Stations, Switching Stations, Switching Unit, etc.) with standardized interfaces enabling the buyers to combine several OEM's components into one full and functional DC-system. In what follows we complement the technological standards that InterOPERA developed with market dynamics, risks and resource constraints to develop a procurement strategy and provide insights about the drivers to best procure a multi contracted DC meshed grid.

This strategy is optimized for owners to procure the first multi-terminal multi-vendor (MTMV) projects depending on commercial availability of the functional components/sub-systems as defined in InterOPERA in the years following completion of the InterOPERA project. The risks of commercially available technology, competences and capabilities that need to be developed within the owners will be key drivers of such strategy and form unique elements which this report adds to InterOPERA.

While the risk analysis shows that MTMV procurement carries material risks, it also concludes that there are sufficient mitigation strategies to make these projects possible. The most critical mitigation tool is the pre-award FEED study.

The Cost Benefit Analysis concludes that bundling the DCSS with one of the PtP contracts is favored for the first projects following InterOPERA. However, it is important to note that CAPEX uncertainty, such as OEM contingencies, can lead to shifting priorities. Because Owners and Transmission System Operators (TSOs) tend to prioritize risk reduction, driven by their risk-averse nature and earning models, lowering risk generally takes precedence over reducing CAPEX costs.

Over the long term, as the market matures and more MTMV projects are completed, the risks and complexities of integration are expected to decrease making multi-contracting more attractive.

1. Methodology

1.1 Overview

In this paragraph we describe the methodology used to develop the Risk Assessment and Procurement Strategy for a multi-terminal multi-vendor (MTMV) HVDC systems under InterOPERA. It consolidates the 5 steps described across the deliverable and details how inputs from main electrical components definitions, reference topology, market screening, risk analysis and a Cost Benefit Analysis (CBA) have been brought together into a coherent decision process. It concentrates on components and interfaces that are specific to enabling interoperability in MTMV HVDC systems and simplifies the procurement and risk decisions and OEMs will face in first MTMV projects following InterOPERA.

The methodology is structured around a clearly defined goal: a Reference Project that reflects first MTMV deployments in Europe. InterOPERA develops a demonstrator project designed to encompass the technological complexity derived from the portfolio of concrete projects currently planned or under development with the InterOPERA participants. While this model captures the technological challenges which increase by adding HVDC terminals in specific configurations, the same is not the case for the parameters in the Cost Benefit Analysis model used to determine the procurement strategy. With interfaces and technological complexity being key drivers for risk, and therefore a major driver of any procurement strategy, Task 5.1 designed its own reference model coherent with assumptions coming from real world constraints.

To converge on guidance for a procurement strategy, Task 5.1 [reference to figure] was organised into a series of interdependent subtasks, each with a defined objective and timeline, deliberately connected to iterate through multiple feedback and hypothesis cycles. The following provides a description of each sub-task.

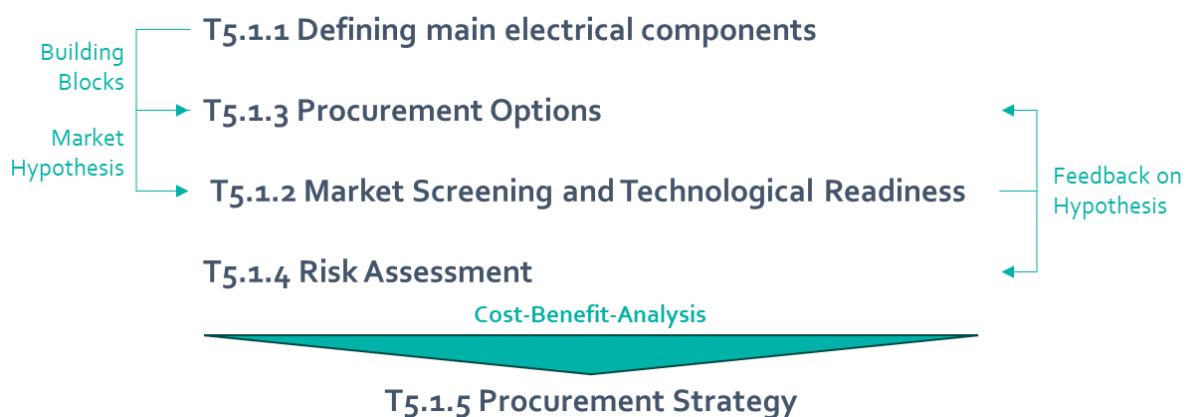


Figure 1 Subtasks and methodology of T5.1

1.2 Defining the main electrical components

D2.1 outlines the functional building blocks of an HVDC system. This report concentrates on a selection of those blocks that specifically facilitate MTMV HVDC systems. Although every system component demands careful interface design and oversight, many (cables, offshore platforms, AC equipment, and the like) are well-established technologies rather than innovations driven solely by interoperable HVDC multi-terminal advances. Thus, even though these interfaces should inform procurement strategies in real-world projects, they fall outside the scope of this theoretical study.

1.3 Procurement Options

Based on the reference model, procurement options are defined by arranging the selected functional building blocks into different lotting structures. The aim is to expose how the distribution of scope across lots influences system integration responsibility, the number and nature of contractual and technical interfaces, and the timing and complexity of testing and commissioning. Further description on this subject can be found in Chapter 5 Procurement Options.

1.4 Market screening and technological readiness

A structured market screening informs these procurement options with realistic views on component readiness, supply constraints and OEM risk analysis. The screening was conducted through a transmission system operator (TSO)-led questionnaire sent to HVDC OEMs and key actors in the supply chain, followed by in-depth interviews to expand on capabilities, roadmaps and market strategies for the main functional components. OEM's inputs were anonymized, validated and summarized across four lenses: the current market situation, the view of InterOPERA, the future perspective, and challenges and risks. The findings are used to understand the likely timeframes for commercial availability, the sensitivity of integration at DC switching station (DCSS), supplier capacity and competition, and the positions of OEMs on interface responsibility in MTMV systems.

1.5 Risk Assessment

The risk assessment framework is then built on a reference topology and procurement options. Risks specific to MTMV procurement, integration and operation are identified and described, including for example the complexity of system integration tests, the limited number of DCSS suppliers, the lack of complete standardization or delays in one functional component affecting development of the others. Each risk is scored via a matrix combining probability and impact on time and/or budget, using the scales defined in "Risk Assessment– Methodology". For each procurement option, risks are assessed without mitigation and then re-assessed with mitigation measures applied. The resulting post-mitigation risk profiles feed into a Cost-Benefit-Analysis (CBA).

1.6 Cost Benefit Model and Procurement Strategy

This final sub-task consolidates the evidence gathered in T5.1.1 to T5.1.4 into a Cost Benefit Analysis (CBA) that compares representative procurement options for first MTMV deployments and concludes the results into guidance for procurement strategy. To execute a CBA a Cost Benefit Model was developed to make visible the trade-offs between the relevant aspects of Contingencies, CAPEX, Construction Risks, Owner Full-Time Equivalents (FTE), Operation and Maintenance (O&M), System Performance, Expandability of the system and Market Fit. The CBA is populated with quantitative and qualitative inputs from the market screening, the risk assessment (using post-mitigation scores) the evaluation of the procurement options and feedback from T5.1 contributors, both owners and OEMs. Evaluation criteria are defined in 7.1 Cost Benefit Model. The scoring and weights are iterated with stakeholders both from an owner and OEMs perspective to reflect practical priorities for early MTMV deployments.

Finally, the CBA outcomes are translated into guidance for a procurement strategy. In line with the scope and timing of InterOPERA, the outcome is not a prescriptive strategy. Project-specific goals, constraints and residual risks at the end of InterOPERA remain uncertain. Instead, this task provides a framework, visibility on the key drivers, and boundary conditions that owners can use to develop a procurement strategy as technology and markets mature. In InterOPERA and WP5 D5.1 will serve as an input to support T5.4 on identifying and timing interaction studies and highlight residual risks to be considered in the technical specifications in T5.3.

2. Defining the Main Electrical Components

The objective of this subtask is to identify the main elements and functional units enabling a typical MTMV HVDC grid system. The focus will be on identifying the components based on functional requirements defined in T2.1 [1], the offshore HVDC grid system design from T3.2 [2].

Defining the building blocks containing the interfaces enabling MTMV

These standardized functional components/subsystems are the building blocks to develop an effective strategy to procure a MTMV reference project. However, there are limits to how small functional components could be to the point that further splitting them up does not add any more relevant flexibility to the owners designing the grid nor are they offered by OEM as a commercial product. Additionally, the demand in the HVDC market is driven largely by regulated companies with a mission to design and operate the grid and not designing the components that make up this grid. Starting from the newly described functional components/sub-systems in InterOPERA, the ones that can drive a procurement strategy enabling MTMV DC mesh grids will be selected. D2.1 outlines the functional building blocks of an HVDC system [1]. This report concentrates on a selection of those blocks that specifically facilitate MTMV HVDC systems. While each building block has interfaces that require careful design and management, some known interfaces e.g.: cables, offshore platforms, AC components, etc. are not newly developed nor exclusively driven by the technological advancements of interoperable HVDC multi-terminal systems. Consequently, although these interfaces should be part of the procurement strategy for practical projects, this theoretical study will not focus on them.

2.1 HVDC Converter Station (DCCS)

An AC/DC converter station exchanges power between the AC and DC grids and includes:

- **Converter Units:** Transfer power between AC and DC networks, with each unit containing switching, earthing, and protective devices necessary for its operation.
- **Switchgear:** Provides self-protection and local earthing.
- **Grounding Unit:** Provides system grounding through a switching unit.
- **Measurement Device:** Automates switching unit and station control.

2.2 DC Switching Station (DCSS)

A DCSS establishes electrical connections between elements in the HVDC system and includes:

- **Switching Unit:** see below.
- **Busbar Unit:** Includes equipment for fault detection and discrimination.
- **Grounding Unit:** Provides system grounding through a switching unit.
- **Measurement Device:** Automates switching unit and station control.

2.2.1 DC Switching Unit (DCSU)

Connects an external unit (transmission or converter) to a busbar, comprising all necessary switchgear, including fault detection and discrimination functions. Some switching units include fault separation devices (FSD). The DCSS is not presented as an indivisible element in D2.1.

DC switching unit

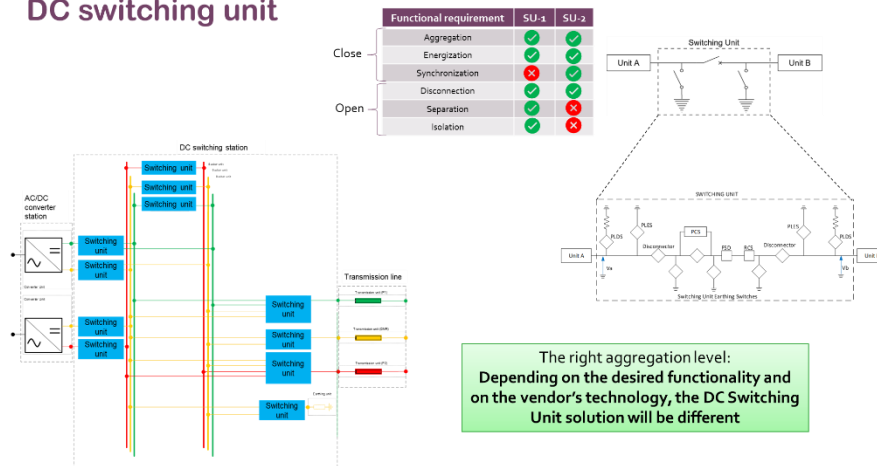


Figure 2: Single line diagram and functions of a DCSU

2.3 DC Grid Controller (DCGC)

With the expectations that, for the first projects being initiated and realized after InterOPERA, the maturity of interoperability is insufficiently matured enabling separately procurement of the individual converter stations within a PtP-system, the procurement strategy for this assessment will be based on a lotting strategy with each PtP-connection included into one contract. The awarded supplier of each PtP-system will then be responsible for the performance and availability of the relevant PtP system, the related control and protection (C&P) system within own scope, including the integration of the potential relevant offshore wind farm (OWF) interface data.

