PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

HALF YEARLY MEETING DTU, ROSKILDE, DENMARK

2 - 5 December 2019

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

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

HALF-YEARLY CONSORTIUM MEETING ROSKILDE

Date: **2 – 5 December 2019**

ACCESS TO THE DTU RISØ CAMPUS

1. AT THE GATE AT RISØ:
   MENTION YOUR NAME AND THAT YOU COME FOR THE PROMOTION CONSORTIUM MEETING
2. GO TO BLDG 112, FOYER :
   PICK UP YOUR NAME BADGE
   (MANDATORY AT THE DTU RISØ CAMPUS)

Schedule:

Time	Monday, 2 December	Tuesday, 3 December	Wednesday, 4 December	Thursday, 5 December
Morning	WP Meetings I	Plenary Session	General Assembly	Exploitation Plan II
Afternoon	WP Meetings II	Plenary Session & General Assembly	a. Exploitation Plan b. PMG Meeting	
Evening		Dinner		

Place: **DTU Risø Campus**
Department of Wind Energy
Frederiksborgvej 399, Roskilde, Denmark

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

AGENDA

Monday 2 December

Work Package Meetings

Time	**Description**	**Where**
Work Package	**Time**	**Room**
WP2	10:00 – 12:00	Bldg. 116, Lille Kantine
WP3	09:00 – 12:00	Bldg. 116, VIP Kantine
WP7	09:00 – 10:00	Bldg. 112, HH Koch
WP4	09:00 – 10:00	Bldg. 109, Room 202
WP6	09:00 – 12:00	Bldg. 116, Pejestue
WP15	11:00 – 17:00	Bldg. 118, Tycho Brahe/Ole Rømer
Coffee/Tea	10:00 – 10:30	Bldg. 112, Foyer
Lunch	12:00 – 13:00	Bldg. 112, Foyer
WP9	10:30 – 17:00	Bldg. 109, Room 202
WP10	13:00 – 17:00	Bldg. 116, Pejestue
WP11	13:00 – 17:00	Bldg. 116, Lille Kantine
WP12	10:30 – 17:00	Bldg. 112, HH Koch
WP16	13:00 – 17:00	Bldg. 116, VIP Kantine
Coffee/Tea	15:00 – 15:30	Bldg. 112, Foyer

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Tuesday 3 December

Plenary Session | General Assembly

Time	Description	Where
08:30 – 09:00	WP13	Bldg. 112, Niels Bohr Auditorium
09:00 – 09:30	WP11	
09:30 – 10:00	WP15	
10:00 – 10:30	Coffee break	Bldg. 112, Foyer
10:30 – 11:00	WP2	Bldg. 112, Niels Bohr Auditorium
11:00 – 11:30	WP3	
11:30 – 12:00	WP16	
12:00 – 13:00	Lunch	Bldg. 112, Foyer
13:00 – 13:30	WP6	Bldg. 112, Niels Bohr Auditorium
13:30 – 14:00	WP10	
14:00 – 14:30	WP4	
14:30 – 15:00	WP9	
15:00 – 15:30	Coffee break	Bldg. 112, Foyer
15:30 – 17:00	General Assembly, WP12	Bldg. 112, Niels Bohr Auditorium
19:00 – Late	Dinner	Restaurant Ilden Algade 62, 4000 Roskilde

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PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Wednesday 4 December

General Assembly

09:00 – 12:00 Bldg. 112, Niels Bohr Auditorium

- Amendment 8 [vote to agree with changes: more detailed information will be sent]
  o Tractebel Engineering leaves consortium and Tractebel Impact is added as full partner
  o KU Leuven and University of Strathclyde are added to WP9
  o Budget transfers
- Announce amendment 9
- D7.9 Regulatory and Financing principles for a Meshed HVDC Offshore Grid
  [Vote to approve the WP7 recommendations to be taken forward into WP12 - please prepare by reading the recommendations of D7.9 (https://service.projectplace.com/pp/pp.cgi/r278548619 , chapter 15, pp72-78). A more detailed preparation document will be shared before the meeting and explained during the meeting]
- Reporting
- Demos

12:00 – 13:00 Lunch Bldg. 112, Foyer

a. Exploitation workshop | PMG

13:00 – 17:00 Bldg. 112, HH Koch

b. PMG

13:00 – 17:00 Bldg. 116, VIP Kantine

Thursday 5 December

Exploitation workshop

09:00 – 12:00 Bldg. 112, HH Koch

12:00 Lunch Bldg. 112, Foyer

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PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

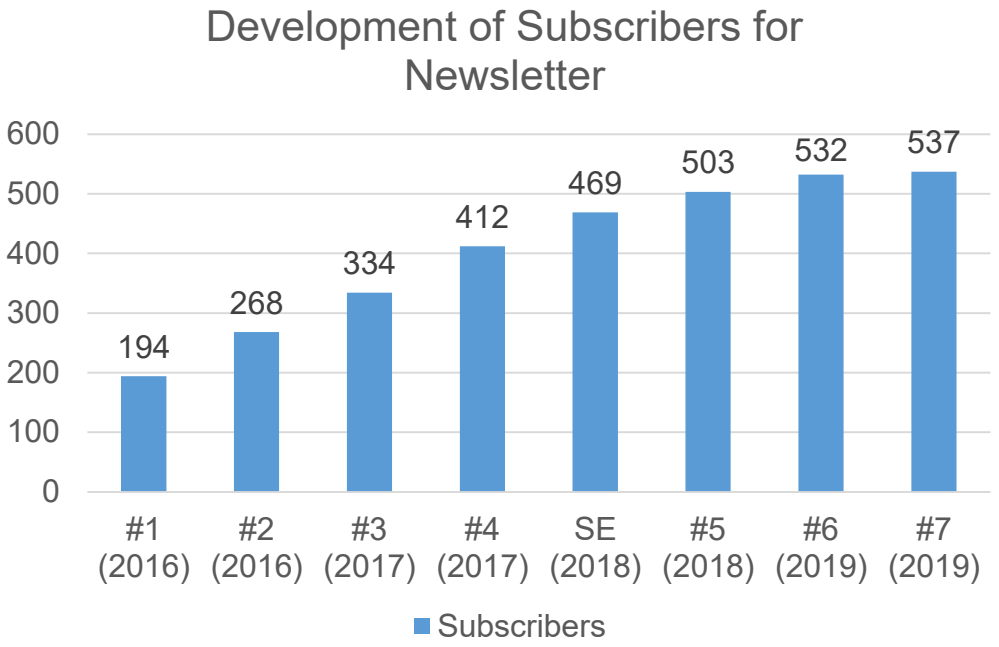
WP13
Dissemination

Stiftung OFFSHORE-WINDENERGIE ● Sebastian Menze

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

Progress Task 13.2 – Development and production of a newsletter

- **Steady increase in subscribers** for newsletter since project start
- Regular cooperation & exchange with PMG
- **Newsletter #7 for Q4/2019, topics amongst others:**
  - Mitsubishi DC Circuit Breaker test
  - Demonstration of HVDC Protection Systems
  - Impedance Characterisation of Wind Turbine Converters using PHiL & CHiL
  - MMC CHiL Test
  - Regulatory principles for meshed offshore grids
  - Summary Copenhagen activities PROMOTioN
  - Further demonstration activities



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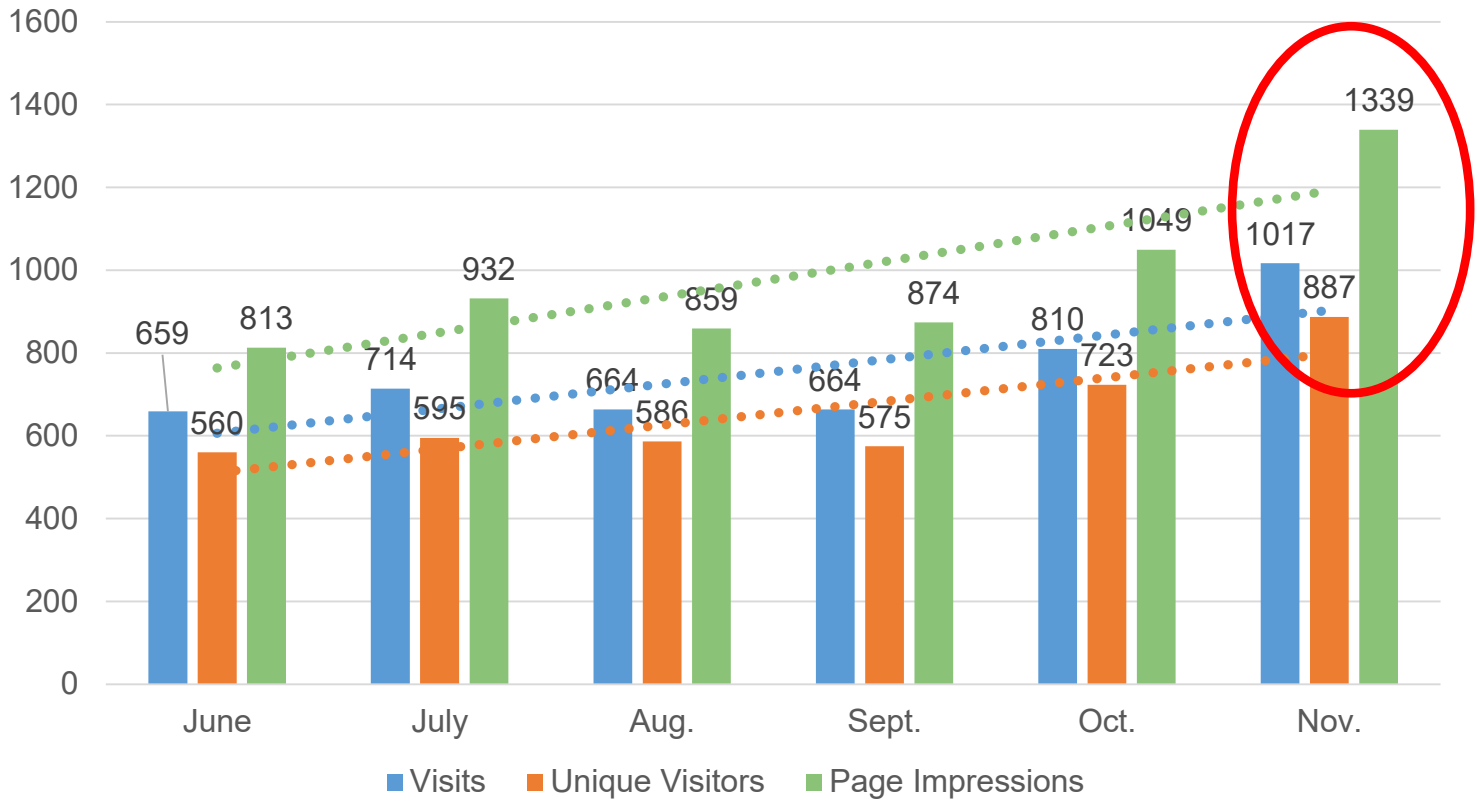
Progress Task 13.3 - Content management for website and intranet

- Main Objective: maintenance and constant improvement of the PROMOTioN website
- Regular updates of news, calendar and download-sections
- Satisfactory numbers of visitors and page impressions – increasing tendency
- People stay roughly **2 minutes** on our website
- Visitors look at ~ 2 different pages per visit (average **bounce rate ~ 60%)**



Visits: Number of overall visits
Unique Visitors: Distinct individuals
Page Impressions: Number of different pages

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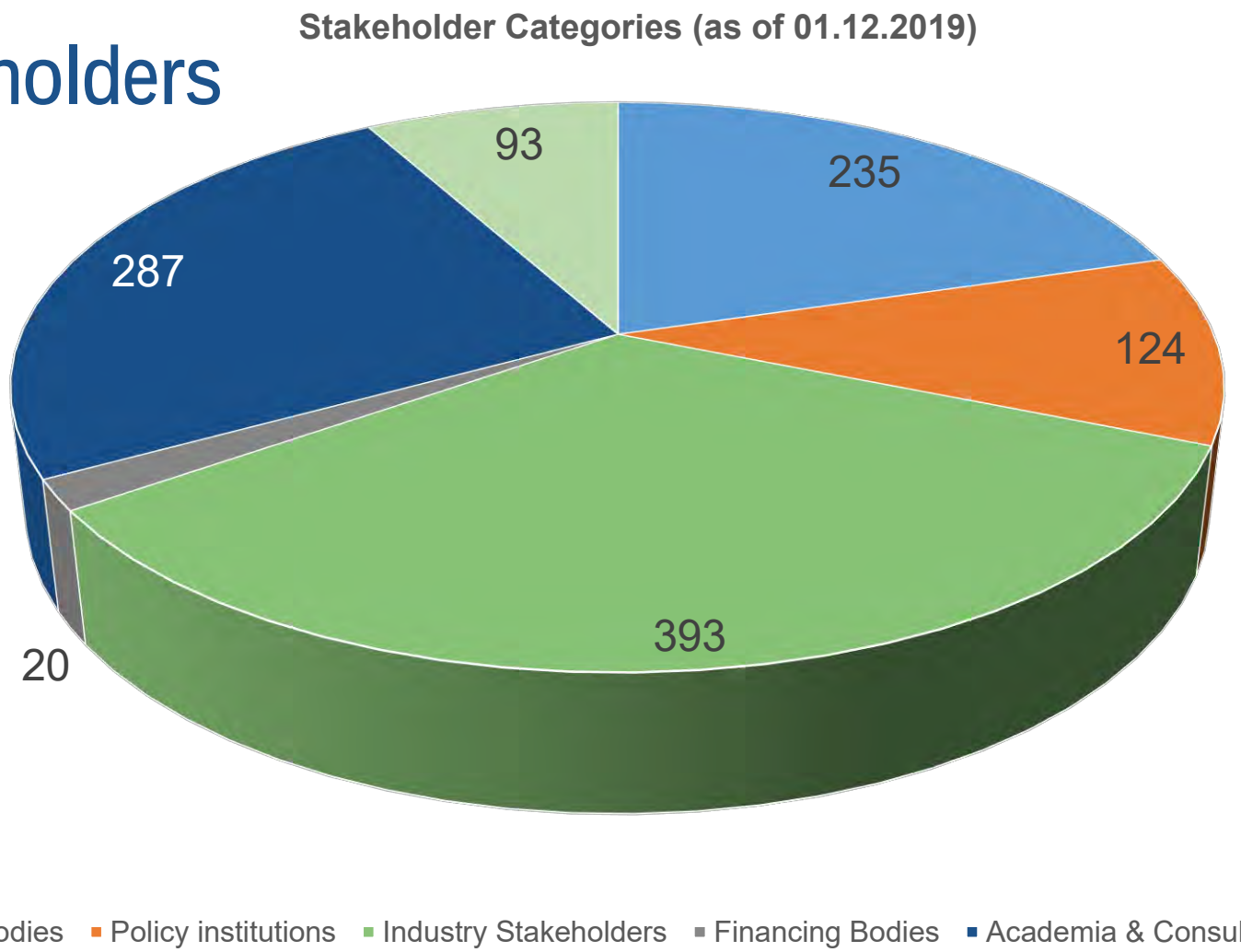
Progress Task 13.4 - Development of a targeted mailing list

1,152 Stakeholders



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Progress Task 13.6 - Production of public reports, papers/articles, presentations

Thank you! We are right on track!

- Objectives:

→ 50 conference papers

→ 25 journal articles

→ Revision until the end of this year

→ Numbers look very promising

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Progress Task 13.6. – Publications

1. Include one of the disclaimers

→"This work has been supported by the PROMOTioN project through the European Union's [...]"

2. Inform the related WP's all partners

3. Upload the paper/presentation/poster to the "Publications" folder in projectplace (https://service.projectplace.com/pp/pp.cgi/0/1474230898)

→Follow the naming manual (https://service.projectplace.com/pp/pp.cgi/r1474238139) and add info to the file.

4. Inform the WP leader or PC (project coordinator, Cornelis Plet, DNV GL) 45 days prior to the publication date!

5. When the paper is published, send the open access version to WP13 (Sebastian Menze s.menze@offshore-stiftung.de) to be published on the PROMOTioN website.

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Progress Task 13.7. – Stakeholder Interaction Review
Q3 & Q4 2019

- **Support of PROMOTioN Demonstration activities**

→ **Converter harmonic model and black start validation**, 15 August, Arnhem

→ **Protection System Demonstration**, 22 August, Cumbernault

→ **MMC CHiL Test**, 21 November, Arnhem

- **HVDC Circuit Breaker & HVDC Protection Workshop**, 27 September, Brussels
- **WindEurope Offshore 2019 conference & exhibition,** 26-28 November, Copenhagen
- **Joint dissemination activities AURES II and PROMOTioN policy study**

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Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 - Converter harmonic model and black start validation

- 15 August, Arnhem
- Around 25 attendees
- Presentations by consortium partners and chinese manufacturer „Ming Yang Smart Energy“
- Link to press release

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Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 - Demonstration of protection of multi-terminal HVDC grids

- 22 August, Cumbernault
- Around 20 attendees
- Real-time simulation test of both PROMOTioN IED as well as MEU IED
- Link to press release

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Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 - MMC CHiL Test

- 21 November, Arnhem
- 25 attendees
- Press release „under construction“

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Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 - HVDC Circuit Breaker & HVDC Protection Workshop

- 27 September, Brussels
- 40 attendees from TSO, Developers, manufacturers academia, consultancy and associations
- Full-day workshop format

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Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 – Regulatory & Financing Side Event

- 26 November, during the WindEurope Offshore 2019 conference & exhibition
- Between 30 and 40 attendees
- Presentation and discussion of regulatory & financing principles for MOG
- Discussion of consideration for a deployment plan for MOG

Time	Title	Speaker
14:00	Introduction PROMOTioN & overview	Marc Schmidt, TenneT TSO GmbH
14:15	Recommendations for a legal regulatory framework	Ceciel Nieuwenhout, Groningen Centre of Energy Law
15:00	Recommendations for an economic regulatory framework	Pradyumna Bhagwat, Florence School of Regulation
15:45	Recommendations for a financial regulatory framework	Alexandra Armeni, Deutsche WindGuard
16:30	Outlook and next steps in PROMOTioN towards meshed offshore grids	John Moore, TenneT TSO B.V.
17:00	End of the side event	

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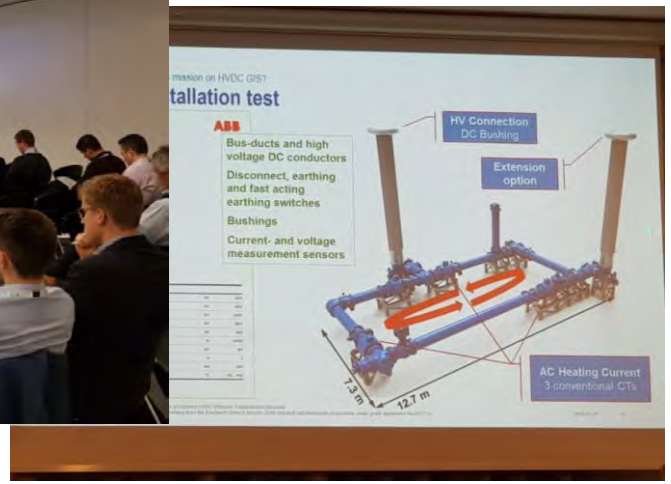
Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 – Technical Side Event

- 27 November, during the WindEurope Offshore 2019 conference & exhibition
- Between 30 and 40 attendees
- Presentation and discussion of various technical challenges and solutions for MOG, e.g. HVDC Circuit Breakers, HVDC GIS, Network Control & Protection, standardization

Time	Title	Speaker
14:30	Welcome and opening	Mark van Stiphout, DG ENER
14:40	Introduction PROMOTioN & overview	Cornelis Plet, DNV GL
14:50	How to export offshore wind using DC grids?	Christina Brantl, RWTH Aachen
15:00	How offshore wind can provide black start?	Ramon Blasco-Gimenez, UPV
15:10	How to protect a DC grid?	Geraint Chaffey, KU Leuven
15:30	How to apply DC Circuit Breakers?	Cornelis Plet, DNV GL
15:50	How to reduce the size of platforms with HVDC GIS?	Michael Gatzsche, ABB
16:10	How to avoid converter controller interaction?	Philipp Ruffing, RWTH Aachen
16:30	What's the progress towards standardization and grid codes?	Poul Sørensen, DTU
16:50	Final Q&A	Moderator: Cornelis Plet, DNV GL
17:00	End of the side event	-



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Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 – PROMOTioN during conference programme

- 28 November, 10:45 – 12:15
- Session A11: **Offshore wind, balancing, inertia and other ancillary services**
- Ramon Blasco-Gimenez presented on "**Grid forming wind turbine and wind power plant control for black start operation**"

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Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 – Innovation Park [I]

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

Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 – Innovation Park [II]

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

Progress Task 13.7. – Stakeholder Interaction Review

Q3 & Q4 2019 - AURES II and PROMOTioN policy study

- Different PROMOTioN partners take part in a **joint policy study** together with the AURES II project
- **Objective**: explore challenges and benefits for cross-border auctions at energy islands connecting offshore wind from different EU member states
- SOW supports joint dissemination activities

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Progress Task 13.8 – External Communication activities

- Includes press and media work (e.g. press briefings, social media)
- Press briefings & background talks as well as **press releases** (WP7, WP9, WP16)
- All press releases created **significant media attention**, e.g. from Renews, Recharge and other media corporations
- Communication of news-items on Twitter channel (**206 Followers**) & LinkedIn

www.windtech-international.com

Demonstration of converter impedance measurement for the stability assessment in converter dominated power systems

Published: 24 September 2019

DNV GL has announced a MW-level wind turbine power converter input-impedance ied out in an independent lab with the commercial partner Ming Yang Smart n, China. A current perturbation measurement setup is prototyped in the DNV rid Lab (FPGL) to measure the input-impedance of a MW-level wind turbine nd verify the harmonic impedance model that is essential for the management ance risks, especially in the practice of offshore wind farm grid integration.

e current perturbation method is its scalability to meet the growing size of st (e.g. wind turbine generator, PV generator etc). The demonstration took of the EU research project PROMOTioN in Arnhem, the Netherlands. The ogress on Meshed HVDC Offshore Transmission Networks) project aims to egulatory, financial and legal challenges to the implementation of offshore nsmission networks.

windtech-international.com/product-news/demonstration-of-converter-ement-for-the-stability-assessment-in-converter-dominated-power-systems

ReNEWS, 6. November 2019 - https://renews.biz/56252/harmonised-regulations-key-to-north-sea-meshed-grid/

Harmonised regulations 'key' to North Sea meshed grid

EU-funded Promotion project sets out recommendations to deliver cross-border HVDC offshore connections

6 November 2019 09:50 Grid [Image: TenneT]

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Examples of social media activity

PROMOTioN Project @PROMOTioN_HVDC · 17. Sep.
@PROMOTioN_HVDC PROMOTioN has successfully demonstrated, how multi-terminal HVDC grids can be protected - great job done at the @HVDC_CENTRE_GB! Find out more in our news- and press release: promotion-offshore.net/news_events/ne...

Du hast retweetet

reNEWS @reNEWS_ · 9. Sep.
Technology to monitor and detect faults in DC multi-terminal grids is being put through its paces at the National HVDC Centre in the UK renews.biz/55206/

3 2

Sebastian Menze
Projectmanager Communication & Dissemination
5 Tage

Dear all,
happy to be at the WindEurope Offshore2019 conference and exhibition in Copenhagen!
Come and find us in Hall E, F-20 and find out what that blue "pipe" next to me is :)
Interesting days ahead of us!
See you all soon!
All the best,
Sebastian

p.s.: get a glimpse of PROMOTioN during our first presentation today at the Innovation Park (Hall E)!

30

Reaktionen

Gefällt mir Kommentar Teilen

1.119 Ansichten Ihres Beitrags im Feed

PROMOTioN Project @PROMOTioN_HVDC · 25. Sep.
Another milestone reached in @PROMOTioN_HVDC: read more about the successful demonstration of converter impedance measurement for the stability assessment in converter dominated power systems in our news item and press release: promotion-offshore.net/news_events/ne...

2 1

Great presentation, Jelle!
Sebastian Menze hat dies kommentiert

Dear all, I hope by now you've took note of all our PROMOTioN dates for next week? I...
Sebastian Menze hat das geteilt
18 Reaktionen

Dear all, happy to be at the WindEurope Offshore2019 conference and exhibiti...
Sebastian Menze hat das geteilt
30 Reaktionen

Dear all, I am pretty excited that not even a week from now, the whole...
Sebastian Menze hat das geteilt
22 Reaktionen

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Save the Date!
MIGRATE Final Conference – 4 December 2019, Brussels

https://lamapoll.de/MigrateFinalConference/

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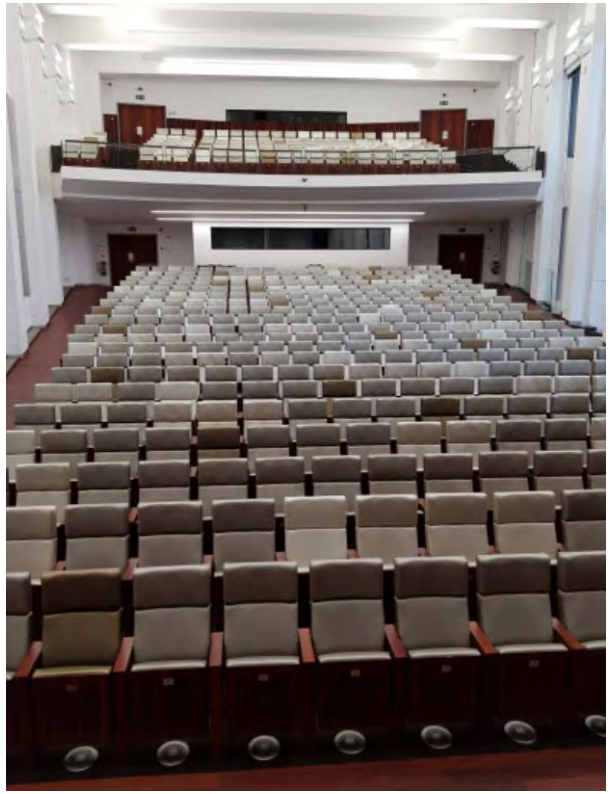
Save the Date!
PROMOTioN Final Conference - 26 & 27 May 2020

- **Royal Museum of Fine Arts of Belgium,** Rue de la Régence 3, Brussels
- **Lunch-To-Lunch** event
- **High-level** panels and speakers
- Presentation of **PROMOTioN results**
- **Parallel** break-out **sessions**
- **Poster** Session
- Our expectation:

→Up to **250 attendees**



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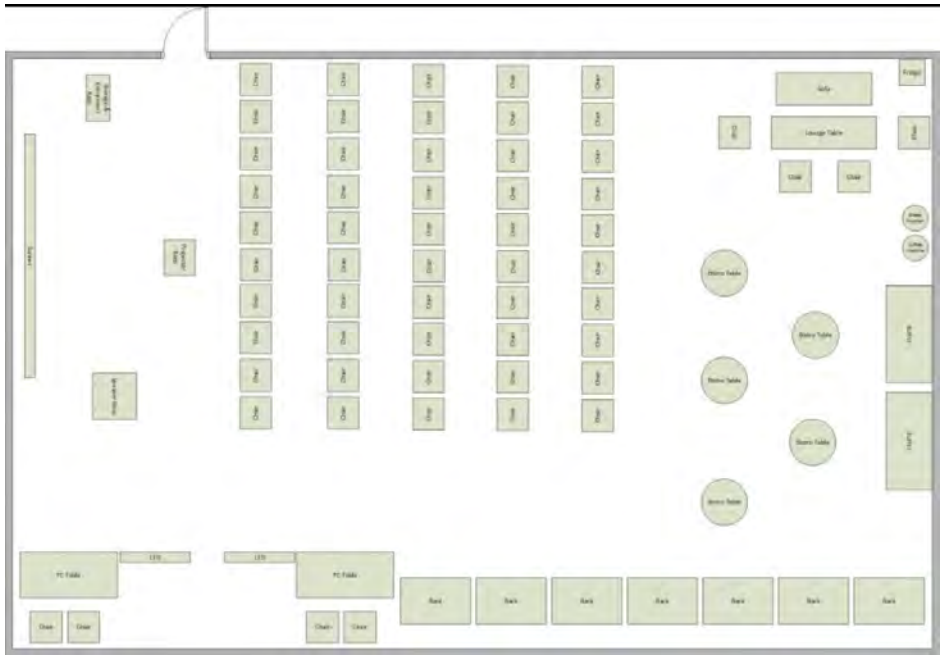
Save the Date!
CIGRE 2020 Paris - 24 – 28 August 2020

- PROMOTioN will be represented with a dedicated half-day session in the conference programme
- Additionally, PROMOTioN plans a separate room for dedicated PROMOTioN side events



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Any Questions?

