Functional requirements for multi-vendor multi-terminal HVDC grids

InterOPERA deliverable D2.1 Cigré 2024

Inter OPERA
Enabling multi-vendor HVDC grids

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Agenda

- Introduction (5’, Mario)
- D2.1 main results (25’, Paul, Pascal)
- Q&A (30’)

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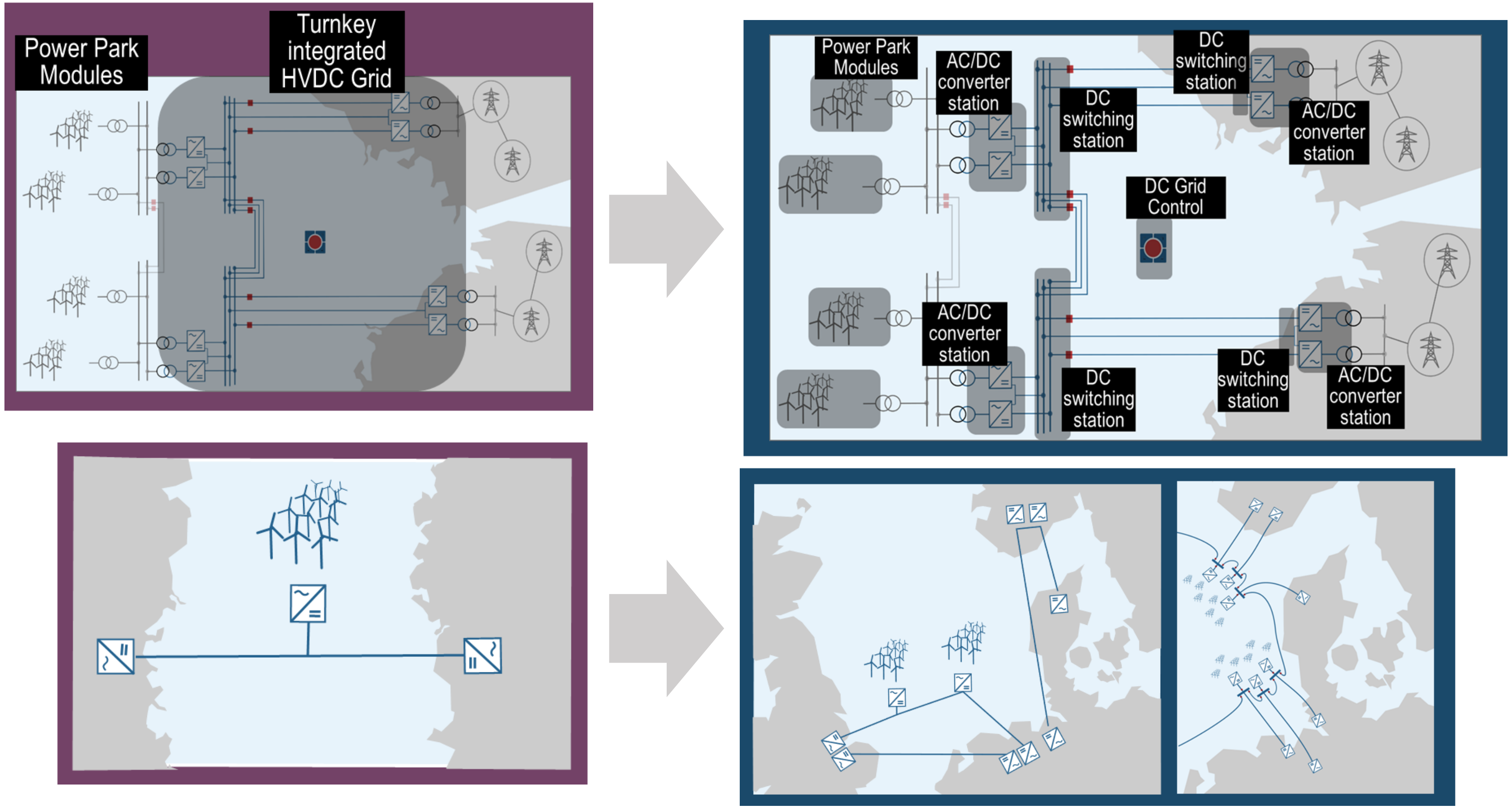
Introduction

Make grids modular & interoperable by design

→Functional requirements for multi-vendor HVDC systems



WP1
WP2
WP3
WP4
WP5
WP6
WP7

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WP2 – Objectives and Structure

- **During the first phase of the project**
  - support the development of the functional requirements
    - at DC-connection point
    - at AC-connection point upgrade with new capabilties like grid forming
    - DC grid control level
  - Develop necessary testing procedures for phase II

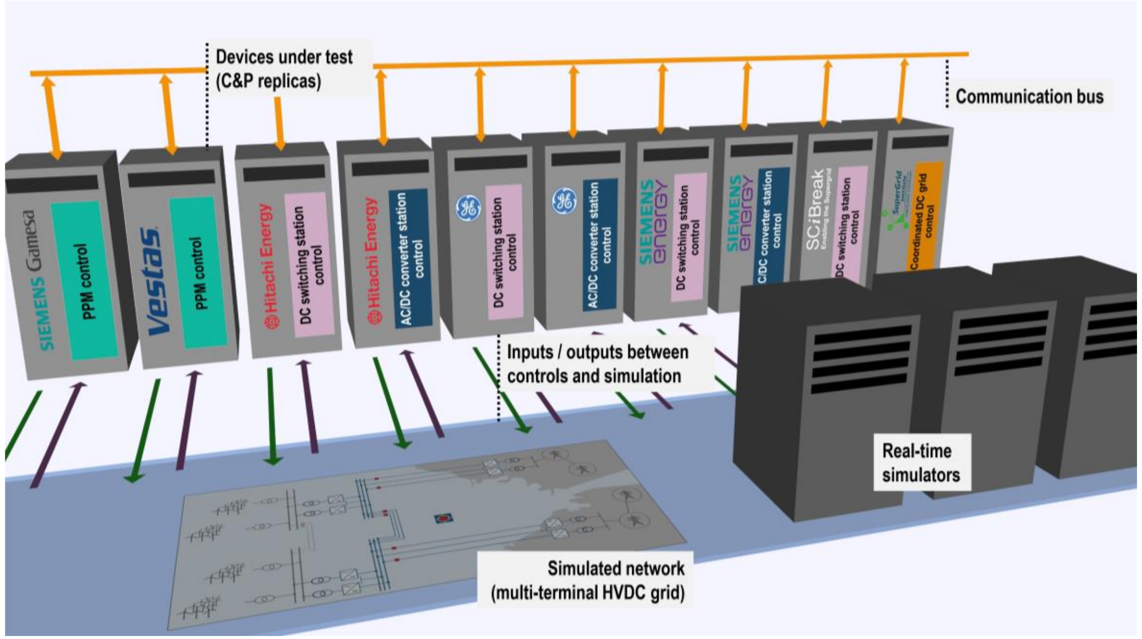
- **During the second phase of the project**

  - Carry out the interaction studies on the control and protection demonstration test set up