When combining two PtP-connections into one joint hybrid interconnector, potentially also collecting offshore wind, each PtP-supplier will be liable for its own DC-system including internal interfaces, whereas the grid operator(s) (= Owner(s)) will own the responsibility and liability for interconnecting the two PtP's into one joint system, without impacting the N-1 criteria for the protection zones connecting the hybrid DC-system. The DCGC depends then on operational aspects of the full HVDC-system relevant for the Owner(s) TSO's.

This new "additional" DCGC can be seen as a separate overlay C&P unit, that based on clear, well-defined C&P interface parameters of the connected individual PtP-systems, manage the communication between those and the control of the potential FSD's, installed as central DCSS and protecting against N-1 incidents in the AC-grid. Following the definition in T3.2

The DCGC:

- Reconfigure power flow and control modes upon violation of constraints, based on modifications by operator beforehand.
- Checks compatibility of control modes and the ability to open/close switchgears

The Grid Operators (Owner(s)) are liable for any system cost impact, deriving for incidents leading to brown out or black out in the connected AC-system as well of cost compensations towards potentially connected offshore wind, costs that are impossible for the OEM's to estimate, control or mitigate, why

the Owner(s) naturally may carry the responsibility for the overall system control against both other PtPs and the connected protection zones in the AC-grid.

For that reason, this assessment does not consider the Grid Controller as part of the procurement strategy, but rather an independent system facility being developed, procured and implemented separately by the Owner(s), but in close coordination with the suppliers of the PtP-connections.

3. Reference Topology

This document aims to develop concepts for the tendering process for the main electrical components of multi-terminal HVDC systems. The focus is on defining how the procurement process can be structured, including the possibility of splitting the procurement into different lots. Several procurement options combining the main electrical components will be considered in so far these are required to enable MTMV HVDC projects. To perform the task of evaluating different procurement processes it becomes important ensuring an aligned view of the MTMV systems topology performing the basis for the risk assessment and CBA evaluation, as small changes in the lotting strategy influence the related risk exposure and consequences. The Reference Topology is based on the InterOPERA Demonstrator definition described in WP3 [3].

3.1 Assumptions behind the reference topology

For the selection of the reference topology, performing the basis for the procurement strategy, the following main assumptions apply:

- Within the InterOPERA Demonstrator, back-up protection is deliberately omitted, and non-selective Fault Separation Zones (FSZ) recovery is either emulated or disregarded altogether. As a result, these technical gaps and limitations are effectively bypassed within the demonstrator [3]. For the reference topology it is assumed that the DCSUs over different FSZ, are interoperable.
- The reference topology has more than one Owner (2-4 owners) resulting in the need for cross border cooperation between them.
- Connection of the two systems into one joint MTMV system, with min. two FSZs, requiring the DC-breaker functionality.
- Further expansion over time (more terminals/FSZs) to be added. A shorter gap in time between every phase (step) is assumed, allowing active engagement and coordination between the different lots/participants.
- Two full P-t-P connections including DCSS on each HVDC-substation.
- A potential need for a second DCSS (*Phase 2*) may occur, in the case that legislation, regulation of operational guidelines may require such, in order for the TSO's to secure own grid against N-1 incidents.

3.2 Scope & Phases

In order for the project participants to reflect and support a more realistic scenario for the first MTMV systems to be purchased in the market, and recognizing the expected level of maturity at the expiry of InterOPERA together with the expected process for the development of offshore wind, a phased development of a reference model was agreed upon, starting with the parallel planning and procurement of two singular PtP-connections of today's technological standard (*Phase 1*) to be

connected to each other via a central DCSS, creating a MTMV system connecting to two FSZ's (*Phase 2*), in total involving 4 terminals (HVDC-substations) and 1 DCSS (potentially 2).

Later in time, ($\frac{1}{2}$ - 2 years), further expansion of the system is foreseen by connecting an additional PtP connection via a central DCSS (*Phase 3*) leading to a system including 6 terminals and 3 DCSS.

Finally, a separate HVDC substation is connected to the central DCSS (*Phase 4*), proofing the interoperability of a stand-alone HVDC-substation to the MTMV system.

Table 1:

Phase	System to be realized in this phase (step)
1	- One PtP HVDC-connection (<i>North-West --> North-East</i>) connected to AC-grid #1. - One PtP HVDC-connection (<i>South-West --> South-East</i>) connected to AC-grid #1
2	- The two PtP are connected to each other (into a hybrid interconnector) by a HVDC cable including a FSDs (DCSS)
3	- A third PtP HVDC connection is established and connected to the existing hybrid interconnector. - An additional fault-separation device (DCSS) is included.
4	- A new onshore AC-station is connected to the hybrid system. - An additional FSDs is included (DCSS)

3.3 Timing between the different phases of the reference topology

The timeline of the reference typology assumes a rather short timeline between the procurement of **Phase 1** and **Phase 2** (0.5-2 years at most). The reason for this is to “stress-test” the scenario, as a short timeline between the two would mean, that the “interface would be more open” and more active engagement between the different lots and tenderers would be necessary to a higher degree, compared to if there is a long-time shift (5-10 years). If the time between is short, then coordination/exchange of design/studies during the tender process itself should be considered – and this creates an additional layer to consider in the procurement process, which is important for the value of Task 5.1. Ideally also **near zero (o) time** in between each phase could be considered, enabling two parallel procurement processes with joint information/data sharing.

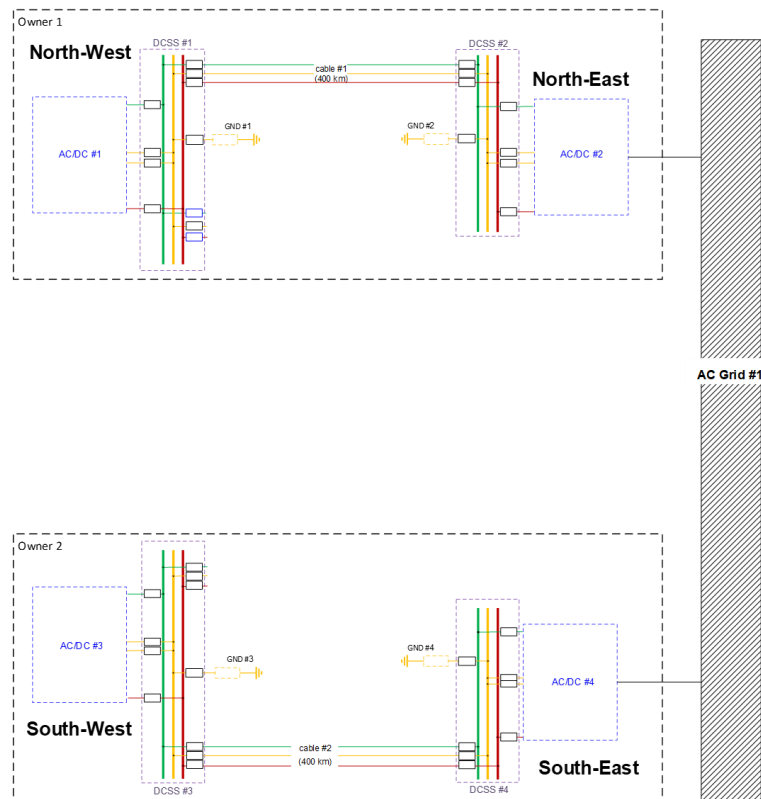
3.4 Single-line diagrams

The diagrams reflect the generic topology agreed upon within InterOPERA, not considering borders, national legislation etc. It is worth to comment, that when it comes to the relevant real projects, being realized after InterOPERA, the layout of the FSZ may differ, as different TSO ownership of the transmission assets and difference in national legislation in the countries involved may influence the FSZ and related operational responsibility.

For each phase, the development in topology is illustrated by a red circle.

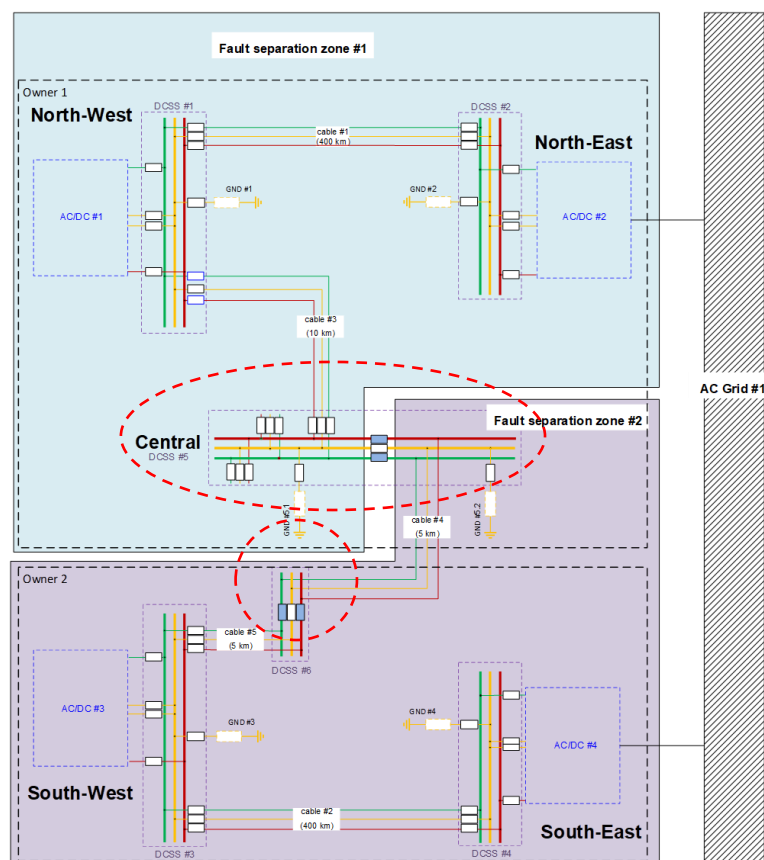
Phase 1

- 2x2GW offshore platforms with connection to shore
- 2 Owners
- Radial connections to AC Grid (same synchronous area)
- No FSDs



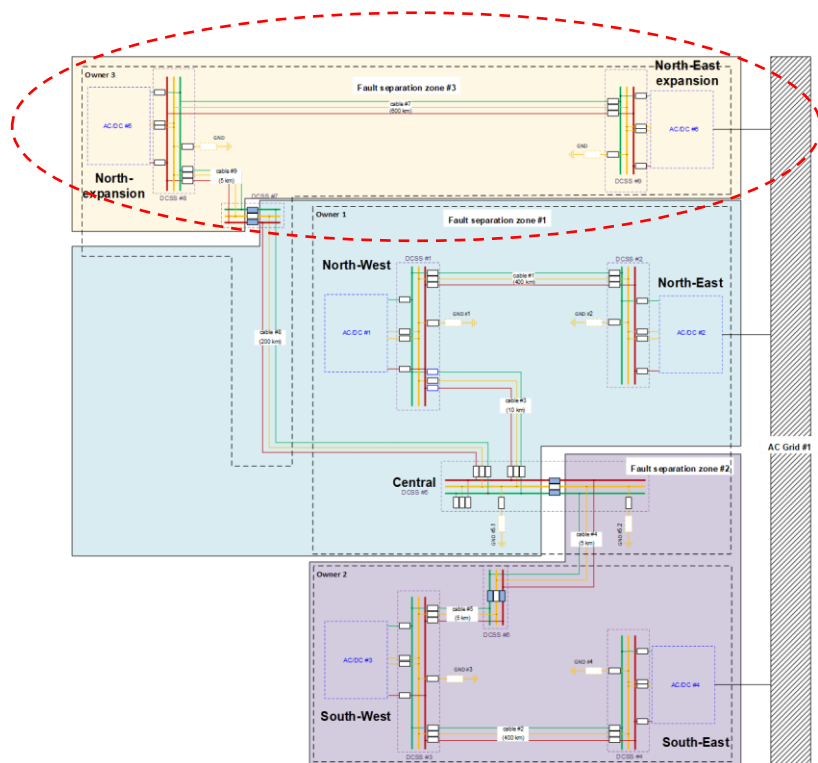
Phase 2

- 2x2GW offshore platforms with connection to shore
- 2 owners
- Interconnected via a central switching station (DCSS #5) installed on an offshore platform or hub
- 1 set of FSDs within DCSS #5
- The DC grid consist of 2 fault separation zones (#1 and #2)
- **Optional:** A second set of FSDs installed on DCSS #6 on a platform in case this is required by the owners for legal purposes