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WP11 – Harmonization towards standardization

Poul Sørensen – Technical University of Denmark

Presentation at Plenary meeting, Aachen 13 July 2019

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Objectives

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 support harmonization of the work between existing and future working groups.
- To ensure that different manufacturer concepts are considered.

Expected outputs:

- Functional specifications / requirements.
- Test and measurement procedures.
- Modelling.
- Procedures for compliance validation.

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WP11 Main Workflow

Harmonization Catalogue

- To provide common overview of relevant harmonization activities and potential PROMOTioN contributions

Initial Workshops

- To discuss possible new harmonization initiatives with external harmonization groups

Writing Contributions

- PROMOTioN WP11 deliverables
- Contributions to existing WGs
- Potential new work proposals
- Other

Final Workshop

- Disseminate PROMOTioN contributions
- Discuss future work

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Deliverables and milestones

- Deliverables and milestones
  - D11.1 Harmonization catalogue (DTU M38)
  - D11.2 Report on harmonization of HVDC systems (RWTH M52)
  - D11.3 Report on harmonization of WPPs connected to HVDC systems (DTU M51)
  - D11.4 Report on justified recommendations to grid codes (FGH M51)
  - D11.5 Report with recommendations to best practice for compliance evaluation (FGH M42>M45)
  - D11.6 Report with summary of findings from PROMOTioN final harmonization workshop (DTU M54)

- Milestones
  - MS50 Recommended functional requirements to HVDC systems and WPPs (DTU M52)
  - MS51 Recommendations received from WP2 to 6 (DTU M38)

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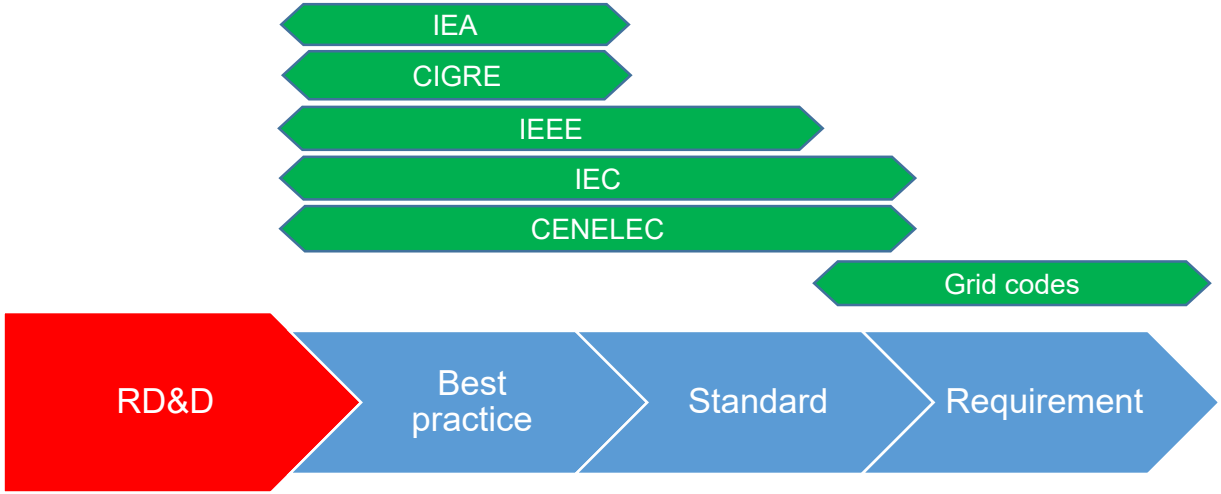
Harmonization Catalogue – Relevant Harmonization Activities

- CIGRE
  - SC B4
  - SC D1
  - SC C2
  - SC C4
- IEC
  - TC88 MT21 / WG27
  - TC8A
  - TC115
  - TC17
- China GB/T
- CENELEC
- IEEE-SA
- Grid codes
  - Commission Regulation – HVDC
  - Commission Regulation – Requirements for generators
  - Commission Regulation – Demand connection Code



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Harmonization factsheets

HVDC system (to D11.2)

- Terminology and Functional Specification
- HVDC converter controls
- Controller HIL testing of MMC HVDC and STATCOM
- MMC Impedance Derivation
- Design of protection
- Classification of protection systems
- Performance evaluation of HVDC protection systems
- Cable overvoltages
- Communication protocols
- Communication interfaces
- Testing of protection devices (IEDs)
- Approach to modelling of HVDC circuit breakers
- Application and specification of HVDC circuit breakers
- Testing of HVDC circuit breakers
- GIS

HVDC connected WPPs (to D11.3)

- Harmonic impedance measurement wind turbine converter
- Black Start study (test) of offshore wind turbine
- Requirements for black-start capability
- Compliance evaluation procedure of (self-start and) black-start operation
- Generic Characterization of Electrical Test Benches for AC- and HVDC-Connected Wind Power Plants

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HVDC systems

© PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
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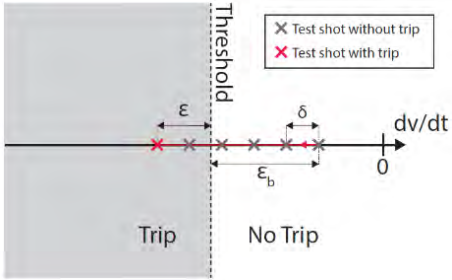
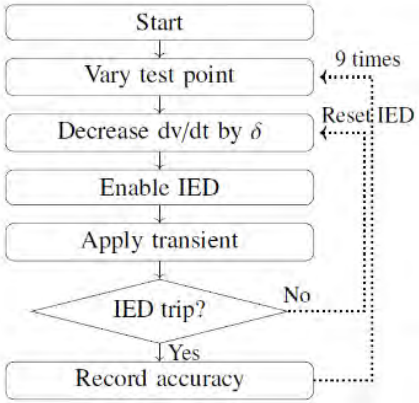
Test procedure for HVDC protection IED

- Test procedures have been developed to assess the functional performance of an HVDC protection IED (Intelligent Electronic Device)
- Test demonstrated on IEC prototype
- The tests use synthesised waveforms to examine the accuracy of the algorithm characteristic
  - Example: du/dt algorithm
- Output of test is accuracy of algorithm
- Standardization groups:
  - Interest from IEC TC95. Measuring relays and protection equipment (so far AC)
  - Others: CIGRE B5. IEEE P2004.





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HVDC connected wind power plants

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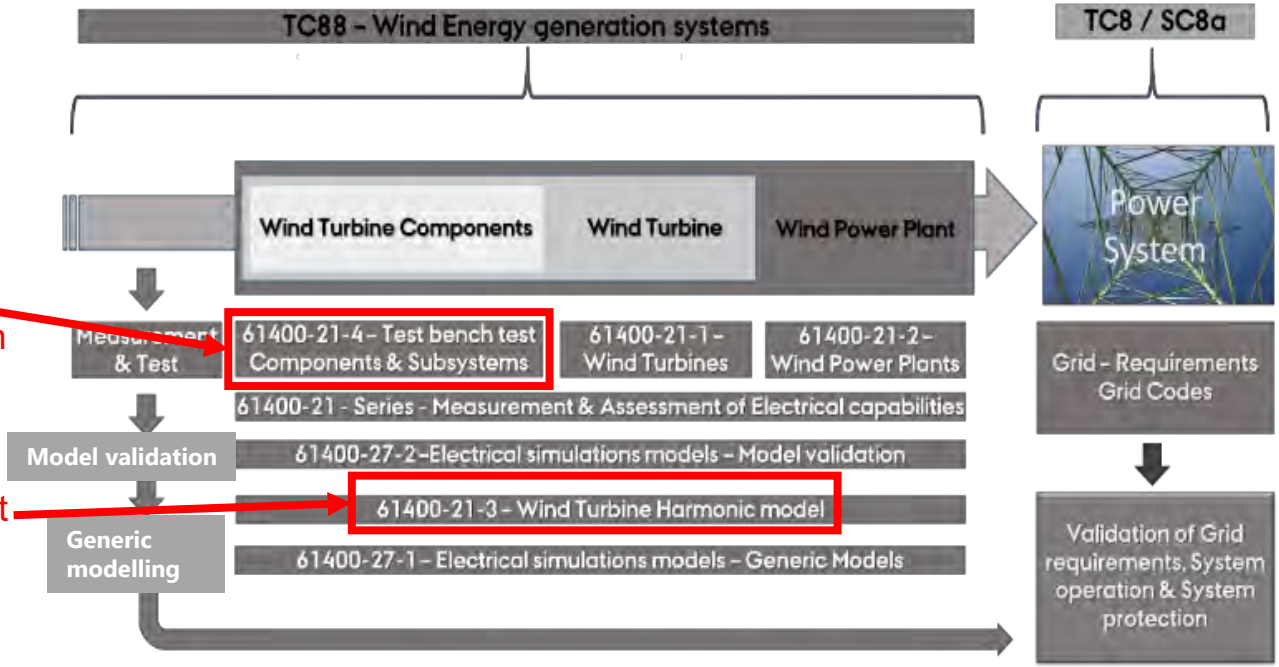
IEC standards for grid connection of wind power

- PROMOTioN contributions:
  - Test bench – Component and subsystem tests
  - Harmonic impedance test (model validation)



From (modified): Andresen, B, Sørensen, PE, Martin, F, Dreyer, T, Ntovolos, K, Kocewiak, ŁH & Brinch Nielsen IEC TC 88 Wind Power Generation standards in relation to grid conneciton requirements in Proceedings of the 18th Wind Integration Workshop. 18th Wind Integration Workshop, Dublin, Ireland, 16/10/201

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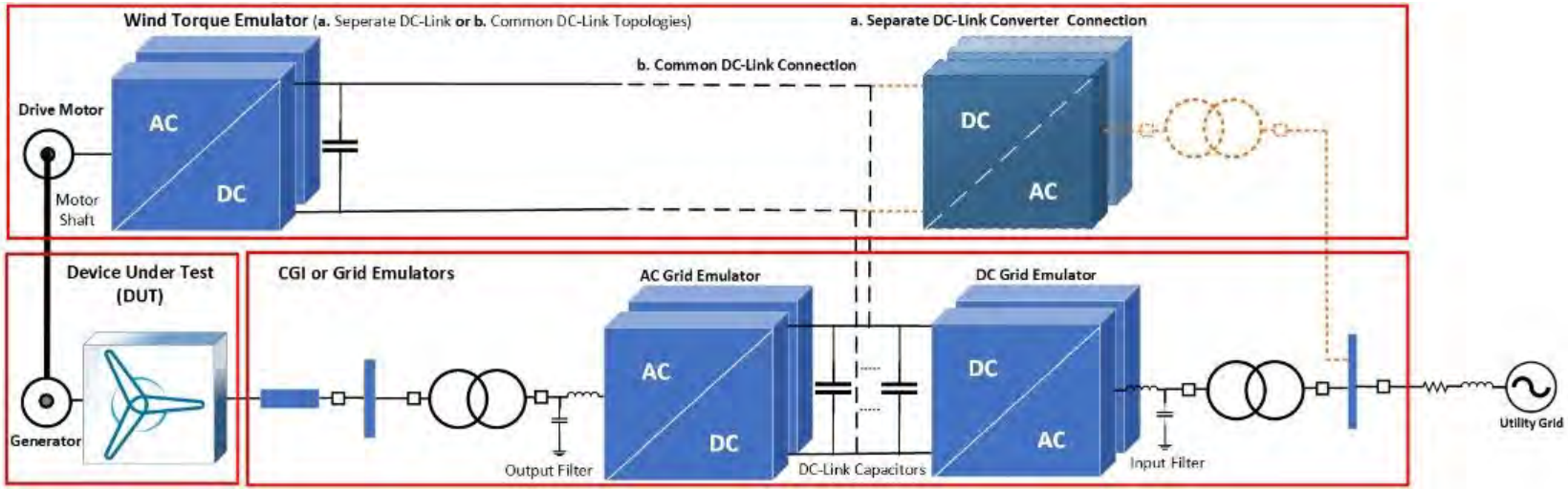
Wind turbine test bench

- Generic structure of wind turbine test bench:



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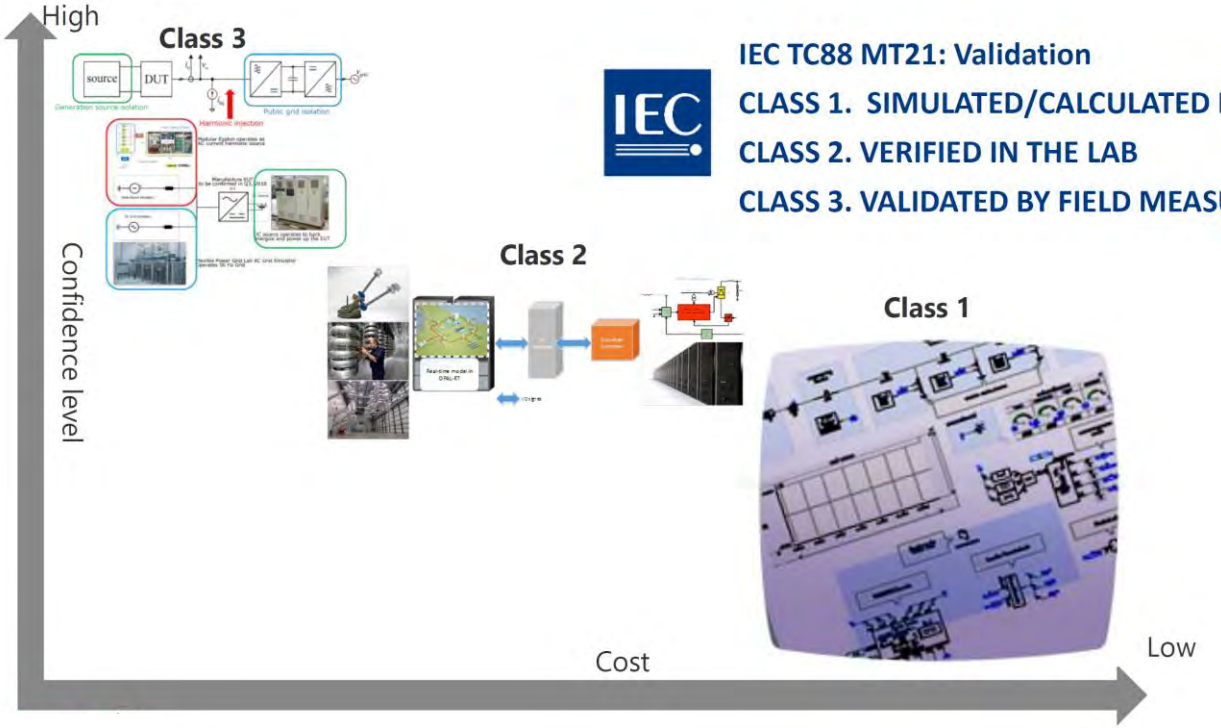
Harmonic model validation – classes and costs



IEC TC88 MT21: Validation

CLASS 1. SIMULATED/CALCULATED BASED ON WT DESIGN

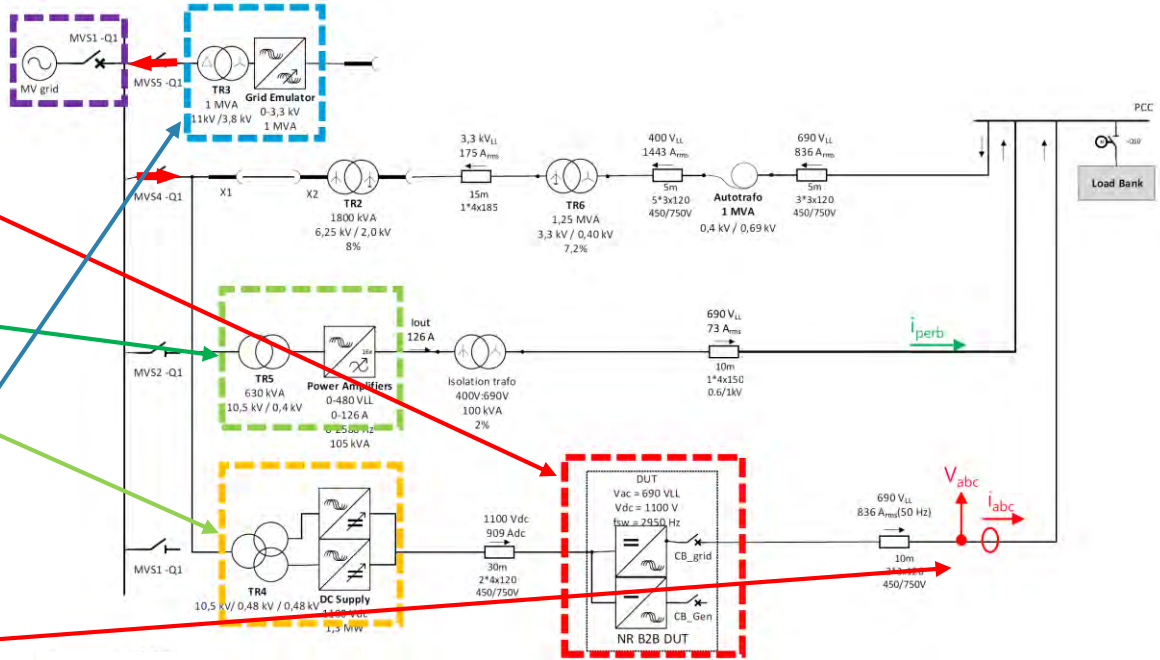
CLASS 2. VERIFIED IN THE LAB

CLASS 3. VALIDATED BY FIELD MEASUREMENTS

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

Test of wind turbine converter (PHIL)

- Power hardware in the loop test
  - DUT is wind turbine inverter (type 4)
  - Wind turbine rectifier inactive (controls power)
  - Controllable harmonic current injection
  - Controllable WT power from DC supply
  - Losses supplied from grid emulator
- Harmonic impedance from changes in FFT of v_{abc} and i_{abc}



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Test of wind turbine converter controller (CHIL only)

- Controller hardware in the loop test
  - Real time simulation of generator, converter, filter, transformer and grid

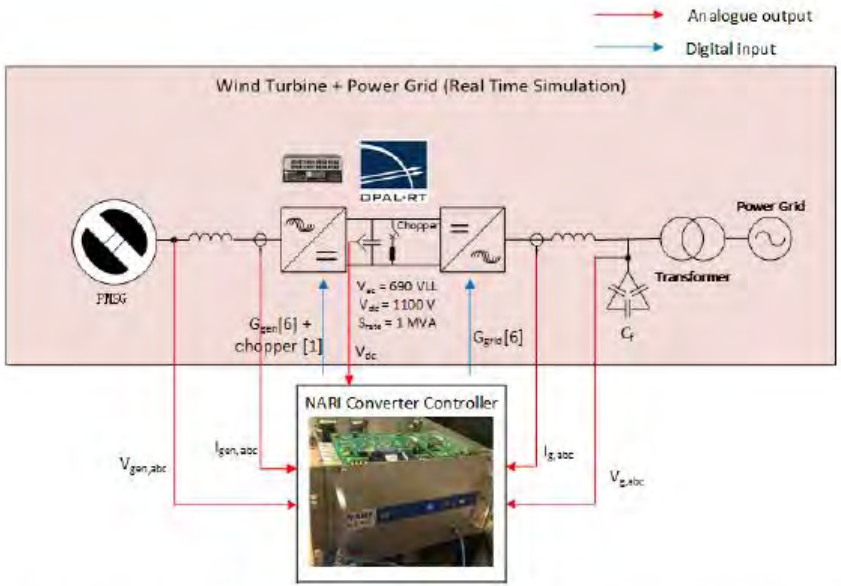

Fig. 5. CHIL setup for the WTG controller replica input-impedance measurement

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Harmonic impedance – comparison of results

- Different levels of validation (IEC 61400-21-3 classes):
  - PSCAD simulation (Class 1)
  - CHIL (Class 2)
  - PHIL (Class 3)
- Purpose to study which level is required
- CHIL test and PSCAD simulation replicate PHIL test in low to medium frequency range (up to ~1200 Hz)
- In higher frequency range, it is reported that PHIL tests suffers from measurement uncertainty and inability to inject sufficient pertubation

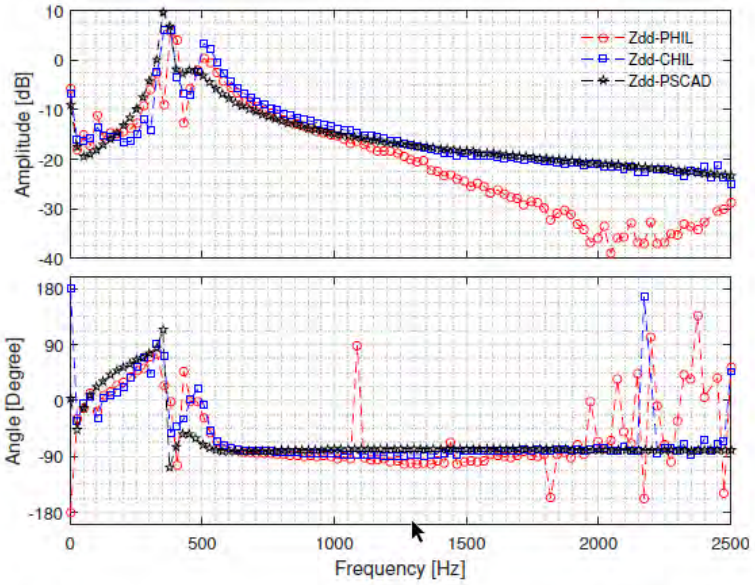

Fig. 7. Impedance measurement results comparison - Zdd full range 2500 Hz

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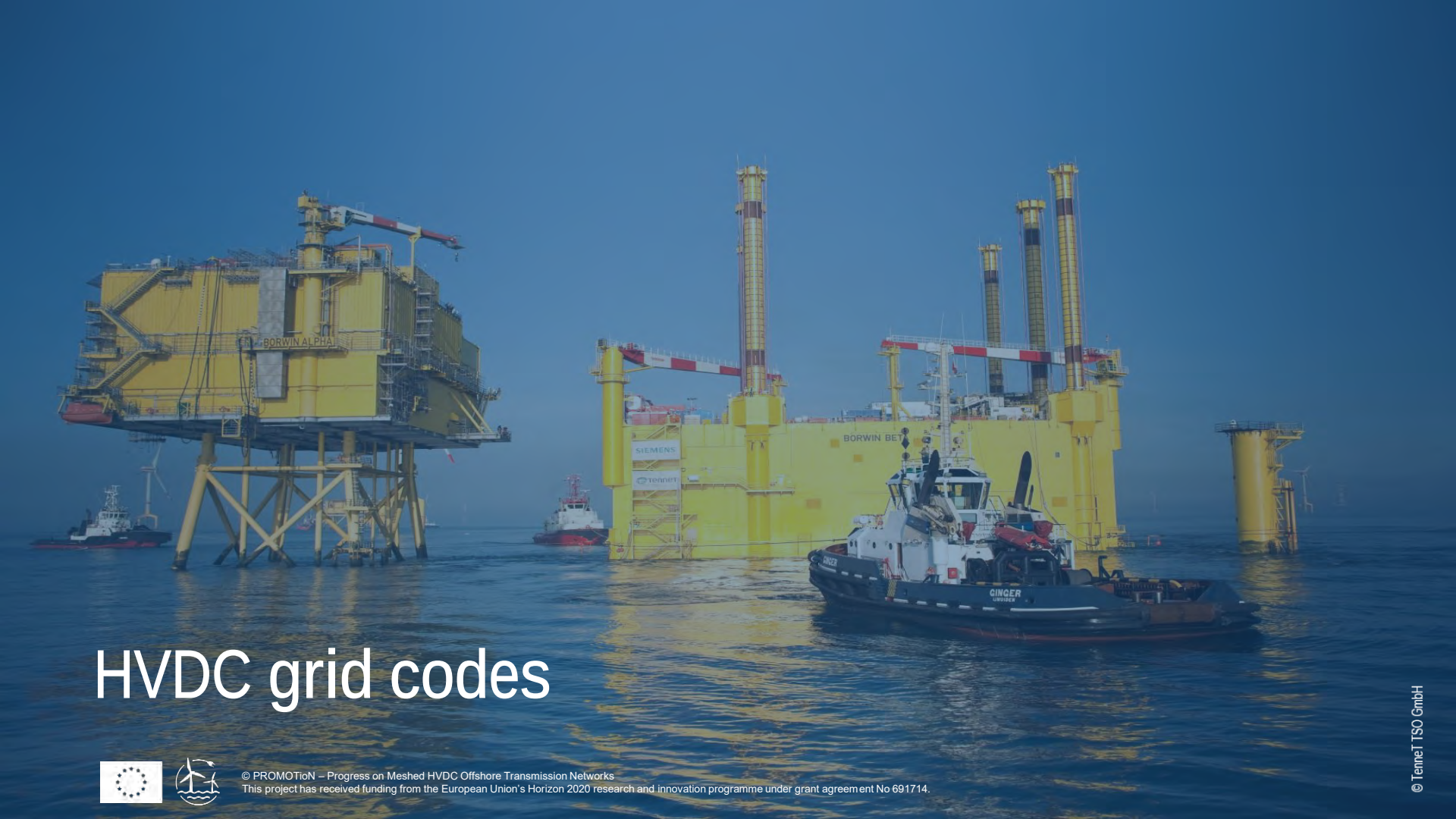


HVDC grid codes

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

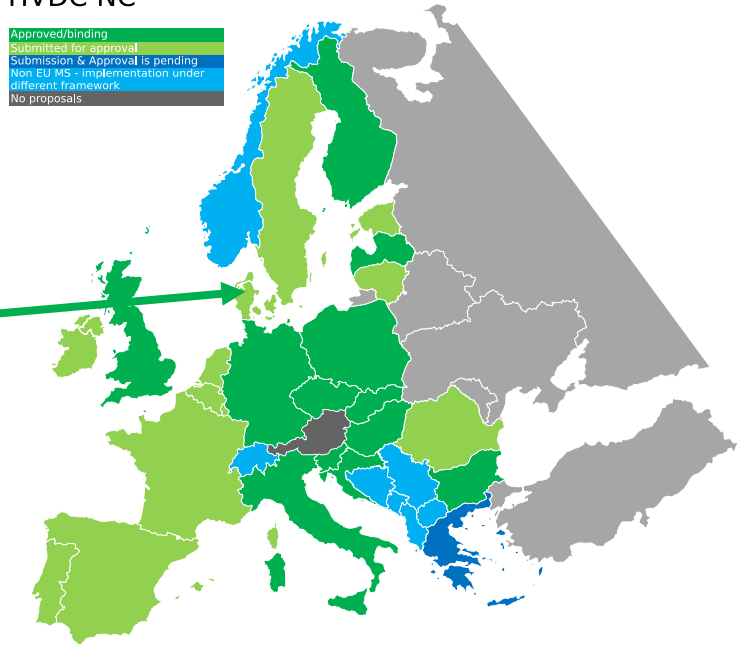
Commission regulation – National implementation

- Commission Regulation – National implementation
  - Requirements for generators (RfG)
  - **HVDC**
  - Demand connection Code (DCC)

- Danish implementation also approved
  - Should be dark green

- PROMOTioN (WP2 – D2.4):
  - Comparison of implementations in Germany, Spain, Denmark and UK
  - Recommendations

HVDC NC



https://docs.entsoe.eu/cnc-al/#implementation-maps
accessed 26 Nov. 2019

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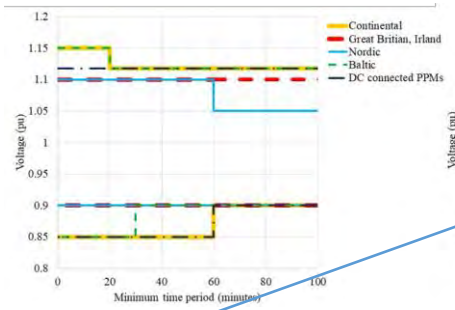
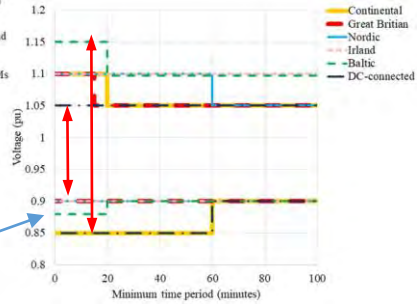
Comparison of European Network Codes

- According to Energinet, the Commission Regulation HVDC
  - Is intended as regulation for connecting HVDC components and HVDC connected PPM to the AC system
  - Was never intended to cover (multiterminal) DC grids
  - Therefore, there are only a very few requirements to the DC side.