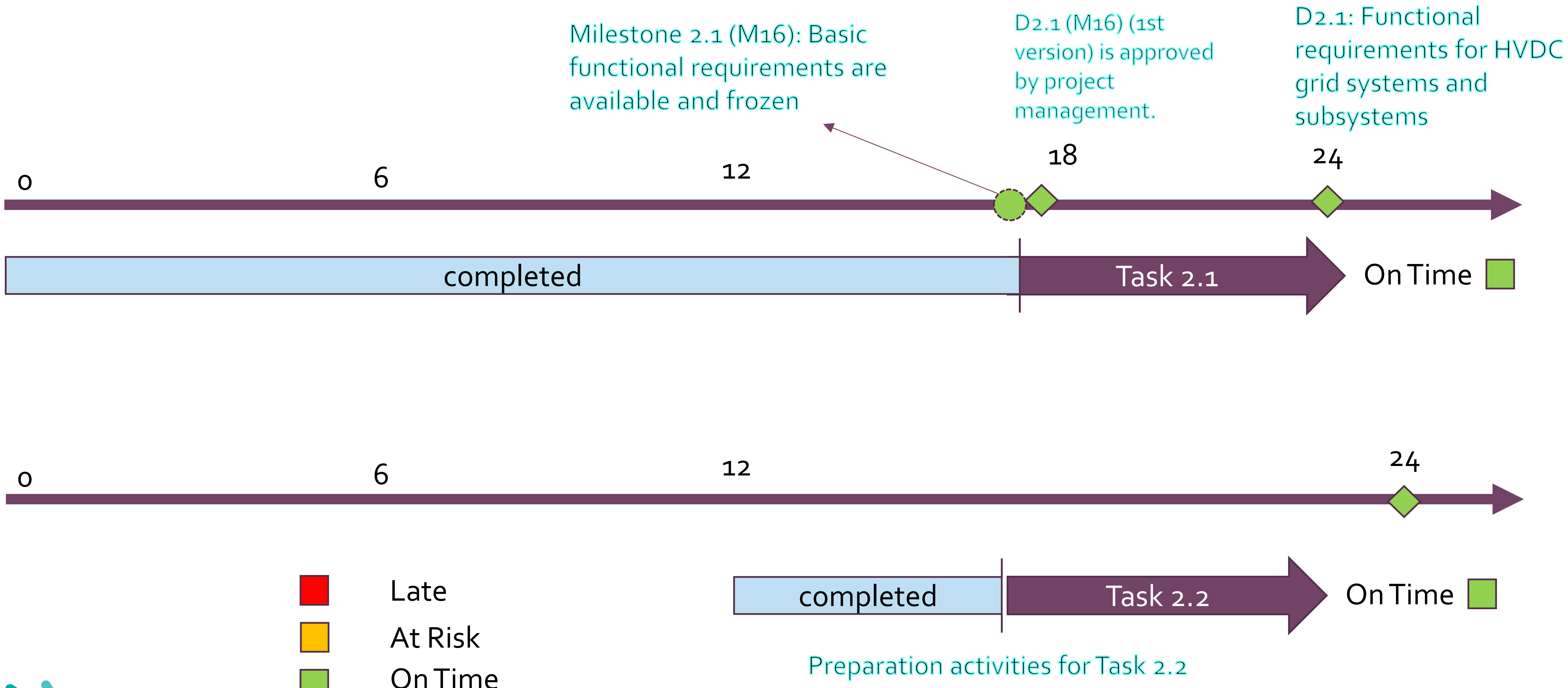
  - Provide recommendations for the decision to move to the next phase (construction of industrial full-scale project) from technical and interoperability perspective

Real-time physical demonstration of a multi-vendor control and protection system

- →at least three terminals (AC/DC converter stations) of three different manufacturers with power rating applicable in the current existing real life use cases
- → Compliance verification and prequalification process for future full-scale projects



Timeline of Active Tasks: milestones & deliverables



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D2.1 main results

D2.1 structure

Published on 17th of June

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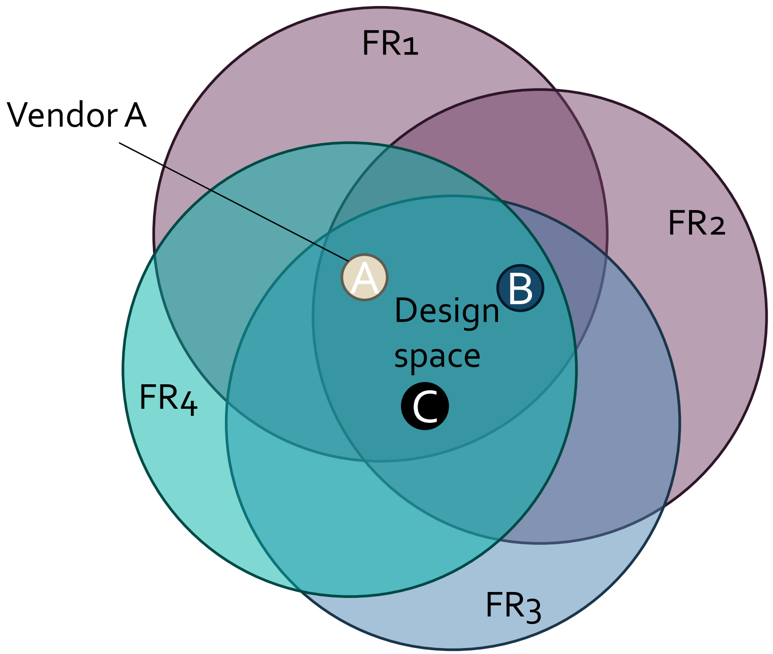
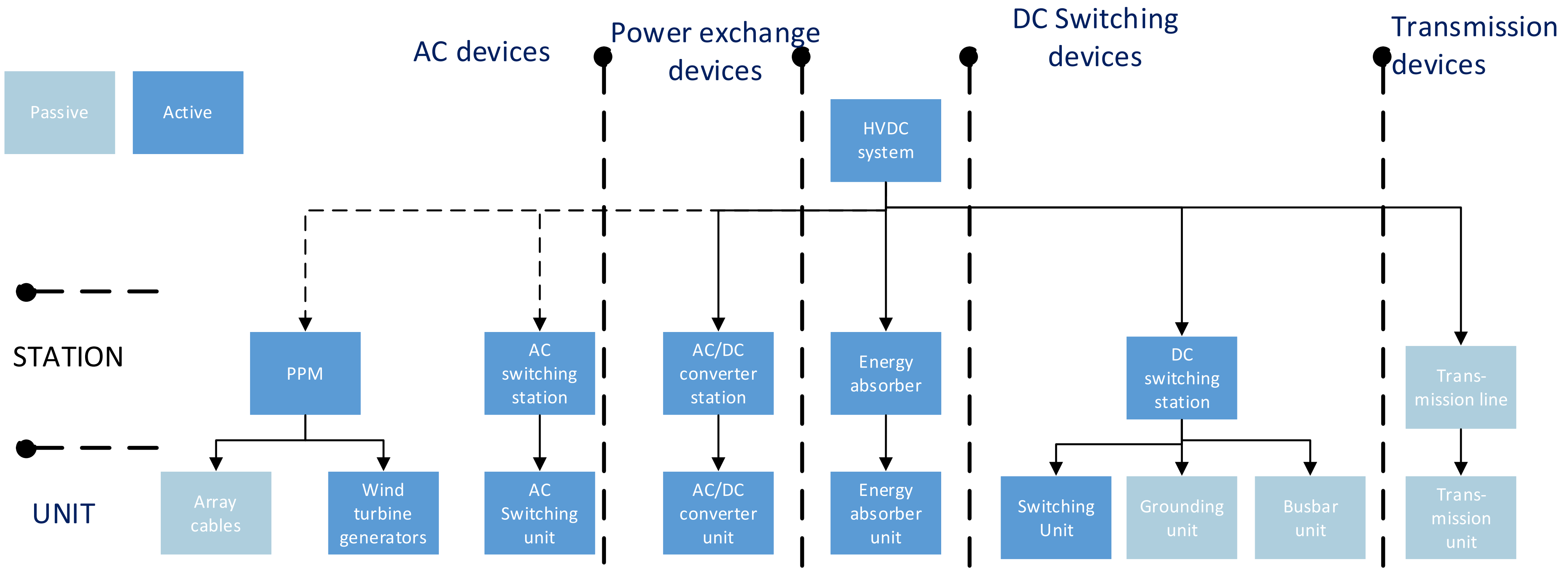
D2.1 objectives of functional framework