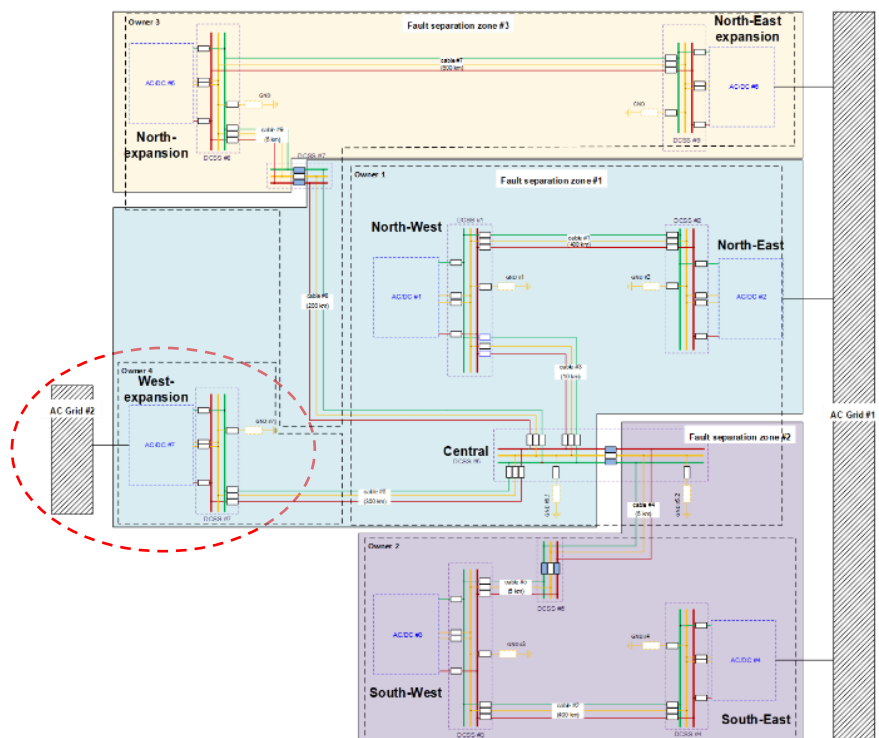
Phase 3

- 3 x 2 GW platforms connected to shore to the same synchronous area
- 3 FSZs
- 3 owners
- 3 platforms With FSDs (one optional — see phase 2)



Phase 4.

- New onshore station connects to the central DCSS #5
- 4 Owners
- 3 FSZs
- 3 platforms With FSDs (one optional - see step 2)



4. Market Screening

In this sub-task, the objective is to conduct a market screening to identify the supplier market players, assess their technological readiness and the commercial availability of the electrical systems and components defined in T5.1.1. This information is essential for making informed decisions regarding procurement options.

4.1 HVDC market analysis

The HVDC converter market is currently experiencing a period of intense transformation driven by soared demand, limited supplier capacity, and significant technological complexity and innovation. Since 2023, the market has transitioned into a pronounced seller's market, with demand tripling and heavily outpacing the available supply capacity. This imbalance is expected to persist in the coming years despite planned investments from incumbent OEMs—Siemens Energy, Hitachi Energy, and GE Vernova—who dominate the non-Chinese market. Notably, these three players form an oligopoly sharing the market. However, the current capacity shortage, higher raw material costs, and increased prices from subcontractors have led to a rise in market prices. At the same time, contractual terms and risks could be changed and more balanced between Owners and OEMs.

These three OEMs' have a network of global partnerships, particularly with fabrication yards responsible for the construction of large-scale offshore substations. These alliances give them the logistical reach and production flexibility necessary to deliver massive 2GW platforms, which are becoming the standard in offshore wind integration.

Despite the presence of emerging technologies and new players, this market concentration is further reinforced by high barriers to entry. New entrants face steep challenges including the need for advanced engineering expertise, massive capital investment in R&D and manufacturing, and a strong project track record to gain TSO confidence. In Europe, Mitsubishi Electric is positioning itself to enter the EU market as a HVDC converter supplier but building up competences at a technological and project delivery level to start supplying at scale is a long-term endeavour. Other players such as SciBreak, and SuperGrid Institute remain on the periphery of the commercial HVDC converter market. While they contribute significantly to the development of enabling technologies—such as the DC Circuit Breaker (DCCB), the commercialization of these innovations will ultimately be carried out by the incumbent OEMs who either partner directly with the innovators or develop technologies in-house, facilitating the integration of new components into established supply chains.

Thus, the structure of the market is unlikely to shift dramatically in the short to medium term. Project timelines remain extended, typically seven to eight years for a 2GW offshore HVDC project, largely due to bottlenecks in engineering, transformer production, and skilled labour availability. While initiatives around global sourcing, standardization, and tender harmonization are underway to improve affordability and supply chain resilience, a substantial rebalancing of market power remains unlikely without a significant external shock—such as a sharp drop in demand.

The market analysis above reflects the perspective in early 2025. In the long term, the InterOPERA project is expected to positively impact market dynamism by reducing barriers to entry, supporting the growing demand to meet EU energy transition goals in a more cost-effective manner.

4.2 Methodology

The questionnaire, interviews and summary were conducted at an early stage of the InterOPERA process, which was finalized in May 2025. This means that only available and shareable information regarding technological readiness and market availability from HVDC OEMs, as well as the progress of technical developments in InterOPERA, are to be considered. It should be noted that more recent developments have not been considered. This means that there is the potential for an updated market screening and reassessment after InterOPERA.

4.2.1 Conducted Questionnaire

A detailed questionnaire was developed by a TSO group to capture a broad spectrum of information from HVDC OEM's and other parties in the supply chain in InterOPERA. This included their current technological capabilities for HVDC functional components/sub-systems (Converter Station, DCSS, DCSU and DC Grid Controller as functional components.), long-term development strategies, and market positioning related to MTMV systems. It is important to note that this questionnaire was conducted during the InterOPERA project (2nd year out of 4 project years), when not all the intended technical requirements had been fully developed. The questionnaire is appended to this document (Annex).

4.2.2 Follow-up In-depth Interviews

Building on the questionnaire responses, individual in-depth interviews were conducted with all the respondents. These interviews aimed to go deeper into the technological and commercial strategies of each vendor, capturing more information about their concerns, drivers and roadmaps for component readiness and adjustment to the market demand. This approach allowed for a more personalized understanding of each vendor's position and challenges.

4.2.3 Anonymized summary of detailed responses and protocols

The vendor feedback was anonymized and summarized, ensuring confidentiality while providing an unbiased representation of the insights gathered. Each respondent approved the use of this anonymized feedback from the questionnaires and interviews for input into this report. Only a small group of TSOs who had also been approved by the respondents had access to the questionnaires and interview feedback throughout the process.

4.3 Summary of the Questionnaire and Interviews

Due to the need to respect confidentiality and the non-use of detailed feedback, the summary does not claim to be complete. It is important to note that it does not reflect the entire market situation, but it does provide a reliable indication of market directions.

4.3.1 Market readiness for MTMV components

We asked the respondents to describe today's market readiness for MTMV components:

The technology for HVDC systems, with multi-terminal ready components such as HVDC Converter Units, DCSSs and DCSUs is increasingly mature and is ready or close to readiness. Less, complex multi-terminal HVDC systems in a multi-vendor setup could be fully tender-ready for the European energy system by the end of this decade. However, the end of the InterOPERA project in 2027 is considered by vendors to be too early for the full commercial availability of all components required for MTMV systems as well as needed common standards. A roadmap has been established for some components and functionalities, e.g. a DC grid controller, to have a marketable solution by the end of the InterOPERA project. The full deployment of other components, such as converters, DCSS and DCSUs remains highly dependent on the development and finalisation of interoperability standards. Once these standards have been defined in a future grid code, for example, the vendors state that the main challenges are not expected to be technological and that the requirements for MTMV projects can be met within a reasonable timeframe. However, developing such a DC Grid Code is expected to be challenging and will almost certainly depend on practical experience gained from the first real projects. With detailed specifications through interoperability standards, timeframes of 5–6 years from then were mentioned for commercial availability. Current market conditions reveal a lack of clear market signals, as well as a need for developments in regulatory, financial, legal and commercial frameworks. Multiple vendors emphasise that valuable experience will be gained in the near future (beginning of the 2030s) through single-vendor MT projects in operation. Some vendors expect this operational experience to become an essential requirement for achieving an economic optimum of MTMV projects and transitioning to more complex configurations.

4.3.2 View of InterOPERA

We asked the respondents how they view InterOPERA's role in market development and standardisation, including its benefits and limitations for enabling MTMV tenders:

With InterOPERA's objective of closing the gap towards a first MTMV project, all OEMs acknowledge the value of guiding standardisation efforts, providing a foundation for understanding current issues and fostering collaboration. It plays a crucial role in promoting the adoption of established standards through its robust guidelines and could validate the adequacy of initial functional requirements.

Despite its significance, InterOPERA has limitations in pinpointing all risks involved in a fully interoperable tendering process, and owners or developers are not driven to identify the most economically optimal system design. While InterOPERA is a vital step forward, definitive standard specifications are required in future grid codes, with further modifications and industrialization anticipated post-InterOPERA.

4.3.3 Future perspective

We asked the respondents for their roadmaps and timelines for market and operational readiness for MTMV solutions, and the conditions they consider necessary to achieve them:

All OEMs are actively engaged in developing HVDC functions and/or components that would align with forthcoming interoperability standards. These developments are pursued both collaboratively and individually. The projected timeline anticipates market readiness for HVDC converter units, DCSSs and

DCSUs by the early to mid-2030s. This results in a broader spectrum of operational readiness, with the majority of vendors expecting MTMV projects in operation by the late 2030s to early 2040s. This timeline depends on addressing integration challenges and establishing precise specifications, with a consensus indicating that technological development is not the primary obstacle to achieving readiness for multi-vendor solutions.

Despite recognizing the maturity of the technology, there is an acknowledged need for industrial-scale demonstrations. Some OEMs underline that operational experience cannot be simulated and will initially be achieved through operational practise with the MT projects in a single-vendor setup.

Additionally, some OEMs highlight that DC protection and DC grid control technology is considered suitable for earlier adoption with marketable solutions end of this decade and operational readiness around 2035.

To manage risks effectively, it is expected by the vendors that initial MTMV projects would come with simpler configurations. These setups would offer all market participants essential experience, laying the groundwork for more complex implementations later on.

With certain manufacturers prioritizing specific HVDC components in the market, there is an expression of openness to entering the broader MTMV market, particularly with regard to HVDC converters. Therefore, the fact that additional OEMs are closely monitoring market demand underlines the need for clear market signals of demand, supporting the opportunity of developing a product line.

4.3.4 Challenges and Risks

We asked the respondents to identify the key challenges and risks of MTMV deployment:

OEMs highlighted that the integration of MTMV systems presents numerous challenges. A primary concern is the coordination of components from different vendors, which requires careful handling of interfaces to minimize risks. The complexity of integrating systems is sensitive, particularly at DCSS, where differing protection algorithms need to be harmonized effectively.

