PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

# Regulation & grid codes
# PROMOTioN WP 2, 3 & 11: recommendations for offshore HVDC grid converter interfaces

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

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- Overview Work on Regulation and Grid Codes in PROMOTioN
- Status of Regulation and Grid Codes for HVDC grids
- Selected aspects for recommendations for offshore HVDC converters
- Outlook


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# Overview Work on Regulation and Grid Codes in PROMOTioN


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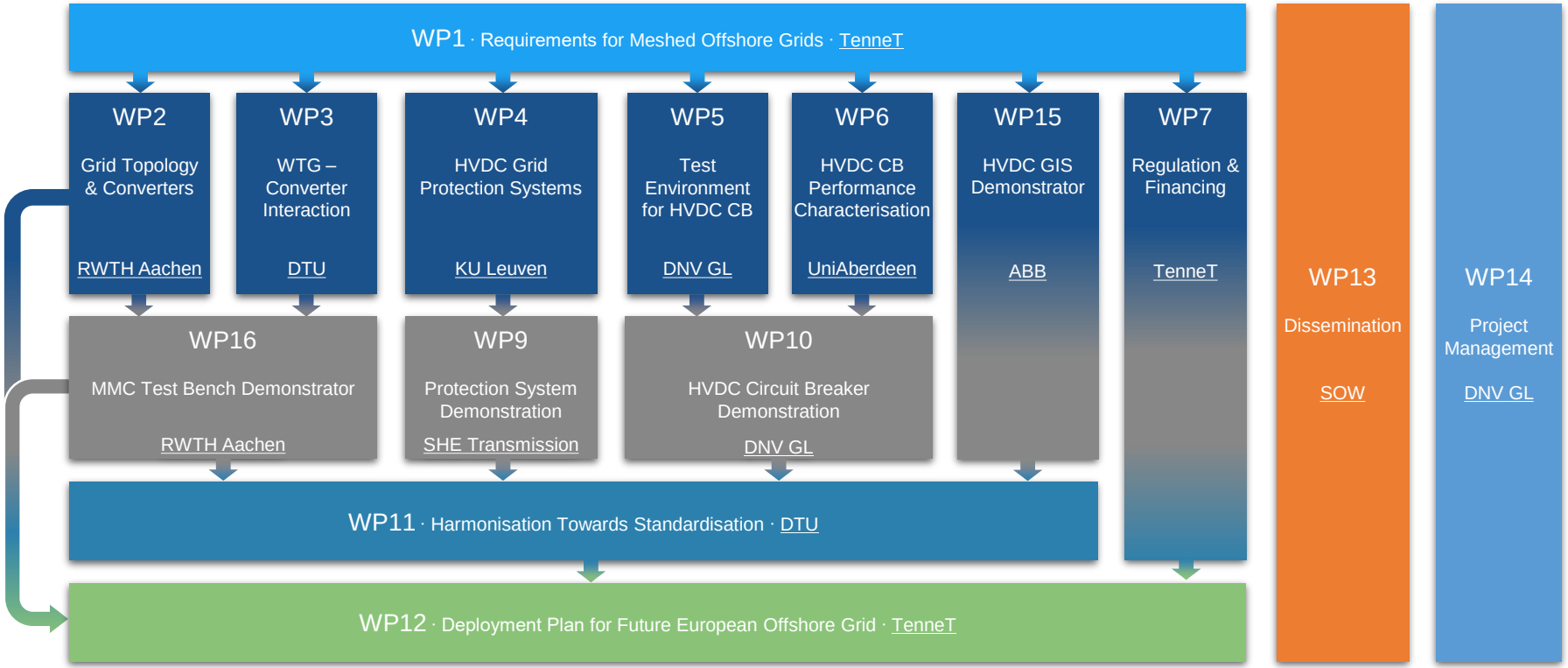
# Work Packages





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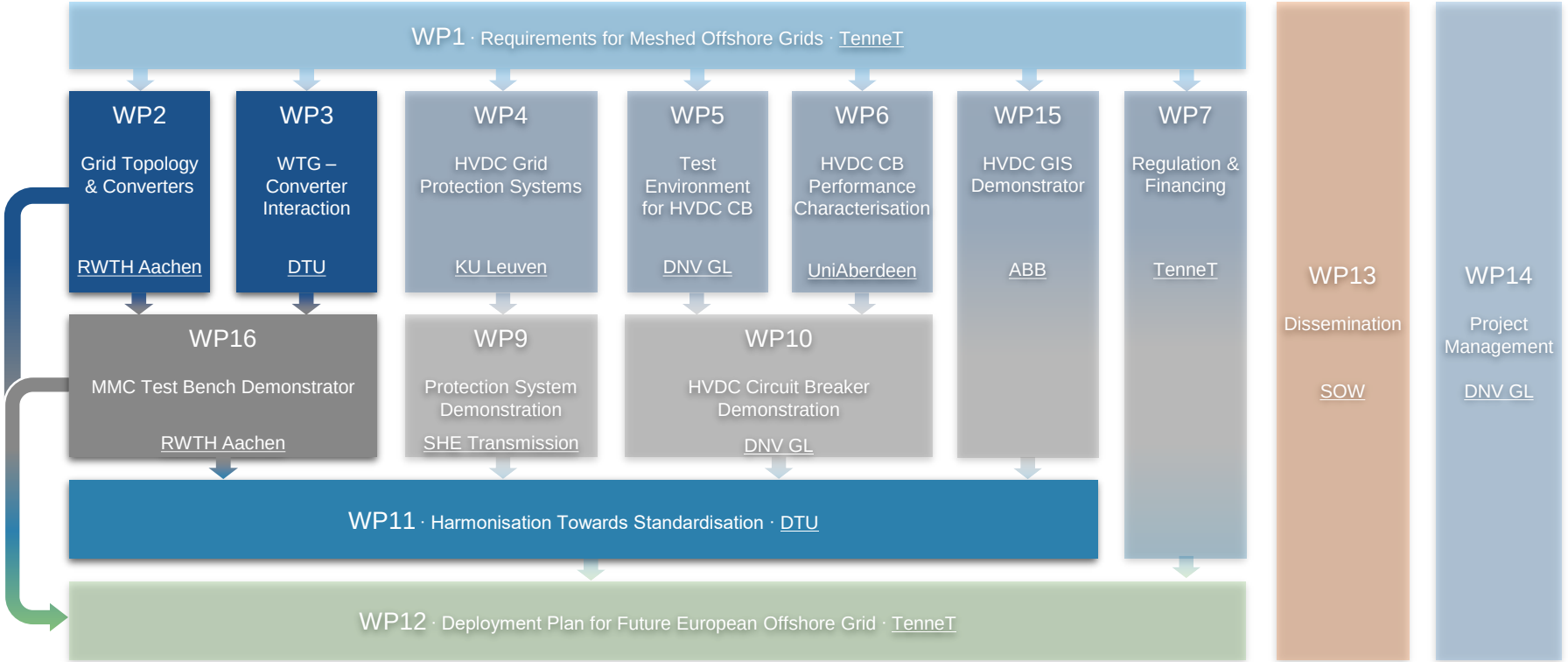
# Work Packages