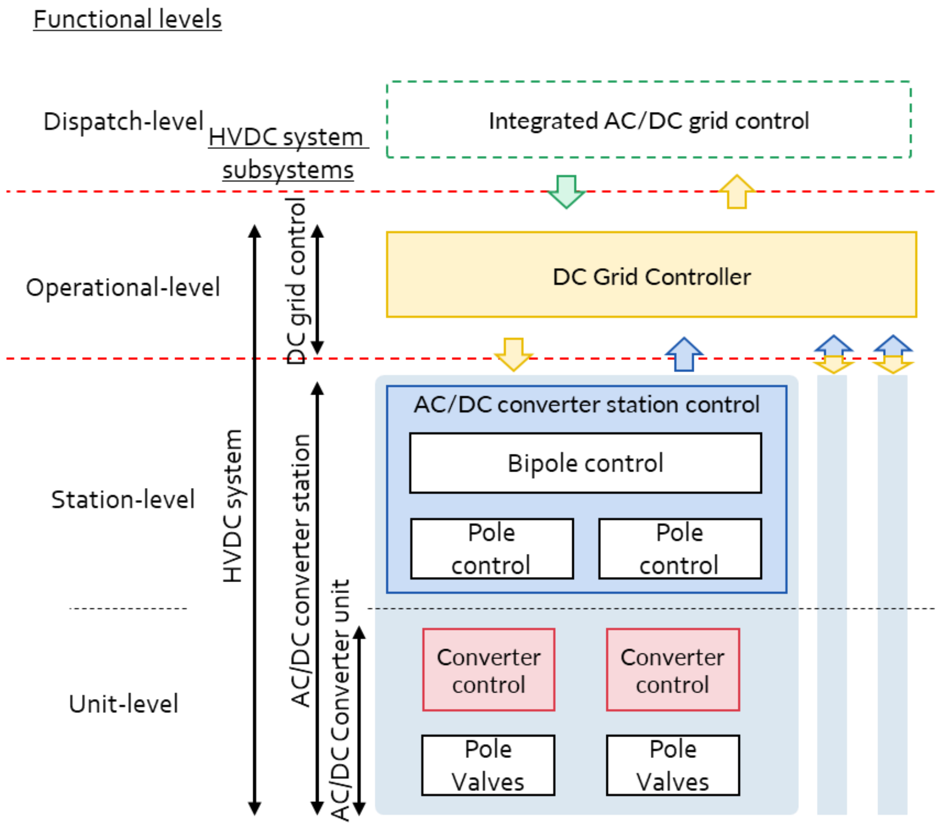
- Basic rules for DC grid operation, control & protection
- Functional requirements (FR) and functional parameters define a subsystem design space for each subsystem vendor
  - Inclusive and technology agnostic
  - Ensure interoperability by design
  - Avoid overspecification

Continuous control
DC grid protection
Sequential control

Functional split HVDC system



Continuous Control



- Dispatch-level:

  Highest layer in the continuous control architecture.

- Operational-level:

  Obtaining information on the power flow conditions and taking appropriate measures to prevent overloading and overvoltages

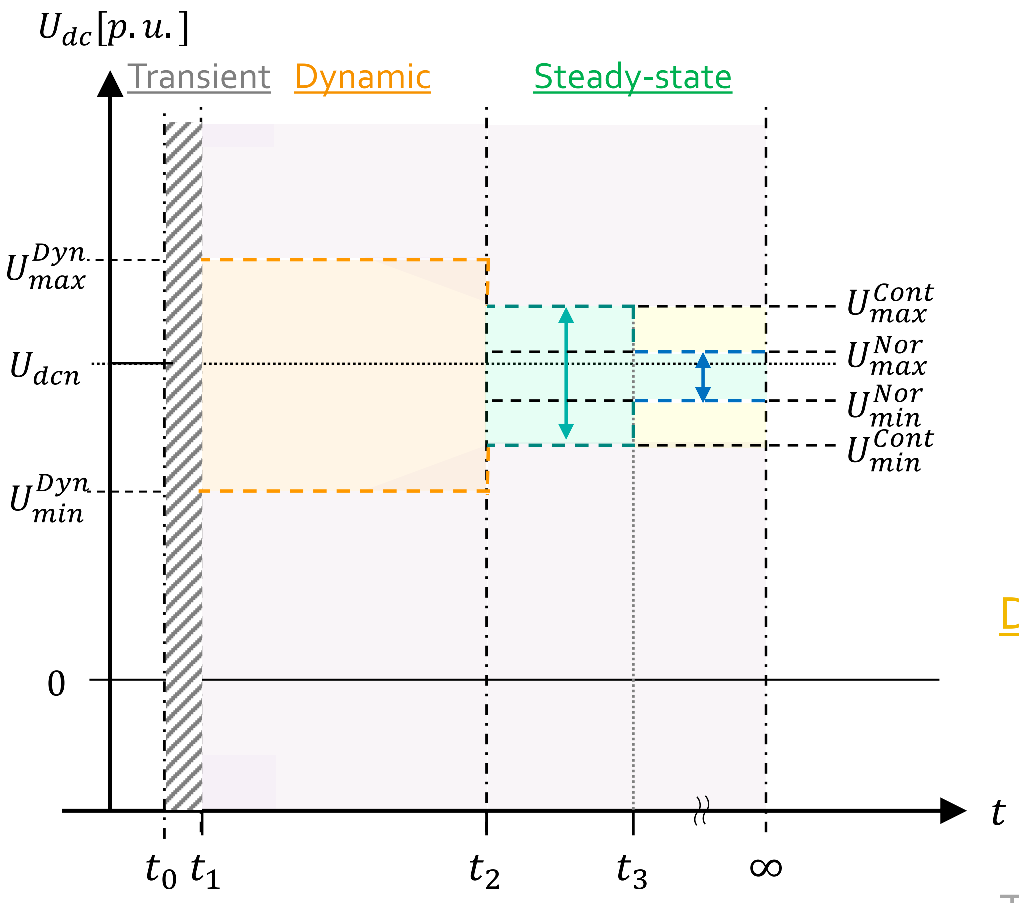
  - HVDC system state analysis
  - DC power flow optimization
  - Secondary DC voltage control
  - Ramp rate coordination
  - Offshore power curtailement
  - Converter control mode coordination

- Station-level & Unit-level:

  Control, monitoring, and protection functions within an AC/DC converter station based on instructions received from the Operational-level

  - Functional requirements for MV MT DC system
    - Specific consideration in Bipolar+DMR system
    - Fixed DC voltage control
    - Fixed Active power control
    - **Primary DC voltage control**

System-level DC voltage ranges



Steady-state time range:

Normal Operating DC Voltage Range $[U_{min}^{Nor}, U_{max}^{Nor}]$

- The range within which the voltage at any point within the system shall fall under normal operating conditions

Continuous Operating DC Voltage Range $[U_{min}^{Cont}, U_{max}^{Cont}]$

- The range within which voltages shall be contained in case of ordinary contingencies.

Abnormal over/undervoltage ranges $[-\infty, U_{min}^{Cont}]$ and $[U_{max}^{Cont}, \infty]$

- The ranges outside the continuous operating range.