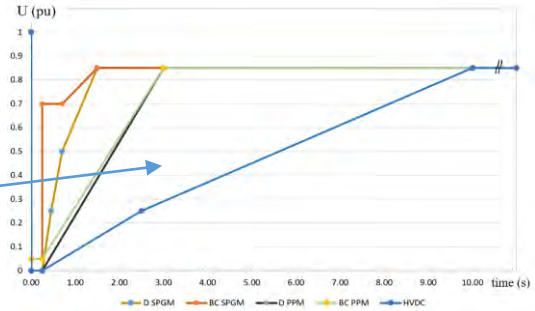
- Some observations from NC review:
  - Voltage ranges
  - LVRT comparison of SG – WPP – HVSC-VSC



<300 kV



>300 kV



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Summary and questions

- PROMOTioN has (/ will) in particular contribute to the development and demonstration of several test procdures – supporting standardization:
  - Harmonic impedance measurement of converter based systems (WTs and HVDC MMC)
  - Functional test of HVDC protection IED
  - Circuit breaker test
  - Black start capability of WPP
- Future HVDC grid code requirements will need to take into account multiterminal (and meshed) HVDC grids – requirements to DC side (from WP2 D2.4)

- Final harmonization workshop: back-to-back with PROMOTioN final conference?

- Questions?

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APPENDIX

DISCLAIMER & PARTNERS

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DNV GL Netherlands B.V., ABB AB, KU Leuven, KTH Royal Institute of Technology, EirGrid plc, SuperGrid Institute, Deutsche WindGuard GmbH, Mitsubishi Electric Europe B.V., Affärsverket Svenska kraftnät, Alstom Grid UK Ltd (Trading as GE Grid Solutions), University of Aberdeen, Réseau de Transport d'Électricité, Technische Universiteit Delft, Equinor, TenneT TSO B.V., Stiftung OFFSHORE-WINDENERGIE, Siemens AG, Danmarks Tekniske Universitet, Rheinisch-Westfälische Technische Hochschule Aachen, Universitat Politècnica de València, SCiBreak AB, Forschungsgemeinschaft für. Elektrische Anlagen und Stromwirtschaft e.V., Ørsted Wind Power A/S, The Carbon Trust, Tractebel Engineering S.A., European University Institute, European Association of the Electricity Transmission & Distribution Equipment and Services Industry, University of Strathclyde, Prysmian, Rijksuniversiteit Groningen, MHI Vestas Offshore Wind AS, Energinet.dk, Scottish Hydro Electric Transmission plc, SCiBreak AB

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

WP15

HVDC Gas Insulated Systems Demonstrator

ABB ● Uwe Riechert

Half-yearly meeting Roskilde, 2019, Tuesday, 3rd December

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

Milestones & Deliverables (2)

MS71 Provided DC GIS systems are tested according to the test program (54)

MS72 Test experience shared with WP11 (48) – PPT prepared

D15.4 Anonymized test reports on tests carried out (54) – first draft in 50

D15.5 Report of diagnostic analysis and condition assessment (54) – first draft in 50

D15.6 White- and position papers on pre-standardization of DC GIS testing (54) – first draft in 50

D15.8 Report on long term monitoring of DC GIS with defects (54) – first draft in 50

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Task Structure

WP15 – HVDC GIS technology demonstrator

WP1

WP4

Task 15.1: SHE Transmission
Defining specifications and long term testing requirements

Task 15.2: TU Delft
Develop monitoring and diagnostic method and applicability of SF_6 alternatives

Task 15.3: DNV-GL
Long term testing of the DC GIS equipment

Task 15.4: ABB
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WP11

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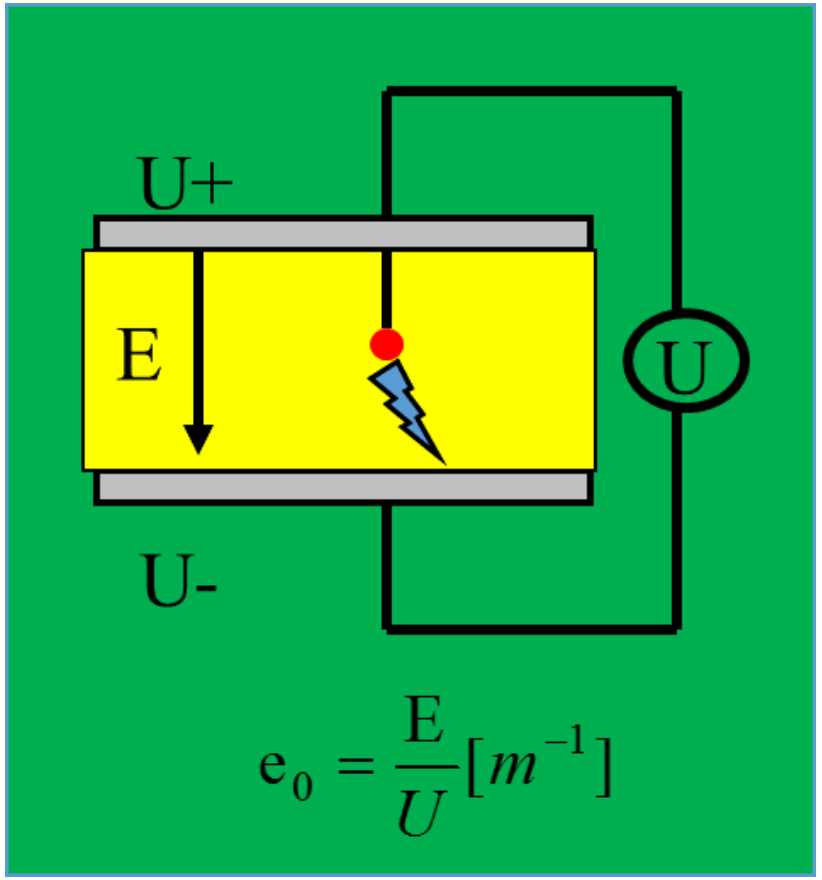
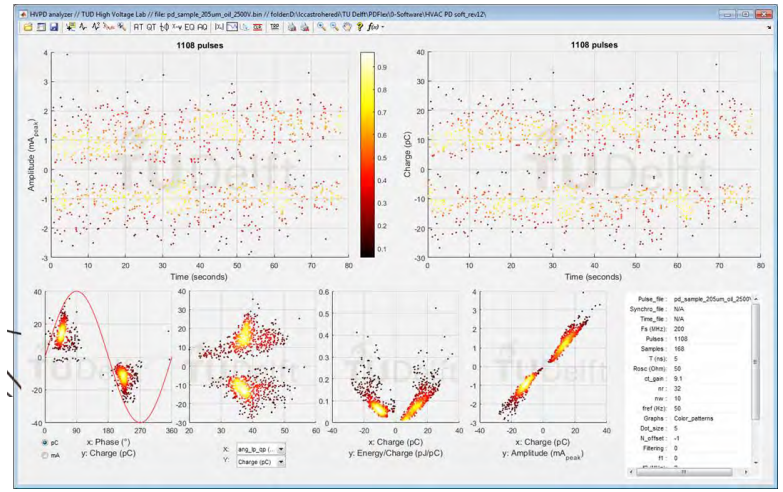
HVDC monitoring and diagnostic methods



- **Fundamental Questions**
  - Type of sensors (HFCT, Antennas)?
  - Correlation AC and DC?
  - Number and where to install sensors?
  - Which other parameters can be monitored?



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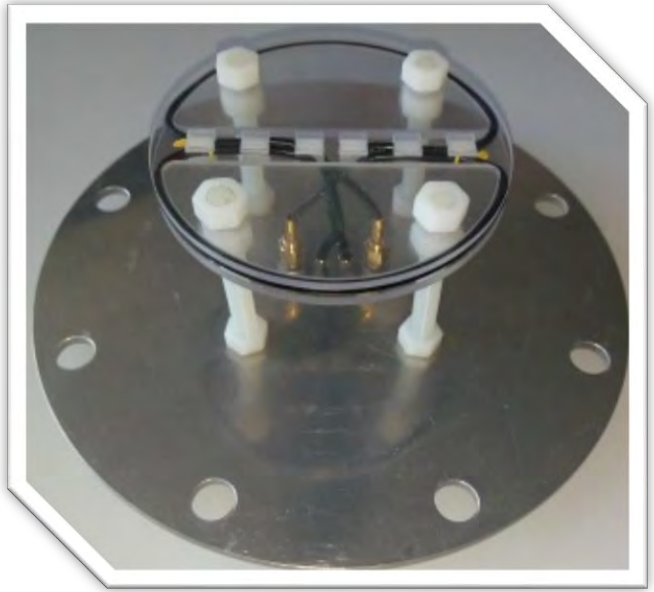
From the HFCT based measuring system to the Magnetic Antenna

D15.5: Report of diagnostic analysis and condition assessment.
This document is the final report of the diagnostic analysis and suitability to assess the condition of DC GIS by partial discharge measurements.

Task	Description	Status
- Processing techniques	Discrimination of PD signals from background noise and external disturbances: Crosswavelet transform technique.	Abstract conference paper submitted (IEEE DEIS)
- Charge estimation	The charge estimation has been studied on small scale test bench and preliminary results have been obtained from actual size GIS.	Journal paper 1: A Novel Antenna for Partial Discharge Measurements in GIS Based on Magnetic Field Detection, ***Sensors***. Journal paper 2: A Magnetic Loop Antenna for Partial Discharge Measurements on GIS, ***Elsevier.***



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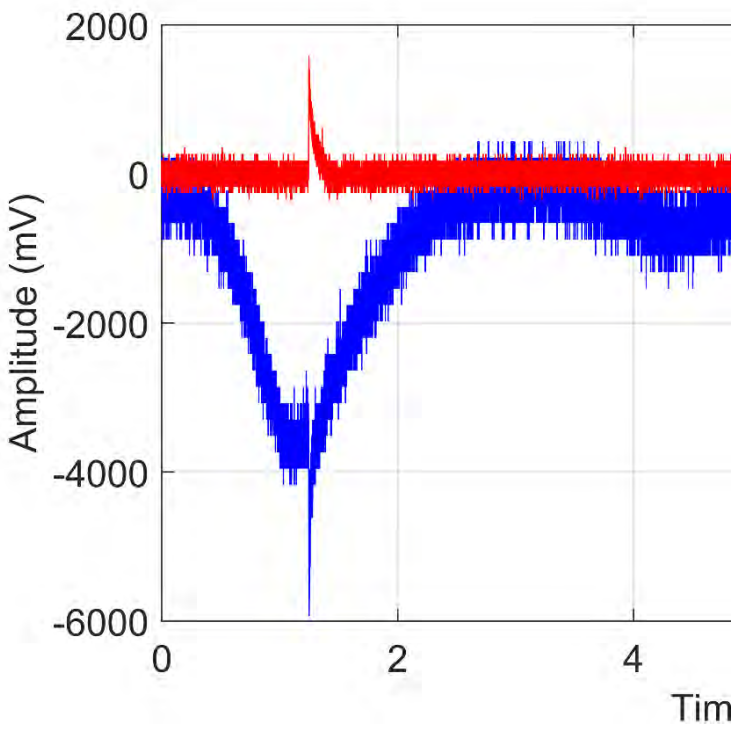
From the HFCT based measuring system to the Magnetic Antenna

D15.5: Report of diagnostic analysis and condition assessment.
This document is the final report of the diagnostic analysis and suitability to assess the condition of DC GIS by partial discharge measurements.

Task	Description	Status
- Localization	Feasibility study of PD source compartment location in GIS	Pending
- Software	Integration of signal post-processing techniques and visualization of data.	All the techniques tested and considered in the development of the project are coded in our software tool PDflex and they will be open to public.



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Subtask WP15.2.4

Mediums	SF_6	$C0_2$	Fluoroketone (FK)	Fluoronitrile (FN)
CAS number	2551-62-4	124-38-9	756-12-7	42532-60-5
Boiling point (°C)	-64	-78.5	26.5	-4.7
GWP	23900	1	<1	2100
Flammability	none	none	none	none
Dielectric strength (relative to SF_6)	1	0.3	≈2	≈2
Toxicity TWA (ppmv)	1000	5000	225	65
Potential insulator	✓	✓	✓	✓
Potential interrupter	✓	✓	✓	✓

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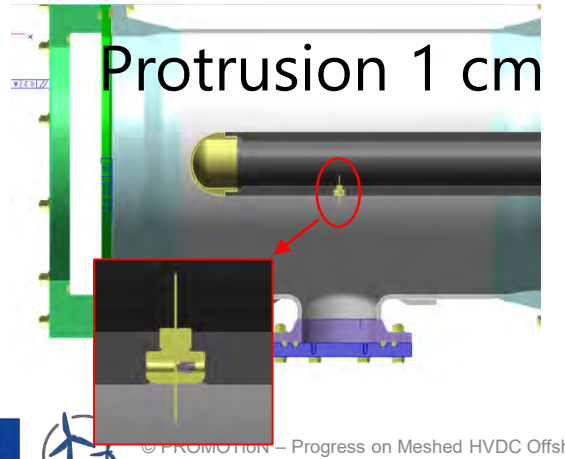
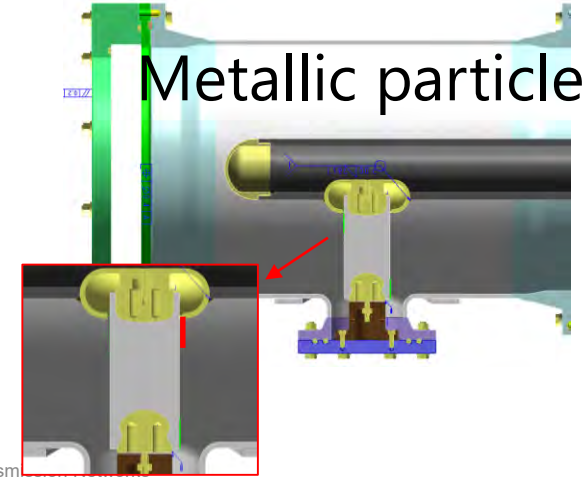
Long term test

- Conventional measuring system
- Non conventional measuring systems:
  - UHF antenna
  - Magnetic sensor (adapted from TUD magnetic sensor)
  - Direct current measurement
- Two defect and three type of filling gas:
  - SF_6 at 5 bar abs
  - 10% Fluoronitrile – CO_2 mixture at 6,5 bar abs
  - 6,6% Fluoroketones –Dry air mixture at 7,5 bar abs





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Long term test

protrusion defect

metallic particle defect

Defect	SF6 equivalent dielectric	Gas	2019										2020																					
			10		11				12				1					2				3				4					5			
			S43	S44	S45	S46	S47	S48	S49	S50	S51	S52	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22
protrusion on HV conductor	5 bar abs	SF6 5 bar abs																																
		10%FN-CO2 6,5 bar abs																																
		FK-Air 7,5 bar abs																																
Metallic particle on solid insulator	5 bar abs	SF6 5 bar abs																																
		10%FN-CO2 6,5 bar abs																																
		FK-Air 7,5 bar abs																																

we are here

1st draft D15.8

final draft D15.8

D15.8

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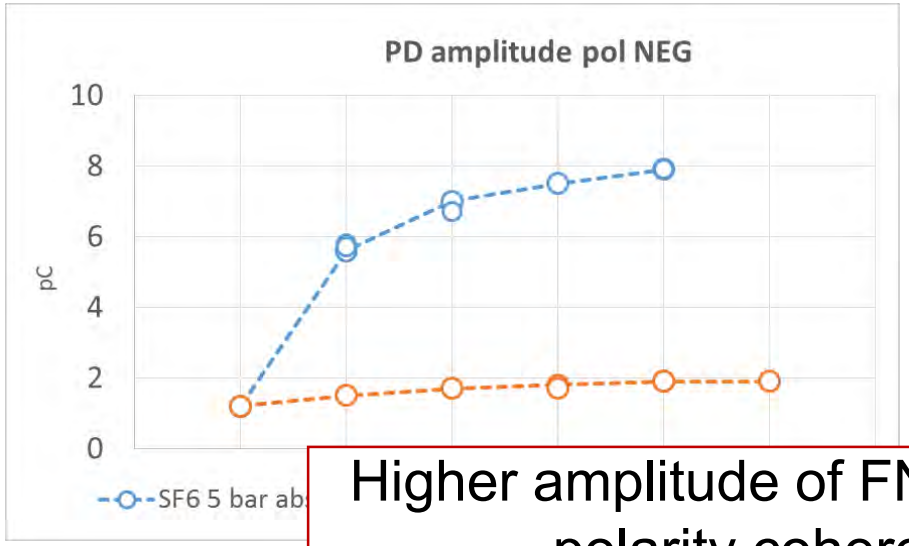
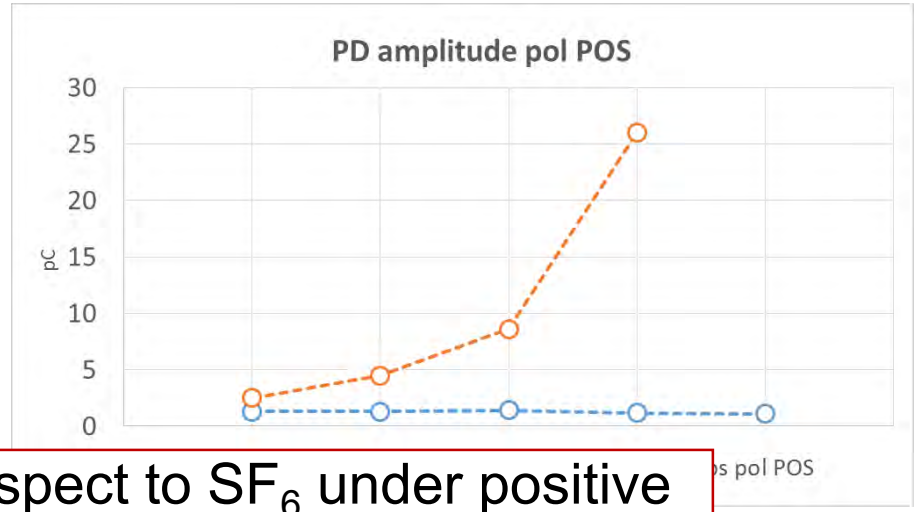
Long term test

DC-



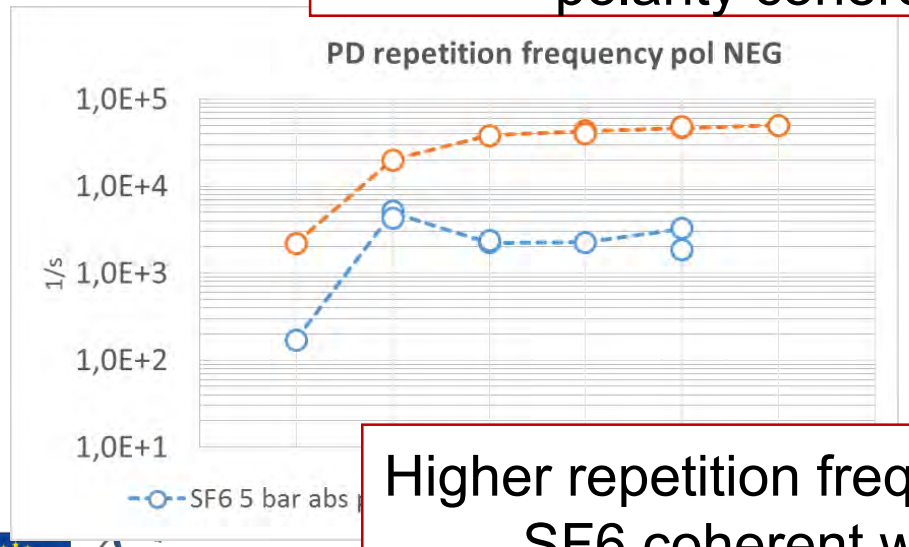
DC+

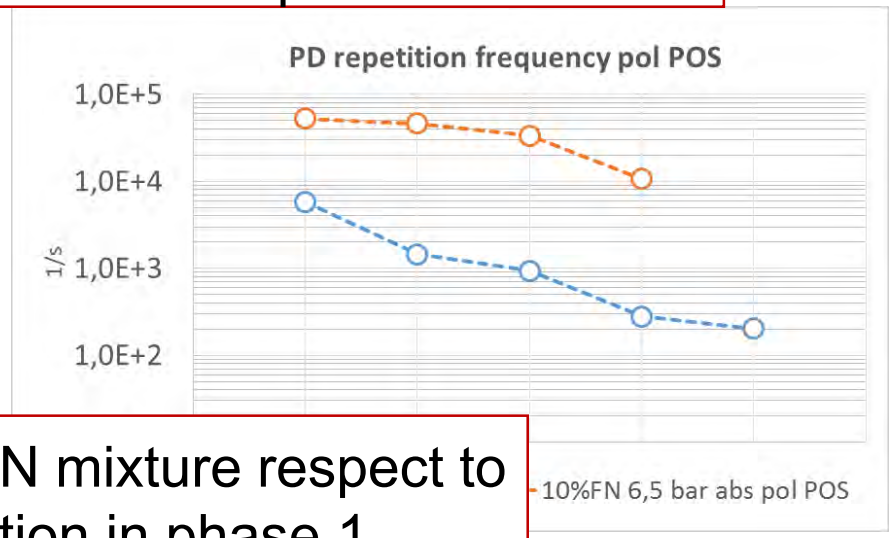


SF_6

$FN\text{-}CO_2$

Higher amplitude of FN mixture respect to SF_6 under positive polarity coherent with observation in phase 1





Higher repetition frequency for FN mixture respect to SF6 coherent with observation in phase 1

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WP15 – HVDC GIS technology demonstrator

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WP11

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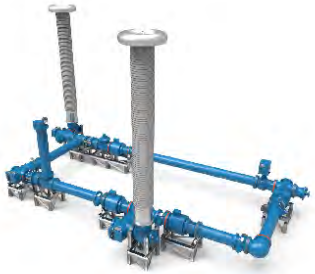
Prototype installation test

- Bus-ducts and high voltage DC conductors
- Disconnect- and earthing switches
- Bushings
- Current- and voltage measurement sensors

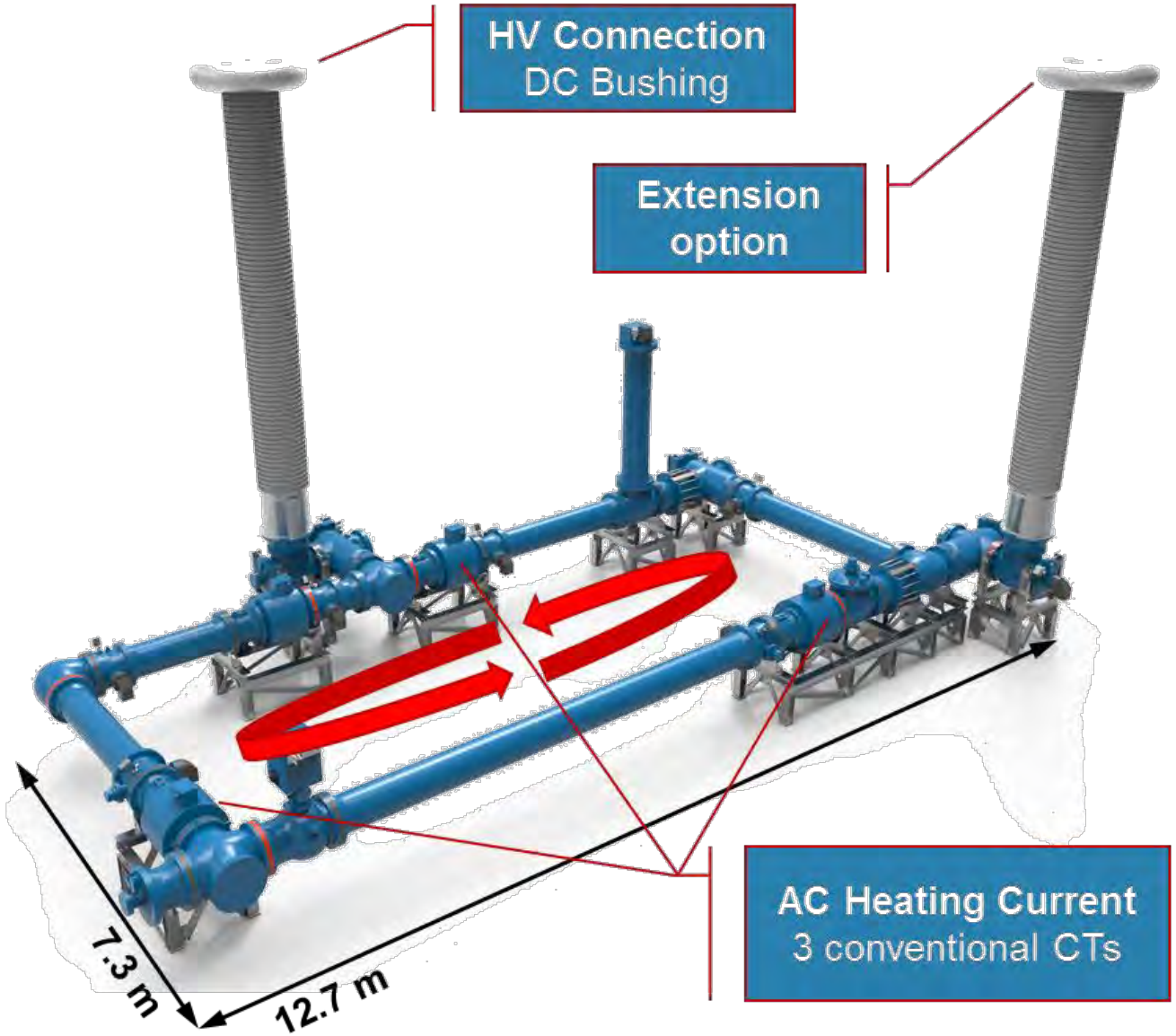
ABB

HIGH VOLTAGE PRODUCTS

HVDC gas-insulated switchgear



Technical data		
Nominal DC voltage	kV	320
Rated DC voltage	kV	350
Rated lightning impulse withstand voltage	kV	1050
Rated switching impulse withstand voltage	kV	950
Rated DC withstand voltage	kV	610
Rated normal current	A	4000
Rated short-time withstand current	kA	64
Rated duration of short circuit	s	1
Rated peak withstand current	kA	160
Ambient temperature range	°C	-30...+40



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Prototype installation test

Pre-Tests	BLOCK 1 60 days -DC ZL SIM LI/SI 10 C/O	2 -DC HL SIM C/O	3 +DC ZL SIM C/O	4 +DC HL SIM C/O	AC PD	5 -DC HL SIM C/O	BLOCK 6 60 days +DC HL SIM LI/SI 10 C/O	BLOCK 7 30 days LC (+ and -) SIM LI/SI	add. Tests

Jan. 2019 — 14 month — April. 2020

Monitoring
Gas density
PD: UHF/Optical/HFCT
Arc Detection
Enclosure Temperature

ZL = zero load (zero heating)
HL = high load (continuous heating)
LC = load cycle
SIM = Superimposed switching and lighting impulse voltage test
ACPD = AC partial discharge measurement at U_{ac}

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Status

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Prototype installation test

Pre-Tests	BLOCK 1 60 days -DC ZL SIM LI/SI 10 C/O	2 -DC HL SIM C/O	3 +DC ZL SIM C/O	4 +DC HL SIM C/O	AC PD	5 -DC HL SIM C/O	BLOCK 6 60 days +DC HL SIM LI/SI 10 C/O	BLOCK 7 30 days LC (+ and -) SIM LI/SI	add. Tests

Jan. 2019 — 14 month — April. 2020

Monitoring
Gas density
PD: UHF/Optical/HFCT
Arc Detection
Enclosure Temperature

ZL = zero load (zero heating)
HL = high load (continuous heating)
LC = load cycle
SIM = Superimposed switching and lighting impulse voltage test
ACPD = AC partial discharge measurement at U_{ac}