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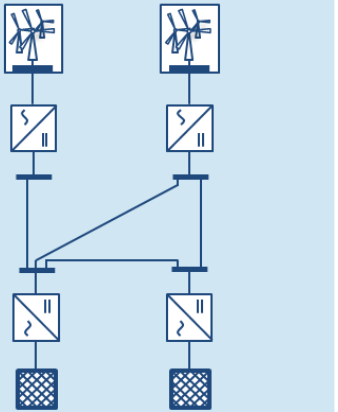
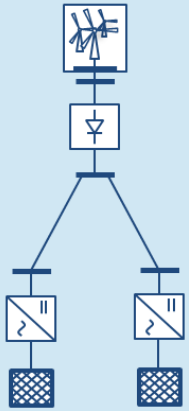
# Overview and Objectives of WP2

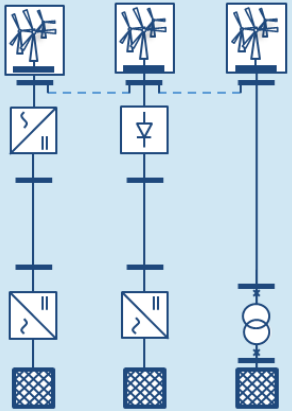
**Trade-off analysis of different topologies**



**Interconnection of VSC and DRC systems**



**Control concepts to ensure interoperability**



**To define recommendations on onshore and offshore power systems for existing grid codes**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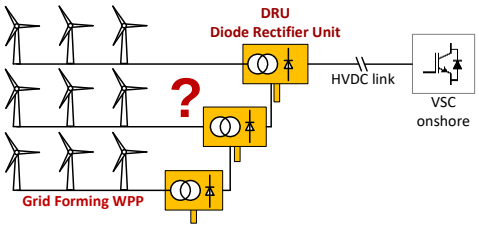
# Overview and Objectives of WP3

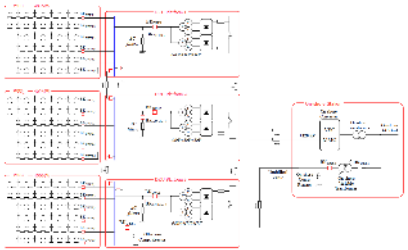
**Objective 1**
**Define functional requirements to OWFs**

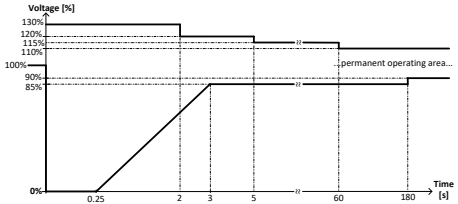
**Objective 2**
**Develop test cases & control algorithms**

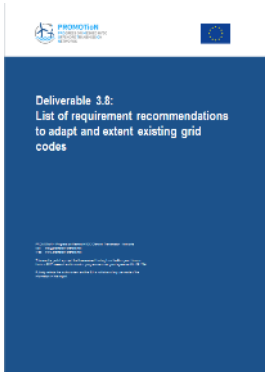
**Objective 3**
**Define & apply compliance evaluation**

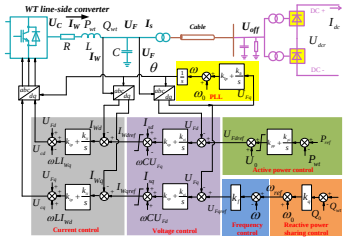
**Objective 4**
**Recommend grid code requirements**