Dynamic time range:

Dynamic DC voltage range $[U_{min}^{Dyn}, U_{max}^{Dyn}]$

- The range within which the primary DC voltage control shall contain peak overshoot and undershoot of DC voltage

Transient time range:

- Protection aspect

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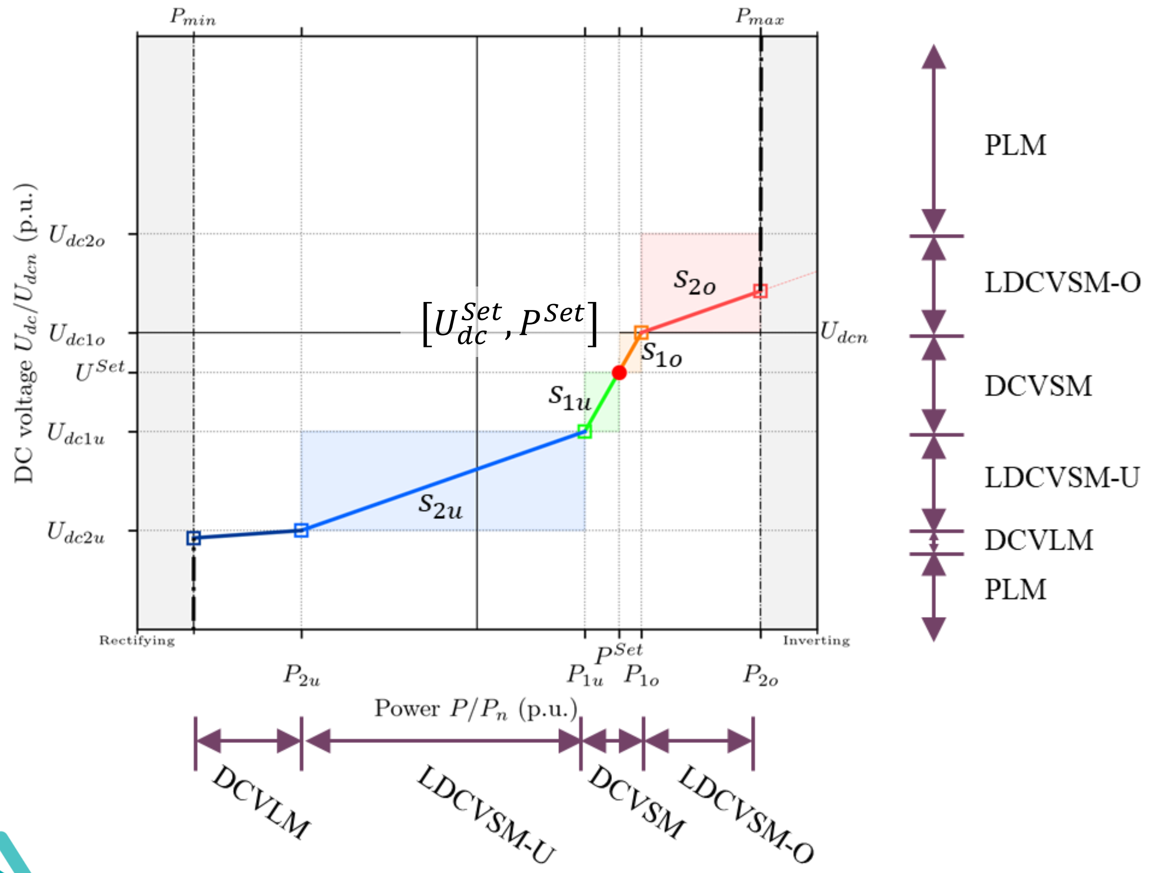
Primary DC voltage control

- **Static requirements**: Multi-segment droop definition



DC voltage sensitive modes:

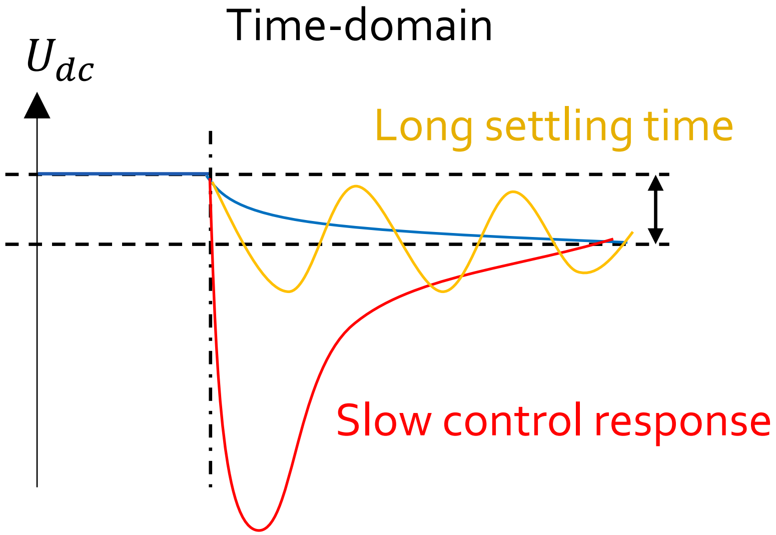
- ❑ DC Voltage Sensitive Mode (DCVSM)
- ❑ Limited DC Voltage Sensitive Mode-Overvoltage (LDCVSM-O)
- ❑ Limited DC Voltage Sensitive Mode-Undervoltage (LDCVSM-U)

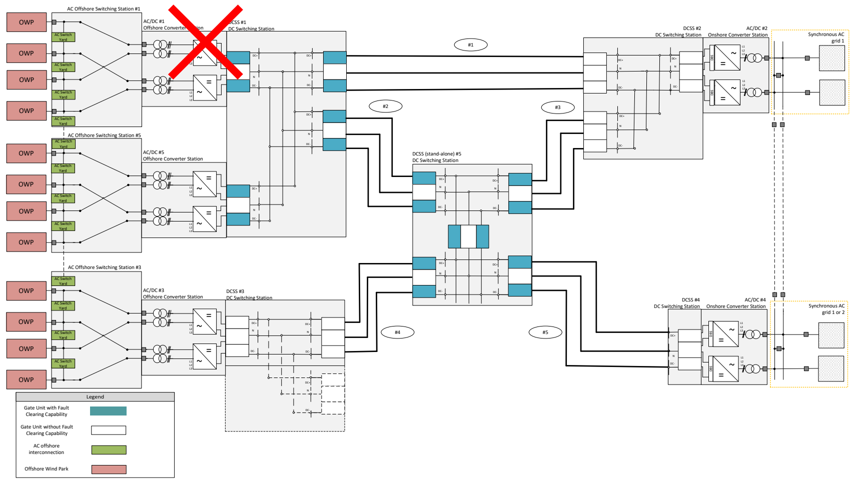
In addition,

- ❑ DC Voltage Limiting Mode (DCVLM)
- ❑ Power Limiting Mode (PLM)

Primary DC voltage control

- **Dynamic requirements**:
  - The system's steady-state is determined by pre-contingency operating points, disturbance, and assigned droops. However, to meet the system requirements, the dynamic behavior immediate aftermath of the disturbance and the post-contingency steady-state must be specified





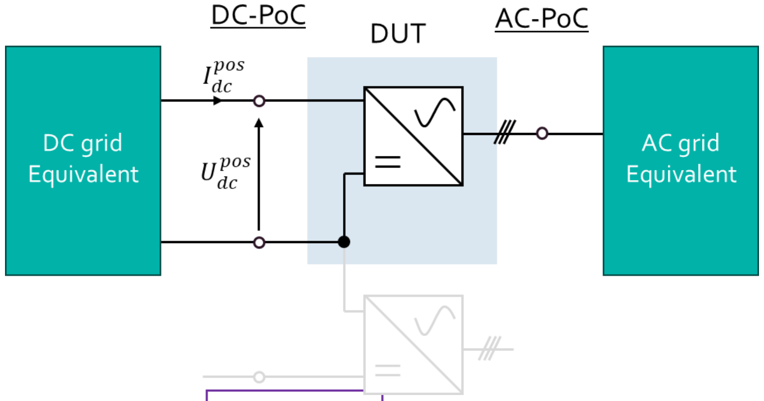
✓ Identification of determinant factors

- **Controller design**
- **Droop gain**
- DC grid
  - DCR size
  - Other converters
  - Cables
  - etc.