Standardized functional requirements and compliance test procedures are essential to ensure seamless integration and interoperability across subsystems. To manage the inherent risks, the majority of OEM's emphasized that owners must oversee interface problems, as vendors generally do not assume responsibility for these issues.

To transition toward MTMV systems, it is recommended to initiate projects with simpler setups. These setups can offer valuable market experience without overcomplicating the initial stages of deployment.

Furthermore, establishing clear procurement strategies is vital, yet bundling procurement may disadvantage certain players within the market. Market direction and signals—specifically from TSOs and developers—are necessary for guiding development efforts and overcoming regulatory hurdles.

Liability management in MTMV systems is complex, primarily due to fault attribution among multiple vendors. Owners are likely to need to absorb larger liability because of system complexities, necessitating adapted liability schemes for various HVDC components.

5. Procurement Options

The procurement options have been designed to support the analysis on the most important challenges, risks and opportunities in relation to procuring converter stations and central DCSS. Focusing on the multiple interfaces following assumptions are considered.

Assumptions on Procurement Options

- This procurements strategy covers the initial projects in prolongation of InterOPERA to be realized. The Procurement strategy therefore considers only a strategy to build up to phase 2 initiated within a year (requiring a jointly coordinated procurement process)
- The "Lotting strategy" for Central Switching Station (CSS) only on Switching Station level, NOT Switching Unit level.
- For phase 1 the project will start with procuring two separate p-t-p systems in two separate lots. As interoperability is not yet proven to an extend providing sufficient rationale for the Owners to split the procurement of the two P-T-P connections into separate lots for each converter station. Splitting into individual lots per converter leads to a significant risk of malfunctions, stranded assets and liability risks the Owners in between and together towards the OFW concession owners.

PHASE 1+2 procured together

- 2x2GW offshore platforms with connection to shore
- 2 owners
- Interconnected via a central switching station (DCSS #5) installed on an offshore platform or hub
- 1 set of FSD within DCSS #5
- The DC grid consist of 2 fault separation zones (#1 and #2)
- **Optional:** A second set of FSDs installed on DCSS #6 on a platform in case this is required by the owners for legal purposes

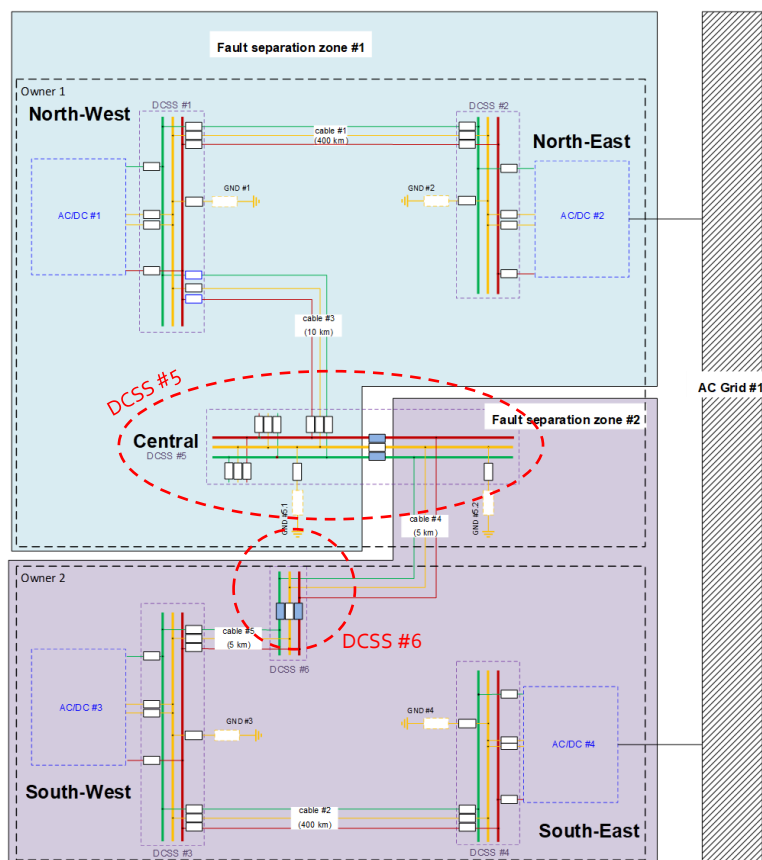


Figure 3: Reference topology with Phase 1 + 2 procured together.

The main prerequisite for the development of relevant procurement options is the general alignment on, that the operational responsibility for each PtP lays within one contract. The central question of the procurement strategy is how the DCSS can be procured in relation to the PtP's and onshore converter station. Considered all lotting options in our reference topology between the different DCSS and DCCS.

When taking the reference topology, assumptions and identified risks into consideration, three options for a procurement strategy of the main electrical components (excl. Cables) can be identified, as shown in the figure below.

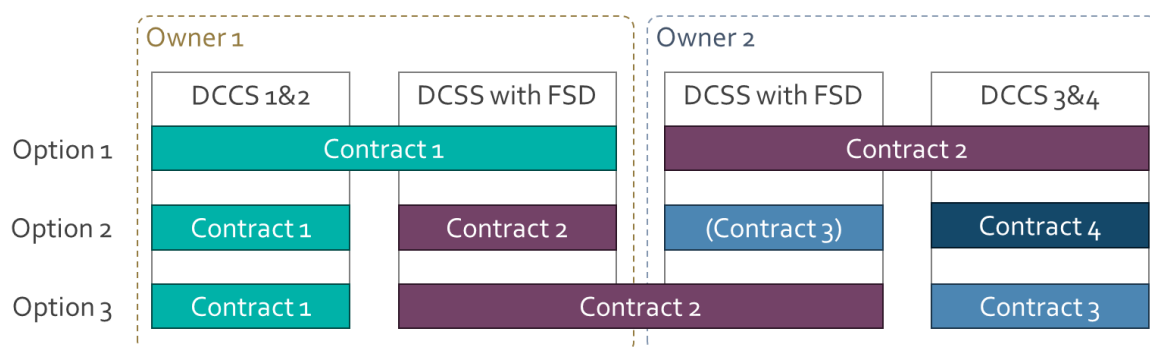


Figure 4: Three procurement options splitting the main electrical components into multiple contracts

General conclusions:

The grid operator will ultimately own the responsibility for the protection strategy in the connected protection zones. Hereby also the responsibility and liability for the overall grid performance and availability, embracing the development, implementation and potential further expansion of the overall Grid Controller enabling the joint and coordinated operation of the different PtP DC systems and/or additional connected individual converter or switching stations.

Table 2: Scoping and Lotting of the three procurement options

Option	Scoping & Lotting
1	Each Owner signs a separate EPCI contract with the relevant PtP converter supplier including the related offshore central DCSS with FSD's (Owner 1: DCSS#5, Owner 2: DCSS#6 if required). All units/components included in the EPCI main contract.
2	Each Owner signs a separate EPCI contract with the relevant PtP converter supplier. Owner 1 signs a contract with the supplier of offshore central DCSS (DCSS#5). Owner 2 signs contract with potential supplier (if required) of second central DCSS ensuring Fault Separation capability in own grid.
3	Each Owner signs a separate EPCI contract with the relevant PtP converter supplier. Owner 1 & 2 signs a joint contract with a supplier both central DCSS (DCSS#5 & 6) (if two are required)

For all scenario's exists a joint "fallback" scenario, where the contracts for the supply of the two PtPs including the central DCSS station(s) are awarded to the same OEM, but this depends fully on the evaluation of the tender bids and the related risk profile of the two Owners. The lotting-strategy shall incorporate a mechanism enabling a combination of the two PtP contracts into one, if the same bidder seems to win both PtP tenders.

In that scenario this mechanism may mitigate most of the potential liability issues for the Owner (Ref. D5.4) regarding the functionality of the grid controller for the full system, although the Owner(s) still maintain the responsibility for the performance of the Grid Controller in relation to potential expansion.

6. Risk Assessment

Interoperability brings new interfaces that need to be technical, legally and economically designed and managed. The risk assessment aims to identify key risks associated with those new interfaces as a starting point for making strategic procurement decisions when developing and procuring the first HVDC MTMV projects.

The risk assessment considers factors such as technical complexity, budget estimation, commissioning failures, construction delays and operational performance issues. It then proposes mitigation strategies to manage and mitigate these risks effectively. It also supports the timing of T5.4 on interoperability studies as integral part of the procurement process.

6.1 Methodology

Each risk is assessed and mapped on a risk matrix to prioritize them and determine whether they are perceived as low, medium, or high. This process helps identify key risks for each procurement option.

Considering all assumptions, the procurement option 2 with the most interfaces was used as a reference.

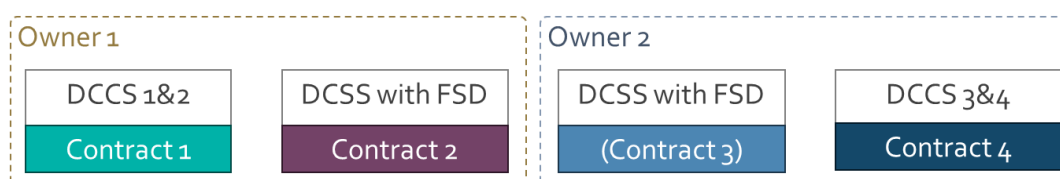


Figure 5: Procurement option 2 with 4 different contractors and 2 owners

Two risk matrices have been developed: initially, risks are evaluated without mitigation measures, such as a Front-End Engineering Design (FEED) study; then, the same risks are reassessed with mitigation strategies applied. In our cost-benefit analysis, we consider risks along with their mitigation measures.

The scoring model comprises a probability factor alongside the budgetary and/or timing impact on the project. At the current stage and level of technological clarity (midway through the InterOPERA project), quality has not been treated as a separate category.

The score is calculated as follows:

$$\frac{\text{Probability score}}{\text{score}} + \text{Maximum score of impact on time or budget} = \text{Risk Score}$$

Table 3: Scoring scale

Probability	%	Score	Budget	Score	Time	%	Score
Nearly sure	>95%	5	> 300M€	5	>12 months	40%	5
Probable	>75%	4	< 300M€	4	6-12 months increase	20%	4
Possible	>50%	3	< 100M€	3	2-6 months increase	10%	3
Low	>25%	2	< 50M€	2	<2 months increase	5%	2
Very low	≤5%	1	< 10M€	1			

6.2 Risk Overview

Below is an overview of all identified risks before and after mitigation. Following this overview, chapter 6.3 Detailed risks elaborates on each risk and its mitigation measure in more detail. Some risks were deemed not significant enough within the scope of a procurement strategy to warrant further detailed description in a separate sub-chapter (and were identified as low after the implementation of mitigation measures), such as *Deviation in budget due to additional adjustments to hardware technical specifications during development* and *Stability/Synchronization issues*. The risks *Attractiveness of DCSS project*, *No price benchmark for DCSS* and *Limited number of DCSS suppliers* are described jointly in chapter 6.3.4. For further details please see the risk matrix table below.