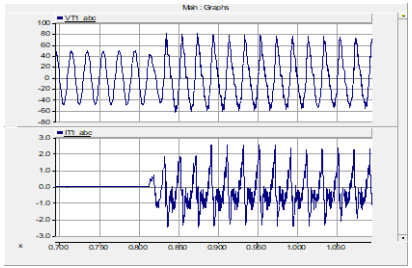






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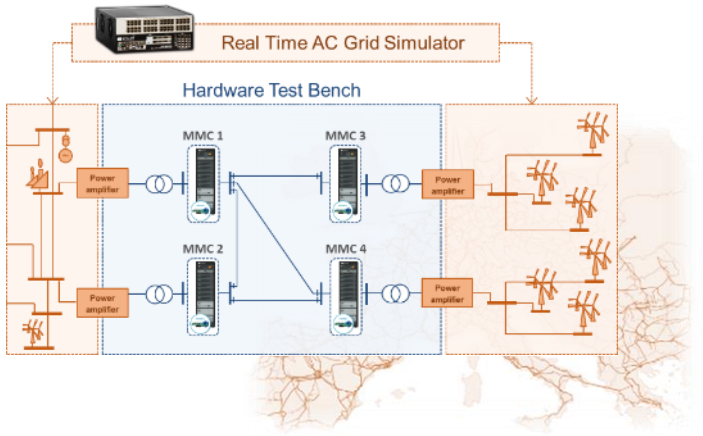
# Overview and Objectives of WP16

Investigation regarding the operation and control of meshed HVDC system

- ✓ Power Hardware in the Loop (PHiL)
- ✓ Control Hardware in the Loop (CHiL)
- ✓ Real-Time Simulation (RTS)




## Objectives

- ➢ **Demonstration** of applicability of developed controls and simulation models of PROMOTioN
- ➢ **Technical de-risking** for the deployment and continuous operation of meshed HVDC systems
- ➢ **Improvement** of certainty for road mapping process and standardization efforts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# Overview and Objectives of WP11

## Overall Objectives

- To support harmonization of the industry's best practices, standards and requirements
- To ensure that the PROMOTioN experience is utilised in harmonization work
- To harmonise the work between existing and future working groups
- To ensure that different manufacturer concepts are considered

## Outputs

- Functional requirements
- Test and measurement procedures
- Simulation models
- Procedures for compliance validation


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# Status of Regulation and Grid Codes for HVDC grids


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# ENTSO-E

## Published network codes

- Network code on requirements for grid connection of HVDC systems and direct current-connected power park modules
- Network Code on Requirements for Generators
- Network Code on Demand Connection

## Legal status of documents

- The published network codes become regulations
- Provides common basis for national regulation

8.9.2016 EN Official Journal of the European Union L 241/1

II

(Non-legislative acts)

REGULATIONS

COMMISSION REGULATION (EU) 2016/1447

of 26 August 2016

establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003 (1), and in particular Article 6(11) thereof,

Whereas:

(1) The swift completion of a fully functioning and interconnected internal energy market is crucial to maintaining security of energy supply, increasing competitiveness and ensuring that all consumers can purchase energy at affordable prices.

(2) Regulation (EC) No 714/2009 sets out non-discriminatory rules governing access to the network for cross-border exchanges in electricity, with a view to ensuring the proper functioning of the internal market in electricity. In addition Article 5 of Directive 2009/72/EC of the European Parliament and of the Council (2) requires that Member States or, where Member States have so provided, regulatory authorities ensure, inter alia, that objective and non-discriminatory technical rules are developed which establish minimum technical design and operational requirements for the connection to the system. Where requirements constitute terms and conditions for connection to national networks, Article 37(6) of the same Directive requires regulatory authorities to be responsible for fixing or approving in least the methodologies used to calculate or establish them. In order to provide system security within the interconnected transmission system, it is essential to establish a common understanding of the requirements for High Voltage Direct Current (HVDC) systems and direct current-connected power park modules (DC-connected power park modules). These requirements that contribute to maintaining, preserving and restoring system security in order to facilitate proper functioning of the internal electricity market within and between synchronous areas and to achieve cost efficiencies, should be regarded as cross-border network issues and market integration issues.

(3) Harmonised rules for grid connection for HVDC systems and DC-connected power park modules should be set out in order to provide a clear legal framework for grid connections, facilitate Union-wide trade in electricity, ensure system security, facilitate the integration of renewable electricity sources, increase competition and allow more efficient use of the network and resources, for the benefit of consumers

(1) OJ L 211, 14.8.2009, p. 15.

(2) Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC (OJ L 211, 14.8.2009, p. 55).


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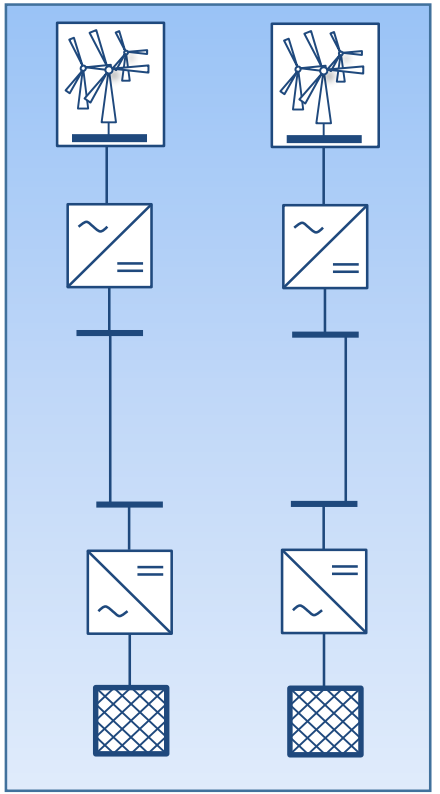
# Requirements for grid connection of HVDC systems and direct current-connected power park modules