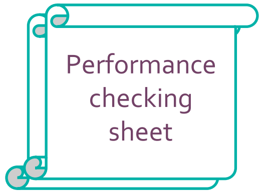
Dynamic performance requirements of AC/DC converter

Primary DC voltage control

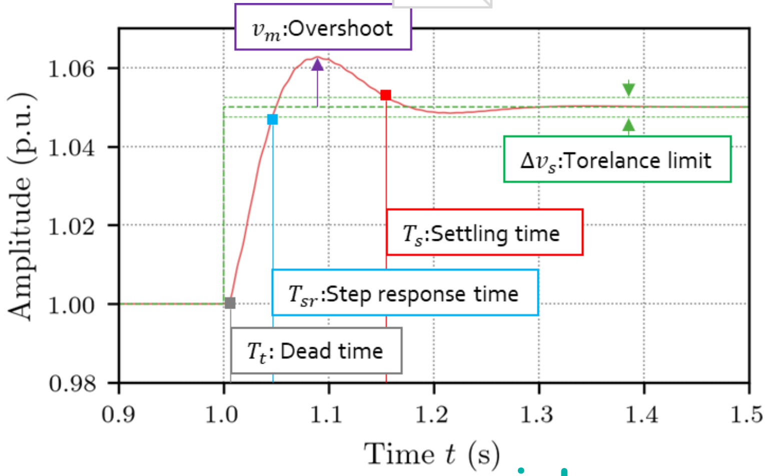
- **Dynamic requirements**:
  - Since controller parameters cannot be specified directly, dynamic requirements must be specified as behavioral requirements (for defined test methods and in specific test environments in order to meet the system expectations)



- ❑ **"Performance Checking Sheets" and Standalone Compliance Testing**
  - For each control mode (Fixed-P, Fixed-Vdc, Droop):

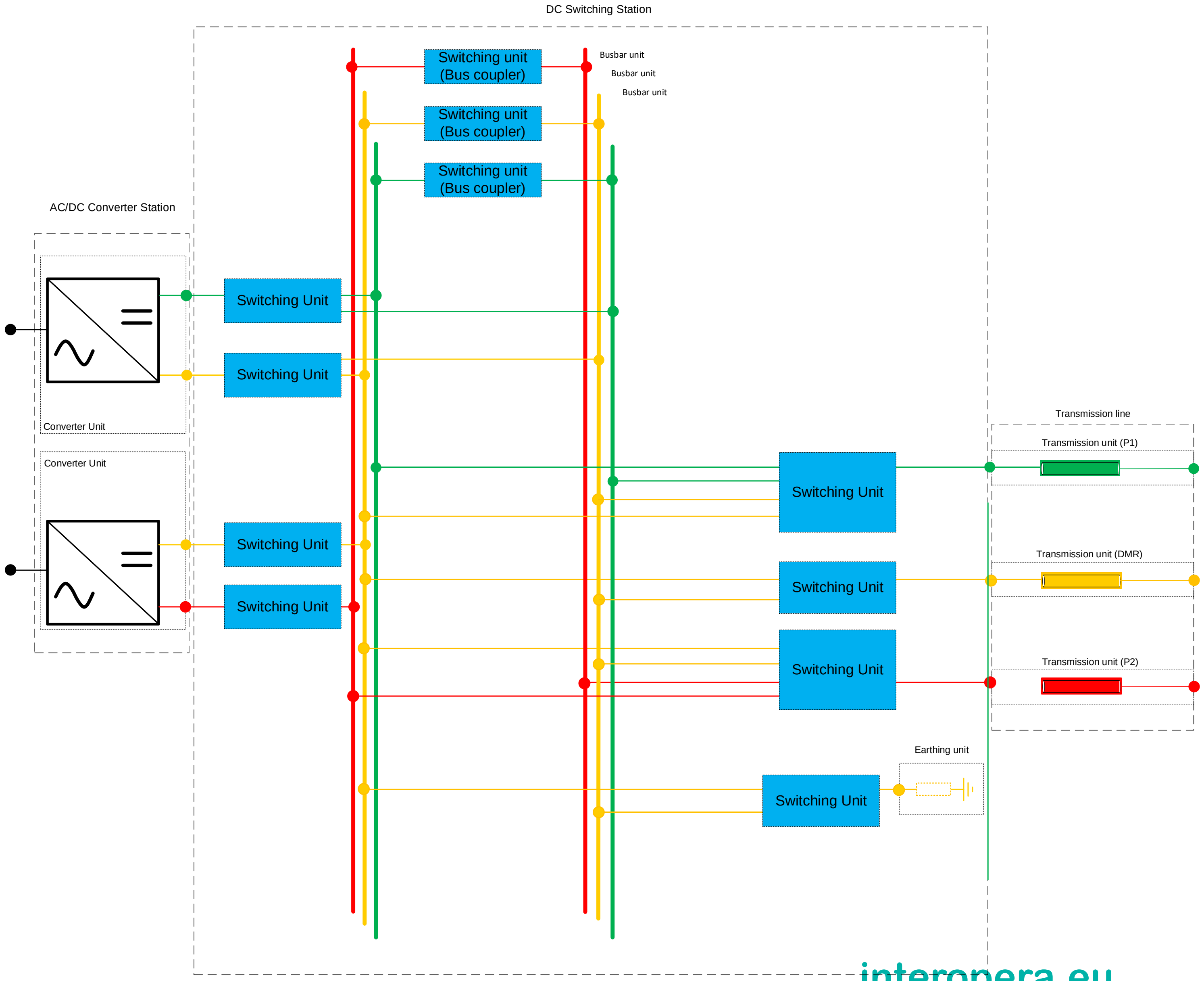


1) Test objective
2) Test environment
   - AC grid equivalent: E.g. SCR
   - **DC grid equivalent:**
     Capture necessary DC grid characteristic
3) Test methods & scenarios
4) Signal to be reported
5) **Evaluation criteria:** Following IEV vocabularies

