# InterOPERA Stakeholder Committee - 2nd technical workshop Summary report

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Inter OPERA
Enabling multi-vendor HVDC grids

## 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.

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# 2nd technical workshop - summary report

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| V1 | 08/10/2024 | Riccardo Longo<br>Nina Mavrogeorgou | Initial version |
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# About the 2nd technical workshop

## 2nd technical workshop

On 28 August 2024, the second in a series of InterOPERA technical workshops took place. This second workshop focused on selected deliverables prepared by the experts of Work Package 1 (Development of standardised interaction study processes and interfaces) and Work Package 2 (Requirements and assessment of interoperability for multi-vendor multi-terminal HVDC systems.

Specifically, three reports were discussed:

- Deliverable 1.3 (D1.3): *Definition of a standard process for interaction studies with EMT simulation in multi-vendor projects*
- Deliverable 2.1 (D2.1): *Functional requirements for HVDC grid systems and subsystems*
- Deliverable 2.2 (D2.2): *Functional requirements for GFC of HVDC systems and PPMs - Recommendations of GFC for connection network codes*

The workshop featured presentations from SuperGrid, Energinet, and Réseau de Transport d'Électricité (RTE), along with over 30 professionals and experts from the Stakeholder Committee. Unlike the first workshop, this one was conducted entirely in person at RTE's premises in Paris.

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***The Stakeholder Committee, meeting entirely in person, provided valuable feedback and inputs on the project deliverables, exchanged views on potential exploitation routes for the project demonstrator, and engaged the keynote speakers with technical questions and observations. The in-person format allowed for more efficient and dynamic engagement, fostering a richer exchange of opinions.***

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The first part of the workshop was opened by SuperGrid and targeted the definition of the functional requirements for HVDC grid systems and subsystems (deliverable 2.1 – referred as D2.1).

This first session was followed by a general discussion involving the Stakeholder Committee.

The second part of the workshop, focused on the grid-forming functional requirements for HVDC converter stations and DC connected PPMs in multi-terminal multi-vendor HVDC systems (deliverable 2.1 – referred as D2.1), was led by Energinet.

The main discussion points included:

- quantifiable dynamic performance requirements for GFM control;
- interaction risks when applying GFM control; and,
- grid-code recommendations.

After a second Q&A session with the keynote speakers, the final presentation by RTE took place, concentrating on the development of practices and guidelines to minimize interoperability issues, specifically related to defining a standard process for interaction studies using EMT simulations in multi-vendor projects (deliverable 3.1 – referred as D3.1).

A third and final Q&A session followed this discussion, concluding with closing remarks and an announcement for the next workshop, anticipated to take place between late 2024 and early 2025.

# Discussion summary

## 1.1 Functional requirements for HVDC systems and subsystems

Task 2.1 developed a functional framework to define functional requirement at the DC-Point of connection for the relevant subsystems such as converter stations or switching stations. The main challenge is to define the requirements in a way that they maximize the design space of each vendor while ensuring interoperability by design. During the presentation key outcomes of different technical areas, as listed below, have been presented: sequential control, continuous control and DC grid protection.

**Sequential control**

- Within a given HVDC system topology, different DC connection modes are possible. The DC connection modes describe the connection between the individual units within the HVDC system at their DC-PoC. The sequential control describes all actions that allow the HVDC system to switch from one connection mode to another. Such transitions may be triggered automatically, or manually by an operator, or a combination of both.
- The communication interfaces have been presented. Vertical communication is preferred, and horizontal communication is deemed exceptional.
- The functional aggregation of the switching unit has been presented. The main states of a switching unit are either "open" or "closed". The transition sequence depends on conditions of surrounding units which are verifiable at switching unit level based on voltage and current quantities. A transition from "open" to "closed" state may be carried out by an aggregation sequence (connection of two discharged units), an energization sequence (connection of one charged and one discharged unit) or a synchronization sequence (connection of two charged units). From close to open the transition sequence is characterized by the presence or not of current. Depending on whether fault, load or residual current is observed, the performed sequence and applicable requirements for the switching unit are different.