Table of Risks before mitigation measures:

Risk Title	Probability	Timing Impact	Budget Impact	Max Impact	Score
Lack of standardization	5	4	5	5	10
Complexity of System Integration Tests	5	4	-	4	9
Delay in one P-t-P system	4	4	2	4	8
Changes to technical specifications along the development phase	5	2	3	3	8
Design of DCCS totally unknown	3	4	5	5	8
Number of DCSS suppliers	5	-	2	2	7
Asymmetric power balance in system	4	1	3	3	7
Stability/Synchronization issues	2	5	4	5	7
Contractual interfaces during O&M increases	5	1	1	1	6
Attractiveness of DCCS project	3	-	3	3	6
No price benchmark of DCSS suppliers	3	-	3	3	6

Deviation in budget due to additional adjustments to hardware technical specifications during development	3	3	3	3	6
Ambiguity leading to design failure	1	5	4	5	6
Post-Commissioning Risks	3	3	3	3	6
Stranded asset risk	2	-	3	3	5

The risk matrix before mitigation measures:

5	1	1	1		1
4				1	1
3		1	4	1	1
2					1
1					1
	Very low	Low	Possible	Probable	Nearly Sure

Probability

Figure 6: Risk matrix before mitigation measures

Table of Risks after mitigation measures:

Risk Title	Probability Residue Risk	Timing Impact	Budget Impact	Max Impact	Score Residue Risk
Complexity of System Integration Tests	5	3	-	3	8
Lack of standardization	4	2	3	3	7
Delay in one P-t-P system	4	3	1	3	7
Number of DCSS suppliers	4	-	2	2	6
Contractual interfaces during O&M increases	5	1	1	1	6
Asymmetric power balance in system	2	1	3	3	5
Attractiveness of DCCS project	2	-	3	3	5
No price benchmark of DCSS suppliers	2	-	2	2	4
Deviation in budget due to additional adjustments to hardware technical specifications during development	2	2	2	2	4
Stranded asset risk	1	-	3	3	4
Changes to technical specifications along the development phase	2	1	2	2	4

Desing of DCCS totally unknown	2	2	2	2	4
Stability/Synchronization issues	1	2	2	2	3
Post-Commissioning Risks	1	1	1	1	2
Ambiguity leading to design failure	1	1	1	1	2

The residue risk matrix after mitigation measures:

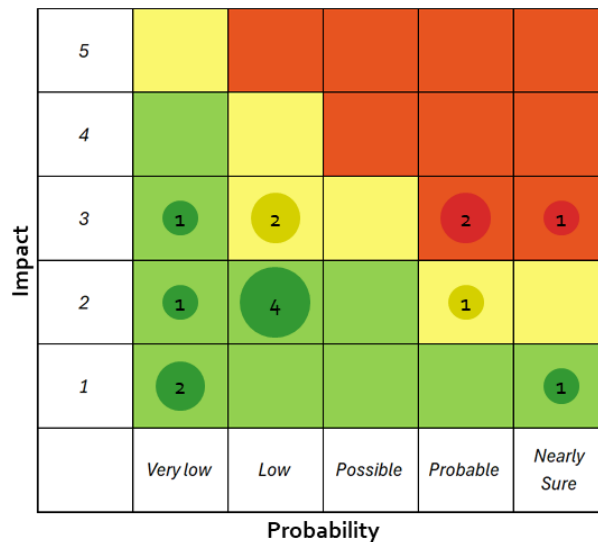


Figure 7: Risk matrix after mitigation measures

6.3 Detailed risks

6.3.1 Lack of Standardization

Whilst InterOPERA will ensure significant technological advances enabling multi-terminal projects, the level of standardization that is expected to be achieved will not allow the first MVMT projects to be delivered in a "plug-and-play" fashion. Some parameters (e.g., DC FRT) will still have to be determined on a project-by-project basis. The reason for this being that HVDC components are very costly and as such, require their design to be optimized to the intended use case and avoid overly costly design margins.

As such, project specific studies will still be necessary to determine the "DC-side" requirements of the individual constituents of a future MV-MTDC project. The outline of these studies and the associated processes are covered by InterOPERA (Further details on such coordination process is detailed out in T5.4), to ensure that the studies for MV-MTDC systems can be delivered. However, to date they require the input of the OEM.

Because of this the DC side requirements, that the initial PtP systems (when independent, sequential build out), need to fulfil to facilitate the MTDC expansion, are to be left open, leading to ambiguity in the requirements for the initial contracts and the associated price uncertainty. Linked to this risk of "lack of

standardization”, is that one TSO can impose more strict requirements onto the other, even if in the end, this is not strictly necessary to operate the final MTDC system.

A mitigation to the above risk, is the execution of a FEED-study (Ref. D5.4 Recommendations for Integration of Interaction) or at least a less detailed Pre-FEED study, including OEM participation, prior to awarding the contracts of the PtP links, enabling to have clear-cut DC side requirements prior to contract award. Time and costing required for such a FEED/Pre-FEED are however still unclear to date, but the ambition on a full FEED study prior to contract award seems very optimistic, as all bidders need to prioritize time and cost for such without the security of a contract. Only sponsor for such pre-contract FEED study cost will then be the Owner(s).

6.3.2 Complexity of System Integration Tests

In the considered procurement concept, the integration of existing PtP connections into the multi-terminal system depends on multiple contracts. If there are any delays in the procurement of one of the contracts, then it will be likely that a/both PtP contract(s) will continue, securing due connection and commissioning of e.g. offshore wind connected to each PtP. Whilst this can be considered as an advantage, as those projects will be able to deliver value sooner, this comes with the downside of a high likelihood that the complex system integration testing will have to take place after the commercial operation of one or both PtP interconnections has commenced.

The multiterminal integration introduces a substantially higher degree of system-level complexity during both the testing and commissioning phases. The coordinated interaction between multiple converters, the DC grid protection and control layers, and legacy PtP control schemes requires a deterministic and tightly synchronized execution of test sequences. Without early and detailed planning of each integration phase, including definition of pre-requisites, interface readiness, simulation requirements, and outage windows, the probability of cascading delays or incomplete test coverage increases significantly.

Given that the DC Grid behavior is highly sensitive to control interactions across vendors, precise alignment of parameter sets, communication protocols, and protection interoperability must be validated well before on-site commissioning. This necessitates a front-loaded integration strategy, where system interaction studies, replica configurations, and cross-vendor integration procedures are established already in the Concept and Feasibility phases. Failure to do so will translate into extended commissioning durations, increased exposure to unplanned disturbances, and elevated operational risk once any PtP element is already in commercial service. Software-in-the-Loop (SIL) environments can be employed to validate control interactions and interoperability at an early stage, thereby reducing integration risk and shortening subsequent on-site commissioning activities.

From a (national) governmental perspective, the timely and safe operation of each PtP has the highest priority, enabling OWF connection and production, and this priority steers the priority of the Owners as well as a compensation regime may apply in the case of delays. From an OEM perspective safe operation of the two PtP's may be prioritized prior to commissioning of the hybrid connection with the DCCB, enabling a robust contractual and payment schedule.

Disturbance of the commercial operation of the PtP connection(s) will be required to complete the test program (e.g., to allow testing all various reconfiguration sequences, power flow combinations, trip tests). Next to this, due to lack of experience and the complexities involved, it is highly likely that unplanned interruptions to commercial power flows may occur.

The risk increases with the number of contracts/lots, as described in the previous risk.

Experience from the first pilot projects, as well as inclusion of thorough interaction studies of the complete MTDC system using offline EMT software and, where possible and if necessary, replicas and real-time simulators can both reduce the likelihood of unplanned power flow interruptions during the system integration testing as well as reduce the time needed for said tests. Provisions to enable the latter to take place are to be included in all contracts (i.e. replica to be provided for both PtP connections and the DCSS/DC grid controller and time provision).

In the Conceptual design and Feasibility phases a protocol is required whereby multiple vendors, contractors and Owners are required to work together. While the most freedom possible will be granted to the OEM's systems design, the freedom once given to vendors in their P-t-P system design will be impacted or potentially constrained as multiple vendors need to work together for alignment across MTMV system interfaces. There will be a transfer to the buyer, in terms of the scope and type of tests that need to be done at each phase of design and feasibility, construction and operation of a MTMV system.

A mitigation is a multi-party cooperation framework and contractual structure, whereby stakeholders work together. Other potential mitigation is securing proper and identical description in all tender and contract documents, covering time schedule for all system parts, interface requirements AC/DC and DC/DC (incl. need for joint interaction studies between Contractors and Owners, RASCI-matrix and financial instruments supporting the lotting strategy).

6.3.3 Contractual interfaces during O&M increases

In a procurement strategy assuming an interoperable HVDC transmission system is split into multiple lots, i.e. each lot potentially awarded to different OEMs or service providers, the concern is increasing risks due to the number of contractual interfaces including during the O&M phase.

Each lot (e.g., converter stations, DCSS, control & protection systems, (cable systems), auxiliary systems) may be governed by separate Long-Term Service Agreements (LTSA) or maintenance contracts with specific technical scopes, commercial terms, and response obligations. This adds complexity to interface management and O&M service. The complexity increases due to HVDC subsystems/components provided from different OEM lots serving interoperability over decades independent of component replacements and software updates, these systems require mitigation measures. Mitigation includes robust planning of network extensions, including adjusting the asset management strategy over ten-year periods for refurbishment.

Currently foreseen causes: a) Procurement of the HVDC system in discrete lots rather than as a single, integrated turnkey package, b) Different OEMs and/or service contractors for each (or some of) the HVDC system subsystems/components), c) No single point (OEM) interface responsibility, and lack of unified LTSA or absence of a single point of responsibility post-commissioning, d) Incompatibilities and/or gaps in interface management, (possibly where contract scopes partly overlap or diverge), e) Variations/differences in OEMs contractual acceptance of interface responsibility and service levels, including guarantees, and lifecycle obligations such as availability, Forced- and planned/scheduled outage from different vendors)

The potential impact for owners would likely include increased Full Time Employee (FTE) base to coordinate multiple contractors for interface management and fault response, preventive maintenance, updates, and diagnostics, increased risk of project and service delays in case of faults or failures requiring

multi-party coordination, risk of interface disputes, assigning responsibilities when issues arise across system boundaries, and likely reduced system availability during operation in the case of fragmented maintenance planning. Updates or configuration changes in one subsystem may inadvertently affect others in the HVDC system, hence, potentially causing technical "interoperability" challenges

OEMs/service providers will in a multiple lots HVDC system have limited total system visibility. The OEMs may be responsible only for a subset of the total HVDC system, making root cause analysis difficult when issues cover multiple components. In case the system faults involve more than one contractor OEM, determining fault ownership may lead to prolonged liability/claims processes. Coordination with other OEMs' service schedules in the field, data sharing, and access requirements is currently foreseen challenging.

Potential foreseen consequences could include increased lifecycle costs, reduced maintainability and asset availability and the likelihood of contractual disputes.

Mitigation proposals to be considered:

- A. Define interface responsibilities/requirements in the procurement specifications and in shared service protocols. Consider an overall coordination of the envisaged project (or group of projects). This would imply a joint project coordination office. This should oversee contracts for all subsystems/components/contracts for the proposed projects. Overall coordination should include a proposed lead from (one of) the Owners representatives from other owners, and (potential) suppliers of the different lots.
- B. Validate that vendor equipment performs according to a defined specification (requires combination of a tight definition of specifications to be furnished by Buyer (TSO) - and if possible as outcome of InterOPERA or follow-up programmes (IEEE, Grid codes, etc.). Poor definition is Owner responsibility; non-matching specification is Vendor responsibility. Given that in first projects there are unknowns, ensure cooperation between vendors and Owners/operators in the prequalification process
- C. Consider maintenance characteristics and equipment performance in the procurement phase in a way that maintenance coordination may be facilitated, and planned shutdowns minimized. NB: in many CBA's the value of the project includes lifetime estimates of the planned downtime and anticipated lost time for unplanned downtime.
- D. During construction and installation, a shift of system responsibility towards Owner/operators is anticipated. They will be obliged to test interoperability of the whole system. Therefore, there needs to be a (continued) protocol of cooperation between Owners and Vendors during this phase. This may be facilitated by protocols being developed in InterOPERA (WP4 and MPCF [4]) In early projects things are likely to go wrong, but a framework is needed to ensure analysis, decide on effective solutions and solve issues - before shifting to any legal processes (which may be inevitable for Government-funded projects)
- E. A centralized O&M coordination team within the TSO or via a lead service integrator in order to coordinate longer term issue identification and solution. The commissioning process may have a longer time span and be phased as each subsystem/component is individually tested and system tests/commissioning follow. The "Operate-transfer" stage may be earlier than earlier Build-Operate-Transfer (BOT) projects.
- F. Consider joint O&M frameworks or consortia-based agreements when possible.