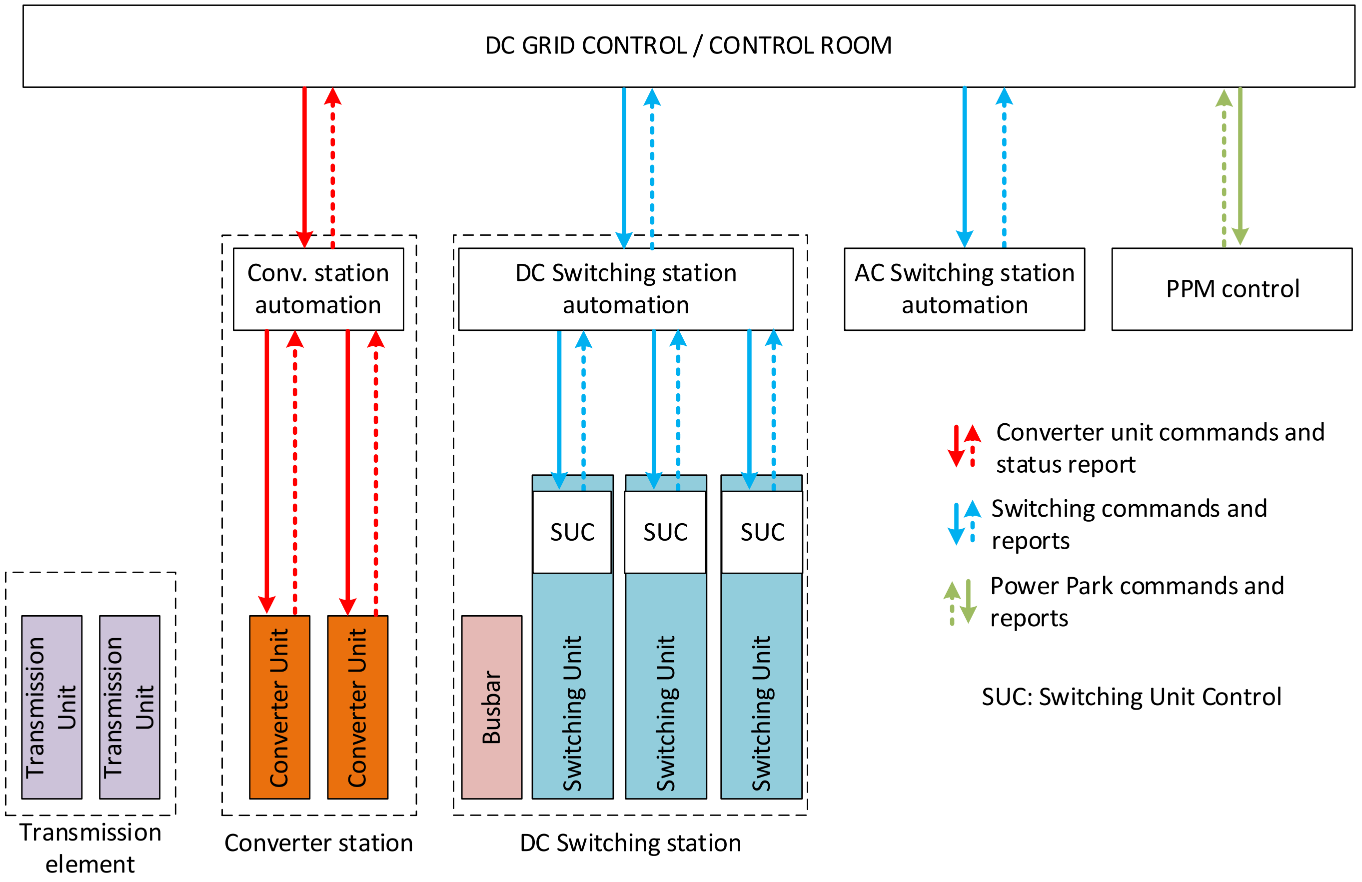


Sequential control

- Objective: define a framework to describe the **connection modes** within the HVDC system and the possible **planned reconfiguration**



Sequential control architecture

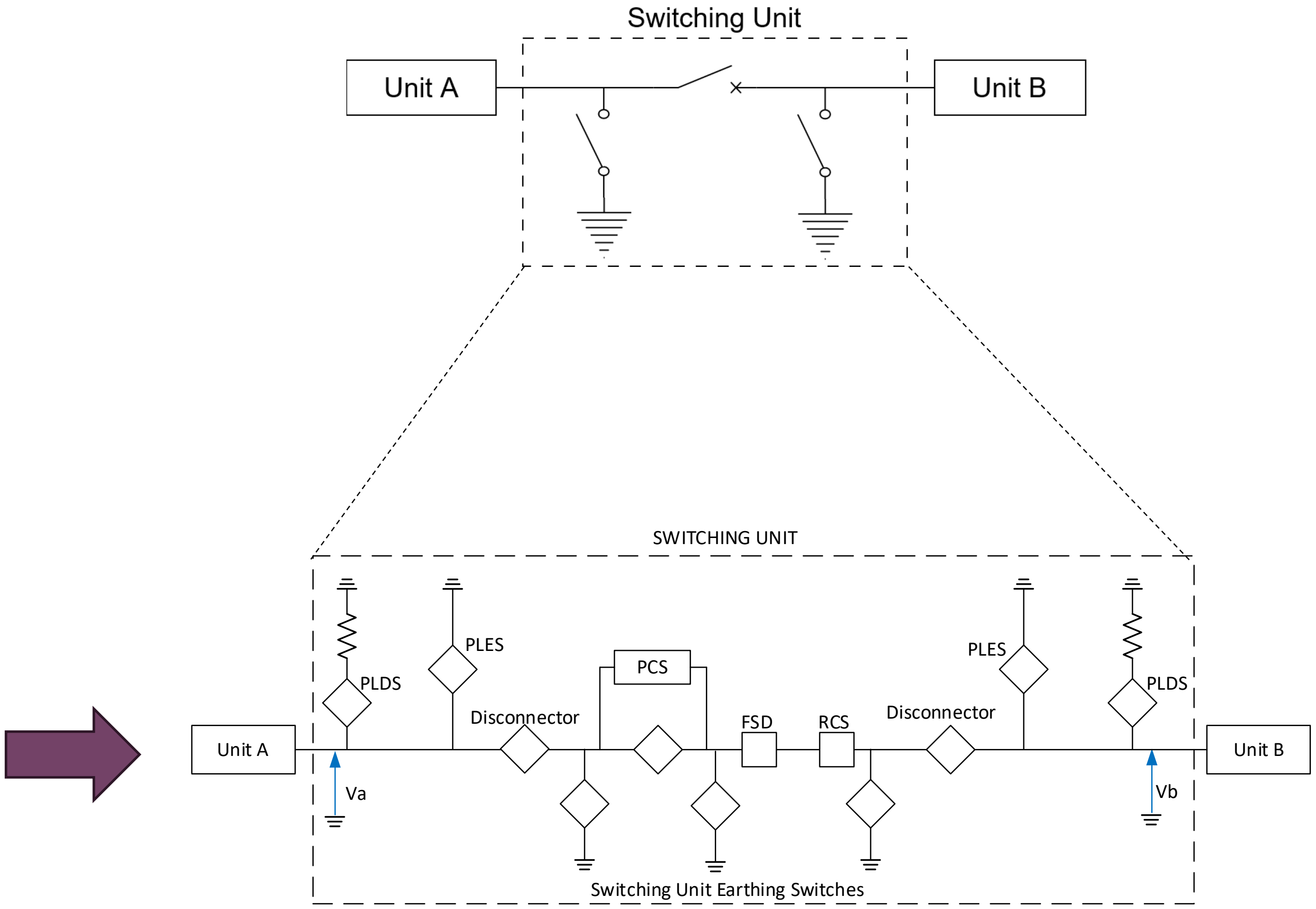


Horizontal communication deemed exceptional

Switching Unit concept

Functional specification

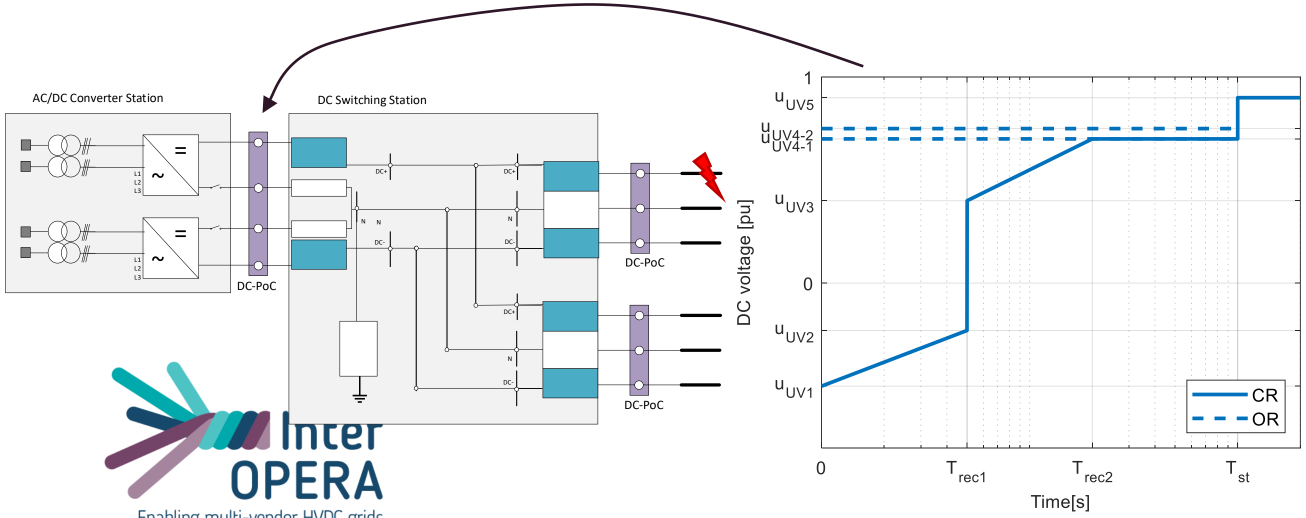
	Functionality	SU-1	SU-2
Close	Aggregation	✓	✓
	Energization	✓	✓
	Synchronization	✗	✓
Open	Disconnection	✓	✓
	Separation	✓	✗
	Isolation	✓	✗



DC grid protection

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
  - Converter safely disconnects in case of protection failure
- **Shall not ensure**
  - Activation of primary protection → protection relays are foreseen
  - DC grid support → Grid serving requirements foreseen



Evaluation criteria

- **Technological agnostic:** Are the functional requirements permitting different technological solutions or are they restricting, excluding certain technologies?
- **Functional split:** Are functional description and design of subsystems independent?
- **Oversizing :** Does the decoupling of subsystem requirements and the genericity / system independence generate an oversizing?
- **Standardization:** Is the DC-FRT description subsystem-dependent or generic? Do several DC-FRT profiles co-exist?
- **Verifiability :** Can the DC-FRT profile be specified at the DC-PoC based on local measurements?