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Additional Tests

- Additional tests
  - Testing across the disconnectors
  - PD measurements with real defects
  - Artificial defects from TU Delft

- Extra cost till 2019 expected 124 kEUR

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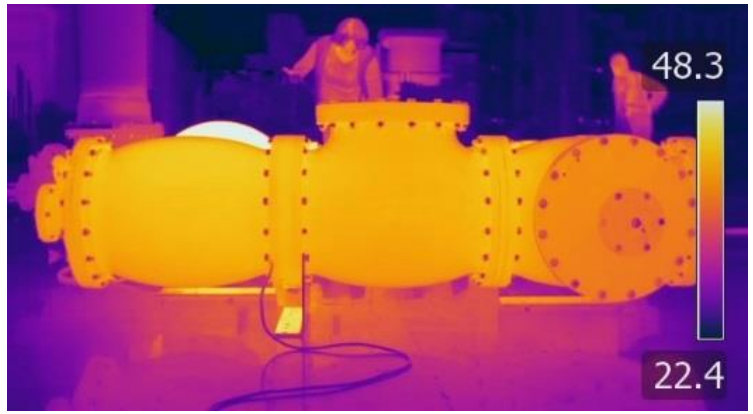
Additional Tests (NON – SF6)



DC INSULATION SYSTEM TEST

Test	Conditions	Load	
Pre-tests	Heating Dielectric Pretests		
Long duration continuous DC voltage test	**Maximum continuous operating DC voltage (-)**	**HL**	**Time duration d**
Superimposed LIWV tests (bipolar and unipolar superposition) Superimposed SIWV tests (bipolar and unipolar superposition)	Rated values	HL	
Polarity reversal		HL	
Long duration continuous DC voltage test	**Maximum continuous operating DC voltage (+)**	**HL**	**Time duration d**
Superimposed LIWV tests (bipolar and unipolar superposition) Superimposed SIWV tests (bipolar and unipolar superposition)	Rated values	HL	

JWG D1/B3.57: Dielectric Testing of Gas-Insulated HVDC Systems

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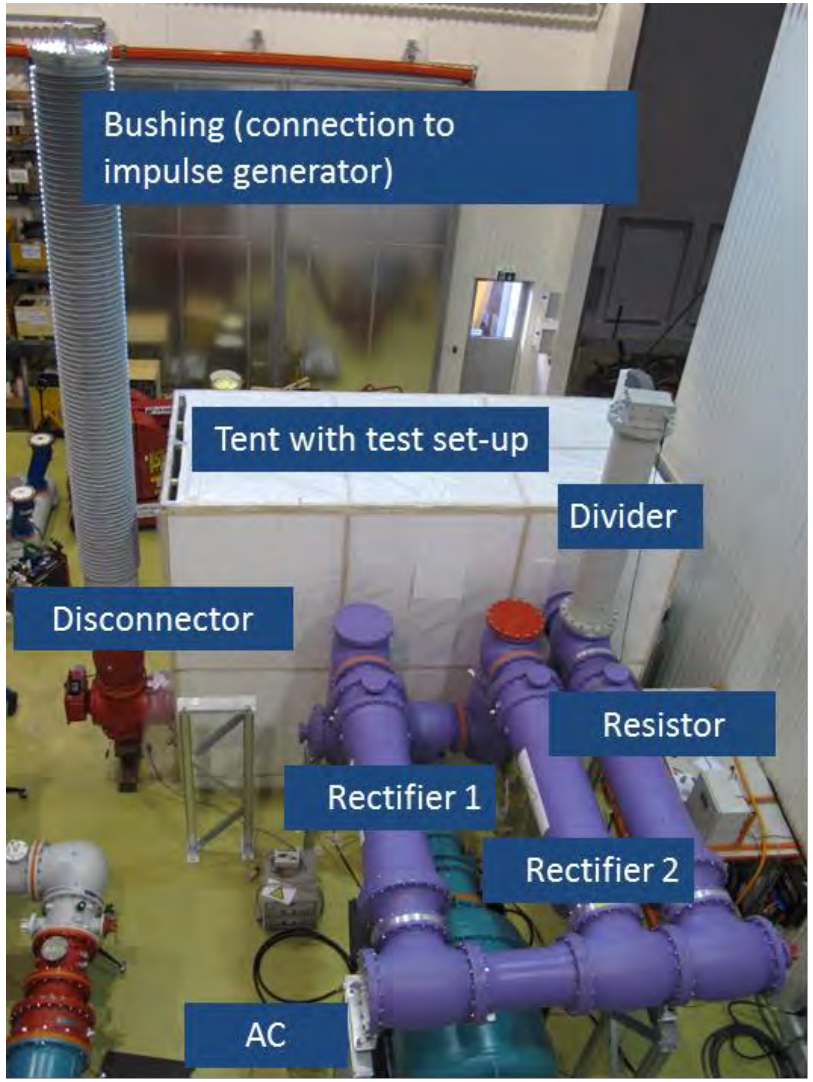
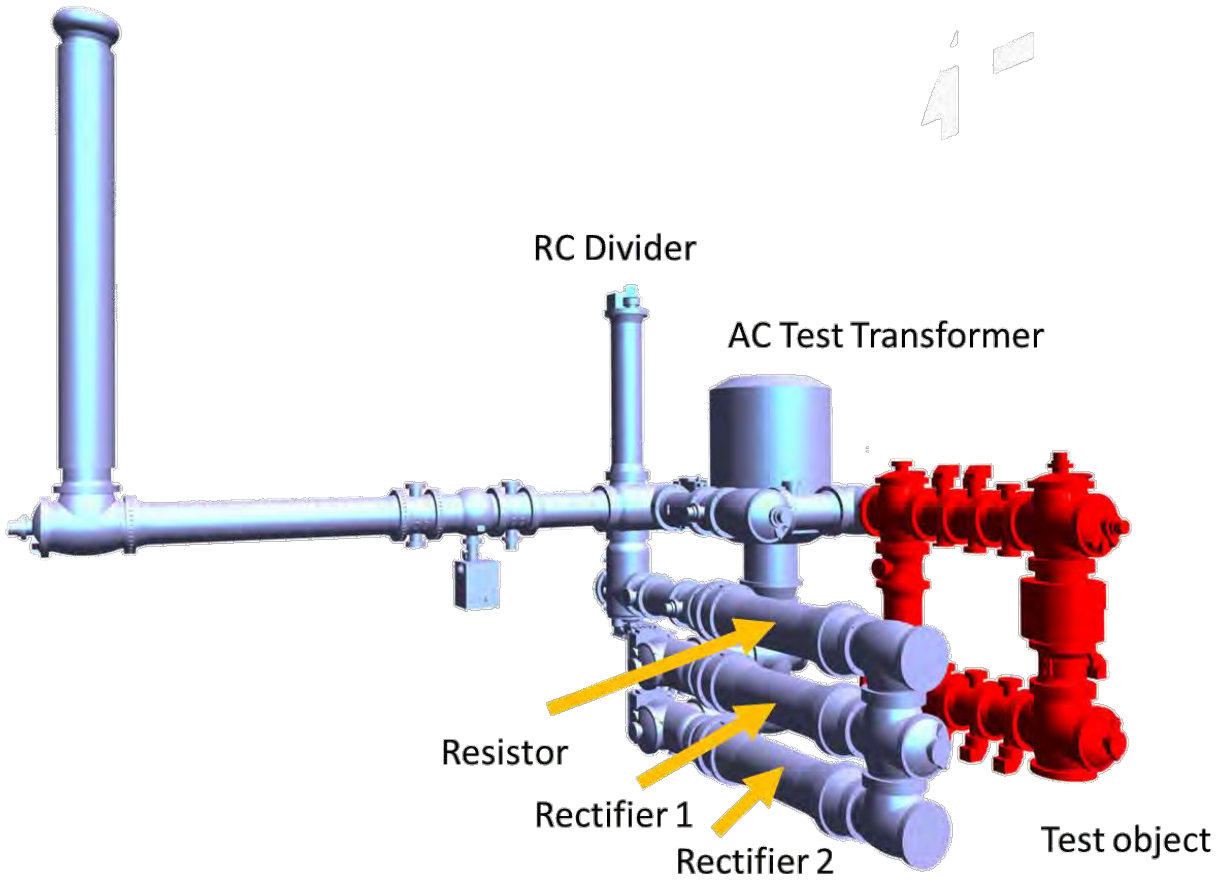
Additional Tests (NON – SF6)





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Additional Tests (NON – SF6)

Test	Conditions	Load	
Pre-tests	Heating Dielectric Pretests		
	m continuou g DC voltage		
unipolar superposition) Superimposed SIWV tests (bipolar and unipolar superposition)	Rated values	HL	
Polarity reversal		HL	
Long duration continuous DC voltage	Maximum continuous g DC voltage		Time
Superimposed SIWV tests (bipolar and unipolar superposition)	alues		

U = 320/350 kV

d ≥ 30 days

U = 320/350 kV

d ≥ 30 days

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Task Structure

WP15 – HVDC GIS technology demonstrator

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WP11

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Publications / Demonstrations

- HVDC GIS and HHB demonstration, 27th February, Arnhem
- CIGRE Session 2020: 2 paper, see ProjectPlace
- Demo –HVDC GIS, Final tests, 2020

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Standardization – WP11

- Integration/addition of DC specific standardization into existing AC GIS standardization - Results from IEC SC 17 C – AHG37:
  - It is recommended to establish a new DC GIS standard
    → **IEC 62271-317 DC GIS "DC gas-insulated switchgear assemblies"**
    - First NWIP draft rejected due to lack of participation, second proposal with more participation
    - Start expected 2020, Uwe Riechert possible convener
  - It is recommended to establish a new DC GIL standard
    → **IEC 62271-3XX DC GIL** - start later
  - It is recommended to establish a new DC Common Specification standard
    → **IEC 62271-5 DC Common Specification for direct current switchgear**
    - This document shall cover all requirements which are common to DC GIS and DC GIL as well as air insulated DC switchgear
    - start 2020
    - Convener Motoharu Shiiki (Toshiba)
- Parallel DC GIS standardization activities
  - CIGRE SC B3 / B1: proposal for the creation of a new working group "Recommendations for dielectric testing of HVDC gas insulated system cable sealing ends"
    - Cees Plet will be convenor
    - Planned start Jan 2020, final report 2021
    - Further members wanted

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Any Questions?

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

WP2

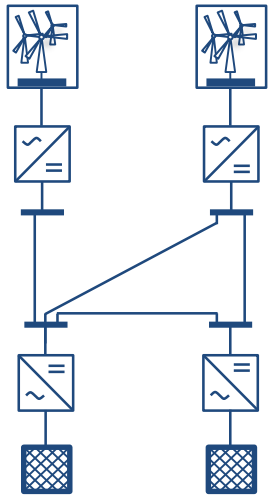
Grid Topology & Converters

RWTH Aachen University ● Christina Brantl

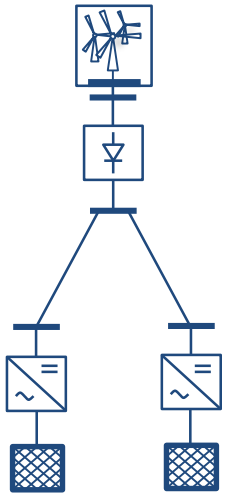
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Objectives

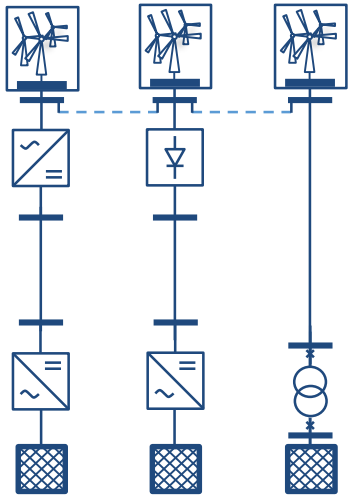
Trade-off analysis of different topologies



Interconnection of VSC and DRC systems



Control concepts to ensure interoperability



To define recommendations on onshore and offshore power systems for existing grid codes

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

Partners - Start

SIEMENS

ABB

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

RWTH AACHEN UNIVERSITY

DNV·GL

University of Strathclyde Glasgow

TRACTEBEL Engineering GDF SUEZ

ALSTOM

DTU Technical University of Denmark

FGH

PRYSMIAN CABLES & SYSTEMS

IBERDROLA

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

Partners - End

SIEMENS

ABB

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

RWTH AACHEN UNIVERSITY

DNV·GL

University of Strathclyde Glasgow

TRACTEBEL

PRYSMIAN CABLES & SYSTEMS

DTU Technical University of Denmark

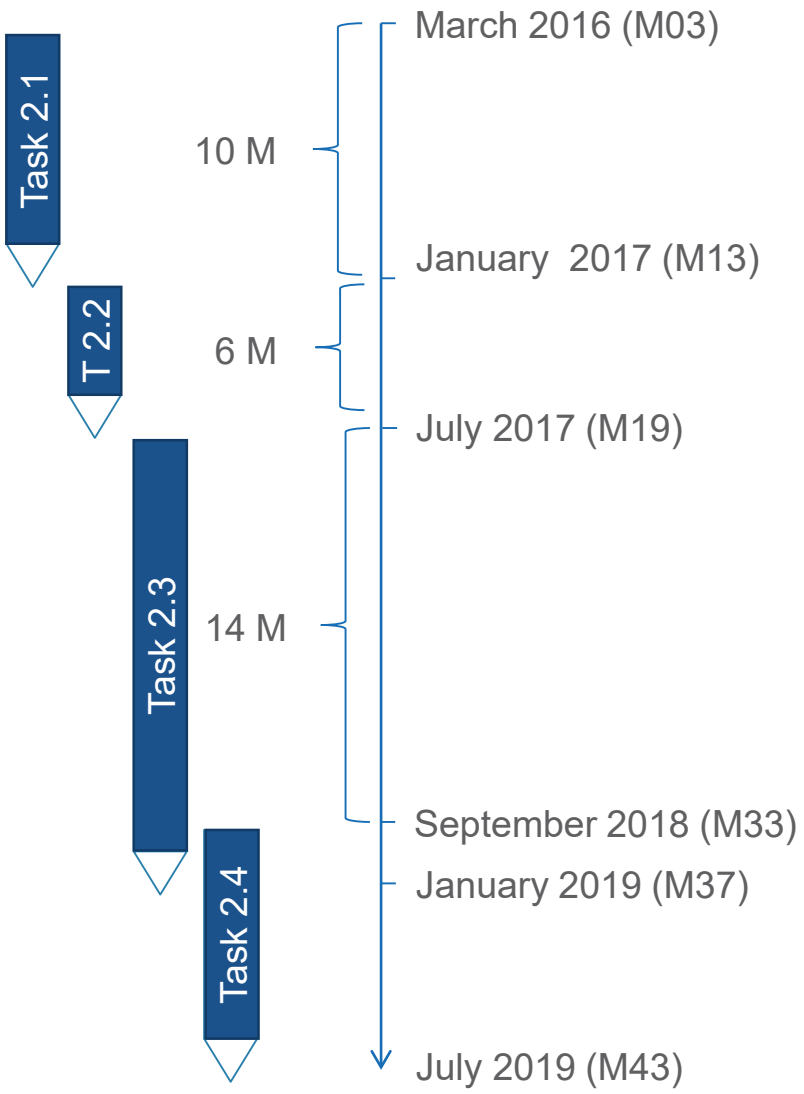
FGH

IBERDROLA

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

Original Timeline

- Divided into four tasks:
  1. Definition of model parameters, control objectives and operational assumptions for the meshed HVDC offshore topologies
     - D 2.1: Grid topology and model specification
  2. Adaption of simulation models for the meshed HVDC offshore topologies
     - D 2.2: Scenario and test case specification
  3. Simulative investigation and functionality demonstration of the meshed HVDC offshore topology system interoperability
     - D 2.3: Simulation results and benchmark
  4. Define recommendations for minimum requirements on onshore and offshore power systems
     - D 2.4: Requirements for grid code extension



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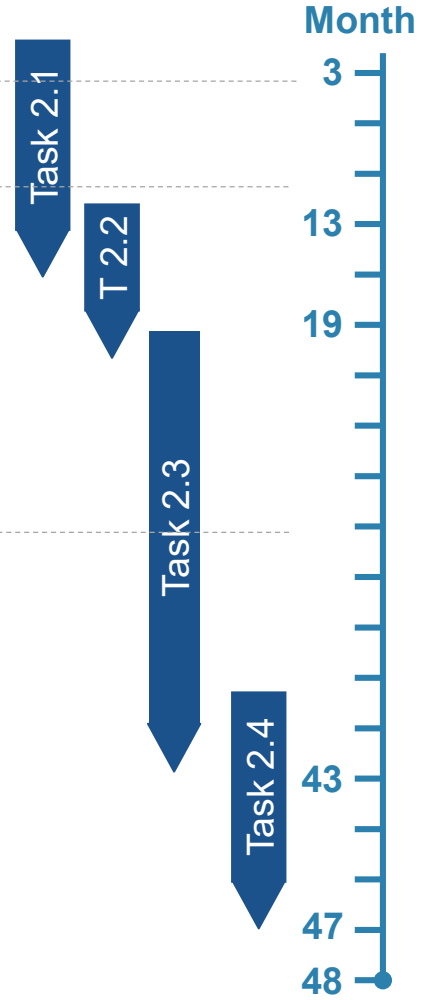
Final Timeline

First discussions on grid topologies

Siemens NoGo decision

WP16 confirmation



Task 2.1

- Definition of model parameters, control objectives and operational assumptions for the meshed HVDC offshore topologies

Task 2.2

- Adaption of simulation models for the meshed HVDC offshore topologies

Task 2.3

- Simulative investigation and functionality demonstration of the meshed HVDC offshore topology system interoperability

Task 2.4

- Define recommendations for minimum requirements on onshore and offshore power systems

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Task 2.1 Grid topology and model specification

1. Analysis of existing and planned systems

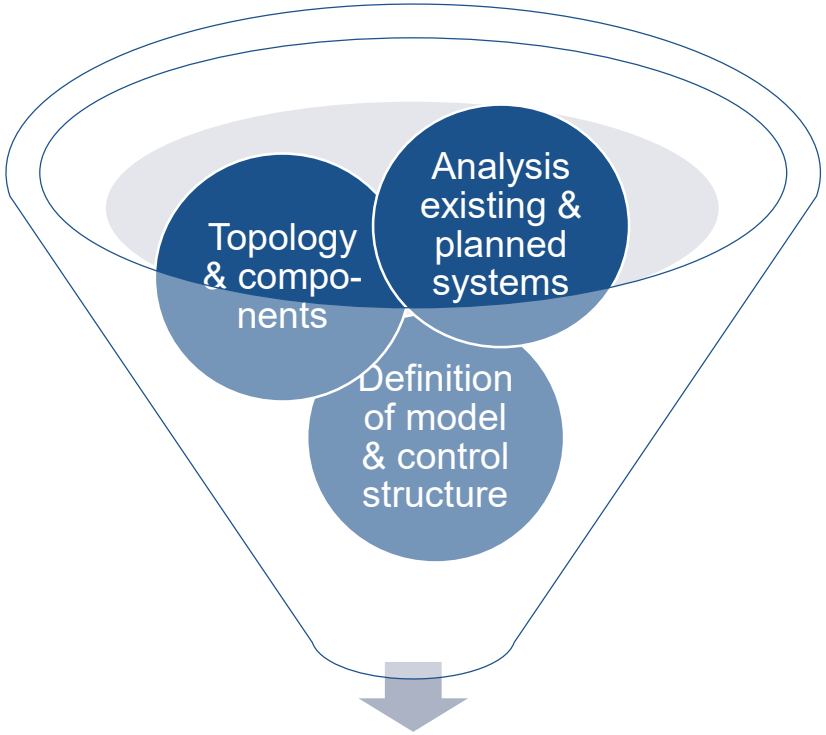
- Input from WP 1 (D1.3)
- Ten Year Network Development Plan (TYNDP)
- Cigré compendium of all HVDC projects

2. Deduction of topology and component specifications

- Comparison of different topologies
- Representation of different technologies

3. Definition of model and control structure

- Based on Cigré definitions
- Different simulation time frames and scopes
- Modelling expertise of beneficiaries



Deliverable 2.1

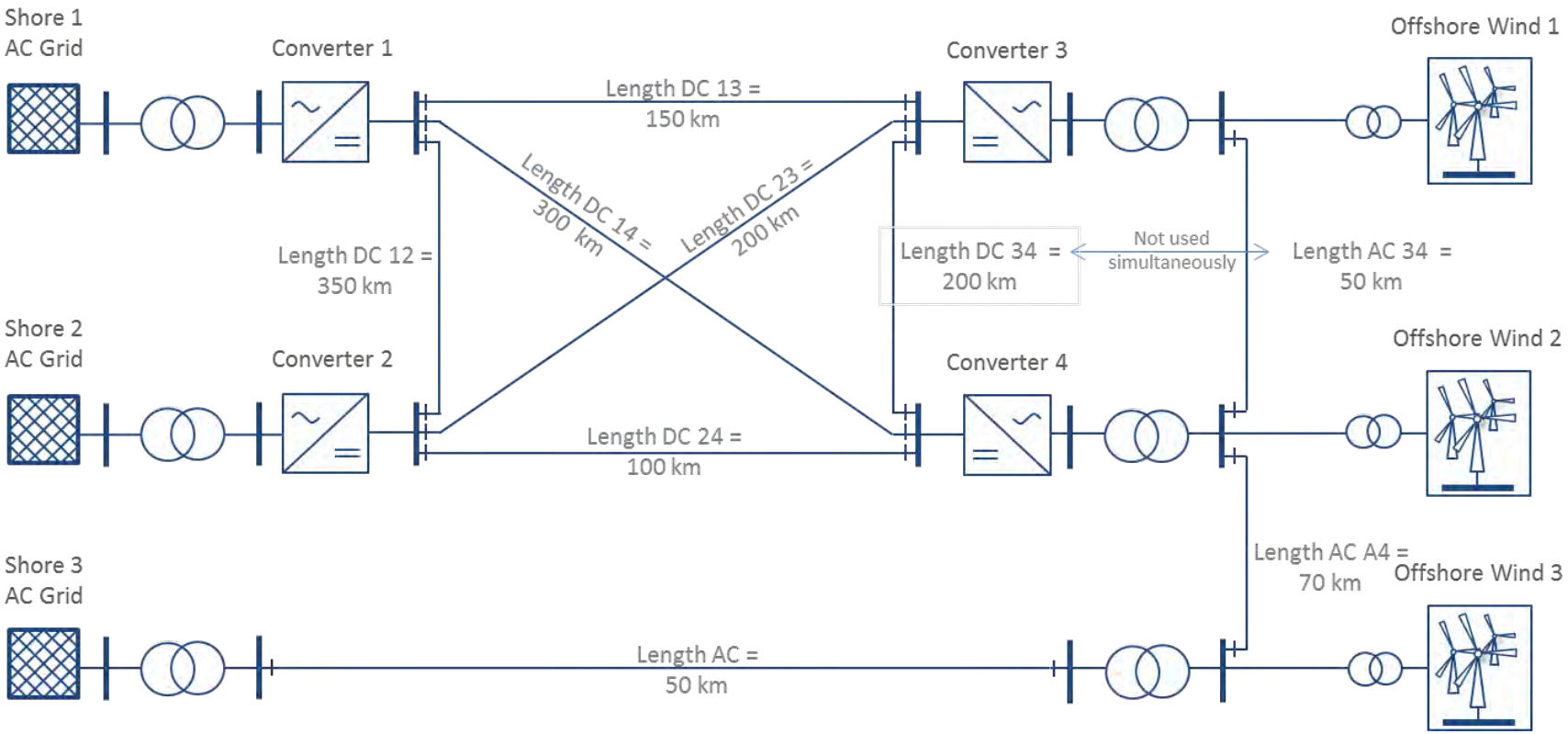
List of grid topology and model specifications

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

Idea: One topology for the investigations of different converter types and studies

Main parameters

- Symmetric monopole
- U_{DC} = 640 kV
- P = 1200 MW



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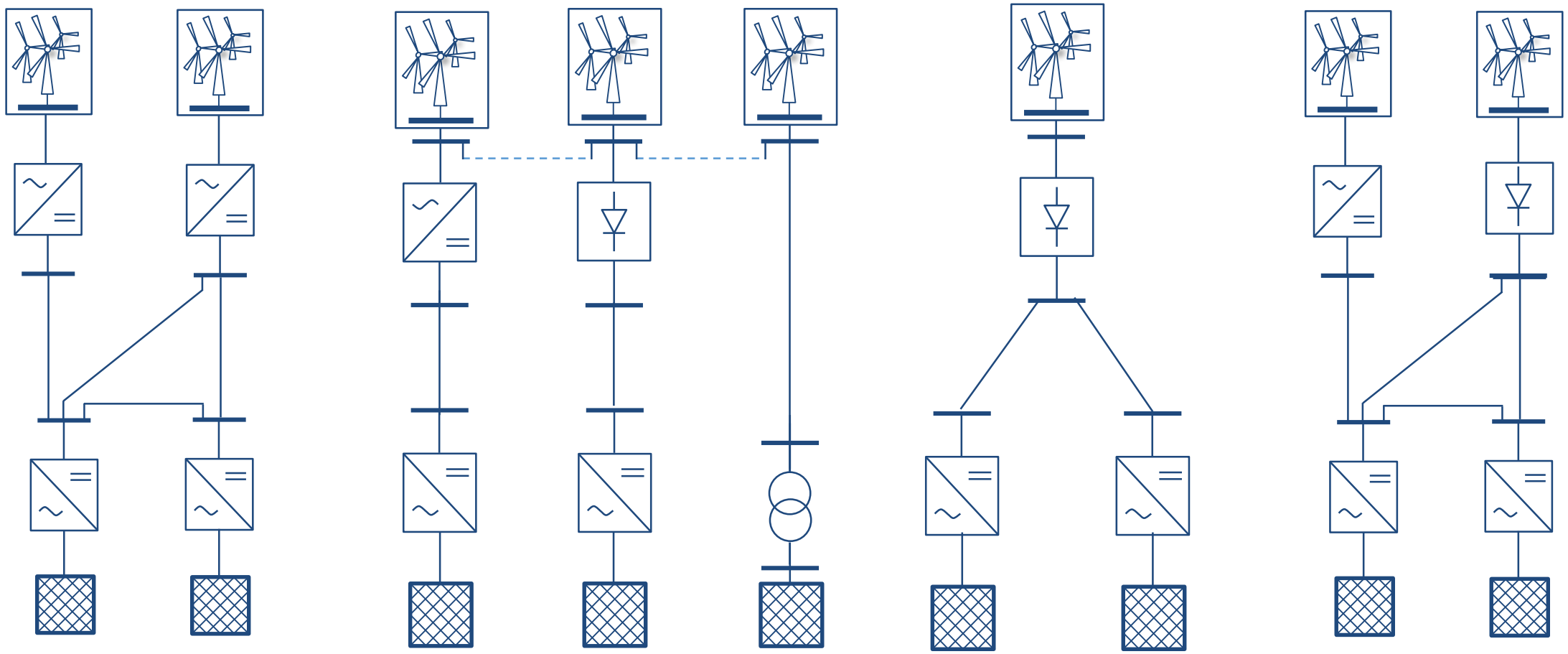
Different topologies for different converter types