## Existing systems in Europe

- Mostly point-to-point turnkey projects
- HVDC as a „new“ system component

➢ Existing AC systems define the requirements

## Content of grid code

- Minimum technical design and operational requirements
- Main focus: Requirements at the connection points to the AC systems
- Little content on the DC-side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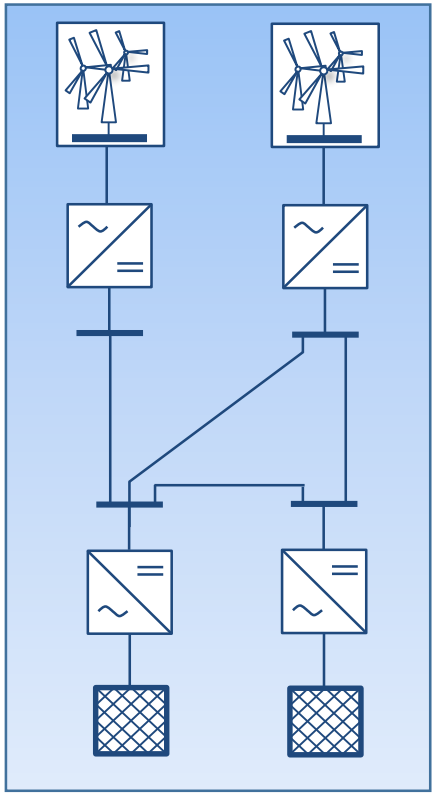
# Requirements on HVDC Grid codes

## Prerequisites

- Discrimination-free
- Vendor interoperability
- Should be “plug-and-play”
- Should not inhibit technological development

## Requirements on the Grid code

- Give functional requirements
- Should find a balance for different solutions and system requirements

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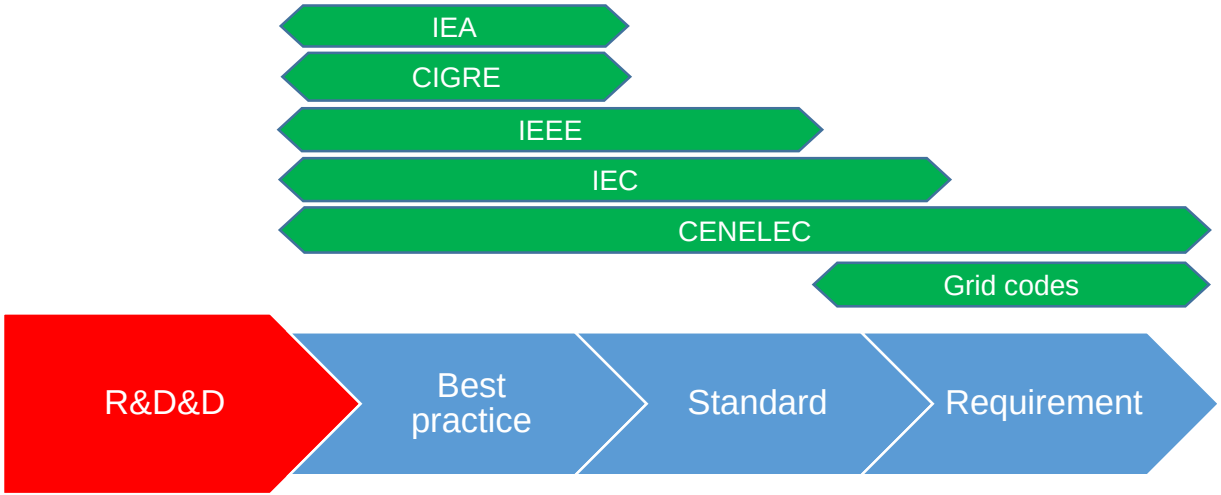
# Relevant Harmonization Activities





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# Cigré

## Study Committees

- B1 Insulated Cables
- B2 Overhead Lines
- **B4 DC systems and Power Electronics**
- B5 Protection and Automation
- C2 System Operation and Control
- C4 System Technical Performance
- D1 Materials and Emerging Test Techniques

## Exemplary Working Groups

- B4.52 HVDC grid feasibility study
- B4.56 Guidelines for the preparation of connection agreements of Grid codes for HVDC grids
- B4.57 Guide for the development of models for HVDC converters in a HVDC grids
- B4.58 Load flow control and direct voltage control in a meshed HVDC grid
- B4.59 Protection of HVDC grids
- B4.60 Designing HVDC grids for optimal reliability and availability performance
- B4.70 Guide for EMT studies with VSC
- B4.72 DC grid benchmark models for systems studies
- JWG B4/B1/C4.73 Surge and extended overvoltage testing of HVDC Cable Systems
- B4.74 Guide to develop real-Time Simulation Models for HVDC Operational Studies
- B4.76 DC-DC converters in HVDC Grids and for connection to HVDC systems


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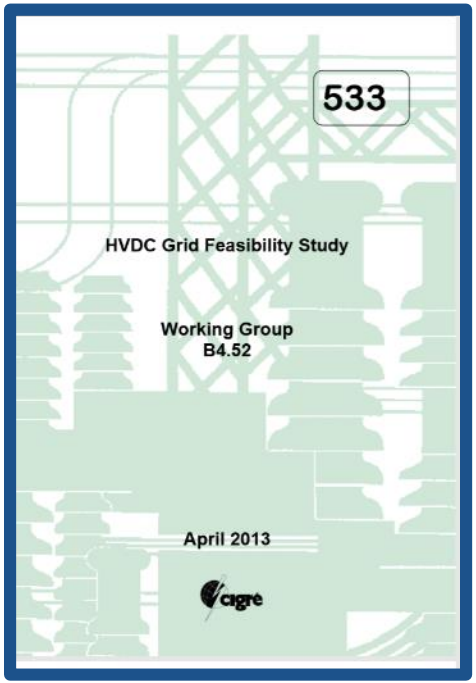
# Cigré