- G. F + joint liability for maintaining replica and “proof of concept” prior to updating components/controls. Note: a balance needs to be held between joint liability and regulatory required litigation in order to complete systems.
- H. The Owner can take on a different role and build expertise regarding the overall system. As an operator of individual systems from different manufacturers within a complex network, they can develop knowledge about both the overall system and the individual systems, comparable to the AC grid.

6.3.4 Limited number of DCSS suppliers

The DCSS is anticipated to become commercially available later in the 2020's or early in the 2030's (in early projects as industrial prototypes) from at least three suppliers, fostering a competitive market. Converter OEMs are likely to play a pivotal role as key suppliers in the DCSS market. Their product strategies and rollout plans could significantly affect market dynamics, potentially leading to a constrained supply. In scenarios of limited availability, a lotting strategy that encompasses both the converter and the DCSS may reduce competition if converter OEMs are unable to qualify for the scope including the DCSS. As the converters represent a much larger part of the overall project cost, constraining this market to include the DCSS is expected to be unattractive from a financial point of view.

A relaxation of tender qualification and evaluation on the DCSS to increase the potential number of suppliers is expected to lead to significant technical, timing, and pricing risks during execution.

6.3.5 Delay in one P-t-P system

For the risk evaluation, following contract scoping is assumed:

Converter system North-West → North- East (PtP) incl. #DCSS₁, #DCSS₂ (**Contract 1**)

Central Switching Station → #DCSS₅ (**Contract 2**)

Converter system South-West → South-East (PtP) incl. #DCSS₃ & #DCSS₄ (**Contract 3**)

In the event that the PtP connection under contract 3 is delayed during the detailed design phase, it could significantly impact the overall system realization, as the data required by Contractor 2 for the design of #DCSS₅ are lacking behind, and suspension of supply (Contract 3) becomes relevant resulting a delay of the entire project due to the necessity of interface and design coordination between the two PtP's (Contracts 1 + 3). Alternatively, it might require the termination of the Contract 2, enabling Owner(s) together with the other contractors (Contractor 1 and 3) to complete the project scope under Contract 1 and Contract 3 separately, to the extent possible and with minimal time delay. However, if such a delay occurs at a later stage, the consequences would be considerably less severe. In the worst-case scenario, the other contractor (Contractor 1) could proceed with their portion of the project and commission it according to the planned schedule, although with adjustments of the contractual conditions relating to the #DCSS₅.

During the development of the tender specifications, the Owners shall consider possible contract mechanisms mitigating such risks. Having potential 3rd parties being involved in the project in mind (eg. OWF), it may be relevant to prioritize the fulfilment of each radial PtP-contract enabling early OWF operation prior to MTMV operation, rather than terminate Contract 2 and potentially have to retender Contract 2.

In a scenario with fulfilment of the agreed operational date for the two PtP-systems, a delay of the central switching station as well generates a financial risk, as the market access for the two connected OWFs will be limited to only one PtP connection. Future projects will have to consider relevant mitigation measures against such risk.

6.3.6 Asymmetrical power balance in system

This risk can materialize when one vendor is awarded a lot significantly earlier than the others, or if one vendor has a substantially larger scope.

In the former case, when lot awards are staged over time, the first vendor may, directly or indirectly, voluntarily or involuntarily, impose its design constraints or choices on subsequent vendors, making them less competitive in the remaining lots under tender. The risk of integration is also perceived as lower if the same initial vendor is selected to deliver lots directly connected to the first one, which can introduce a positive bias in the selection process.

In the latter case, a vendor with a larger scope, such as delivering both a PtP and the DCSS, compared to others delivering only PtP, may similarly impose its design constraints or choices, to the detriment of the other PtP contractor.

Ensuring balanced lotting and conducting a FEED study will help mitigate this risk. InterOPERA standards are designed to be as open as possible while being as closed as necessary, supporting technological agnosticism and enabling interoperability. Combined with a FEED study, this ensures technical parameters are defined in a vendor-neutral way, with no vendor pre-selected at this stage, thereby preserving a level playing field.

6.3.7 Design of the DCSS is totally unknown

A dedicated DCSS platform has not yet been constructed. Even the design of the core constituent components consists as yet of only prototypes (e.g., DCCBs). Additionally, the technical characteristics (DC side requirements) considered/imposed by the contractors of the PtP links can significantly impact the design. Because of this, there is no clear expectation regarding the design and dimensions of a central DCSS.

Firstly, this leads to difficulties in assessing the viability of different offers received, rendering the selection of the best candidate more complicated, as all candidates might not have been equally conservative in their assumptions.

Secondly, because of the impact between the HVDC design & the DCSS design, the staggered procurement approach proposed by the strategy might not lead to an overall optimal design (from a cost perspective). Indeed, if an HVDC vendor is selected in the first procurement phase, who's design causes constraints on the design of the DCSS, causing this one to be more expensive than necessary, then this might lead to an overall cost increase (or could even exclude some vendor and making the schemes incompatible), compared to selecting a less competitive HVDC link bid in the first phase.

The above risk can, with reference to D5.4 scope, be mitigated by inclusion of a FEED study, aiming to define the optimal DC grid requirements, and removing the ambiguity surrounding the DCSS dimension and requirements, prior to awarding the HVDC link contracts. Still, with the optimistic ambition of a full pre-contract FEED-study in mind, further steps shall be considered, referring to coordination process within D5.4.

6.3.8 Post-commissioning risks

Managing multiple interfaces in an interoperable MTMV HVDC system post-commissioning through e.g. expanding the system or handle fault detection presents significant technical and contractual challenges. Despite initial technical interoperability, prolonged periods of operation can increase compatibility issues and organizational complications.

Interface Incompatibility

Over time, open protocols and standards evolve, leading to slight variations in interpretation by different manufacturers that can result in incompatibilities among system components. Firmware or software updates can further exacerbate these differences, complicating the integration of new parts into the system. This issue becomes particularly problematic in the expansion of complex systems with diverse interfaces among several OEMs.

Mitigation measures:

Interface Register and Regular Interoperability Tests: Establishing a continuous interface register to document versioning and specific release notes is crucial. Sufficient LAB tests verifying compliance to existing system setup can be performed by every OEM presenting new components.

Contractual Challenges with inadequate Post-Commissioning OEM Support

If OEMs are not contractually obliged to provide post-commissioning support for system faults and root cause investigations, any emerging incompatibilities between multi-vendor components may remain unresolved or experience significant delays. Each manufacturer may consider interface- or protocol-related questions as proprietary and refer the operator to separate service agreements or third parties. The result can be prolonged downtime, recurring operational interruptions and substantial additional costs due to ad-hoc renegotiations.

Mitigation measures:

Define agreements with each OEM specifying guaranteed response and specifying guaranteed response times and root causes assessment obligations for interoperability incidents. Include clear escalation procedures and designated points of contact to ensure rapid handling of support requests. Establish a clear process for root cause assessment managed by the Owner(s).

Build up own capacities to identify the source of unwanted behaviour and provide the required system operational data for the RCA.

Responsibility in System Shutdown and Restart

Expansions often require a temporary shutdown of normal system operations for connecting new components, which can lead to delays in restart. Technical complications, such as delayed interface integration or unforeseen incompatibilities, extend downtime and can bring potential financial losses for operators and involved third parties. Often, it is unclear whether the responsibility for lost network usage fees or compensation for delays lies with the operator or the OEMs.

Mitigation measures:

- Contracts should contain clear guidelines on the responsibilities during shutdowns and restarts. Planned downtime windows, escalation procedures, and mechanisms for calculating compensation for additional downtime help prevent potential disputes.

- Early laboratory tests that identify and resolve typical failure cases in the shutdown-restart process can minimize delays. Collaboration among all involved parties ensures that uninterrupted system functionality is maintained even in complex scenarios.

6.3.9 Changes to technical specifications along the development phase

For onshore system solutions the risk is lower than for offshore solutions, as consequential costs are lower, and accessibility is higher.

For offshore system solutions, the future 2GW converter concept is today considered as becoming the market standard. It is relatively mature via the German/Dutch Innovative Partnership program, and to be validated further via their projects, then space for C&P equipment and production time for PtP solutions is well known.

For the relevant offshore DCSS, the requirements for space/weight/time/costs are less mature. No industry validated information exists, for the components (DCSS/FSD) and auxiliary equipment that make up a DCSS the project contingency for same must be foreseen and with relevant project/contract management instruments implemented from the beginning.

The project setup and related contracts (both OWF-contracts and TSO-contracts) shall foresee flexibility in the time schedule for the test/commissioning of the hybrid connection, allowing for design changes during the engineering and tendering phase. Regarding the functionality related risk of the DCCB/Hybrid, the project/system framework should consider radial, independent operation of the PtP (Radials), which again may require a regulatory compensation regime towards the OWF-operators.

As multiterminal HVDC systems are typically developed progressively, starting from a PtP configuration and evolving into a multi-terminal topology by adding new converter stations, DCSSS, and other possible subsystems, there is an inherent risk that initial technical specifications may not fully account for the final system setup.

This need calls for a robust and forward-looking FEED (and/or Pre-FEED) that captures the complete functional, spatial, and interface requirements of the final multiterminal setup, to the extent possible, from the early stages of the project. A pre-requisite for such robust FEED-studies is sufficiently maturity of the models necessary for the FEED, which is an inherent risk to the FEED itself.

In the case the Pre-FEED and/or FEED is not sufficiently aligned with the future system architecture, and does not capture all missing inputs, subsequent adjustments to technical specifications during the development, design, execution and operation phases may become necessary, requiring further collaboration between the stakeholders involved. Ref. D5.4 to relevant coordination steps in relation to a FEED-study. These changes carry a high risk of budget overruns, delays in commissioning, and engineering rework, especially where procurement or installation has already begun. Moreover, if constraints such as space limitations (notably on offshore platforms) or timeline rigidity prevent rework or adaptation, the only fallback mitigation may be to impose operational constraints on the final system.

Even when a comprehensive FEED is performed, residual risks remain namely, that insufficient time, budget, or spatial allowances are embedded in early decisions to accommodate future expansion.

Specifically for primary equipment (e.g. main circuit equipment, converter valves, DC equipment, filters, AC equipment): early-stage specifications for primary equipment may be based on a PtP configuration, underestimating that the final multiterminal system could require different ratings, topology, or configurations and physical or functional mismatches may occur. One example is the impact of transient

overvoltage studies on insulating distances of primary equipment in MTDC configuration. In InterOPERA system design studies are extensively discussed further in T5.4.

Specifically for secondary equipment: early-stage specifications for control and protection (C&P) may be based on a PtP configuration, underestimating the complexity and interdependencies required for multiterminal operation (e.g. multi-node control logics, redundancy schemes, or communication architecture).

Impact on Asset Owners / Operators: Physical constraints, particularly offshore, may prevent late-stage adaptation. This may lead to suboptimal operation, curtailment of future lines, or need for costly retrofit. Time impact could be huge, delays in asset energization can have material financial consequences. Increased engineering iterations and potential delays in system integration testing. The time needed to update logic, re-test control sequences, and validate protection coordination may push commissioning timelines, affecting revenue streams.

Impact on Vendors: Risk of rework, scrap, or underutilized equipment. Schedule pressure increases as redesign must fit into fixed fabrication slots. Engineering and project teams face significant resource strain.

Late-stage redesigns or upgrades of control and protection systems increase engineering workload and may require additional testing cycles. Interface mismatches can also lead to duplicated efforts with third-party vendors or system integrators.

Residual Risk: Even if FEED considers the full system, logistic and capacity limitations (platform size, fabrication windows) and evolving requirements may still cause irreversible decisions or necessitate costly workarounds.

Magnitude: High CAPEX impact, especially in offshore or constrained environments, combined with significant risk of delays and engineering overload.