Different approaches investigated

Option	Description	Quantity
1	Design / topology dependent	DC Current based
2	Design / topology dependent	DC Voltage based
3	Generic	DC Current based
4	**Generic**	**DC Voltage based**

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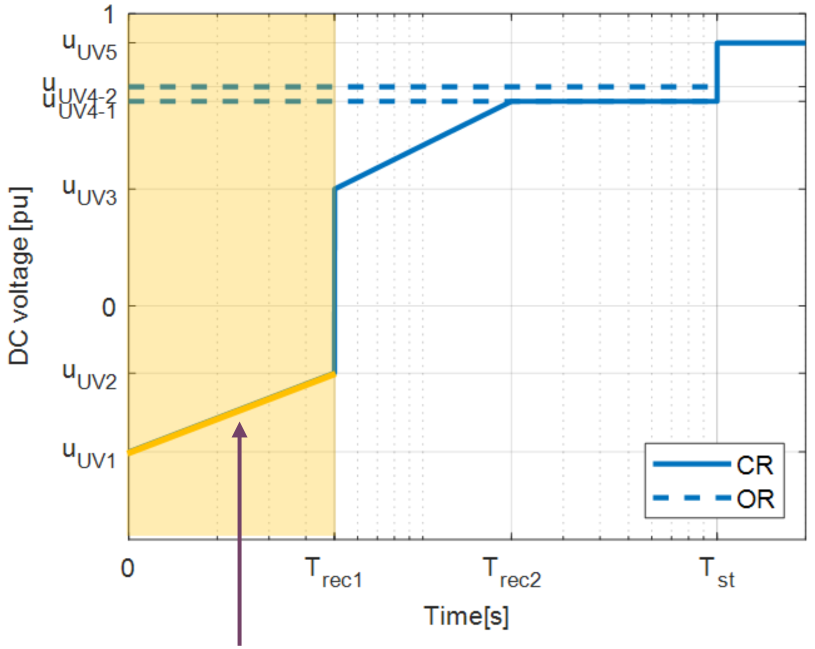
Generic DC-FRT requirement description (DC voltage)



Predictable outer voltage envelope based on fault transients

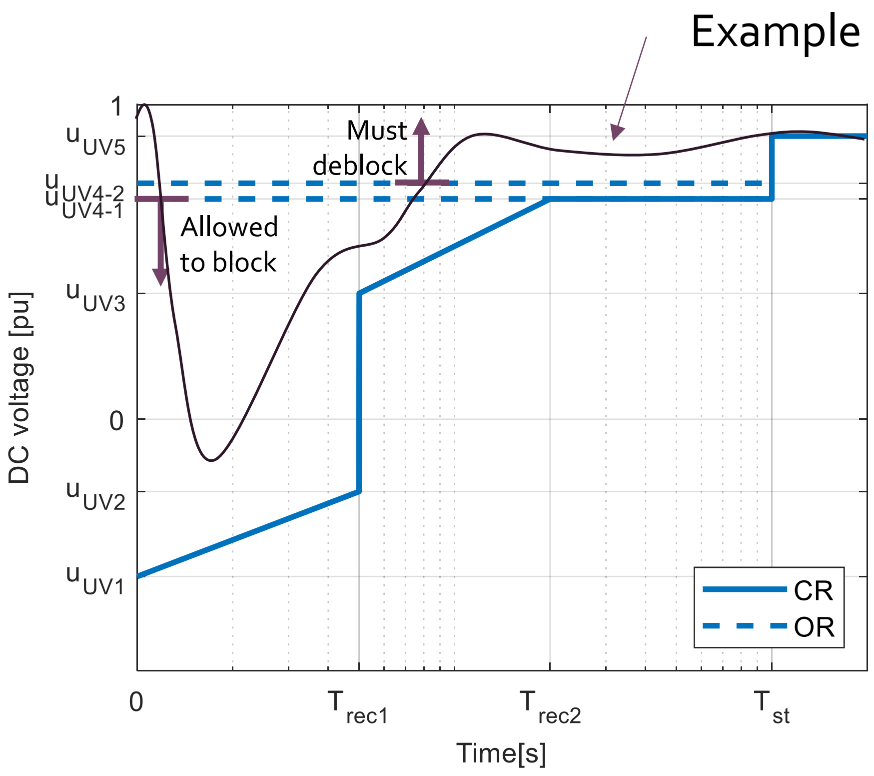
Functional parameters (from requirement definition)

Functional Parameter examples	Definition
U_{UV1} / U_{UV2} T_{rec1}	Maximum undervoltage during fault transients including traveling waves
U_{UV4} T_{st}	Dynamic voltage bands (continuous control)
U_{UV5}	Static voltage bands (continuous control)
T_{rec1}	Maximum voltage recovery time (at least equal or greater than the fault neutralization time)

Design parameters (left to vendor's solution)

Design Parameter examples
Overcurrent capability
DC/arm inductor size
Internal energy
Temporary blocking function

Generic DC-FRT requirement description (DC voltage)



- **$U_{UV_{4-1}}$: Optional undervoltage blocking limit outside dynamic voltage bands U_{dyn}** considering a security margin k_{dyn}. In the transient region, the converter is allowed to block below this limit.

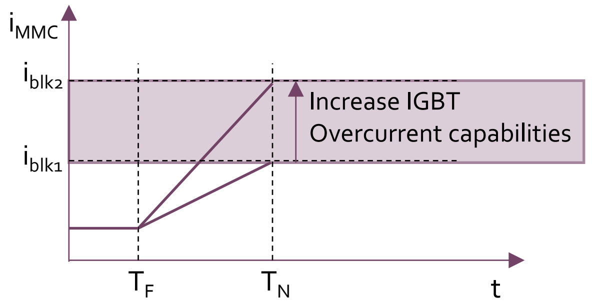
$$U_{UV4-1} = k_{dyn}\, U_{dyn}$$

- **$U_{UV_{4-2}}$: Optional deblocking limit after full system voltage recovery to dynamic voltage bands** U_{dyn}. If the converter is blocked In the transient region, the converter shall deblock above this voltage limit. The deblocking shall be ensured within a maximum deblocking time ΔT_{dblk}.*