## Published documents relevant to HVDC Systems (exemplary)

- 2013 - TB 533 - B4-52 - HVDC Grid Feasibility Study
- 2013 - TB 563 - B4-38 - Modelling and Simulation Studies to be performed during the lifecycle of HVDC Systems
- 2014 - TB 604 - B4-57 - Guide for the Development of Models for HVDC Converters in a HVDC Grid
- 2015 - TB 619 - B4.55 - HVDC connection of offshore wind power plants
- 2016 - TB 657 - B4.56 - Guidelines for the preparation of "connection agreements" or "Grid Codes" for multi-terminal schemes and DC Grids
- 2017 - TB 683 - JWG A3/B4.34 - Technical requirements and specifications of state-of-the-art HVDC switching equipment
- 2017 - TB 684 - JWG B4/C1.65 - Recommended voltages for HVDC grids
- 2017 - TB 699 - B4.58 - Control methodologies for direct voltage and power flow in a meshed HVDC grid
- 2018 - TB 739 - JWP B4 / B5.59 - Protection and local control of HVDC-Grids





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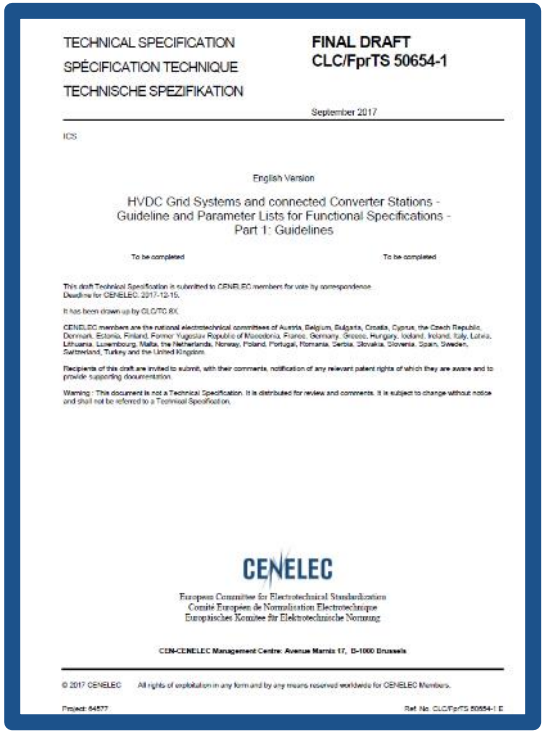
# CENELEC

## Working group: CLC TC 8X WG 06 – System Aspects of HVDC Grids

- 5 Sub Groups dealing with different technological aspects
  - Coordination of HVDC Grid and AC Systems (Tasks are completed – not active)
  - HVDC Grid Control
  - HVDC Grid Protection
  - HVDC Grid System Characteristics and HVDC Grid Equipment
  - Models and Validation, HVDC Grid System Integration Tests

## Published documents

- HVDC Grid Systems and connected Converter Stations – Guideline and Parameter List for Functional Specifications
  - Part 1: Guidelines
  - Part 2: Parameter List



TECHNICAL SPECIFICATION
SPÉCIFICATION TECHNIQUE
TECHNISCHE SPEZIFIKATION

**FINAL DRAFT**
**CLC/FprTS 50654-1**

September 2017

ICS

English Version

HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 1: Guidelines

To be completed

To be completed

This draft Technical Specification is submitted to CENELEC members for vote by correspondence.
Deadline for CENELEC: 2017-12-15.

It has been drawn up by CLC/TC 8X.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

Warning : This document is not a Technical Specification. It is distributed for review and comments. It is subject to change without notice and shall not be referred to a Technical Specification.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels



Project: 64577

Ref. No. CLC/FprTS 50654-1:E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# IEC 61400-21. Test and measurements of electrical characteristics

## IEC 61400-21-1: wind turbines

- Definition and specification of electrical characteristics:
  - Power quality (flicker, harmonics)
  - Steady state operation (max power, reactive power capability)
  - Control (active power, ramp rate limitation, frequency control, synthetic inertia, reactive power control)
  - Fault-ride-through (dip and swell)
- Test conditions and test systems
- Measurement procedures

## IEC 61400-21-2: wind power plants

- Definition and specification of the quantities to be determined for characterizing the electrical characteristics
- Measurement procedures for quantifying the electrical characteristics
- Procedures for assessing compliance with electrical connection requirements
- Test procedures for commissioning of wind power plants
- Procedures for measurement and fault recording for the verification of wind power plant models


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# IEC 61400-21. Test and measurements of electrical characteristics

## IEC 61400-21-3: wind turbine harmonic modelling

- Technical report (best practice, not standard)
- Specifies harmonic model properties (for type 3 (doubly-fed) and type 4 (full converter))
- Specifies validation classes (simulated / lab tests / field measurement)
- Misses specification of test and model validation procedures

## IEC 61400-21-4: wind turbine component test

- Newly started work (from convener Björn Andresen):

**Move electrical and grid compliance measurements & tests**

**from expensive and uncontrollable field test setups to a controllable test bench setup**


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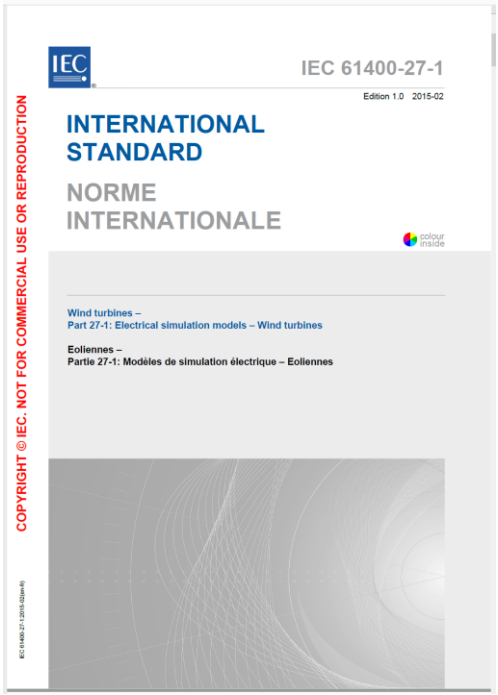
# IEC 61400-27-1 Edition 1.0 (2015-02)
# Electrical simulation model for AC connected wind power