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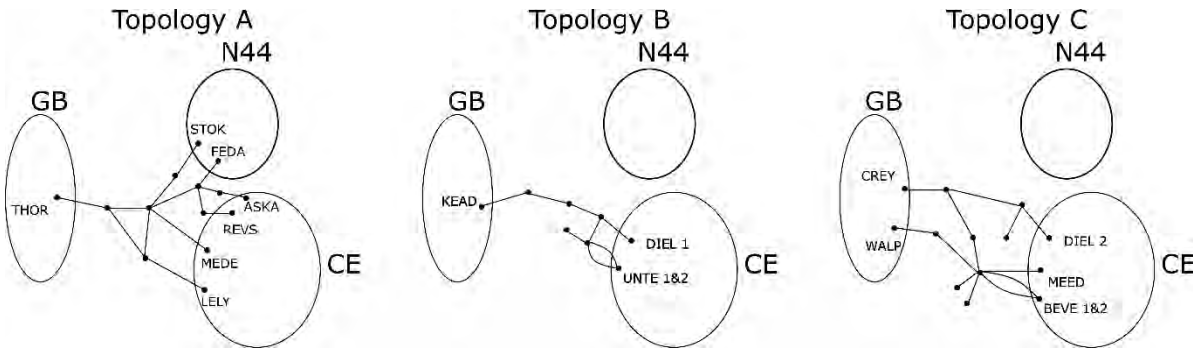
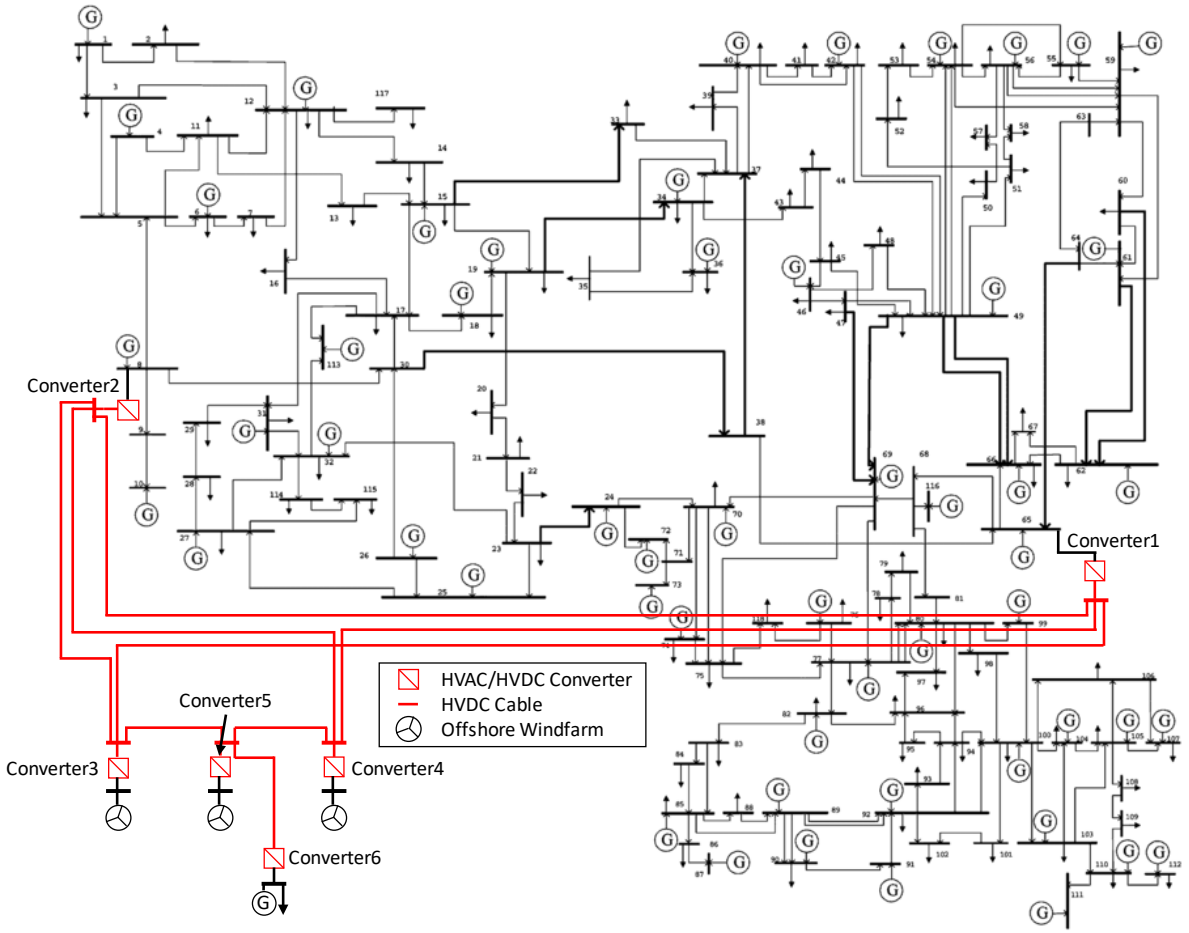
Different topologies for different system studies





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

Task 2.2 Implementation of converter and network models

EMT Models in PSCAD

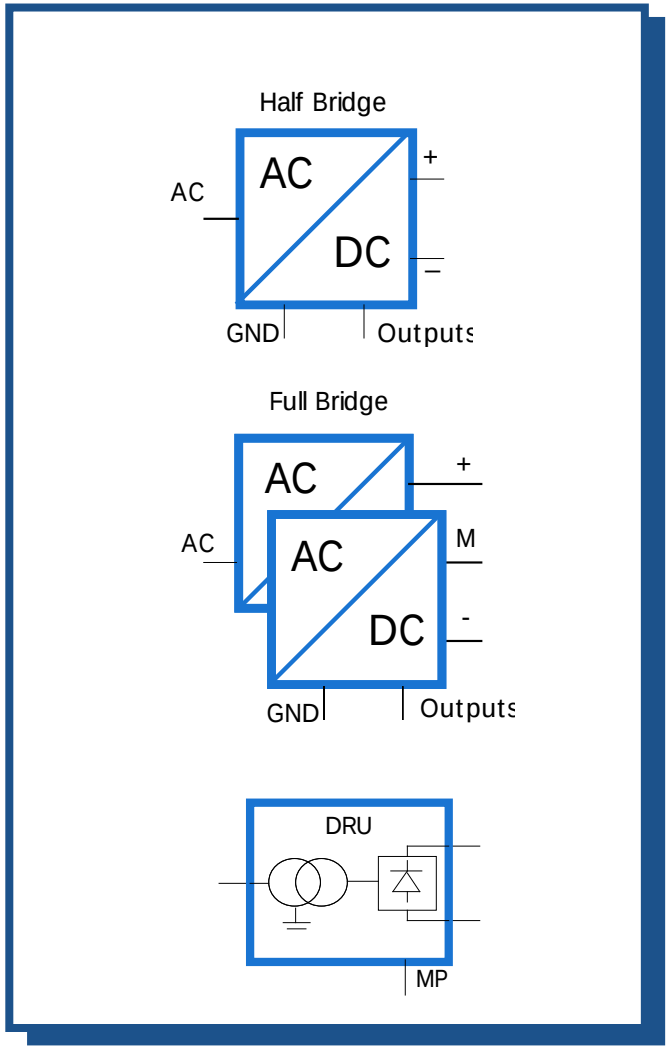
- Mainly for AC and DC fault studies
- Variety of converter types and configurations
- Suitable for system studies according to vendors' check
- Benchmark for other models

RMS Models

- In Eurostag, MatPat and Siemens internally
- Interaction of the DC and the AC grid
- Focus: Frequency support

Quasi-stationary in Integral

- Investigation of operational strategies
- Mainly basis for WP12 studies



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Task 2.3: Simulative investigation and functionality demonstration of the meshed HVDC offshore topology

Grant Agreement description

a) Steady-state analysis
b) Investigation on operational strategies
c) Offshore DC grid operation
d) RMS dynamic analysis
e) Transient fault analysis
f) Transient analysis during AC and DC faults
g) FRT, fault handling
h) Performance evaluation during AC and DC faults
i) Combination of HVDC VSC and DRC solution
j) Simulations on combined AC-DC systems

- D2.3: Report on the simulation results (confidential)
- Considering 7 topologies for the different aspects
- Variety of test cases

➢ Extensive document > 250 pages

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

Publication of content of confidential deliverable via papers

DRU

- DC voltage control in off-shore wind farms with distributed diode rectifier units
- Hybrid Full Bridge-Half Bridge MML Power Converter for HVDC Diode Rectifier Connection of Large Off-Shore Wind Farms
- Hierarchical control of offshore wind farm connected by parallel diode-rectifier based HVDC and HVAC links
- Offshore AC Fault Protection of Diode Rectifier Unit-Based HVdc System for Wind Energy Transmission
- Coordinated Control of Parallel Connected DR-HVDC and MMC-HVDC Systems for Offshore Wind Energy Transmission
- Interoperability Assessment of MMC and DRU based offshore windfarms in meshed multi-terminal DC grids

Frequency support

- Droop-Based Frequency Support from Offshore HVDC Grids
- Primary Frequency Support from Offshore Wind Power Plants Connected to HVDC Grids
- On Feasibility of Autonomous Frequency-Support Provision from Offshore HVDC Grids

AC & DC fault studies

- A Novel DC Fault Blocking Concept for Full-Bridge Based MMC Systems with Uninterrupted Reactive Power Supply to the AC Grid
- Impact of the HVDC system configuration on DC line protection
- Post-Fault Recovery for Multiterminal HVDC Networks based on Fault Blocking Converters
- Fault current control methods for multiterminal DC systems based on fault blocking converters
- Control of Offshore AC Collection Network of HVDC Connected Wind Farms during Asymmetric Offshore AC Faults
- DC Fault Control and High-Speed Switch Design for an HVDC Networks Protection Based on Fault Blocking Converters
- Impact factors on the power flow recovery in multi-terminal HVDC systems after fault clearance

To be continued…

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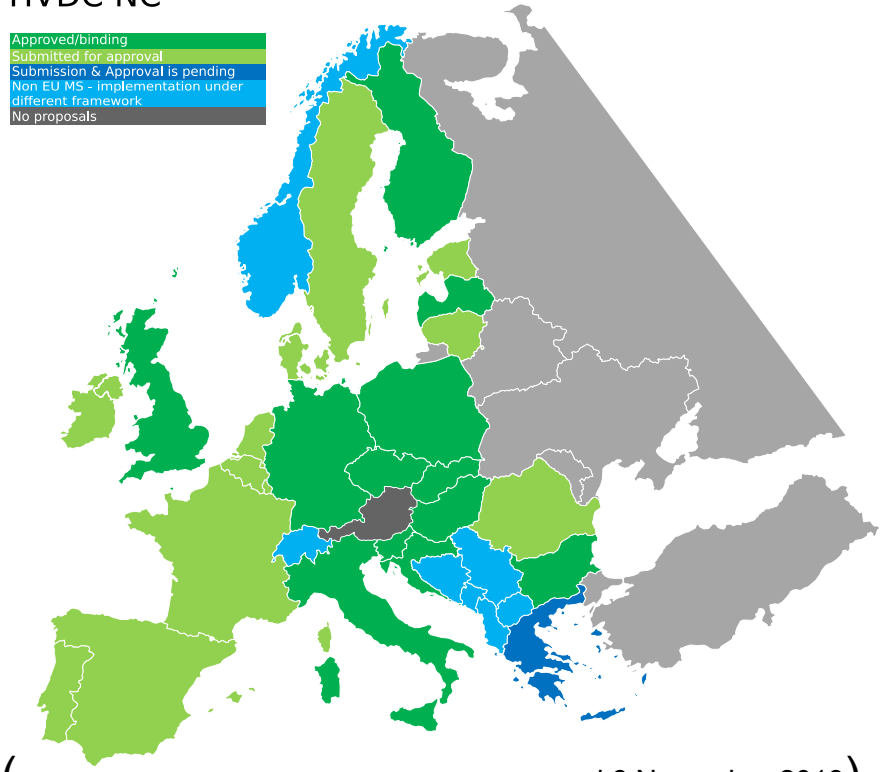
Task 2.4 Define recommendations for minimum requirements on onshore and offshore power systems

Basis

- ENTSO-E / EC network codes
- Selected national implementations of grid codes
- ENTSO-E NC gives a broad range of values, several requirements are left open to be specified by the TSO
- Not intended for multi-terminal HVDC systems

HVDC NC



(https://docs.entsoe.eu/cnc-al/#implementation-maps, accessed 6 November 2019)

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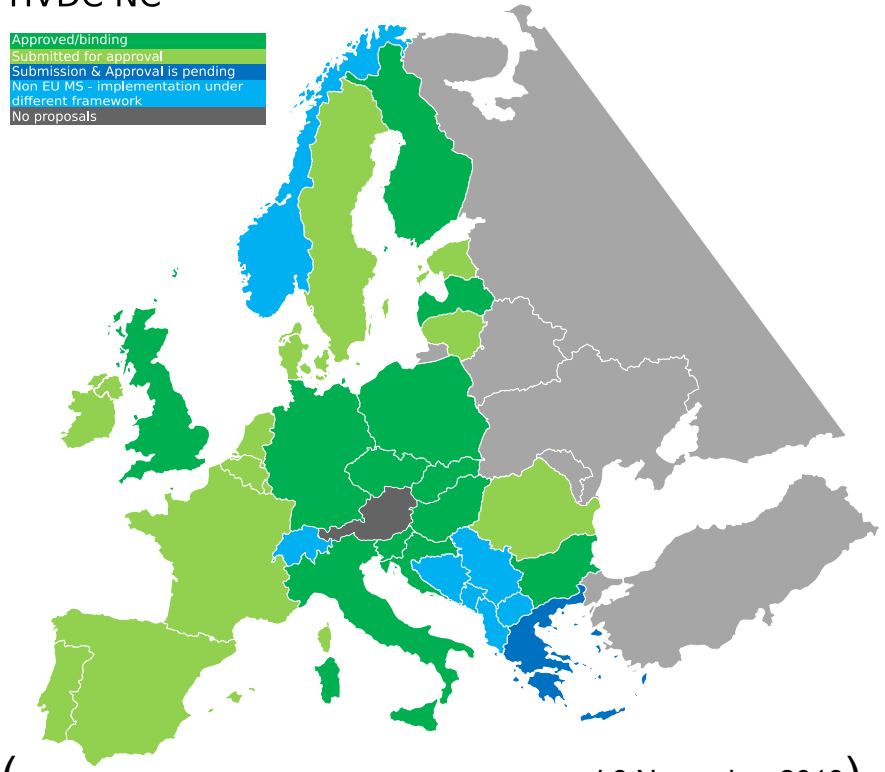
Task 2.4 Define recommendations for minimum requirements on onshore and offshore power systems

National implementations

- Some aspects are specified in a similar fashion, e.g. AC FRT levels and the requirement of reactive power support
- Some aspects are specified with different timings, e.g. fast fault current contribution
- Some requirements are imposed for some countries for others not (inertia provision)
- Some national implementations exhibit more detailed requirements than others
- Some implementations specify requirements on the converter, some on the system

➢Alignment still needed on the AC side

HVDC NC



(https://docs.entsoe.eu/cnc-al/#implementation-maps, accessed 6 November 2019)

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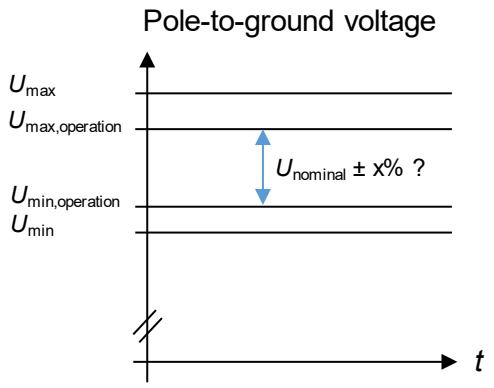
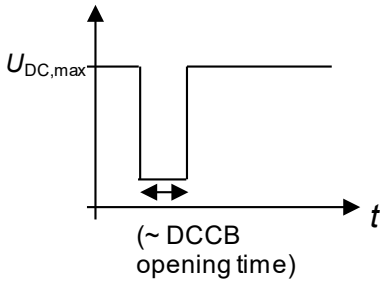
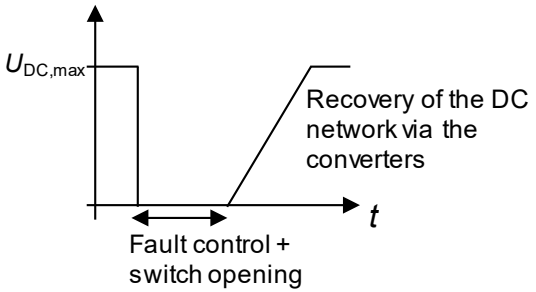
Task 2.4 Define recommendations for minimum requirements on onshore and offshore power systems

DC side recommendations

- DC voltage levels → Agreement should be achieved on voltage levels
- DC FRT → Not possible to specify without a dedicated
- General comment from TSOs: The requirements should be specified at the connection point







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Thank you for your attention!

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

WP3

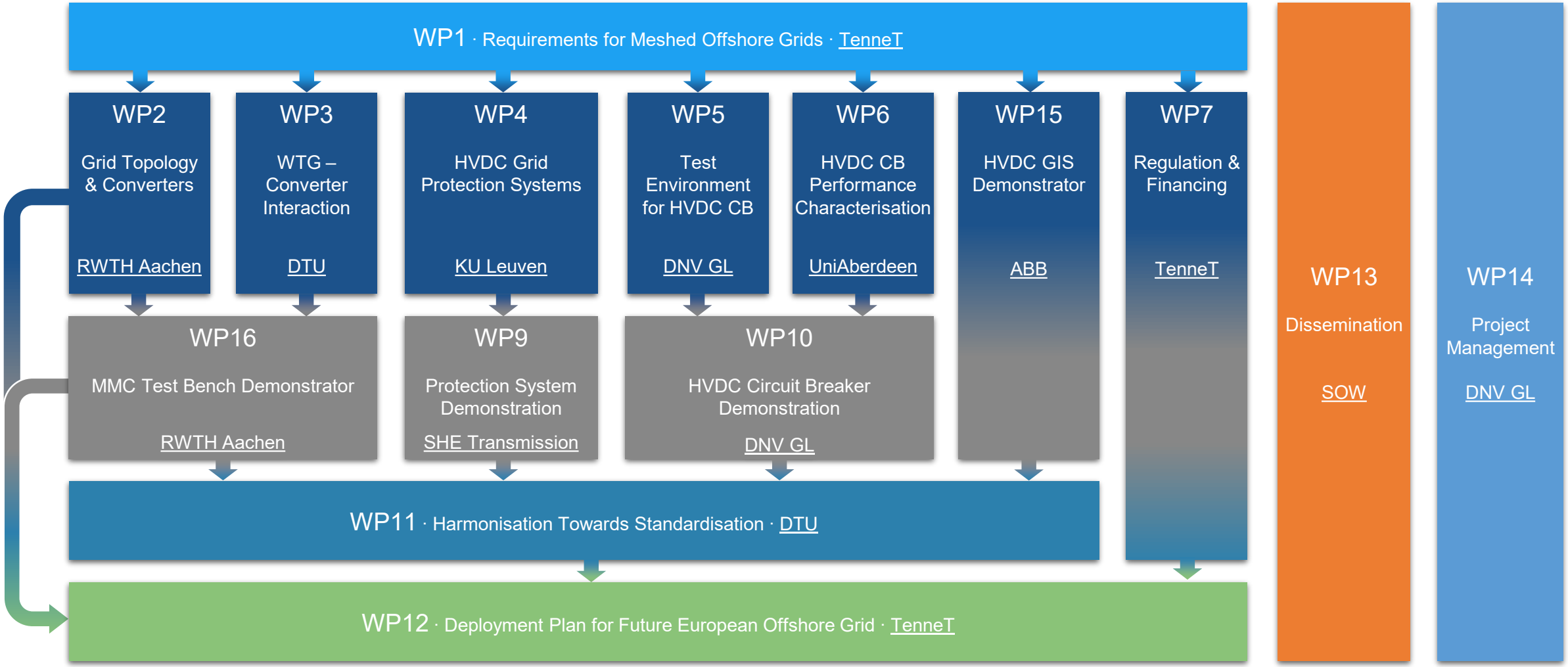
Wind Turbine Generator – Converter Interaction

DTU ● Nicolaos A. Cutululis

3 December 2019, Roskilde, Denmark

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

Work Packages



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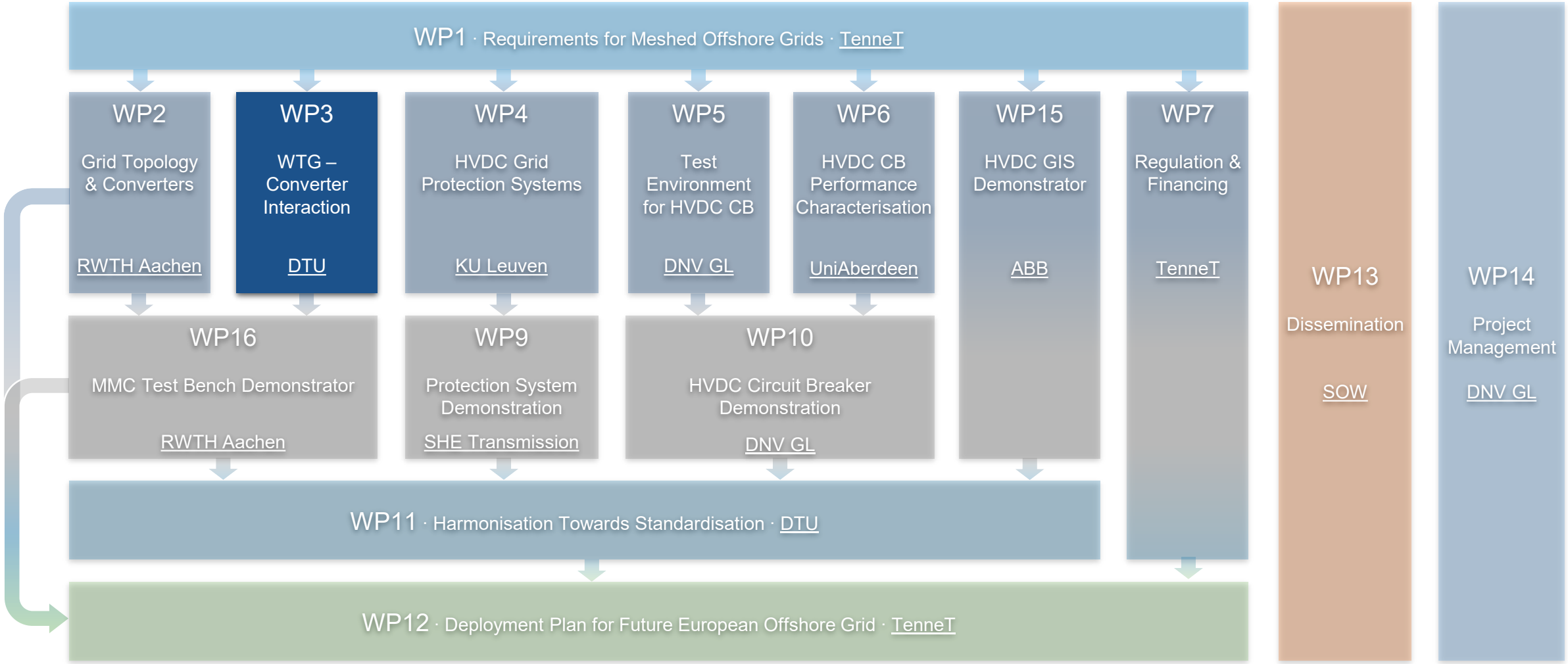
Work Packages



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

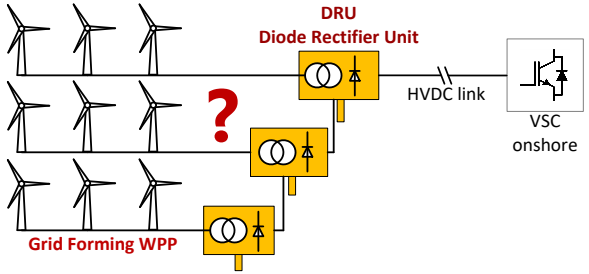
Objectives

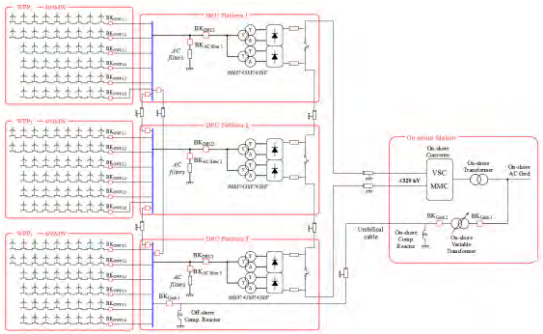
Objective 1
Define functional requirements to OWFs

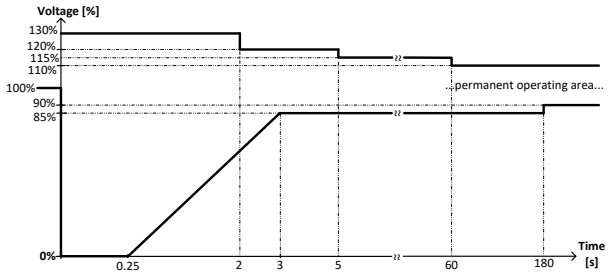
Objective 2
Develop test cases & control algorithms

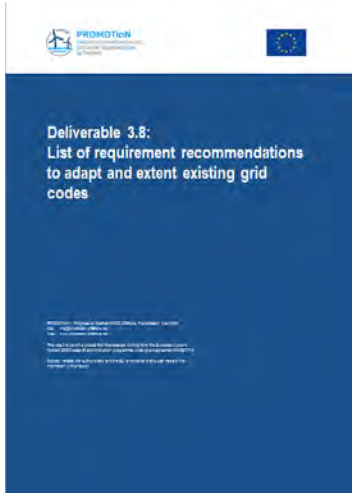
Objective 3
Define & apply compliance evaluation

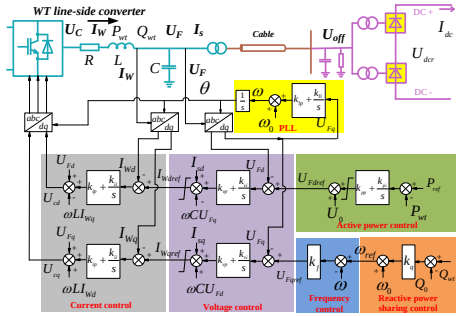
Objective 4
Recommend grid code requirements