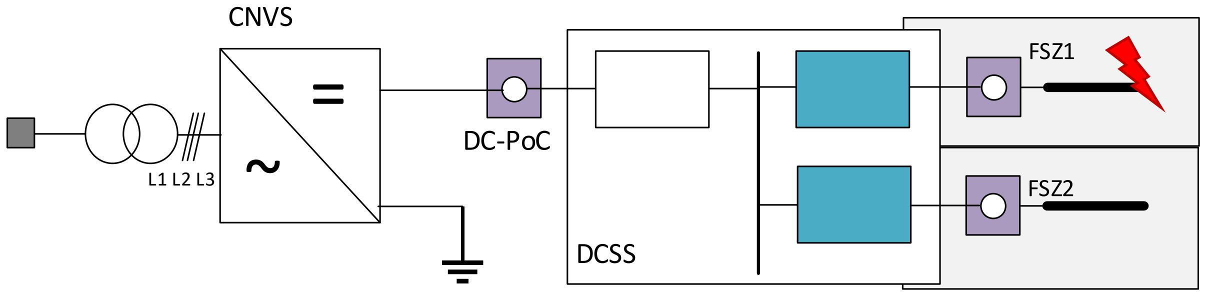
$$U_{UV4-2} = U_{dyn}$$

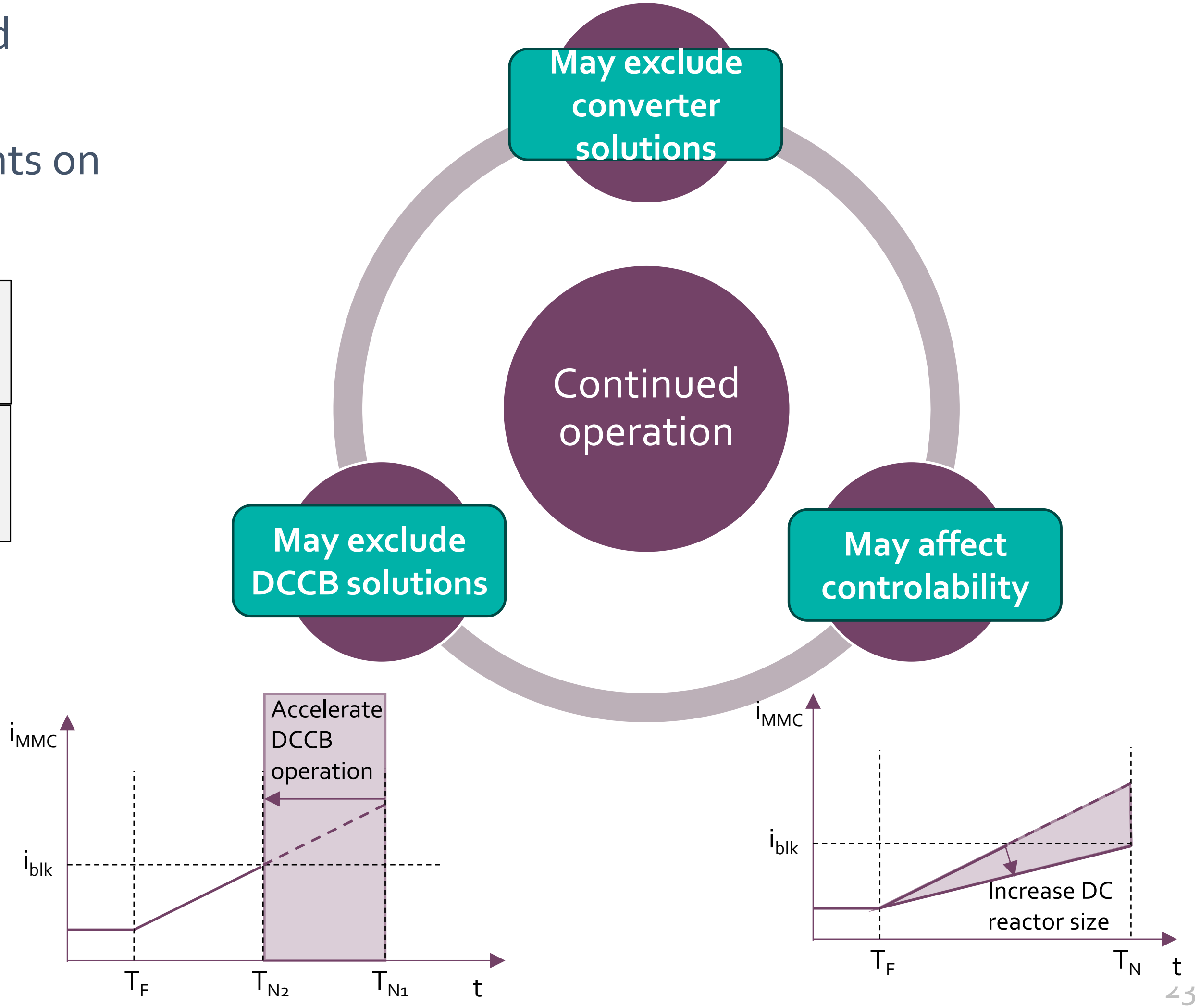
*For the specification of ΔT_{dblk}, maximum fault current suppression times and converter process times for deblocking shall be considered.

Relevance of temporary blocking



- During DC faults half-bridge converters have very limited control capabilities
- Continued operation may impose major design constraints on both converter and DC Circuit breakers

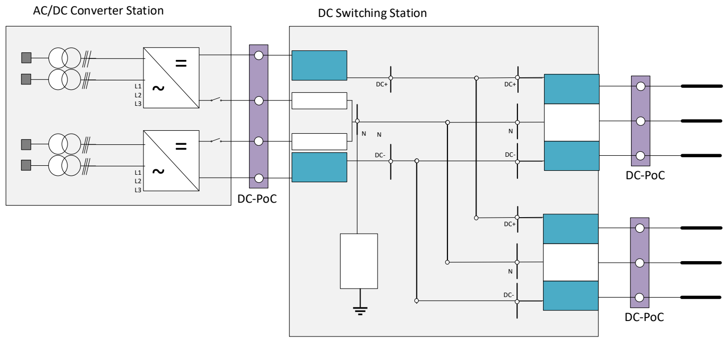


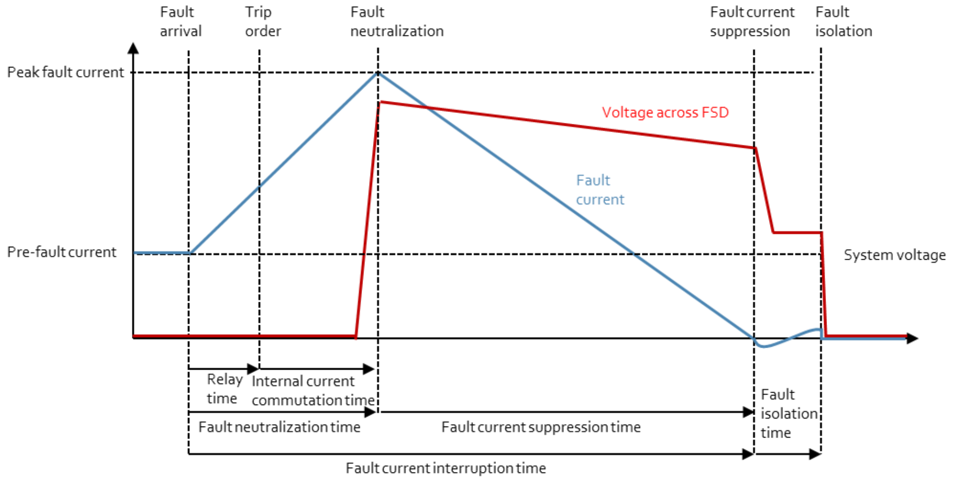


The temporary blocking may reduce the need of DC reactor significantly allowing an inclusive specification/design of both converter and DCCB

Functional requirements for fault current interruption

- The switching unit is responsible for
  - Providing enough fault current capability to interrupt all faults defined as ordinary contingency by the relevant TSO
  - Respecting maximum fault neutralization time $T_{N,max}$
- The switching unit is not resposible for
  - Converter operational behaviour during DC-FRT (e.g. ensure continued operation)





Next steps

WS2
Continuous control

WS3
DC grid protection

Functional requirement (D2.1)

Dynamic control requirements

DC-FRT

Standalone compliance test development

- Define DC & AC grid equivalents
- Define test scenarios & compliance evaluation criteria
- Develop functions in EMT model
- Test DUTs with different technical solutions

System level validation

- Define system-level compliance criteria per FR
- EMT model integration and simulation

New initiatives

WS3 DC grid protection

Temporary converter blocking offshore

TF Insulation coordination

System grounding
Insulation coordination (neutral)
Insulation coordination between subsystems

WS AC/DC security & dispatch

MTDC grid operation

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Thank you

Any questions?

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