6.3.10 Stranded assets

Where assets are tendered, procured and constructed, it is assumed that the assets are required for the prognosed end situation– e.g. the design of a platform with additional connection points or with space for additional equipment (i.e. larger platform); an over scaled Converter for absorption of over-voltages; etc. Where a later phased is decided upon as unnecessary or providing too little additional value, and is cancelled, the additional assets already purchased may be viewed as stranded assets – especially if unused.

The Final Investment Decision (FID) on a hybrid system (2 PtP for offshore wind connections and including a DCCB for the hybrid operation) will require parallel tendering and contracting of both the offshore wind and the HVDC transmission systems. With an expected longer run time for the HVDC PtP's than for the offshore wind parks and therefore earlier initiation of the PtP tender process than for the OWF concessions. With a financing mechanism, where the OWF's partly finance the PtP a significant risk of potential sunk cost occurs, as a too expensive DCCB tender will result in no signing of the hybrid contracts, and then no OWF contracts.

Logically the tendering and contracting process for the entire system needs to be considered and planned carefully, recognizing the challenges and risks by the involved parties. Otherwise, the decision making should be based on radial operation of the PtP solely (which might result in a commercial project

without critical infrastructure, depending on country), and the introduction of a later DCCB, enabling a hybrid solution, which requires a standalone and marginal business case and decision process.

As a mitigation, the buyer needs to be able to recoup the stranded asset investment from the Regulated entity that has approved the investment.

6.3.11 Ambiguity leading to design failure

To date, no dedicated offshore DCSS have been constructed. As such, there is ambiguity around all the information that will be required to properly construct the central DCSS platform. It is however evident that design information of the parties designing the two HVDC PtP links will be required to ensure the design of the DCSS is fit for purpose (e.g., information associated to insulation coordination, (short-circuit) current ratings), and this data will not be standardized, even after the conclusion of InterOPERA. Given the ambiguity around all the information being required to design the DCSS, there is also ambiguity in the interface between the different contracts. This ambiguity might lead to a design failure, i.e., the DCSS not being fit-for-purpose, whilst not being able to assign a clear accountable party.

6.3.12 Regulatory and Market Risk related to Hybrid Assets

InterOPERA does not research the Regulatory and Market issues associated with multiterminal grids. Interconnection of two PtP systems may need to the creation of so-called Hybrid assets combining the functions of interconnection between countries and energy evacuation. The purpose of an interconnector is strictly regulated at the EC level and power flow availability may be an issue. It is necessary to address this prior to investment in such infrastructure.

There is market risks associated with construction and exploitation of Offshore wind. The construction of such assets leads to potential new market structures and opportunities.

6.4 Conclusions

The risk analysis indicates that there are material risks to a multivendor procurement programme for multiterminal grids. However, there is also sufficient mitigation to make these projects possible.

6.4.1 FEED as a major risk mitigation measure

The change in the risk profile before and after mitigation is significant. The initial assessment identified 15 risks, with 7 classified as high, including the unknown design of the DCSS, potential stability issues, and risks from late-stage technical specification changes. After applying mitigation measures, the profile improves considerably: the number of high risks is reduced to 3, and 9 of the 15 risks are successfully mitigated to a "low" status.

A central finding of this analysis is the critical value of a FEED study or alternatively less detailed Pre-FEED study. This step is the key mitigation measure for several of the most severe risks. For instance, executing pre-award FEED (Pre-FEED) study with OEM participation *before* awarding the main contracts is essential to:

- Define clear-cut, vendor-neutral DC-side requirements, addressing the Lack of Standardization risk.

- Remove ambiguity surrounding the DCSS design, which is currently unknown.
- Prevent costly changes to technical specifications during the development phase by capturing the final system's complete requirements from the start.

Despite these mitigation efforts, 3 high-impact risks remain in the residual profile:

1. Lack of Standardization: InterOPERA will not fully deliver a "plug-and-play" solution. Costly HVDC components will still require project-specific studies to optimize their design rather than using overly costly, conservative margins.
2. Complexity of System Integration Tests: Integrating components from multiple OEMs remains highly complex. These tests will likely need to disturb the commercial operation of the initial PtP links, as they may be commissioned before the full multi-terminal system is finalized.
3. Delay in one Functional Component: The system's high degree of interdependence means a delay in one functional component can halt progress on another, as critical interface and design data would be missing, delaying the entire project.

6.4.2 Evolution in long term risk profile

It should be noted that the risks related to numbers of interfaces and complexity of integration tests when compared to a single vendor system are almost certain to happen for the early projects. These risks will potentially be reduced in the short term by extensive testing in early project phases and even potentially before contract allocation— but at a cost. As more projects are completed, and technology converges on interoperable sub-systems the risks should diminish. The different (HVDC) vendors also provide diverse technical solutions that behave differently – both at the converter level and for other subsystems (DCSS). InterOPERA has limited scope and will test only a specific system design. We can understand more about the behaviour of combined systems and potential technology convergence as more projects are completed.

It should be noted that the complexity and costs of testing and integration depend on the ability to be confident of Software-in-the-loop (SIL) models rather than requirement for Hardware-in-the-loop (HIL) testing of planned grid infrastructure. Over time and as grids are constructed, meaning after the finalization of InterOPERA and even realization of the first projects, we would anticipate the knowledge and anticipation of behaviour to make full HIL testing unnecessary. This will be a major cost saving for TSOs and reduces the risk impact.

7. Procurement Strategy

Based on the Market Screening (5.1.2), Risk Assessment (5.1.4) and additional feedback from Owners (mostly represented by TSOs) and OEMs and other suppliers in InterOPERA the different Procurement Options (5.1.3) are evaluated with a CBA to identify a procurement strategy that outlines the most optimal approach to source the main electrical components that are part of the Reference Topology Phase 2.

7.1 Cost Benefit Model

To execute a CBA a model was developed to make visible the trade-offs between the relevant CBA indicators of Contingencies, CAPEX, Construction Risks, Owner FTE, O&M, System Performance, Expandability of the system and the Market Fit. The selected indicators reflect the value and risk profile of MTMV HVDC projects, consistent with established CBA practice for large capital infrastructure projects. Furthermore, for MTMV HVDC project the CBA model considers O&M, System stability and Expandability of the system to account for costs and benefits related to multi-vendor multi-owner projects and the potential increase of interface complexity. Figure 8 provides a comprehensive overview and description.

CBA Indicators	Owner Contingencies	Cost of risk mitigation measures
	CAPEX	Total contract(s) value
	Construction Risks	Residue risk on cost and time
	Owner FTE's	Amount of FTE the owner needs to realize the project.
	O&M	Subcategories: OPEX, liability risk in case of a trip (availability reliability), preventive and curative maintenance, software updates, IP.
	System Performance	Flexibility, reaction time, etc.
	Expandability of the System	Scheduled and unscheduled expandability
	Market fit	Attractiveness to the market with the goal of a bidding process with multiple bidders.

Figure 8: Overview of the CBA indicators in the Cost Benefit Model to evaluate the Procurement Options

Each procurement option will be analysed by scoring the CBA indicators with InterOPERA stakeholders both from an owner and contractors' perspective to reflect practical priorities for early MTMV

deployments. The CBA is populated with quantitative and qualitative inputs from the market screening, the risk assessment (using post-mitigation scores) the evaluation of the procurement options and feedback from T5.1 contributors, both owners and contractors. Some indicators are only relevant from an owner's perspective, such as the amount of owner FTE, while others are only relevant from the perspective of contractors, such as the market fit of the procurement options. This results in a CBA in which not all indicators were scored by all stakeholders. Each CBA indicator and the scoring system is described in more detail below.

The scoring and the underlying rationales were collected within InterOPERA from participants of the T5.1 group.

7.1.1 Owner Contingencies

Project contingencies for the procurement options reflect the capability for the owners to estimate total project costs, taking the lotting strategy into consideration. For contingency, as a matter of risk mitigation, only the risks directly related to the coordination of the various lots and interfaces apply.

Contingencies include in general all activities and measures foreseen by the Owners related to mitigating identified risks as well of known unknowns plus unknown unknowns. The evaluation of contingency in this chapter embraces contingency in all the stated CBA categories.

Scoring

The contract value for future MTMV systems is still unknown and depends on many assumptions, such as technological development, standardisation and regulatory frameworks, to name but a few. Therefore, it is challenging to score the contract values for the different procurement options, so a ranking is used based on the likelihood of having the highest (3) or lowest (1) contingencies out of the three procurement options.

7.1.2 CAPEX

The total contract(s) values are evaluated, principally by comparing the different scenarios against each other. Although actual costs for the future MTMV systems are unknown the comparison can indicate which options are related to higher or lower costs. In this item the Contractor's risk contingencies are included.

Scoring

Similar to the contingencies a ranking is used based on the likelihood of having the highest (3) or lowest (1) contract value (CAPEX) out of the three procurement options.

7.1.3 Construction Risks

Measures the probability-weighted impact on time, quality and safety arising from e.g., multi-lot integration, interface complexity, logistics, complexity of site coordination and different installation procedures and technical standards which relate also to the risk regarding safety.

Score

0 = Unacceptable high risk, not possible to realize project.

2 = High risk level, difficult to mitigate risks.

5 = Neutral level: Acceptable with proper risk mitigation management.

8 = Low risk level, attractive.

10 = very low risk level of contractors / parallel works / interfaces / FTE's, lowest degree of control regarding site coordination.

7.1.4 Owner FTE's

An evaluation will be conducted to determine the number of FTEs that the Owners require to implement the various procurement options. The corresponding change in the FTE number of the contractor's is not considered, as the impact here is covered via the change in each amount of contract value and by that in the category CAPEX and the Market Fit. A change in FTE can be the result of various factors, such as the need for engineering, interface management, model exchange, testing, and site coordination.

Score

0 = Unacceptable high number of FTE's required.

2 = High level of FTE required with high complexity of interfaces to manage

5 = Neutral level: Acceptable with proper organization and contract management.

8 = Low complexity in contract setup, attractive and manageable with less FTE's

10 = Highest score 10 equals the project with min. challenges, min. number of contractors / parallel works / interfaces / FTE's, lowest need of control regarding site coordination.

7.1.5 O&M

The O&M indicator assesses lifecycle maintainability, availability, coordinated repair works and integration across vendors and owners and the effect of the amount of interfaces on responsibility & liability. The different procurement options face different risk to plan and perform operational maintenance.

Score

0 = Unacceptable high risk, not possible to plan and perform operational maintenance & coordinate repair works. Inacceptable conditions for liability allocation.

2 = Difficult, but still possible, to plan O&M, but with some major challenges in responsibility & liability allocation.

5 = Acceptable. With proper planning and coordination of O&M related activities and clear allocation of responsibility & liability.

8 = Good. The conditions for allocating responsibility & liability for O&M activities, requiring normal planning and coordination activities.

10 = Very Good. Optimal conditions for later operation of Owner's asset and minimum planning/handling of maintenance operations. Crystal clear liability allocation.

7.1.6 System Performance

The system performance assesses the expected stability and availability of the MTMV HVDC system based on the main electrical components and station-level subsystems, explicitly excluding any contribution from a central DC grid controller. In the evaluation following aspects can be considered:

- added flexibility from more lots and contractor products
- the aggregated impact of mixed-vendor equipment (including risk of repeated failures and related liability risks)
- the quality of interface coordination (requirements, model exchange, joint studies, etc.).

Score

- 0 = Unacceptable poor system performance, impossible to fulfil requirements, securing system stability.
- 2 = Barely acceptable. Low system operability/stability, difficult to mitigate critical failures. High risk of “Brown out” & “Black out”
- 5 = Neutral risk level: Acceptable with a proper test & commissioning planning, supported with clear system operation procedures.
- 8 = Good. Efficient and stable system operation procedures, clear interface coordination during test & commissioning, optimal conditions for coordination of station/component specific measures.
- 10 = Very good. The scenario with the estimated best performance e.g. high availability/reliability/stability, efficiency, low degree of maintenance

7.1.7 Expandability of the system

Expandability examines the ease and cost of future system growth, adding terminals, DCSS, and FSZs without major rework. It considers modularity and standardized interfaces and the option value of staged build-out.