**Continuous control**

- The overarching control architecture of HVDC systems (dispatch level, operational level, station & unit level) and associated roles and responsibilities have been presented. These conditions serve as a basis for the functional description of static and dynamic requirements for primary DC voltage control.
- System level DC voltage bands have been introduced. These bands are associated to system behaviors during static and dynamic grid disturbances. Leaving these ranges indicates that the system faces abnormal conditions which may require dedicated local or central remediation actions. A deviation of DC system voltage is an indicator of an imbalance in power flow from the initial load flow, which was originally at equilibrium. The primary DC voltage control plays a crucial role in preventing this imbalance and reaching an equilibrium point of the system.

- To achieve improved security while achieving the maximum exploitation, the multi-segment droop characteristic for primary DC voltage control is defined as a distinct set of control capabilities, each with specific operational requirements.
- The stability of the system is determined by the dynamic response of each AC/DC converter and their interactions through the network. In a multi-vendor and multi-terminal DC grid, each converter controller would likely be unique to each vendor, reflecting different dynamic control design concepts. Therefore, the established static requirements for the primary DC voltage control are complemented by appropriate dynamic primary DC voltage control requirements. The AC/DC converter station shall comply with several characteristic values such as step response time, overshoot, and damping coefficient to be specified by the TSO. First considerations for the performance evaluation in a standalone test environment are made.

**DC grid protection**

The functional group DC grid protection defines the system states (normal, alert, emergency, blackout) and associates them to ordinary and extraordinary contingencies. Requirements for fault detection and fault current suppression are defined on DC switching station level and a DC-FRT profile for AC/DC converter stations is defined with the objective of a clear functional split between AC/DC converter station and DC switching station.

- **DC-FRT profile for converter units**
  - Shall ensure that
    - Converter has enough withstand capability to ride through DC faults without disconnection while primary protection is operating;
    - Converter resumes stable operation after DC-FRT event; and,
    - Converter safely disconnects in case of protection failure.
  - Shall not ensure
    - Activation of primary protection → protection relays are foreseen; and,
    - DC grid support → Grid serving requirements foreseen.

The DC-FRT profile ensures that the AC/DC converter station has sufficient withstand capability to ride through a DC fault while the primary protection operates avoiding any unplanned disconnection. The functional group DC grid protection has investigated different ways to define DC-FRT requirements, mainly distinguishing between a generic and design-based approach and between DC voltage and DC current profiles. To leave freedom to the vendors for different converter design strategies, only a DC-FRT profile based on DC voltage quantities is defined, and no overcurrent capabilities are prescribed. The actual fault current level in the converter is left unspecified and then depends on the design strategy of the converter vendor.

- **Fault current interruption requirements for a switching unit**
  - The requirement for the switching unit is to provide enough current breaking capability to interrupt all faults defined as ordinary contingency by the relevant TSO
    - Respect maximum fault neutralization time TN max
  - The requirement for the switching unit is not to satisfy the converter operational behaviour during DC-FRT (e.g. ensure continued operation)

### 1.1.1 Comments from stakeholders

<u>**Continuous control requirements**</u>

**1. Bipole level station control**

- The bipole level station control can should be able to handle unbalanced operation. Overloading of the DMR or ground return current must be avoided. A balancing control structure has been proposed in this context.

2. **System level voltage bands**

- The time between t1 to t2 is important as it describes in which time dynamic perturbations settle and to describe which type of perturbations are observed;
- It seems that in the figure the bands are defined in a symmetrical manner around nominal DC voltage. Suggestion to consider adaptable voltage ranges depending on the operational context of the converter (i.e. offshore converter, always in rectifier mode and onshore converter in either recitifier or inverter mode). Some converters could operate at lower/ higher voltage due to long distance connections. The voltage bands could be defined around this operational voltage level to avoid oversizing; and,
- The voltage ranges are very sensitive for the overall design of the HVDC system, it is important to specify the values in an inclusive way.