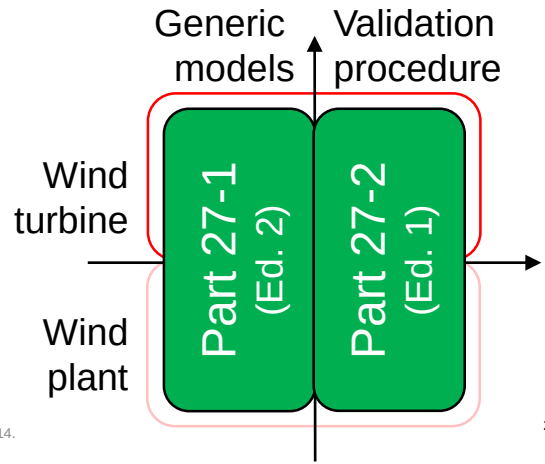
## First edition:

- Part 27-1 (2015):
  - Specifies standard models for ***wind turbines***
  - Specifies standard validation procedures for wind turbine models
  - Provides draft models for wind power plants in informative (i.e. not normative) annex
- Part 27-2:
  - Intended to specify standard ***wind power plant*** models and validation procedures




## Second edition (expected 2019)

- Part 27-1: Standard generic models (for wind turbines and wind power plants)
- Part 27-2: Standard validation procedures (for wind turbines and wind power plants)





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# Selected aspects for recommendations for offshore HVDC converters


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# Coordination of DC grid protection and AC system requirements

## Different technologies for HVDC grid protection proposed

- Converter AC breakers
- Fault-current blocking converters
- DC circuit breakers
- …

## Different fault clearing strategies possible

- Proposed categorization as defined by Cigré Technical Brochure 739
  - Non-selective
  - Partially selective
  - Fully selective

## Classification based on the impact at a point of connection

- Fault separation concepts as defined in the CENELEC guidelines of TC8X WG06
  - Continued operation
  - Temporary Stop P
  - Temporary Stop PQ
  - Permanent Stop P
  - Permanent Stop PQ


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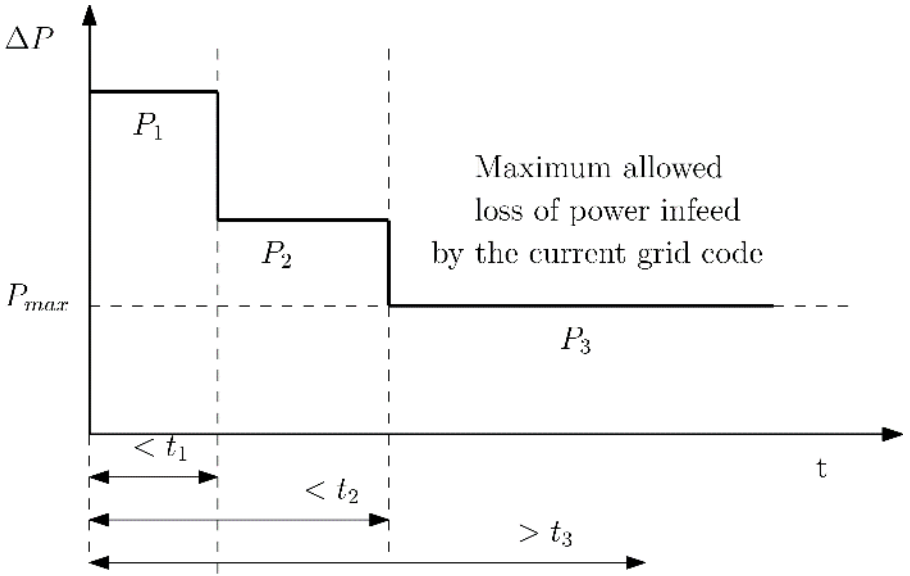
# Possible future AC grid code

Current AC grid code only defines maximum allowed permanent loss

- Possible future AC grid code:
  - Transient loss $P_1$: restoration within $t_1$ (e.g. one cycle)
  - Temporary loss $P_2$: restoration within $t_2$ (e.g. hundreds ms)
  - Permanent loss $P_3$: equal to maximum allowed permanent loss