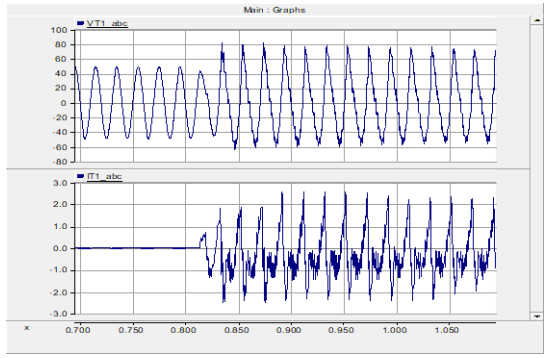












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WP3 Partners

DTU
Technical University of Denmark

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

MHI VESTAS OFFSHORE WIND

University of Strathclyde

RWTH AACHEN UNIVERSITY

FGH

DNV·GL

ENERGINET

Ørsted

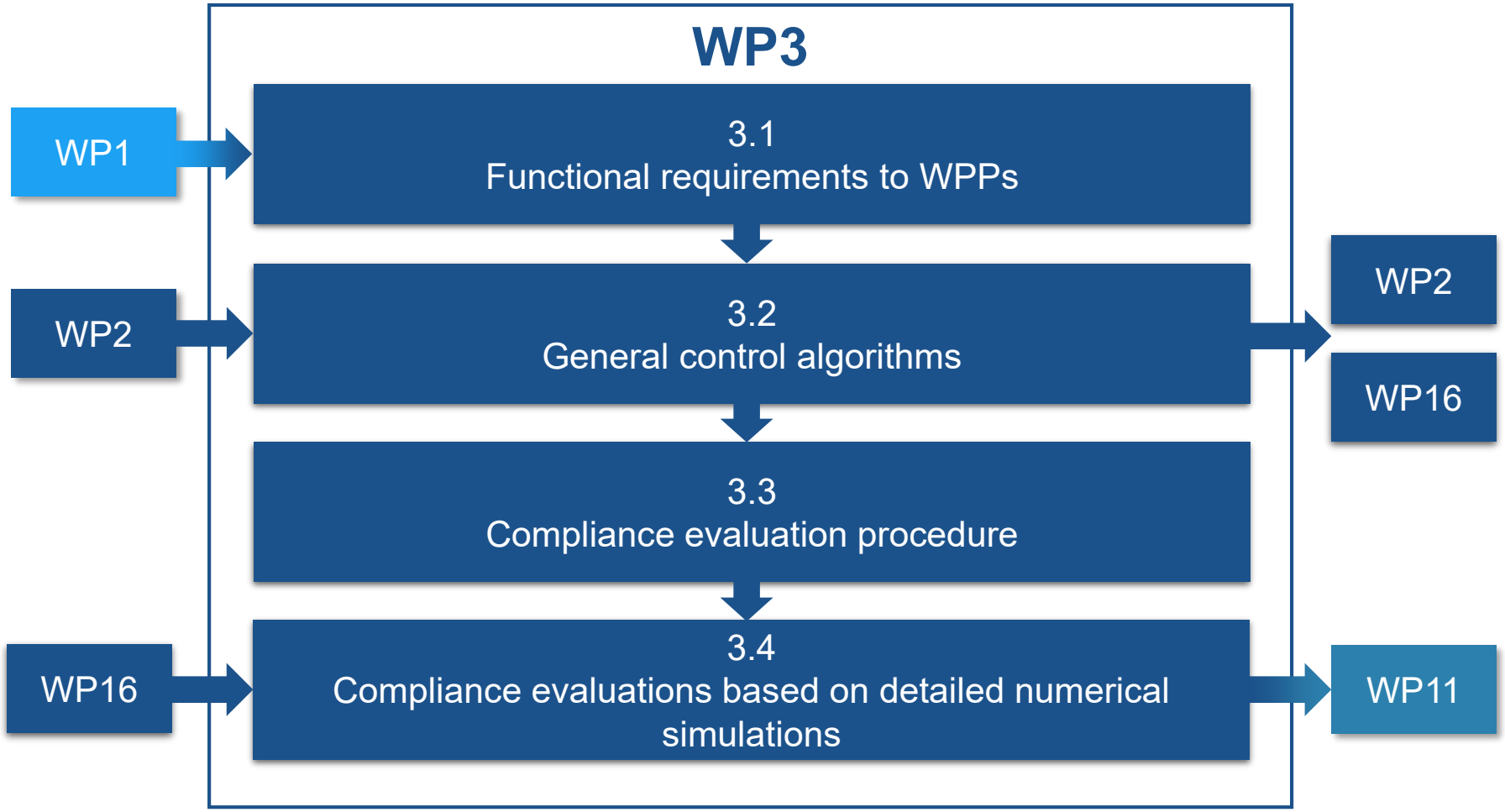
ABB

SIEMENS

equinor

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

Task Structure



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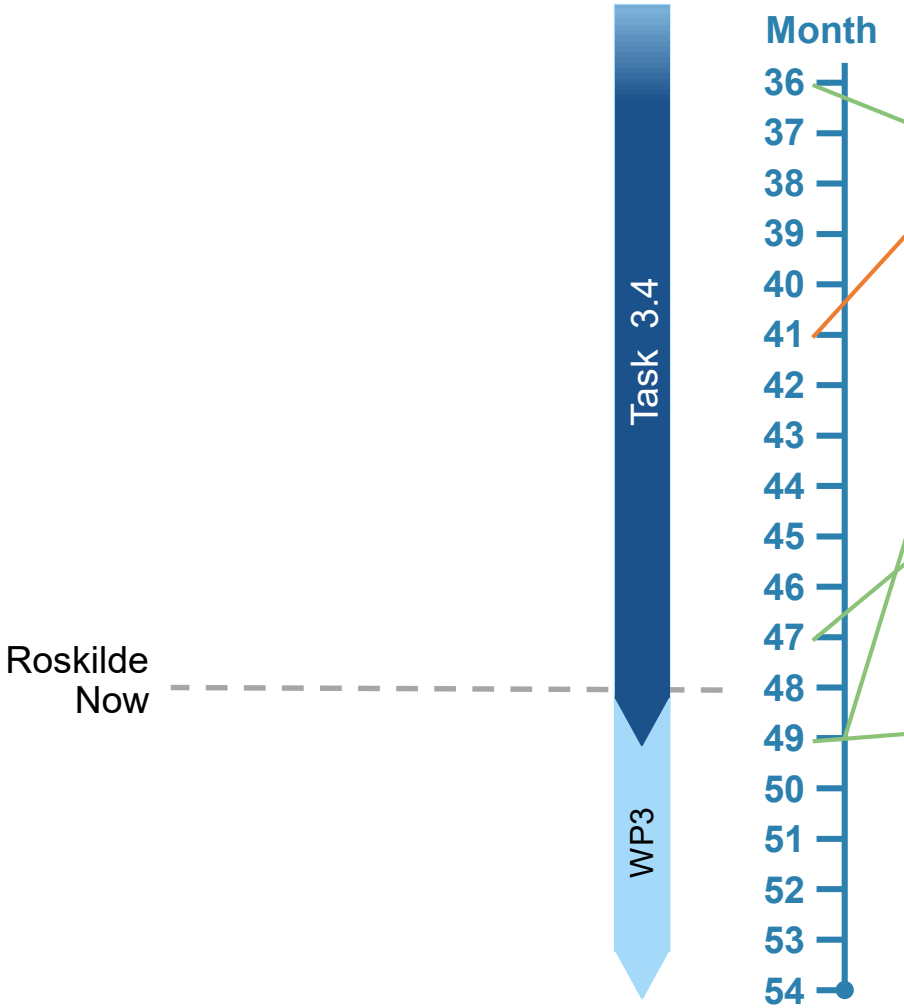
Ongoing Work



MS20 Recommendations on requirements to existing grid codes provided to WP11 ✓

- An internal deliverable with the recommendations

MS80 WP16 Test cases regarding WP3 successfully completed

- Test reports received from WP16

D3.8 List of requirement recommendations to adapt and extent existing grid codes ✓

- Requirements for DRU connected OWPPs

D3.7 Report with the compliance evaluation results using simulations

- Compliance test procedures for DRU connection
- Self-Energization & Black Start
  - Requirements and Test Scenarios – HVAC and HVDC connected OWPP
  - Simulations results
  - Black start capability assessment
- Paradigm shift from grid following wind turbines to grid forming

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D3.8 Recommendations for Requirements

Some general remarks:

- **D3.8 is providing "recommendations", rather than specific grid code requirements**. The objective of D3.8 is to give insight and a reference when the DRU or a similar concept is being deployed in the future.
- **The set of grid code recommendations given in D3.8 are the outcome of the studies performed in WP3 and should not be considered as a complete set of requirements for DRU connection**.
- **Some of the requirements might be based on the specific structure(s) studied in WP3 (for instance the WTs are assumed as Type 4 – Full converter interfaced WTs)**. Hence, the requirements should be studied together with the previous Deliverables of WP3, especially D3.1 and D3.2. For the sake of brevity, the detailed structures are not provided here.
- **The quantitative requirements in D3.8 are valid for the studied case(s) in WP3**. Hence the values (e.g. voltage range) can change depending on the case/project.
- **This document does not include a study on existing codes to identify existing requirements which indirectly assume grid following WTGs connected to VSC-HVDC rectifiers and might be incompatible with DRU use.**
- **The grid code recommendations and conclusions expressed in D3.8 are those of the authors and do not necessarily reflect those of the PROMOTioN partnering organizations.**

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D3.8 Recommendations for Requirements

Requirements	Existing grid codes	DRU OWPP specific
2.1 Dynamic Active Power Control	X	
2.2 Island Support (No HVDC or AC Connection)		X
2.3 Minimum Production Limit		X
2.4 Steady State Frequency Control		X
2.5 Optimized (narrow) frequency range		X
2.6 Dynamic Frequency Control		X
2.7 Rate of Change of Frequency (ROCOF) Limits		X
2.8 Steady State Voltage/Reactive power Control		X
2.9 Dynamic Voltage Control		X
2.10 Offshore Fault-Ride-Through	X	X
2.11 DC Fault Ride Through Requirements		X
2.12 Onshore AC Fault Ride Through	X	
2.13 Onshore Frequency Support Requirements	X	
2.14 Synthetic Inertia	X	
2.15 Onshore Oscillation Damping Requirements	X	

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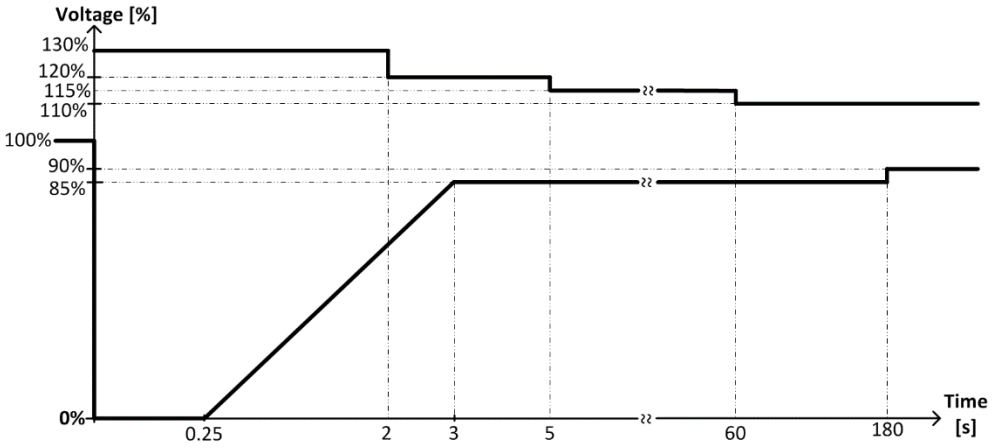
Example - **2.10 Offshore Fault-Ride-Through**

OWPP shall be capable of staying connected to the network and continuing to operate stably after the (offshore) power system has been disturbed by faults on the offshore ac network. That capability shall be in accordance with the voltage-against-time profile at the connection point […]



Fgure 2.1 Example voltage-time profile for offshore AC faults [ENTSO-E NC RfG Article 16 (3) (a) (i)].

Added:

After offshore AC fault isolation, the OWPP should restore the offshore AC voltage and frequency to the pre-fault condition, without significant overvoltage or overcurrent

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D3.7 Report with the compliance evaluation results using simulations (ongoing)

- DRU-connected WTs
  - Fundamental Operation
  - Fault response
  - Ancillary Services
- Self-Energization & Black Start
  - AC-connected offshore WPP
  - VSC-HVDC-connected offshore WPP
  - Identify gaps with respect to TSO requirements
  - Requirements recommendations
  - Comparison with industry results (MVOW and Energinet)

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DRU-HVDC – Technical compliance testing via simulations

Normal operation
- HVDC link and off-shore AC grid start-up operation
- HVDC link and off-shore AC grid disconnection operation
- Intentional islanding
- Dynamic voltage control
- Wind farm power control and power tracking
- Response to changes in reactive power sharing command
- Response to active power reference commands when connected to external AC
- Disconnection / reconnection of filters

Fault ride-through and protection
- Unintended transmission capability limitation
- Umbilical AC cable faults
- Offshore AC faults

Ancillary services
- Onshore Frequency support
- Onshore power oscillation damping

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DRU-HVDC – Technical compliance testing via simulations Example of results

Test case	4.2.11.a. DISCONNECTION OF DRU FILTERS		
Simulation detail	WT	Level 4: Perfect DC link control is assumed	
	OWF	Level 4: One detailed string and aggregated strings…	
	On-shore MMC	Level 2: Averaged model	
	On-shore grid	Level 3: Thevenin equivalent	
	Configuration (connected strings)	Compliance	Comments
Simulations (sensitivity analysis)	6 Strings + 6 Strings + 6 Strings	pass	P_{TOT}= 1200 MW; Max U^-/U^+ = 0.012; Max Δf = 0.2 Hz; Max df = 0.9 Hz/s
	6 Strings + 3 Strings + 1 String	pass	P_{TOT}= 680 MW; Max U^-/U^+ = 0.013; Max Δf = 0.2 Hz; Max df = 0.9 Hz/s
	6 Strings + 1 String + 1 String	pass	P_{TOT}= 544 MW; Max U^-/U^+ = 0.015; Max Δf = 0.2 Hz; Max df = 0.9 Hz/s
	3 Strings + 3 Strings + 3 Strings	pass	P_{TOT}= 624 MW; Max U^-/U^+ = 0.014; Max Δf = 0.2 Hz; Max df = 0.9 Hz/s
	3 Strings + 3 Strings + 1 String	pass	P_{TOT}= 488 MW; Max U^-/U^+ = 0.015; Max Δf = 0.2 Hz; Max df = 0.9 Hz/s
	3 Strings + 1 String + 1 String	pass	P_{TOT}= 352 MW; Max U^-/U^+ = 0.016; Max Δf = 0.2 Hz; Max df = 0.9 Hz/s
	1 String + 1 String + 1 String	pass	P_{TOT}= 260 MW; Max U^-/U^+ = 0.016; Max Δf = 0.2 Hz; Max df = 0.9 Hz/s

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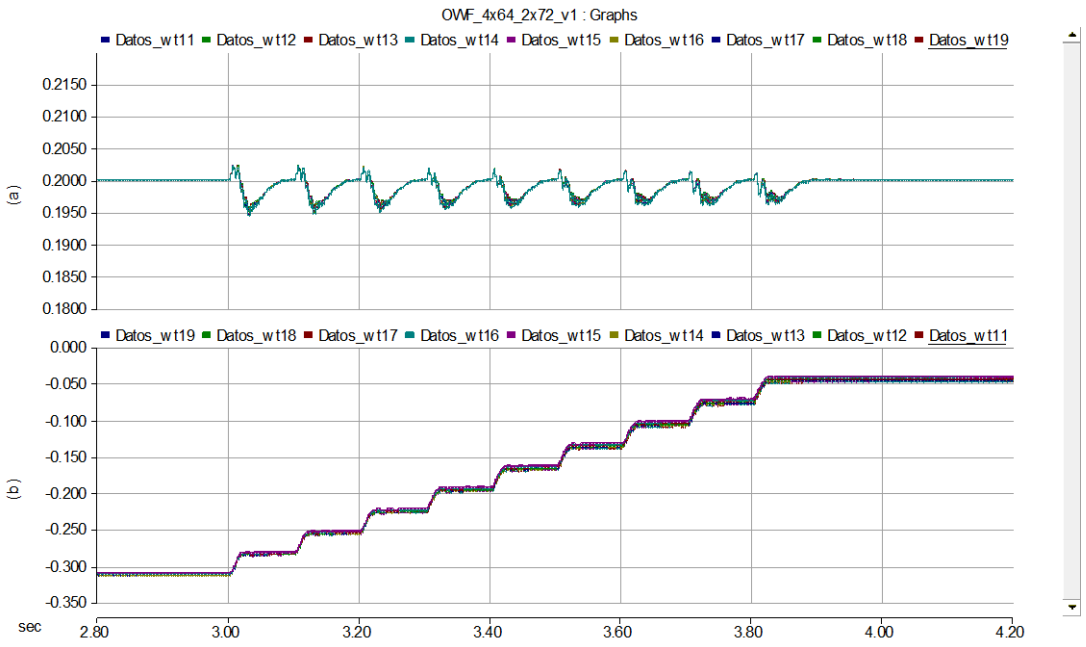
DRU-HVDC – Technical compliance testing via simulations Example results

Comments

The connection of the DRU filters reduce the required reactive power of the off-shore ac grid. It reduces the losses of the grid. The result shows the active and the reactive power of the WTGs within a string. It shows that the active power remains at its reference value (power drop lower than 0.5%). Initially, the system has all filters connected and hence, it is over-compensated. As the filters are disconnected, the reactive power absorbed by the WTGs decreases. The opposite is true when the filters are connected.



(a) Active power (pu) of WTGs in string 1 of OWF1; (b) Reactive power (pu) of WTGs in string 1 of OWF1

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Self start and black start

Off-shore wind farm Self start

Operational and stability requirements

- Frequency ranges
- Voltage ranges
- Block load size
- Reactive power capacity
- Dynamic voltage control
- Frequency control capability
- Harmonic distortion
- Low Voltage Ride-Through
- Over-Voltage Ride Through
- Power Sharing between Wind Turbines
- Synchronisation capability
- Inertia Response

Considered Scenarios

- HVAC connected WPP
- VSC Connected WPP

Simulation test cases

Normal operation

- Off-shore AC grid start-up operation (Self-Start to Houseload Operation)
- Response to changes in reactive power sharing command (ISL operation)
- Response to Changes in Frequency Set-point
- Dynamic voltage control
- Harmonic compliance
- Off-shore hvac substation energisation
- HVAC export cable ENERGISATION
- Off-shore HVDC station energisation
- On-shore HVDC station energisation
- On-shore hvac substation energisation
- Synchronisation to on shore grid
- Power block delivery
- Soft energisation (from Houseload to Power block)

Fault ride-through and protection

- Unintended transmission capability limitation
- HVAC cable faults
- Offshore AC faults

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Self start and black start
Example results

2.4.15. HARD SWITCHING		
System Configuration	HVDC connected WPP	
Control hierarchy levels affected	OWF controller, WT controller	
Related functional requirements		
Methodology	The considered functional requirements will be validated by means of EMT simulation.	
Minimum simulation detail (maximum level of aggregation)	WTG	Level 4 (from Deliverable 3.2)
	OWF	One complete string and aggregated strings
	MMC	N/A
	On-shore grid	Passive load
Case description	The black start operation included in the description is carried out when the off-shore wind farm is in ILS mode. Soft energisation shall be carried out as considered in the description.	
Sensitivity analysis	PIR size and insertion duration.	
Result assessment	For each one of the tests, the functional requirements will be evaluated and quantitative and qualitative results will be tabulated and compared with the considered functional requirements.	

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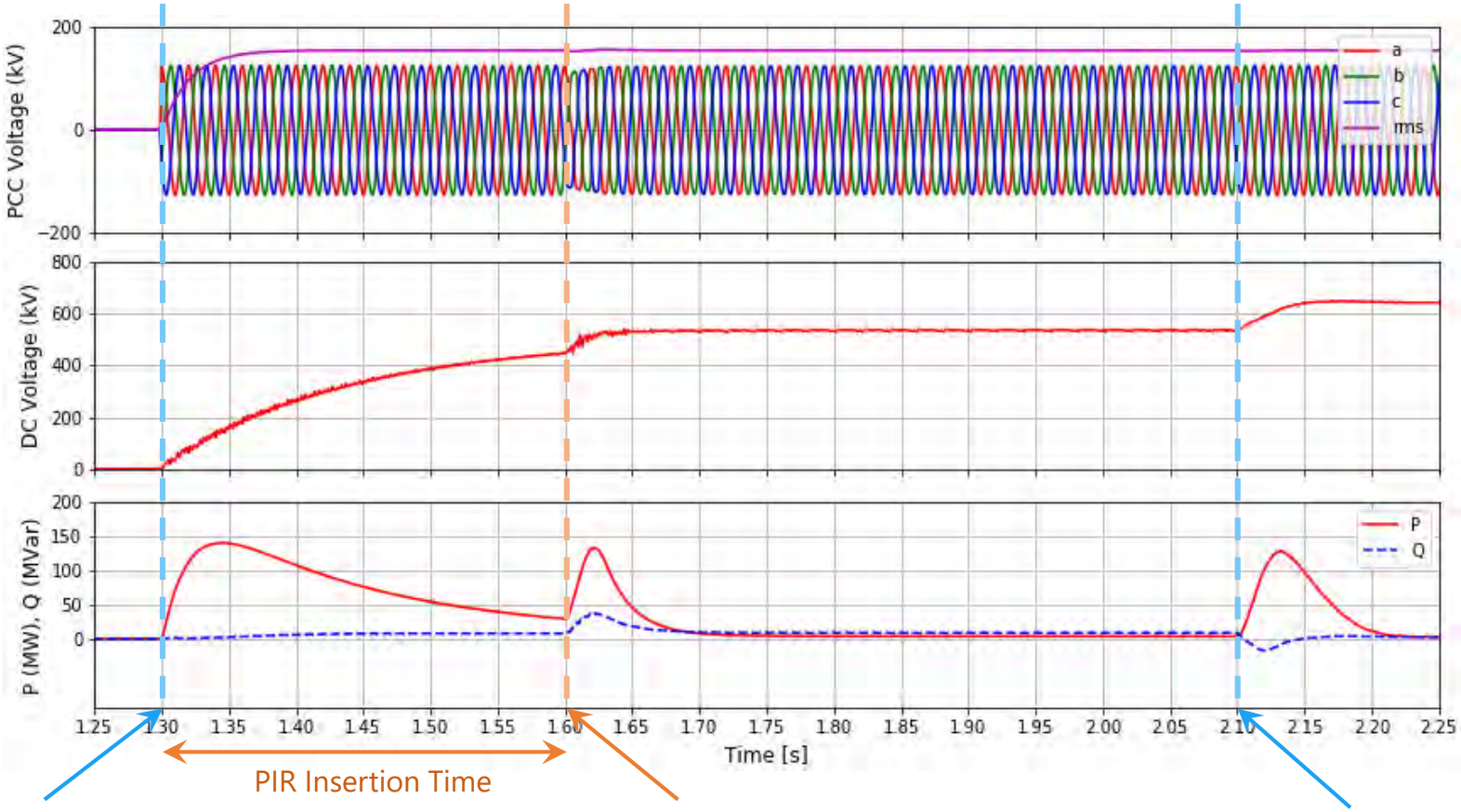
Self start and black start
Example results



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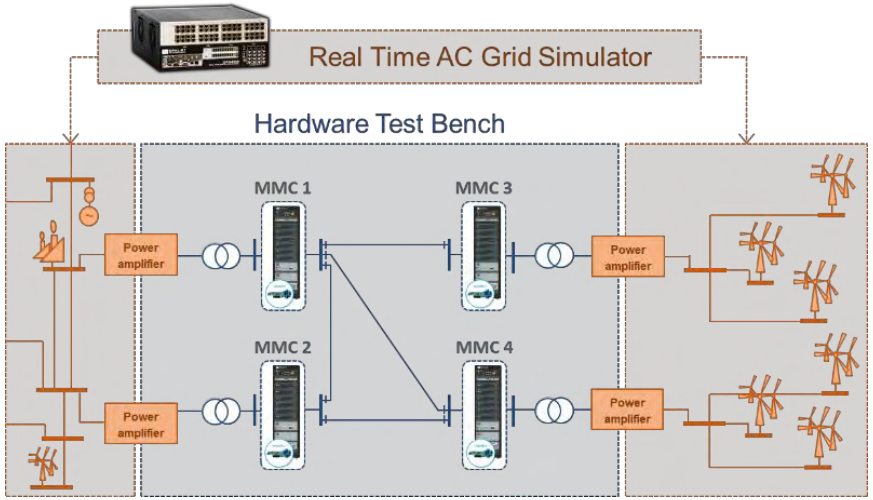
Progress Towards Demonstration in WP16



WP3 controls → WP16 setups

- Grid forming OWPP cluster
- Offshore AC and DC faults
- Fault Handling with Grid-Forming WTGs
- Black start capability of HVAC and DRU-connected offshore wind farms
- Harmonic impedance analysis for DC grids with DRU

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WP3 Wind Turbine – Converter Interaction

Objectives

The main objective of this work package is to identify and specify appropriate analyses and tests to demonstrate the interoperability of the wind turbine (WT) and wind power plant (WPP) controls with two different types of HVDC systems: diode rectifiers (DR) and VSC converters respectively to connect the wind power plants to the DC network.

The focus will mainly be on the novel DR-HVDC link. The tests will be formulated such, that they serve as a basis for type technical compliance testing of both WT and WPP. The goals are:

- to analyse the functional requirements to WPPs connected to DR- and VSC-HVDC
- to identify and specify general control algorithms
- to define and demonstrate compliance evaluation procedures by simulations and tests

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

Main messages from WP3

- DRU-HVDC connection concept is technically feasible

- A very large body of simulations (and scientific publications) has been performed and analysed, increasing the level of knowledge and confidence in the DRU-HVDC connection concept

- Technical requirements and compliance evaluation procedures have been developed and tested for:
  - Fundamental operation
  - Fault response
  - Ancillary services

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Main messages from WP3

- Self-energization of the WTs and black start – feasible & achievable

- Lessons learnt:
  - Hard-switching of large transformers and long AC export cables might be a challenge for the WT converters
  - Soft-start (voltage ramp-up) by the WTs very useful and recommended:
    - Eliminates inrush effects on transformers
    - Avoids over-voltages
    - Allows for fast energization of onshore AC network
  - Aspects related to transients during the ramping period need further investigation, including protection behaviour

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Any Questions?

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

WP16

MMC Test Bench Demonstrator


© Martin Braun

Plenary Session 03.12.2019

Philipp Ruffing – RWTH Aachen

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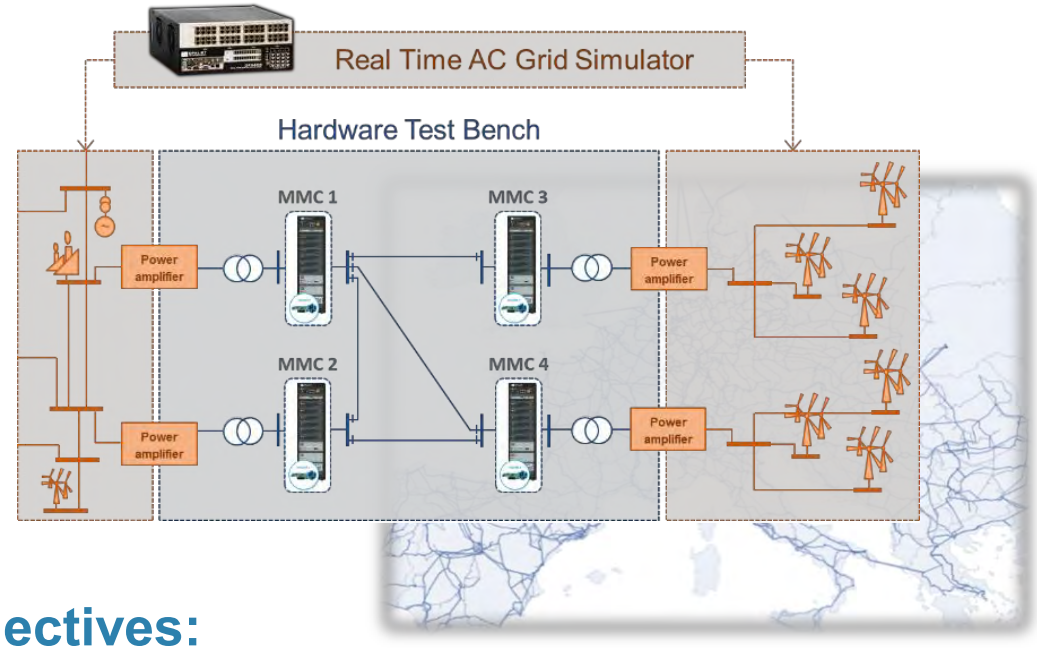
Overview and Objectives of WP16



Motivation:

- Meshed offshore DC systems lead to novel challenges for TSOs, manufacturers and grid planners
- Experience missing concerning
  - Multi-terminal operation
  - Interaction with the large AC transmission systems
  - Interaction with offshore wind farms

Work Package 16: 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:

- Derive appropriate principles and policies to ensure interoperability between different components and technologies in meshed HVDC offshore grids
- Analysis of harmonic resonance phenomena in offshore grids (analysis of the freq. dependent impedance of MMC and WT-VSC)
- Demonstrate the operation of DRU