**3. Multi-slope droop scheme:**

- The droop control concept with different control sloops in different voltage ranges introduces higher control complexity/risk. The non linear transitions shall be specified on a functional level as they may introduce a risk for interactions due to converter impedance change; and,
- Advise for testing: Have a case where more than one converter moves across a discontinuity in the droop control area simultanously (change of droop gains).

**4. Dynamic response requirements**

- The step response criteria are hard to evaluate on the DC grid, e.g. rise time, overshoot, settling time, tolerance limit. A converter might be compliant to a step change but may have a different behaviour at the PoC in the actual HVDC grid; and,
- The step response shall be repeated for different grid scenarious / grid equivalents, the method should still be valid and representative.

**<u>Sequential control requirements</u>**

**1. Sequential control architecture**

- It is very risky that all communication is going to and from the DC GRID CONTROL. This rely on telecommunication and has 100-200 ms delay. It is safer if the converter station can communicate faster to the DC switching station on horizontal basis; and,
- Comment: The amount of different configurations hugely increase the complexity of the DC grid -> what can you do to simplify?

**DC grid protection**

**1. Generic DC-FRT requirement description based on DC voltage**

- Consequences for the DC cables when polarity reversal as shown in the figure is happening shall be considered as boundary conditions; and,
- The profile shall represent values associated to fault transients and DC voltage recovery.

# 1.2 Grid-forming functional requirements for multi-terminal multi-vendor HVDC systems with DC connected PPMs

The efforts of InterOPERA Task 2.4 to develop grid-forming (GFM) functional requirements for HVDC converter stations and DC-connected PPMs in multi-terminal multi-vendor HVDC systems was presented. The main objective of the task within InterOPERA was to develop the functional framework to ensure the ability of offshore wind power plants to remain connected and support the isolated offshore AC system during temporary loss of transmission capability and the ability of onshore HVDC converter stations to provide inertial power by drawing energy from the HVDC system.

## 1.2.1 Key points that were presented to the stakeholders

1. **Literature review**
    - Most literature defines grid-forming (GFM) control as a controlled voltage source behavior, such as an internal voltage source behind an impedance;
    - GFM capabilities are divided into mandatory and optional capabilities, or universal and additional performance requirements;
    - Capabilities are also divided based on operational conditions, such as non-disturbed and disturbed grid conditions;
    - The active power response following a disturbance is separated into different components (active phase jump power, active inertia power, active damping power, etc.) to represent different active power contributions based on different characteristics from GFM control with different time constants;
    - Most literature provides high-level qualitative instead of quantitative specifications on GFM capabilities;
    - Some quantitative specifications are provided but can be too restrictive as the requirements should only specify the AC side performance instead of detailed control schemes implemented in converters; and,
    - None of the existing literature on the topic has mentioned GFM in multi-terminal HVDC connections, and the deliverable of InterOPERA Task 2.4 would be the very first documenton this topic.

2. **Definition of grid-forming functionality**
    - GFM functionality is defined as a slow-changing voltage source behind an impedance within its current, voltage, and energy limits;
    - In withstand operation, the GFM converter shall preserve its GFM capability whenever possible, while maintaining stable operation and staying connected to the grid. The GFM converter is not required to act as a slow-changing voltage source behind an impedance when in withstand operation; and,
    - The transition between normal operation and withstand operation shall be as seamless and continuous as possible, considering the characteristics and severity of the event disturbing the converter into withstand operation.
3. **Application of GFM Control in Multi-terminal Multi-vendor HVDC Systems**

- Different concepts of achieving GFM control in multi-terminal HVDC systems were discussed, including grid-forming from one synchronous area to another with and without support from wind power plants.