Score

- 0 = Unacceptable, not possible to extend the system at all.
- 2 = Expansion possible but with high risk level, interoperability low, difficult to mitigate black outs.
- 5 = Neutral level: Acceptable with proper interface management.
- 8 = Good expandability, multi-vendor friendly, Low risk level, attractive
- 10 = Very good. The scenario with the estimated most optimal conditions for later extension of Owner’s asset and minimum planning and/or handling of technical/legal implications.

7.1.8 Market Fit

The appeal of the various options to the market will be evaluated by the contractor’s independently, based on the overall risks and capability of the contractor’s/suppliers. The Market Fit assessment determines how attractive the different procurement options are to the market, and therefore how well they fit into a future business strategy. This includes the contractors' FTE requirements

Score

- 0 = Unacceptable, no bidders willing to offer.
- 2 = limited market fit, less rationale for business. Very few bidders are willing to offer.
- 5 = Neutral risk level: Acceptable with a certain business opportunity.
- 8 = Low risk level, attractive business potential. Fits into business strategy.
- 10 = Min. challenges & interfaces. Scope fits perfectly into business strategy.

7.2 Cost benefit analysis (CBA)

Ranking 1-3			
Scoring 0(Unacceptable)/2/5/8/10			
	<i>Option 1</i>	<i>Option 2</i>	<i>Option 3</i>
Contingencies	1	3	2
CAPEX	1 or 3	1 or 3	2
Construction Risks	10	5	8
Owner FTE	10	2	5
O&M	8	5	5
System Performance	8	5	5
Expandability of the system	Unconclusive		
Market Fit	8	8	8

Figure 9: Overview of CBA scoring results

7.2.1 Owner Contingencies

The risk of delay depends on the specific testing requirements outlined in each contract. If we consider the DCCS and central DCSS as two separate projects, it is assumed that contracts 1 and 2 cannot be tested simultaneously. This builds on the assumption that InterOPERA will provide an initial reference framework to support the de-risking of grid-level control interface definitions through preliminary functional signal lists and guidance on communication standards. However, further evaluation and validation of InterOPERA's input might be needed for use in future projects. Grid controller expansion is also assumed to be possible. There are three types of testing to consider: non-physical testing, physical interface signal testing, and power flow testing. It is important to note that power flow testing is not a differentiator between the options, as it requires the entire system to be tested together.

Option 1 – Ranked 1st

The key interface between the DCCB and the converter it protects lies on the Contractor's side. The Contractor can manage these interfaces effectively, issues and interface clarifications can be managed directly and internally, without involving third parties or the relevant owners. For example, C&P concepts can be addressed within the Contractor organization, eliminating the need for additional interface work.

Figure 10: Overview of CBA scoring results

Option 2 – Ranked 3rd

This option involves the highest number of interfaces, meaning the owner must plan for contingencies. For example, if there is a lack of standardization or non-performance, it may be necessary to rework assets from contract 1 when implementing option 2 or 3.

Option 3 – Ranked 2nd

Same drivers as option 2 but one interface less.

7.2.2 CAPEX

Option 1 or 2 – Ranked 1st or 3rd

Option one creates synergies by using a single project execution team and having a simpler integration process. However, it also means that the Contractor must plan for greater risk contingencies related to interface liabilities. Currently, it is unclear what the overall effect of these two factors will be, as the exact risks at the interface are not fully known. Furthermore, quantifying these risks in monetary terms is outside the scope of InterOPERA.

Option 3 – Ranked 2nd

Option 3 may be less attractive because both DCSS will have to be designed according to the strictest converter requirements. However, this approach does enable standardization in central DCSS design, which can help to reduce costs.

7.2.3 Construction Risks

Option 1 – Score 10

There is very limited risk of a mismatch between the DCCB and converter designs because they are covered under the same contract. This arrangement also provides optimal conditions for testing interface risks between converters and the DCCB.

Option 2 – Score 5

With several companies working in parallel, there is a higher risk of delays because of their interdependencies in design interfaces. Score 5 assumes a FEED was implemented before contract signing.

Option 3 – Score 8

There is less interface risk between the DCCBs in this option, resulting in a higher score compared to option 2.

7.2.4 Owner FTE

Option 1 – Score 10

There are limited interfaces, which also means the Owner will need only a limited number of FTEs. The complexity is comparable to a converter or cable interface, assuming the Control & Protection (C&P) interface is developed by InterOPERA.

Option 2 – Score 2

With this option, the Owner is responsible for integrating all four contractual interfaces, which involves managing many interfaces and will require a significant number of internal FTEs.

Option 3 – Score 5

This option requires less coordination and fewer FTEs compared to Option 2. The additional alignment needed between the two owners in the DCSS contract is considered minimal—mainly necessary during contract preparation and very limited during contract execution.

7.2.5 O&M

The most complex interaction is expected to happen between converters. Those between converters and DCSS are considered more trivial assuming standardized C&P interface. We assume that in the contracts liability schemes on station rather than system level will be put in place.

Option 1 – Score 8

There are only one or two parties involved in coordinating planned or unplanned maintenance. This results in the most straightforward liability hierarchy.

Option 2 – Score 5

With four parties involved clearly defining liability and responsibility, and identifying the causes of failures, will be complex. Compared to other options, this scenario is likely to result in more scheduling issues and greater downtime.

Option 3 – Score 5

Option 3 faces the same challenge as Option 2, but with only one central DCSS supplier, there is less interface management for owners. Despite this decrease, the minor difference is not significant enough to increase the score from 5 to 6, as the interface between DCSS and DCCS is considered the most critical.

7.2.6 System Performance

Option 1 – Score 8

Most complex interaction is expected to happen between converters and especially between converters across contracts. Those between converters and related DCSS are considered more trivial assuming standardized C&P interface, securing safe operation of the DCSS at each converter station. Putting liability schemes on station level rather than system level keeps liability allocation at a single contract level when connecting more converter stations to the system. There are more contracts to manage however, no management of simultaneous operations (SIMOPS) in the same location (converter station) is required. For the first projects following InterOPERA the two DCCS in each PtP-system are considered within a single contract, reducing the number of interfaces.

When connecting two PtP systems to each other, a need for a Central DCSS occurs and with a fault clearing capability included (DCCB) if two FSZ's are necessary.

With two converters in a PtP-system and a central DCCB supplier in one contract, a successful fault clearance capability for that joint system becomes vendor's motivation, but the Owner carries the responsibility for the availability and performance of the full system when connecting two PtPs via a central DCSS e.g. grid controller.

With one party liable for system performance within each HVDC system, two different DCCB contractors may lead to lowest risk of malfunction within and between FSZ.

Option 2 – Score 5

Even with liability schemes per station, the consequences of the DCSS mis operation can lead to discussion on liabilities in case of damage.

With 2 different DCCB suppliers, the probability of successful FCS should be high, but with higher responsibility of Owner for master controller in both HVDC systems.

Option 3 – Score 5

Even with liability schemes per station, the consequences of the DCSS mis operation can lead to discussion on liabilities in case of damage.

Lower probability for successful Fault Clearing Sequence (FCS) performance as only one contractor, meaning both may fail simultaneously.

7.2.7 Expandability of the system

Although the number of different parties involved can affect the practical execution of expandability, we have concluded that this is not a decisive factor when comparing procurement options. The feasibility of expandability mainly depends on the Single Line Diagram and the quality of the Owner's interface requirements defined at the start of the project. InterOPERA has not set any limits on the number of substations.

7.2.8 Market Fit

Option 1/2/3 – Score 8

This factor is not considered a differentiator. The overall score of 8 indicates that all procurement options could attract enough interested parties to guarantee competitive tenders. However, Option 1 may exclude certain market participants who are unable to offer the complete product line required.

This evaluation is under the assumption that the owner will take on the responsibility of the MTMV system integration, owners proposed liability schemes would further influence the attractiveness.

7.3 Procurement strategy recommendations

While the risk analysis shows that MTMV procurement carries material risks, it also concludes that there are sufficient mitigation strategies to make these projects possible. The most critical mitigation tool is the pre-award FEED study, which may be understood as a kind of Pre-FEED study or Pre-Specification study, as some coordinated studies are necessary for closing the tender requirement specifications prior to contract, but with less resources than for a full FEED.

For developing a procurement strategy by the Owners of a potential first project with relevant MTMV topology, the following considerations should be evaluated:

- What is the level of competences by the Owners to administrate and take responsibility for MV interfaces across protection zones?
- What ambitions do the Owners have regarding building up internal knowledge on MTMV interface management, and by that size up the organization?
- How does ownership of the assets involved (incl. DCSS) correspond to the definition/borders of the relevant protection zones, and if misalignment, how to manage that?

- To what extent does future expandability play a role? To be considered/ignored? Simplification of project design scope influences the risk exposure of both owners and suppliers positively.
- Is the responsibility and liability regime clearly defined, enabling proper project/contract management during design, construction, commissioning and operation?
- During tender, negotiation priorities will evolve around maintaining a similar system of liability allocation through all contracts.
- Does the MPCF [4] developed within InterOPERA fulfil the need for legal alignment, and/or is further specifications/clauses required?
- How is the market view on the project? The initiation of early market dialogue with contractors for clarification of MTMV maturity and supplier's appetite on MTMV and view on risk ownership is strongly recommended.
- Concrete cost estimations from the market for a specific project are required to make the CBA conclusive
- System performance risk analysis should be updated
- During the tendering process a joint "Rock drill" (exercise with all relevant stakeholders, testing the different scenarios for all phases of the project incl. operation (failure scenarios)), Managed by the owners might support the identification and alignment of the scheme for responsibilities and related liability.

The executive summary indicates that after scoring the options, Option 1 (bundling the DCSS with one of the PtP contracts) is favoured for the first projects following InterOPERA.

It is important to note that CAPEX uncertainty, such as contractor contingencies, can lead to shifting priorities. However, because Owners and TSOs tend to prioritize risk reduction—driven by their risk-averse nature and earning models — lowering risk generally takes precedence over reducing CAPEX costs.

Over the long term, as the market matures and more MTMV projects are completed, the risks and complexities of integration are expected to decrease making multi-contracting more attractive.

Abbreviations and Acronyms

Acronym	Full Text
BOT	Build-Operate-Transfer
C&P	Control & Protection
CBA	Cost Benefit Analysis
DCCB	Direct Current Circuit Breaker
DCCS	HVDC Converter Station
DCGC	DC grid controller
DCSU	DC Switching Unit
DCSS	Direct Current Switching Station
EMT	Electromagnetic Transients
EPIC	Engineering, Procurement, Installation and Construction
FEED	Front-End Engineering Design
FCS	Fault Clearing Sequence
FID	Final Investment Decision
FRT	Fault Ride Through
FSD	Fault Separation Device
FSZ	Fault Separation Zone
FTE	Full-Time Equivalent
HIL	Hardware-in-the-loop
HVDC	High voltage direct current
IEEE	Institute of Electrical and Electronics Engineers
LTSA	Long-Term Service Agreement
MPCF	Multi-Party Cooperation Framework (InterOPERA)
MTMV	Multi-terminal multi-vendor
O&M	Operation and Maintenance

OEM	Original Equipment Manufacturer
OWF	Offshore Wind Farm
PtP	Point-to-Point
RASCI	Responsible, Accountable, Support, Consult, Inform
SIL	Software-in-the-loop
TSO	Transmission System Operator

References

[1]:

InterOPERA D2.1, "Functional requirements for HVDC grid systems and subsystems", 2024.

[2]:

InterOPERA D3.2, "Subsystem pre-design phase process and outcomes", 2024.

[3]:

InterOPERA D3.1, "Demonstrator Definition & System Design Studies", 2024.

[4]:

InterOPERA WP4, "Multi-Party Cooperation Framework - draft version", 2024.