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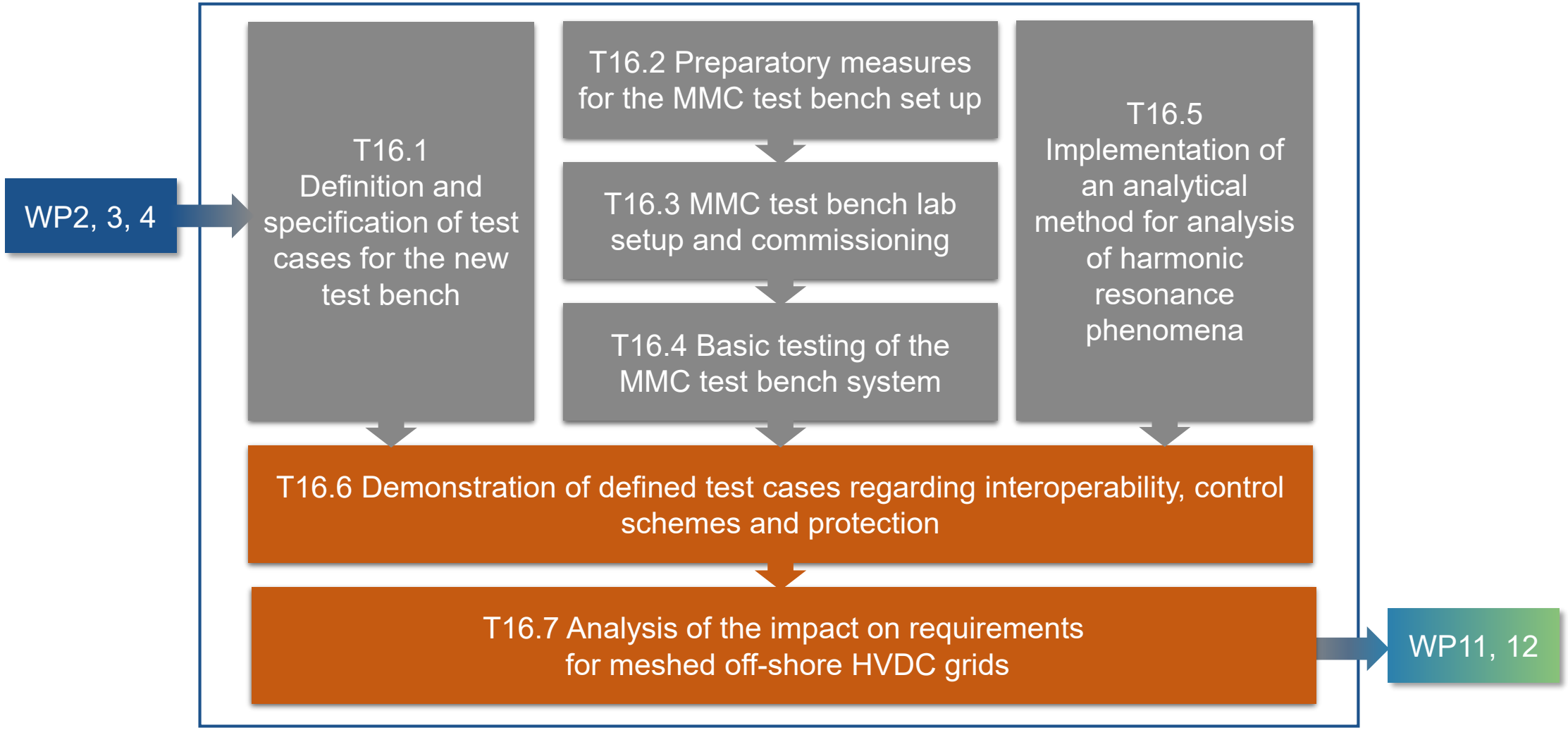
Task Structure of WP16



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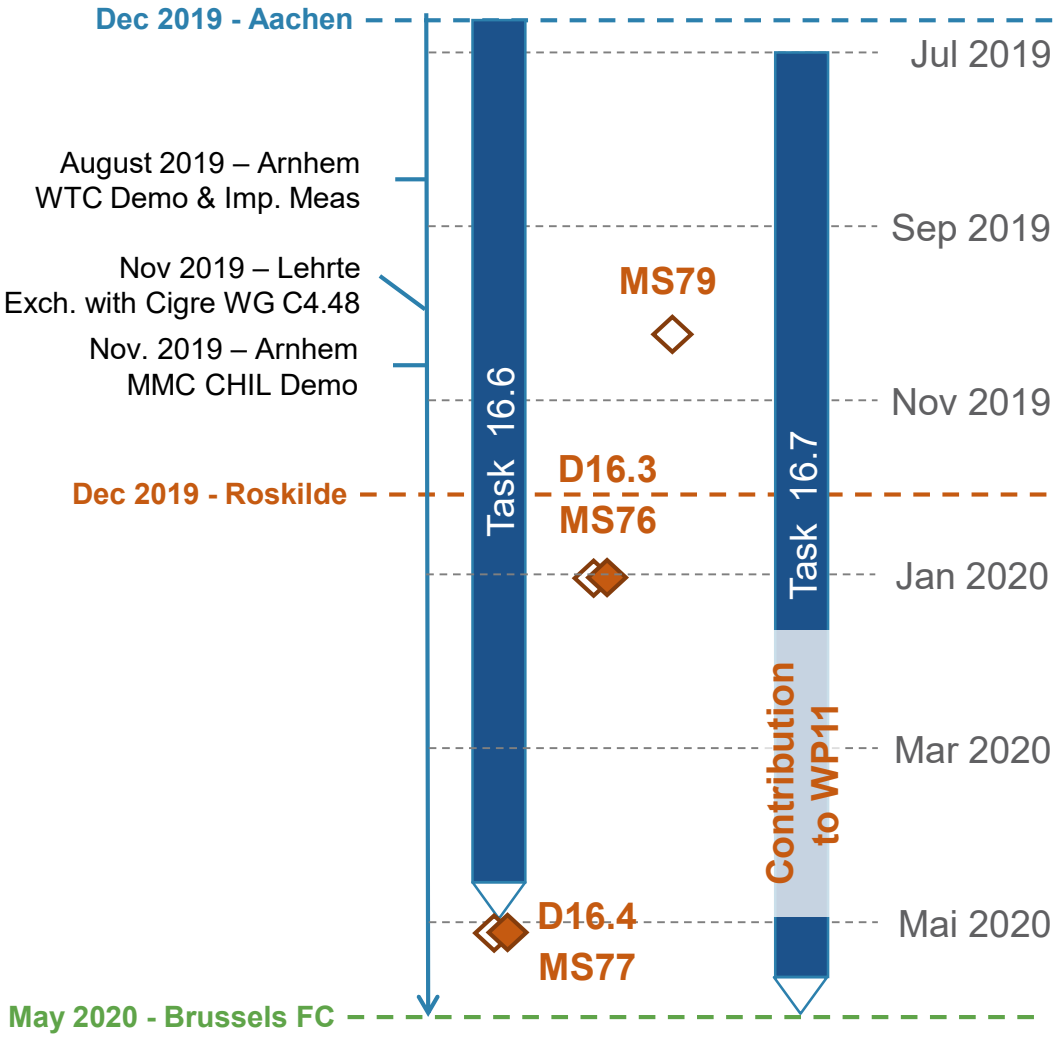
Progress

Milestones & Deliverables

MS / D	Due	Topic	
D16.1	28 (Apr 18)	Test case overview	✓
MS73	28 (Apr 18)	All test cases defined	✓
D16.2	32 (Aug 18)	Lab documentation	✓
D16.5	38 (Feb 19)	Analytical converter impedance modelling	✓
MS74	38 (Feb 19)	Set up completed	✓
D16.7	38 (Feb 19)	Updated Lab documentation	✓
MS75	39 (Mar 19)	First tests completed	✓
MS79	46 (Oct 19)	WT-CHIL Lab Documentation	✓
D16.3	49 (Jan 20)	Test case analysis for WP3	
D16.6	51 (Mar 20)	WT Control + Protection HIL	
D16.4	53 (Mai 20)	Test case analysis WP3	



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Agenda

- MMC Test Bench Demonstrator
- WT Control-Hardware-in-the-Loop
- Resonant Phenomena Studies

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MMC Test Bench Demonstrator

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MMC Test Bench Demonstrator

Status Update

Achievements:

- ✓ Comparison between MMC Test Bench and Simulations
- ✓ Controller optimisation for similar dynamics of the demonstrator and full-scale simulations
  - ➢ Per-unitized controls
  - ➢ Parameter dependent “optimum” control
- ✓ PHiL with (strong) transmission grids and wind power plant

Ongoing Work:

- Implementation of the protection strategy for MTDC grids with full-bridge MMCs
- Improvement of the PI sections towards freq. behavior
- PHiL with weak transmission grids and wind power plant
- PHiL with OWPs in grid forming control
  - ➢ Black-Start, DC-FRT, …

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MMC Test Bench Demonstrator

Status Update

Next Steps:

- Integration of KTH small-scall HVDC Breaker
  - ➢ Build & tested at KTH
  - ➢ Computable with KTH protection IED
- Investigation of PHiL methods for OWP in grid forming control
- Implementation of the protection strategy for MTDC grids with full-bridge MMCs
  - ➢ Small-scale HSS under construction

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Resonant Phenomena Studies

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WP16 Approach

Resonant Phenomena Studies

Stability analysis methods

- State-space modeling
- Time domain
- Frequency domain

➢ No consensus yet which method is applicable

➢ Close collaboration with CIGRE WG C4.49
Multi-frequency Stability Of Converter-based Modern Power Systems

Analytical derivation of the input impedance ✓

↓

Selection/development of a accurate method to measure converter input impedance ✓

↓

Input-impedance measurement of relevant converters ⟲

↓

Stability analysis in the frequency domain ⟲

↓

Validation of the results in the time-domain

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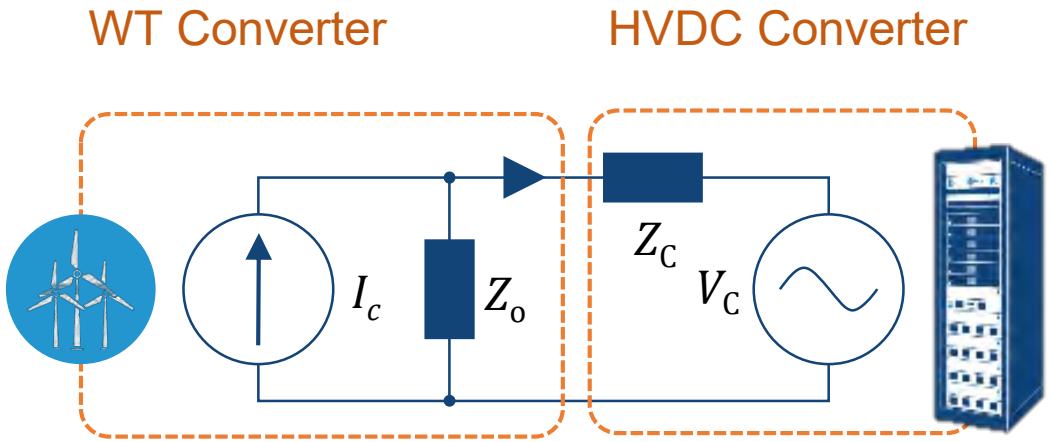
Impedance-based Stability Criterion

Resonant Phenomena Studies

- Harmonic stability is assessed in the frequency domain
- System is modelled as two subsystems having frequency dependent impedances
- Stability is assessed by analyzing the loop gain $G_o(s)$ of the system

$$I(s) = \left[I_{WTC}(s) - \frac{V_{MMC}(s)}{Z_{WTC}(s)}\right]\frac{1}{1+\boxed{\frac{Z_{MMC}(s)}{Z_{WTC}(s)}}}$$

- System is stable if $G_o(s) = \frac{Z_{MMC}(s)}{Z_{WTC}(s)}$ satisfies Nyquist stability criterion



Characterisation of real converter behaviour is required

→ **Impedance Measurement**

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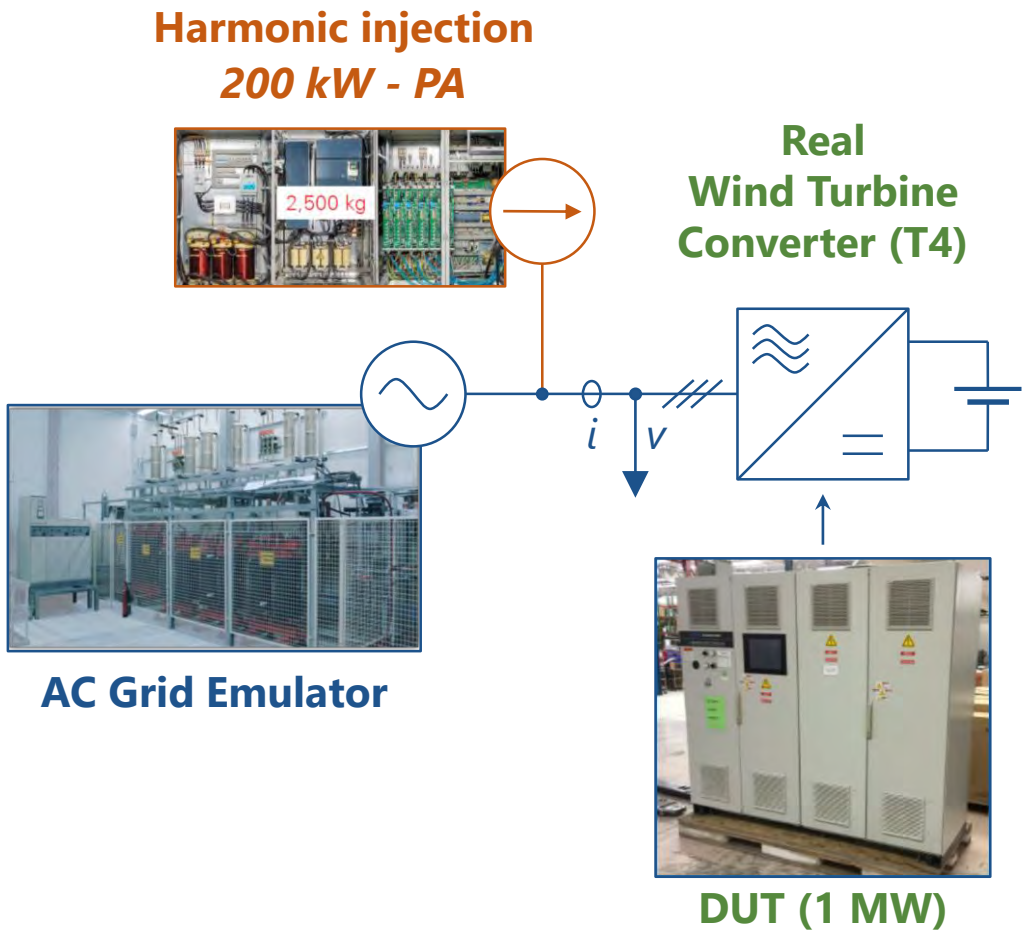
Impedance Measurement – WT Converter

Resonant Phenomena Studies

Achievements:

- ✓ Development and validation of a impedance measure setup at DNV GL in Arnhem
  - MW-scale converter
  - Control replicas
- ✓ Input-impedance measurement of a commercial 1 MW wind turbine converter from Ming Yang Smart Energy, China
- ✓ Input-impedance measurement of the corresponding control replica

Flexible Power Grid Lab @ DNV GL



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Impedance Measurement – WT Converter Controller

Resonant Phenomena Studies

Flexible Power Grid Lab @ DNV GL

Achievements:

- ✓ Development and validation of a impedance measure setup at DNV GL in Arnhem
  - MW-scale converter
  - Control replicas
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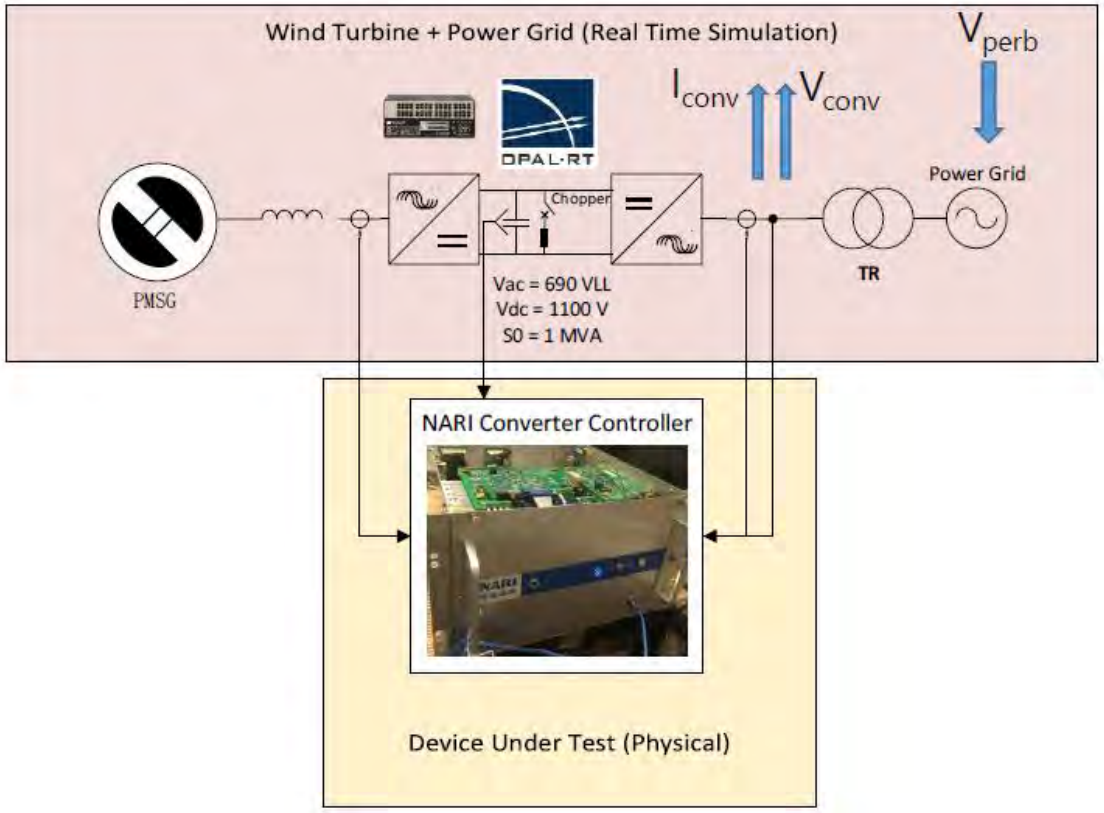

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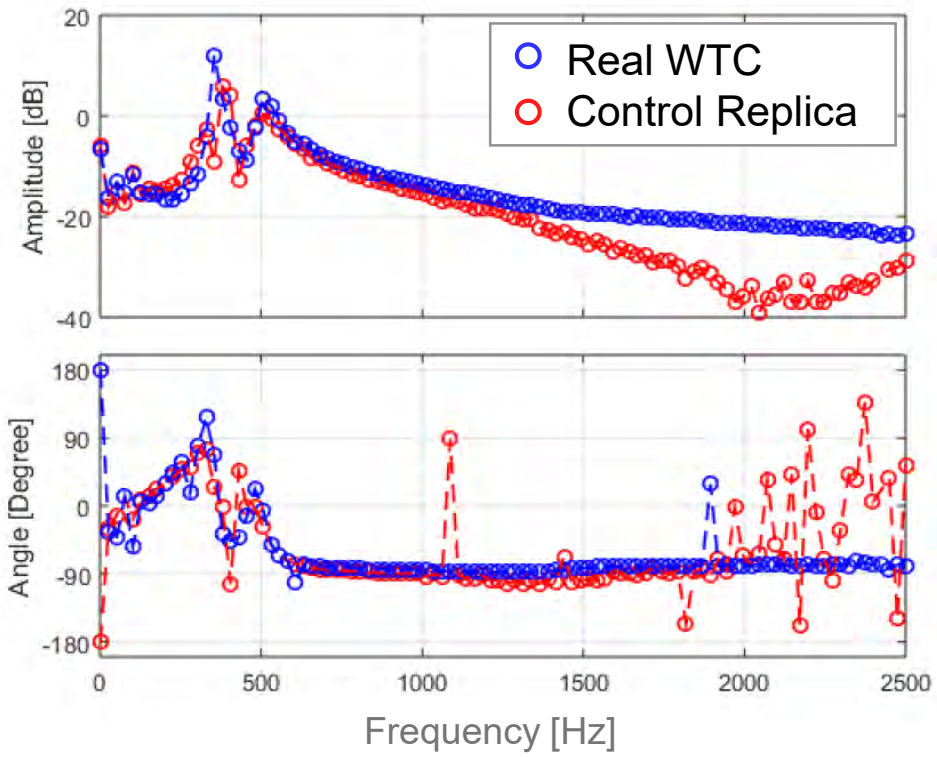
Impedance Measurement – WT Converter

Resonant Phenomena Studies

Impedance Measurement of Z_{dd}



Results:

- ✓ Current perturbation method is feasible for the input-impedance measurement
- ✓ Input-impedance measurement of a commercial 1 MW converter
- ✓ Good matching between the hardware and control replica approach in the low to medium frequency range

- For frequencies above 1500 Hz:
  - Higher impact of measurement noises
  - Current perturbation through damped by decoupling transformer

DC Link
Phase Lock Loop
Current Control Loop

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \underbrace{\begin{bmatrix} Y_{dd}(s) & Y_{dq}(s) \\ Y_{qd}(s) & Y_{qq}(s) \end{bmatrix}}_{Y^m_{tcl,dq}} \begin{bmatrix} E_d \\ E_q \end{bmatrix}$$

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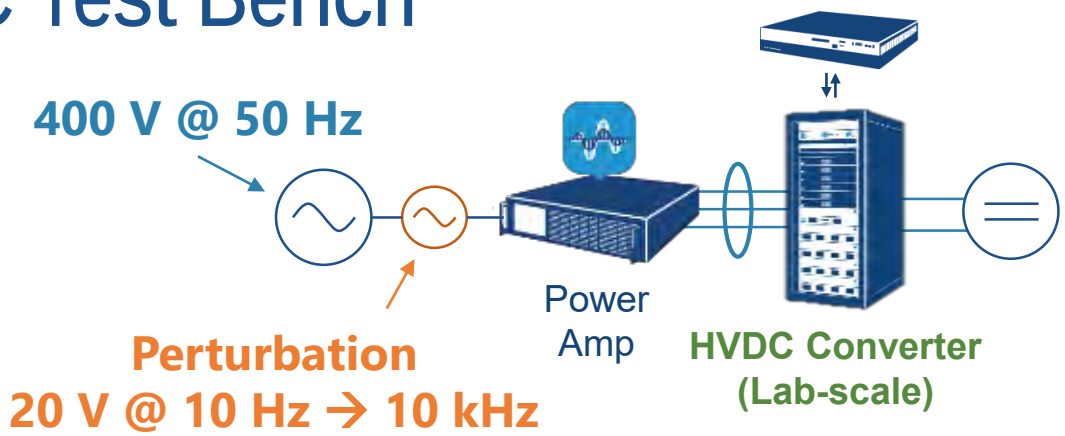
16

Impedance Measurement – MMC Test Bench

Resonant Phenomena Studies

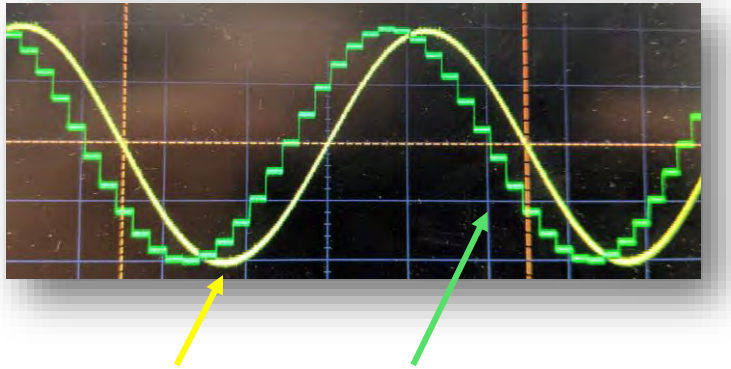


Investigated Control Modes

- ✓ DC Voltage Control
- ✓ P/Q Control
- • Grid Forming Control

Method

- Impedance measurement is carried out in real time
- Real-time simulation part has the AC grid signals and measurement method
  - Small-signal perturbations are superimposed on grid voltage or current
  - Impedance measured online
  - Part of the measurement model is implemented on the FPGA to enable smaller time steps



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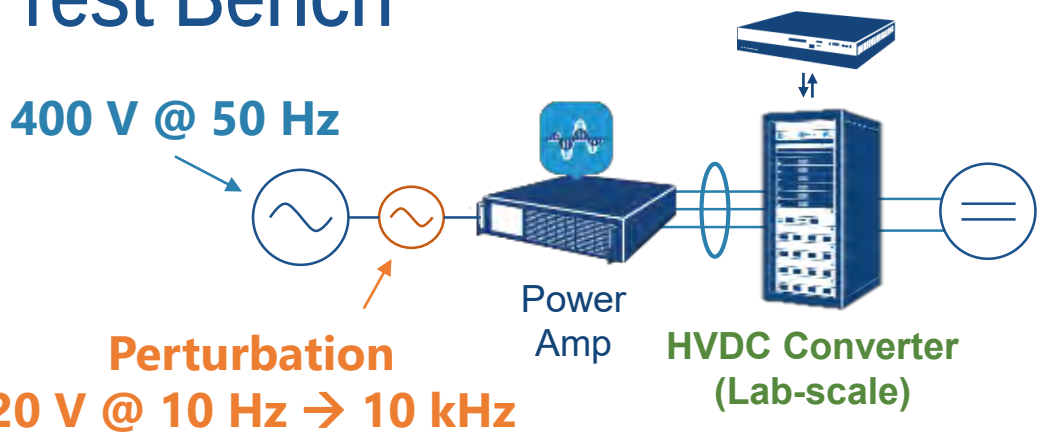
Impedance Measurement – MMC Test Bench

Resonant Phenomena Studies

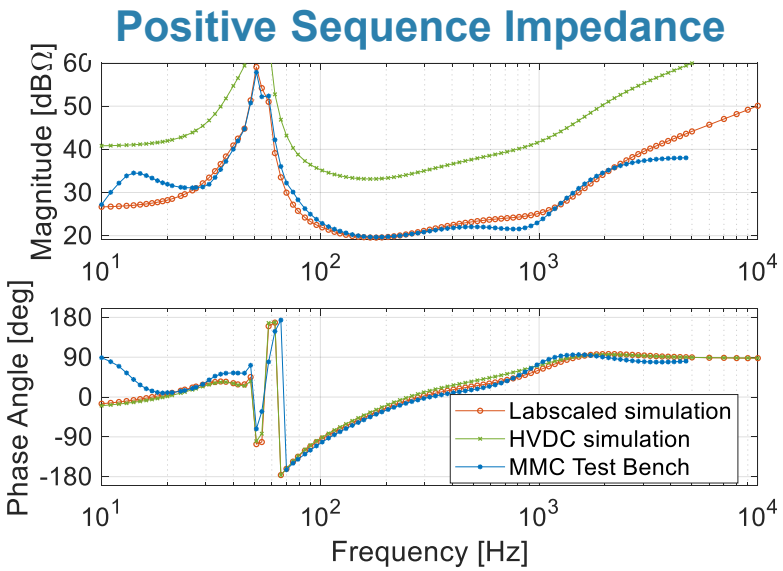


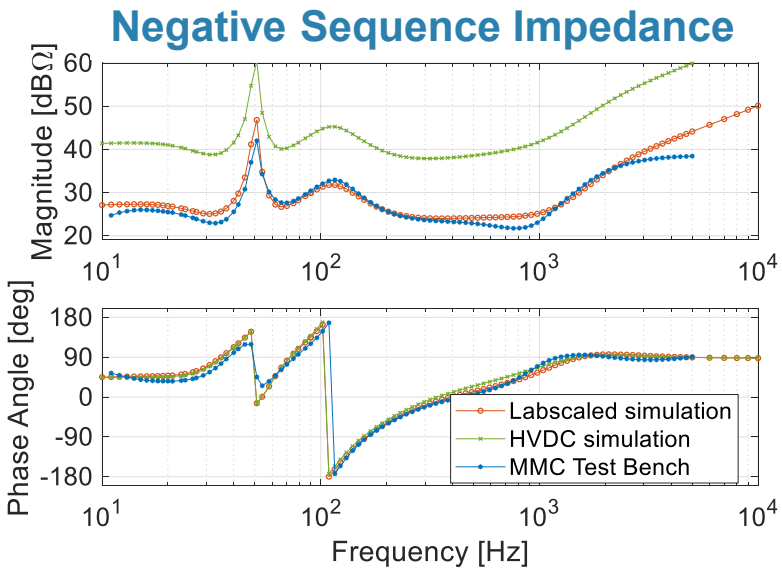
Comparison between

- Full-scale simulation (1.2 GW – 400 $kV_{RMS,LL}$)
- Lab-scale simulation (6 kW – 400 $V_{RMS,LL}$)
- Lab-scale HVDC Converter (6 kW – 400 $V_{RMS,LL}$)

MMC set-point

- P-control mode
- P_{ac}^{*} = 0.5 p.u.
- Q_{ac}^{*} = 0.0 p.u.