4. **Energy Balancing and Grid-Forming Control**
   - Significant grid-forming action requires energy, which is extracted from or injected into the DC system. This leads to a decrease or increase in DC voltage. To maintain DC system stability, the DC voltage must be controlled by other HVDC converters in the system. The energy balance is restored by taking power from the other AC interfaces.
5. **Coordination of GFM Control in an HVDC System**
   - The capability of any HVDC converter station to deliver GFM functionality in a multi-terminal HVDC system depends on:
     - The tuning of the GFM control itself;
     - The strength of the AC network to which the GFM converter is connected; and,
     - The dynamic capability of all other DC sources in the DC grid to supply or extract the energy imbalance seen as a DC voltage deviation.
   - Consequently, GFM control performance must be coordinated with DC voltage control schemes and DC voltage operational limits.
6. **Functional Requirements**
   - General GFM requirements for HVDC converter stations and DC-connected PPMs include:
     - self-synchronization functionality;
     - phase jump active power functionality;
     - inertial active power functionality;
     - inherent reactive power functionality; and
     - positive damping power functionality.
   - Optional requirements include black-start functionality and sink for voltage unbalances functionality.
7. **Three discussion points were presented**
   - Formulating Quantifiable Performance Requirements
     - The challenge of providing well-exhausted functional requirements with quantifiable performance criteria due to the lack of references and the grid-dependent nature of GFM control; and,
     - Some ideas and suggestions are presented, and the proposal is to develop this further in a joint effort between WP2 and WP3 and to utilize the demonstrator to explore potential performance requirements.
   - Interaction Risks and Secure Operation
     - The risk of interactions imposed by applying GFM control in multi-terminal multi-vendor systems; and,
     - Considerations on what happens if the onshore AC grids are interconnected.
   - Recommendations for the HVDC Grid-Code

- Recommendations provided for the HVDC grid-code to ensure secure and efficient operation of GFM in multi-terminal multi-vendor HVDC systems.

### 1.2.2 Comments from stakeholders on discussion point 1: Formulating Quantifiable Performance Requirements

1. Responses to phase jumps can be specified as already existing in grid codes, such as a 5ms dead time.
2. It is discussed that GFM performance requirements maybe need to be site specific in the connection agreement for a specific configuration and not fully exhausted/specified generally in grid-codes.
3. The current practice is to generate reference curves which vendors tune the converter for. A specific extreme case could limit the way of implementation and lead to a suboptimal solution based on all the other requirements that must be fulfilled.
4. It is suggested that defining envelopes should be the goal of InterOPERA based on the learnings and outcomes of the demonstrator. An iterative process to learn and develop should be accepted. It should be acknowledged that the "perfect requirements" cannot be developed in the first iteration.
5. It is mentioned that in Germany, envelopes are provided based on ideal voltage sources behind an impedance, but it may not reflect realistic performance. There is a difference between contractual obligations and DUT test performance.

### 1.2.3 Comments from stakeholders on discussion point 2: Interaction Risks and Secure Operation

1. **Risk of Applying Grid-Forming Control**
   - The risk of applying grid-forming control in multi-terminal HVDC systems is considered large. It is suggested that battery systems or E-STATCOMS should deliver grid-forming services instead; and
   - Including the requirement for a DC power oscillation damping functionality (DC POD) should be considered to handle DC side oscillations caused by grid-forming control actions.
2. **Expansions of the multi-terminal HVDC system and coordination of GFM control and DC voltage control**
   - HVDC system topologies can change over the lifetime of the system, and it is advised not to put such a burden on the DC grid with respect to interaction risks and careful coordination between DC voltage control and grid-forming control. Instead, grid-forming should be provided by dedicated devices such as synchronous condensers.

# 1.3 Interaction studies process

## 1.3.1 Task 1.3 - Development of practices and guidelines to limit interoperability issues

Task 1.3 intends to define a standard process for interaction studies with EMT simulation in multi-vendor projects. Task 1.3 will issue D.1.3.

In multi-terminal multi-vendor projects, such as meshed offshore energy grids or HVDC grids in general, power electronics-based systems connected together (notably HVDC converter stations and OWPPs) and manufactured by different vendors have risks of adverse interactions. To de-risk the interoperability issues, a standard interaction study process for EMT simulations is proposed by the InterOPERA consortium.

Traditionally, any facility owner connecting to the grid shall perform a defined list of studies to demonstrate its compliance with the requirements set by the owner and operator of the grid. In case of HVDC projects owned and operated by the same owner and operator as the grid, design and interaction studies shall also be performed by the HVDC OEM and discussed with the grid owner and operator to demonstrate the compliancy with the requirements.