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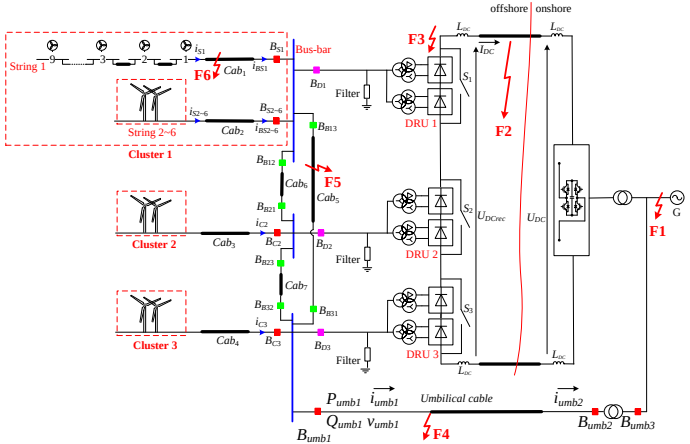
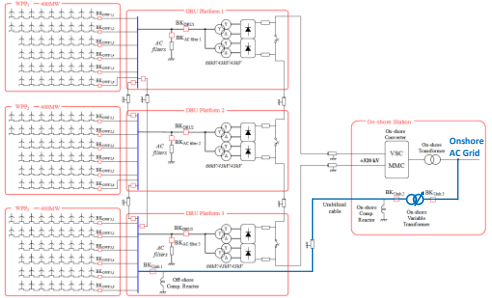
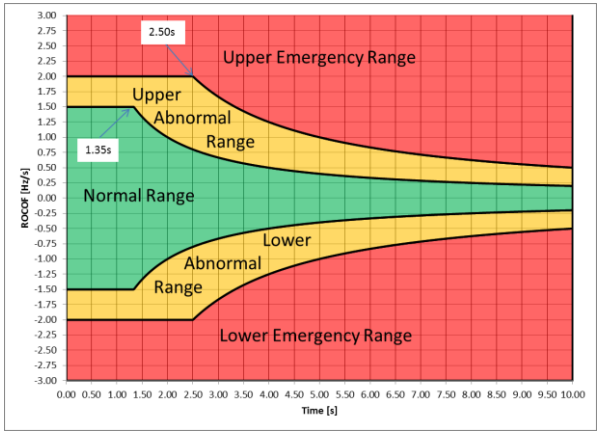
# WP3 Preliminary list of Recommendations for Requirements DRU-HVDC connected WPPs

- **Grid forming WTs for DRU connection**
  - Energization
  - Operational ranges (e.g. V, f, df/dt)
  - Control gains (e.g. droop, reserve)
  - Onshore and offshore FRT (100% Power-Electronics)




https://www.promotion-offshore.net/fileadmin/PDFs/D3.1_PROMOTioN_Deliverable_3.1_Detailed_functional_requirements_to_WPPs.pdf
https://www.promotion-offshore.net/fileadmin/PDFs/D3.4_PROMOTioN_Results_on_control_strategies_of_WPPs_connected_to_DR-HVDC.pdf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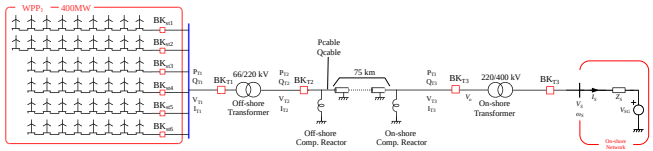
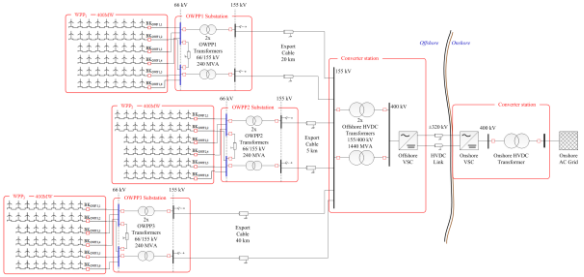
# WP3 Preliminary list of Recommendations for Requirements HVAC & VSC-HVDC connected WPPs

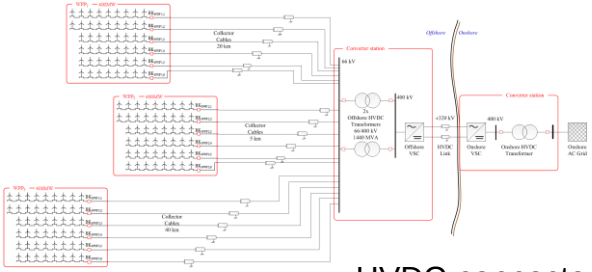
- **Self-Energization and Black Start requirements for OWPPs [D3.8; coming soon]**



HVAC-connected OWPP



HVDC-connected OWPP(s)
with AC collector substation(s)



HVDC-connected OWPP(s)
directly (66kV) connected to the HVDC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Selected aspects for recommendations for offshore HVDC converters

# Workshop on HVDC connected WPPs Roskilde 15 January 2019

| Topics |
| --- |
| Introduction to IEC 61400-21 series – Measurement and assessment of WT and WPP and the relation to the IEC TC8/SC8A activities |
| Introduction to IEC 61400-27 Electrical simulation models |
| State-of-the-art for harmonic modelling in IEC 61400-21-3 |
| Plans for test and validation of harmonic modelling in PROMOTioN project |
| Grid forming wind power plants |
| Blackstart with HVDC connected wind power plant |
| AC and DC FRT of HVDC connected wind power plants |
| State-of-the-art of ancillary services from HVDC connected wind power plants |
| Frequency support from wind power plants connected to HVDC via diode rectifiers |
| Discussion of harmonization potential |


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# Workshop on HVDC connected WPPs Roskilde 15 January 2019

- Main conclusions:
  - It is recommended ***not to make specific standards*** and requirements to tests, controls and modelling ***of HVDC connected wind power plants***. Instead, the existing standards and requirements should be developed ensuring that they also apply to HVDC connected WPPs.
  - The specific implementation of new advanced control such as grid forming control and black start control should not be standardized because this would block the development of new solutions. Instead, the harmonization should focus on providing ***functional specifications***.
  - Tests of ***harmonic emission and resonances will be increasingly important*** in the future. PROMOTioN should make sure that the results expected late in the project will be used in harmonization after PROMOTioN ended.
  - ***Grid forming control and black-start capability*** of WPPs is also expected to be advanced in the end of the PROMOTioN project. PROMOTioN should make sure that this work is concluded with ***functional specifications*** which can be used in harmonization after PROMOTioN ended.
  - PROMOTioN should ***follow*** the development of ***new IEC SC8A proposals*** for large scale offshore wind energy integration using multi-terminal HVDC. This work is expected to focus on best-practices, for instance publishing technical reports.


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# Outlook


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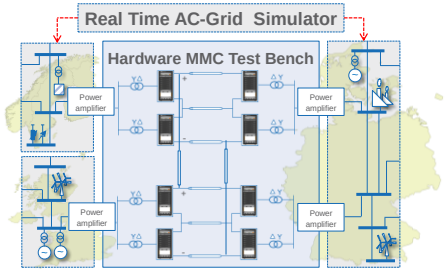
Outlook

# Demonstrators

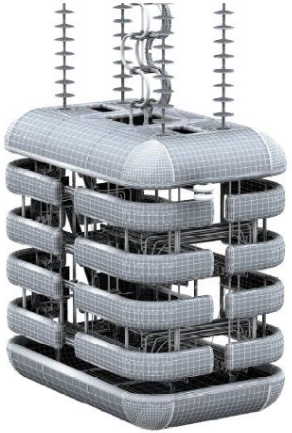



**HVDC network control**

MMC test bench
RWTH Aachen
Aachen, Germany

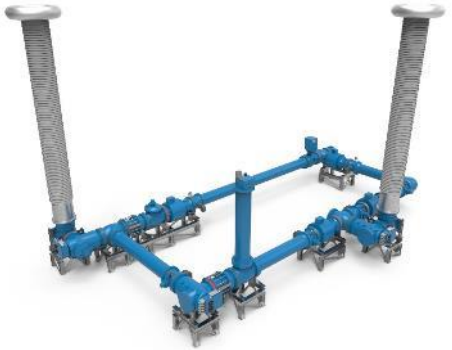
**HVDC network protection**

Multi-terminal test centre
SHE Transmission
Glasgow, UK



**HVDC circuit breakers**

KEMA High Power Lab
DNV GL
Arnhem, Netherlands



**HVDC gas insulated system**

KEMA High Voltage Lab
DNV GL
Arnhem, Netherlands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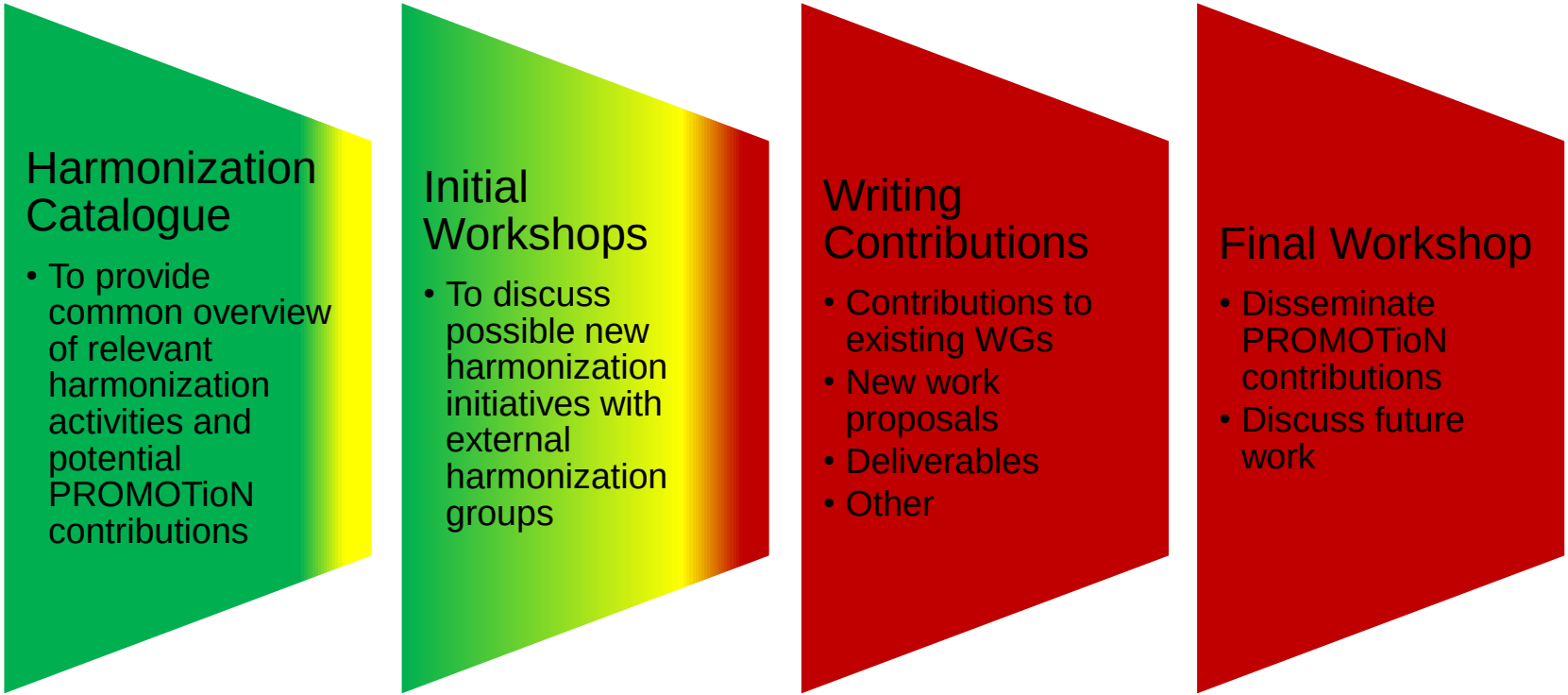
# WP11 Upcoming Contributions





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# Thank you for your attention!


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