The purpose of this deliverable is to define how the existing list of studies and the process for conducting them should be adapted for multi-vendor and multi-terminal HVDC grids:

- Are more studies needed?
- Should the studies be categorized and packaged in a different way?
- How to iterate the studies in a joined cooperation between parties?

D1.3 is under preparation and a first version of this deliverable should be available in December 2024. The structure of the draft document has been presented during the meeting and each main section listed below has been illustrated with examples:

- Project Phase and lifecycle;
- Model sharing and iteration;
- Preparatory activities; and,
- Overview of the interaction studies to be performed.

## 1.3.2 Comments from stakeholders

<u>**Interaction study process**</u>

**1. Impedance based scanning techniques**

SSEN and the HVDC Centre mentioned that impedance based scanning techniques can provide a solution to limit the number of EMT interaction studies. A methodology has been developed with such a technique within the Aquila project. The main idea is to request passivity of converters in a predefined range of frequency. This topic has been discussed with the following considerations:

- Passivity requirement may have an impact of the converter performances especially for fault recovery. FRT requirements and passivity requirements may be incompatible between each other;

- Impedance based scanning methods do not include nonlinearities and protections. As a consequence it cannot be the only solution to identify adverse interactions; and,
- Impedance based scanning methods and state space based methods have been included in the scope of D1.3 and will be discussed.

**2. Delivery of models at different stages of a project**

Wind generator models are typically provided later than HVDC models, raising the question of how to handle models that arrive at different stages in a project.

The approach proposed in D1.3 is based on a step by step solution with generic models when vendor models are not available yet; and then update the system model with vendor models when they are available. This solution requires validated and representative models of WTG but also HVDC models at the planning stage when the HVDC supplier has not been selected.

**3. Availability of parameters**

The question of availability of parameters for models provided by suppliers has been raised. This topic was discussed with suppliers in WP1. A minimal list of parameters will be provided. Depending on the outcomes of the interaction studies performed in WP2, availability to additional parameters can be provided. Suppliers do not want to provide access to too many parameters even if they understood the benefits they may provide to limit the number of black box model deliveries. The main objective to request accessibility of parameters is to avoid as much as possible the cumbersome process of reissuing vendor models when a control tuning is needed. Instead of delivering an updated model, they can instruct the final user with a new set of parameters. This topic is discussed in D1.1 and D1.3. InterOPERA will show what is the extend of openess required in MTMV projects.

**4. Tool independant SiL solutions**

D1.1 provides specifications for models and replicas. One key requirement is to get models and replicas that are tool independant. For the offline EMT models the proposed solution was to use the IEEE/CIGRE DLL approach specificied by the JWG IEEE/CIGREB4-82. For replicas the solution is to provide a detailed documentation of the interfaces used by suppliers. A question has been raised to know if the same requirement applies for the Software In the Loop (SiL) solutions (running in real-time). The answer is yes.

First the same DLL approach used for offline models can be applied. It has been tested with SGI with dynamic library in Linux. When proprietary hardware is used for running SiL solutions a technical solution shall be discussed to be able to interface this solution with a RTS provided by a different supplier.

# Abbreviations and acronyms

| | |
|---|---|
| **AC** | Alternating Current |
| **DC** | Direct Current |
| **DC-FRT** | DC- Fault Ride Through |
| **DC-FSD** | DC-Fault Separation Devices |
| **DMR** | Dynamic Maximum Rating |
| **EMT** | Electromagnetic Transient |
| **GFM** | Grid Forming |
| **HVDC** | High Voltage Direct Current |
| **OEM** | Original Equipment Manufacturers |
| **OWPPs** | Offshore Wind Power Plants |
| **PoC** | Point of Connection |
| **PPMs** | Power Park Modules |
| **RTS** | Real-Time Simulation |
| **SC** | Stakeholder Committee |
| **SiL** | Software In the Loop |
| **SGI** | SuperGrid Institute |
| **TSO** | Transmission System Operator |
| **T1.3** | Task 1.3 of the InterOPERA project |
| **WP** | Work Package |