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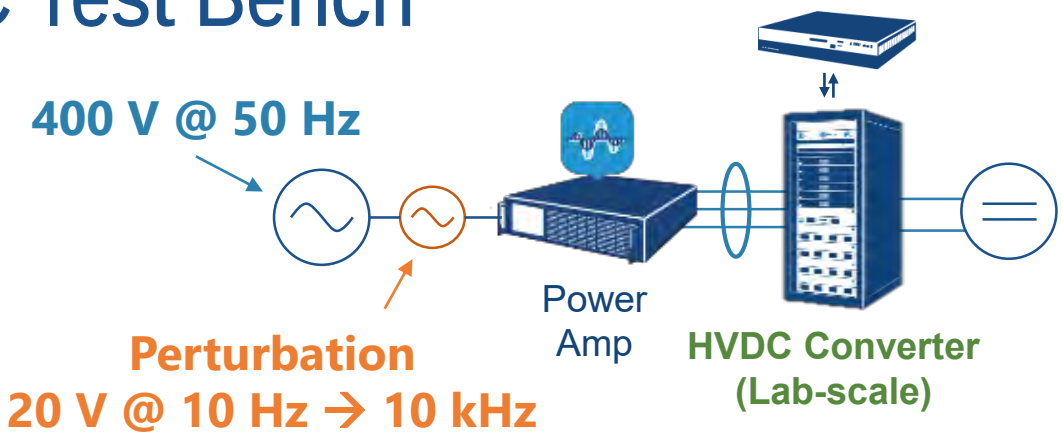
Impedance Measurement – MMC Test Bench

Resonant Phenomena Studies



Comparison between

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- Lab-scale simulation (6 kW – 400 $V_{RMS,LL}$)
- Lab-scale HVDC Converter (6 kW – 400 $V_{RMS,LL}$)

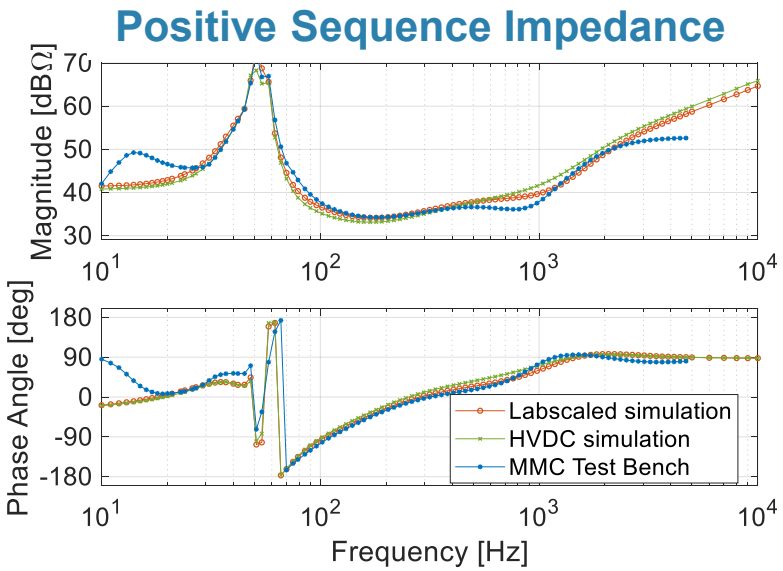
Scaling

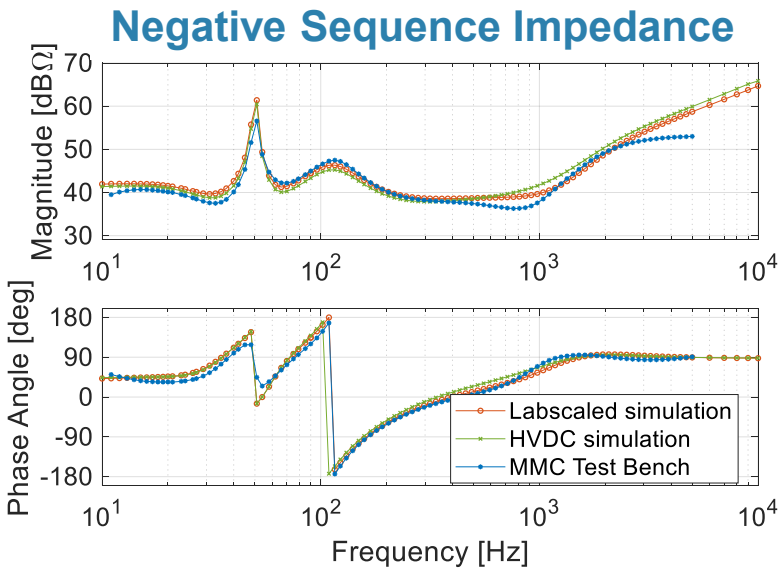
$$|Z_{scaled}| = |Z| \cdot |k|$$

$$\varphi Z_{scaled} = \varphi Z - k_\varphi$$

$$|k| = \sqrt{\frac{r_{FS}^2 + (\omega \cdot l_{FS})^2}{r_{SS,TB}^2 + (\omega \cdot l_{SS,TB})^2}}$$

$$k_\varphi = \arctan \frac{r_{FS}}{\omega \cdot l_{FS}} - \arctan \frac{r_{SS,TB}}{\omega \cdot l_{SS,TB}}$$





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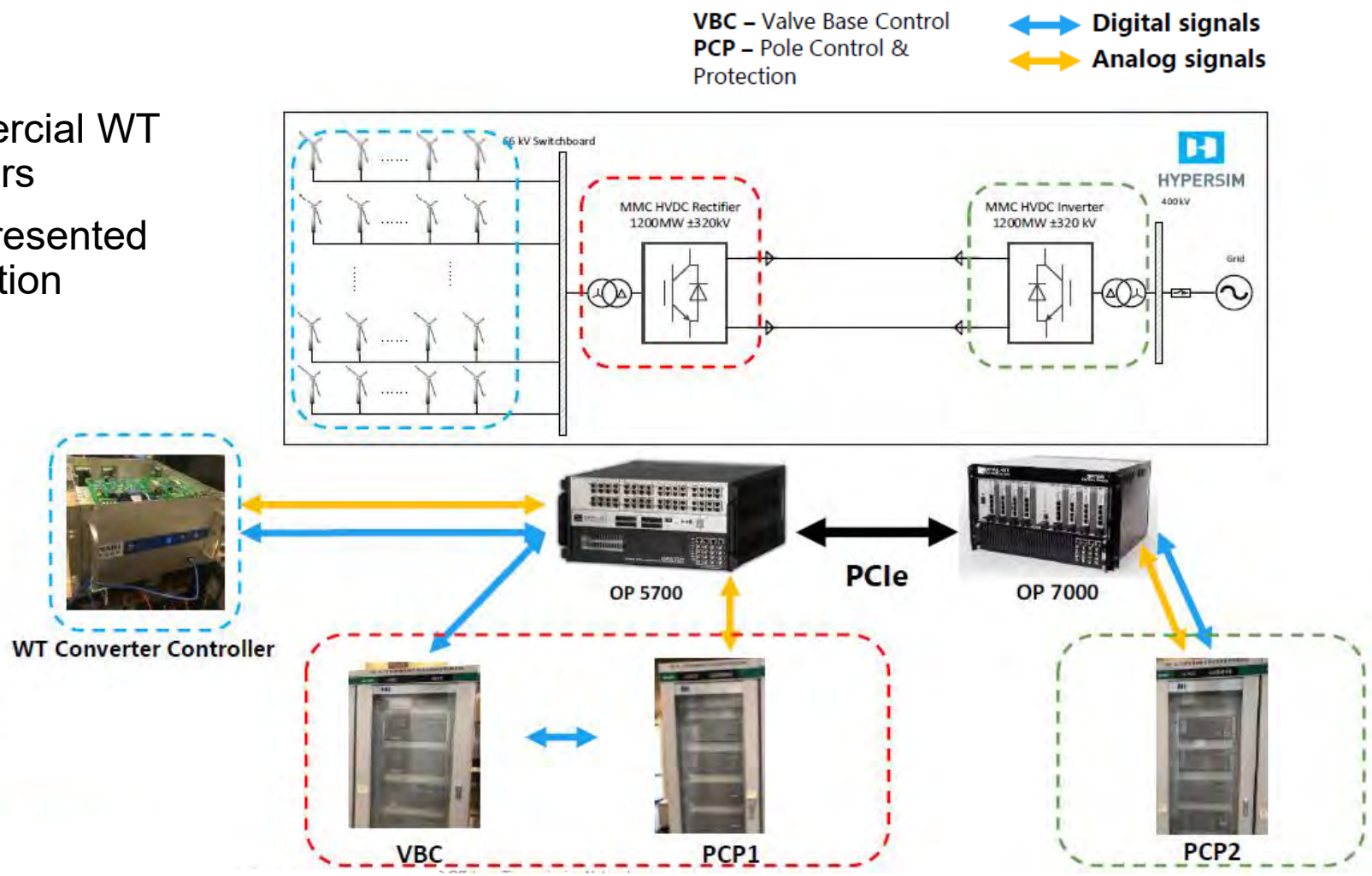
MMC / WT CHiL

Resonant Phenomena Studies

- ✓ Real-time Replica with commercial WT and HVDC converter controllers
- ✓ HVDC and WT Converter represented with detailed real-time simulation

Harmonic Resonance Analysis:

- Impedance model of a commercial HVDC MMC controller
- Time-domain validation of the results obtained in frequency domain



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DRU connected OWP – CHiL

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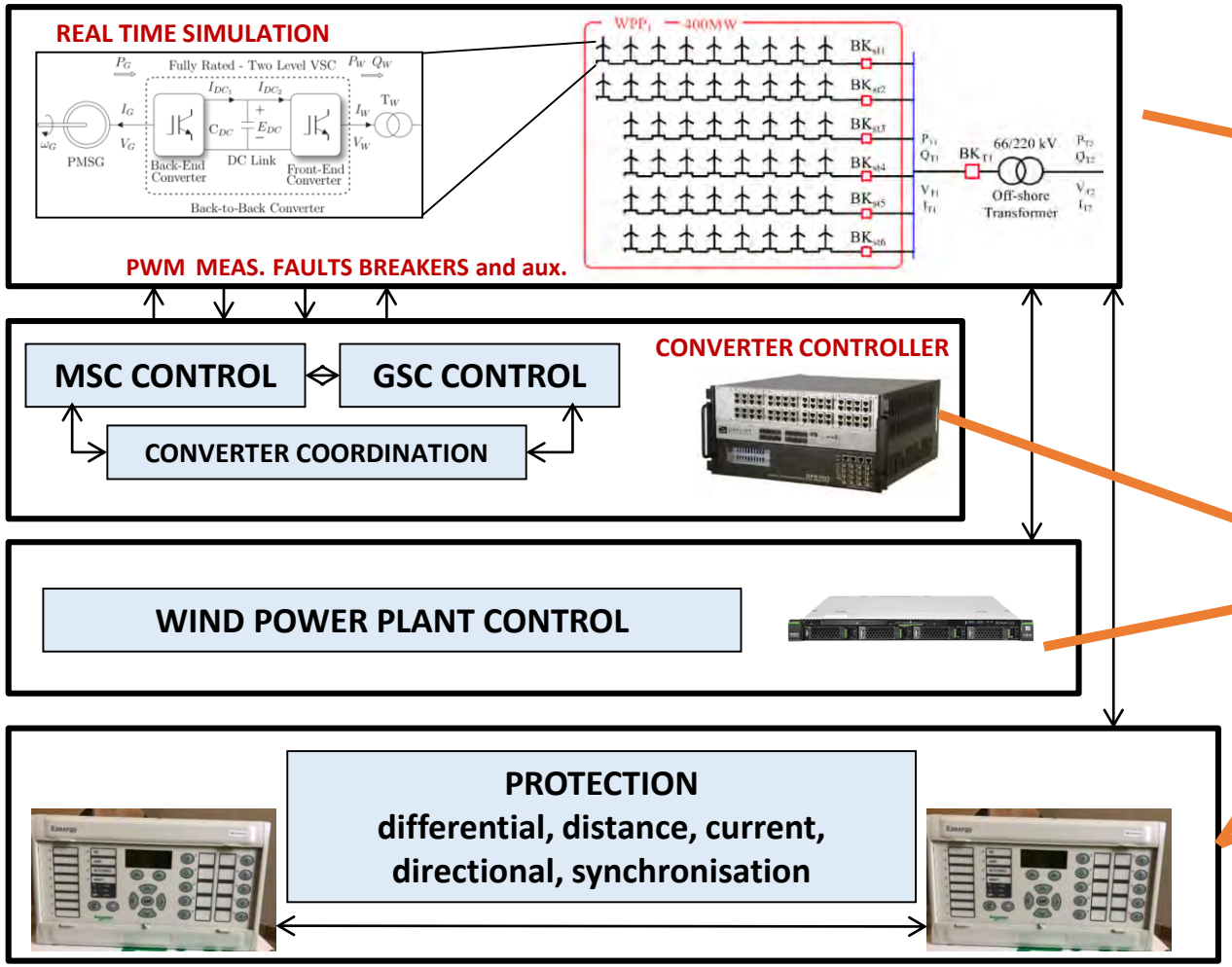
DRU connected OWP – CHiL



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DRU connected OWP – CHiL

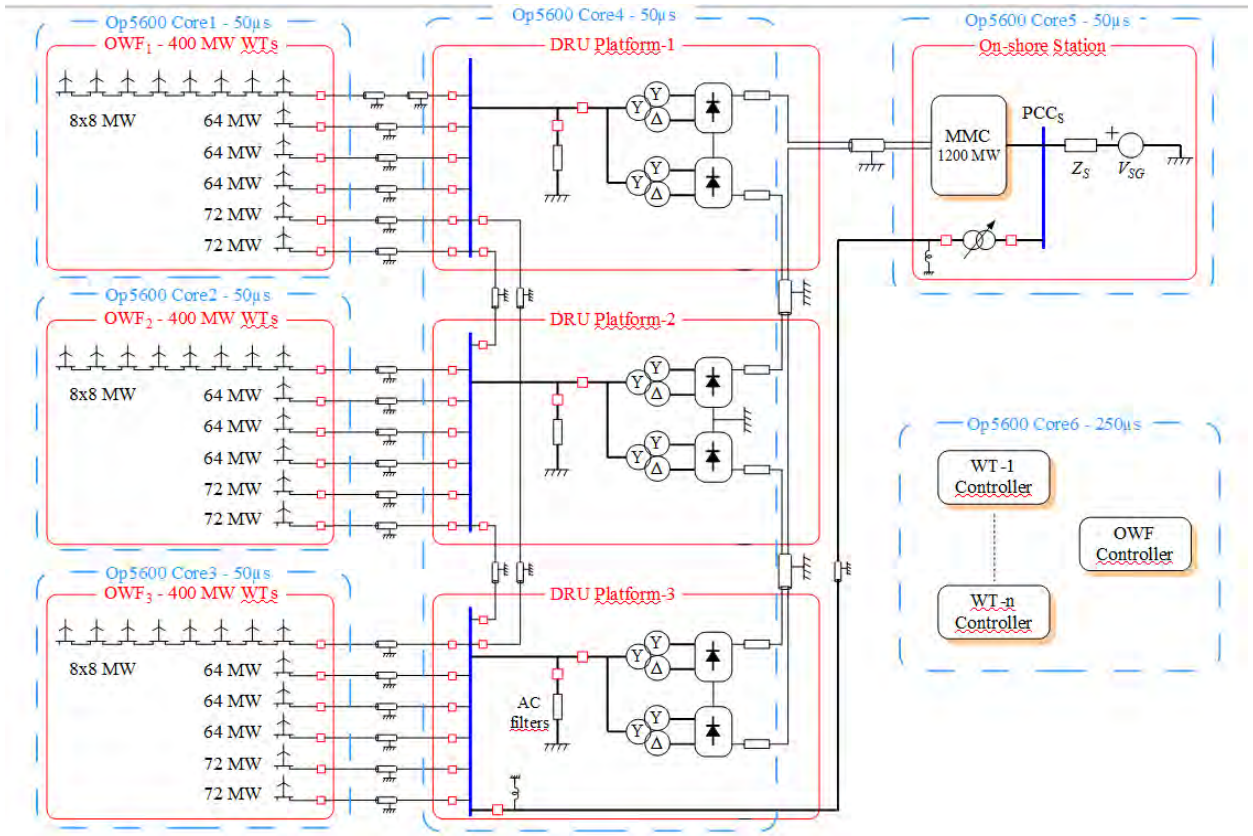
Achievements:

- ✓ Implementation of DRU models and wind turbine controls from WP3 on real-time simulators (RTS)
- ✓ Integration of commercial protection IEDs into CHiL system

Next Steps

- Implementation of ~ 20 independent WT controllers (DSP)

- ➢ Investigation of the Black Start Capability of HVAC and DRU-Connected OWP
- ➢ Fault handling (detection) in collector grid with grid forming WTG



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Dissemination

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Dissemination

Demonstrations Events:

- ✓ WT Impedance Measurement and Testing (DNV GL) → August 2019
  - WT Impedance Measurement → WT converter and control replica
  - WT Black-Start Capability
- ✓ MMC Impedance Measurement and Testing (DNV GL) → November 2019
  - MMC CHiL
  - MMC control replica impedance measurement
- DRU-WT CHiL (UPV) → Beginning 2020
- MMC Test Bench (RWTH) – Interactions between DC grids and OWPPs → Mai 2020
- MMC Test Bench (RWTH) – Full-bridge based Protection & SWL/HPB → March 2020
- CIGRE 2020 (Demo and Paper) → September 2020

Working Groups:

- CIGRE WG C4.49 – Multi-frequency Stability Of Converter-based Modern Power Systems

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Dissemination

Past Conferences/Events:

- WESC Wind Energy Science Conference 2019 (Cork) → Presentation
- IEEE PES General Meeting 2019 (Atlanta) → Presentation
- WindEurope 2019 (Copenhagen) → Presentation

- IEEE PES PowerTech Conference 2019 (Milan)
  RWTH – Quester - Impact of Offshore Wind Farm Grid Configuration on Harmonic Stability
  DTU – Arasteh - On the Methods of Resonance Identification in Power Systems
- ISGT Conference (Bucharest)
  RWTH – Quester - Online Impedance Measurement of a Modular Multilevel Converter
- Wind Integration Workshop 2019 (Dublin)
  DTU – Arasteh - Coordinated Control of Wind Turbines in Diode-Rectifier-connected Offshore Wind
  DNV GL – Sun – Harmonic Resonance Demonstrator: Wind Turbine Generator Input-Impedance Measurement in DQ Frame
  DNV GL – Pérez – Co-Simulation Hardware in the Loop Test Bench for a Wind Turbine: Validation of a Wind Turbine Black Start Capability
- IECON 2019 (Lisabon)
  UPV - Añó-Villalba - Impedance-based Stability Analysis for HVDC Diode-Rectifier Connected Off-shore Wind Farms

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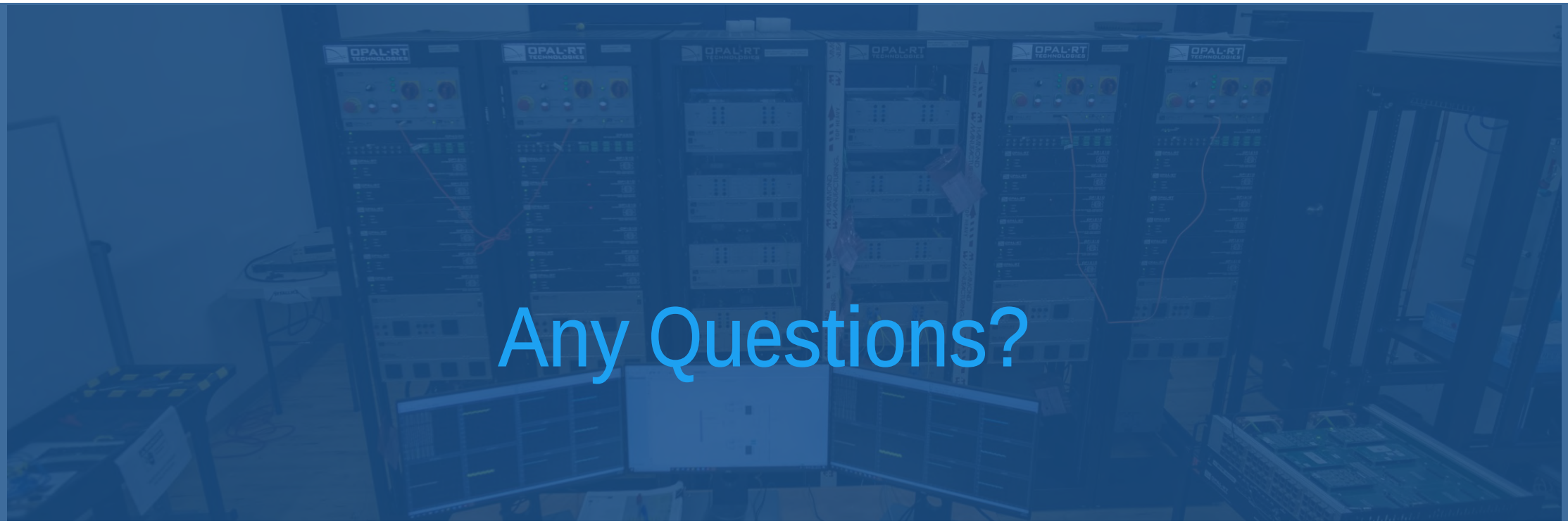

Any Questions?

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APPENDIX

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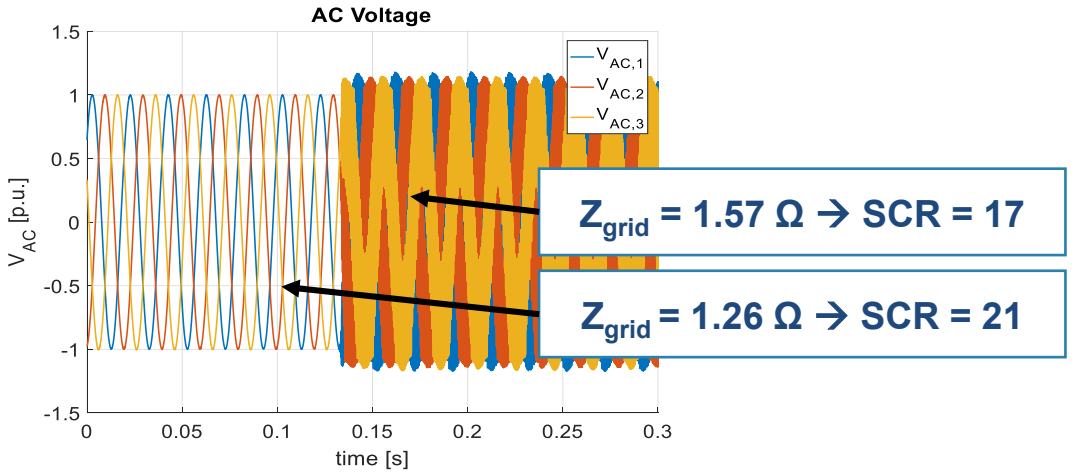
DNV GL Netherlands B.V., ABB AB, KU Leuven, KTH Royal Institute of Technology, EirGrid plc, SuperGrid Institute, Deutsche WindGuard GmbH, Mitsubishi Electric Europe B.V., Affärsverket Svenska kraftnät, Alstom Grid UK Ltd (Trading as GE Grid Solutions), University of Aberdeen, Réseau de Transport d'Électricité, Technische Universiteit Delft, Statoil ASA, TenneT TSO B.V., Stiftung OFFSHORE-WINDENERGIE, Siemens AG, Danmarks Tekniske Universitet, Rheinisch-Westfälische Technische Hochschule Aachen, Universitat Politècnica de València, SCiBreak AB, Forschungsgemeinschaft für. Elektrische Anlagen und Stromwirtschaft e.V., Ørsted Wind Power A/S, The Carbon Trust, Tractebel Engineering S.A., European University Institute, Iberdrola Renovables Energía, S.A., European Association of the Electricity Transmission & Distribution Equipment and Services Industry, University of Strathclyde, ADWEN Offshore, S.L., Prysmian, Rijksuniversiteit Groningen, MHI Vestas Offshore Wind AS, Energinet.dk, Scottish Hydro Electric Transmission plc, SCiBreak AB

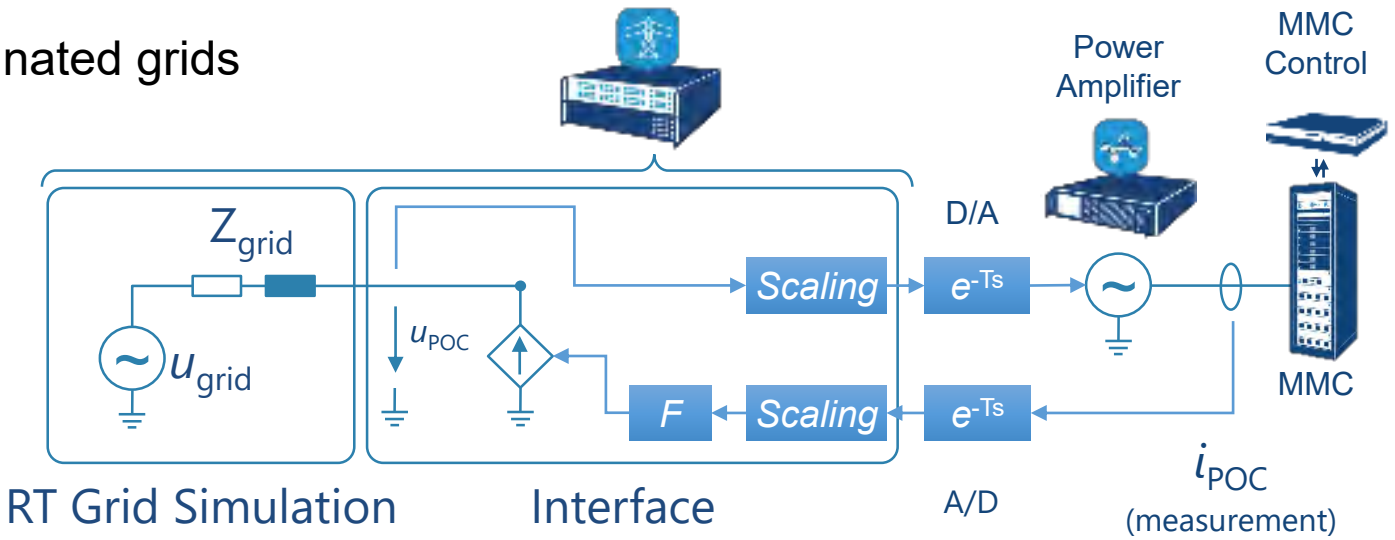
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Power-Hardware-in-the-Loop

What is the challenge?

- Interface algorithm to transmit signals between the digital and the physical system
- Instabilities with PHiL
  - Caused by delay times and sensor inaccuracies
  - These do **not** occur in reality
- PHiL with weak and converter dominated grids
  - Island & small countries
  - Offshore WPPs
  - Future transmission grids





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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

WP6 Characterisation of DC Circuit Breakers

December 2019

Dragan Jovcic, University of Aberdeen

PROgress on Meshed HVDC Offshore Transmission Networks

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

CONTENT

- ↗WP6 overview,
- ↗WP6 work completed and conclusions,
- ↗WP6 contribution towards objectives and outputs to be taken by WP11 and WP12,

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

1) WP6 Characterisation of DC CBs, overview

	Tasks	Lead	partners	status
6.1	Develop system-level model for hybrid DC CB	UAbdn	ABB, SGI, DNV-GL	Submitted M11
6.2	Develop system-level model for mechanical DC CB	DELFT	MEU, DNV-GL	Submitted M11
6.3	Develop component-level and real-time model for hybrid DC CB	UAbdn	DELFT, ABB, DNV-GL	Submitted M30
6.4	Develop component-level and real-time model for mechanical DC CB	DELFT	MEU, DNV-GL, UAbdn	Submitted M30
6.5	*Develop kW-size hardware prototypes for hybrid and mechanical DC CBs*	*UAbdn*	*ABB, DEFLT, DNV-GL*	Submitted M31
6.6	Demonstrate DC CB failure modes on kw-size hardware prototypes	UAbdn	DELFT	Outline submitted, Due M48
6.7	Analyse hybrid DC CB integration into EHV DC grid	UAbdn	DELFT, TenneT	Outline submitted, Due M48
6.8	Develop roadmap for VARC DC CB scaling to EHV DC voltage	DELFT	SciBreak, TenneT	Outline submitted, Due M48
6.9	Develop standard DC CB verification plan and RTDS models	UAbdn	ABB, DELFT, MEU, DNV-GL, SGI, SciBreak	Submitted M36
6.10	Develop roadmap for mechanical DC CB scaling to EHV DC voltage	MEU	DNV-GL, TenneT, UAbdn	Outline submitted, Due M48

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

1) WP6 Characterisation of DC CBs, overview

Meetings

1. Meeting 1: Arnhem, January 2016, 9 participants in person and 3 over phone
2. Meeting 2: Aberdeen, 03 June 2016, 15 Participants
3. Meeting 3: Teleconference, 24 November 2016, 8 Participants
4. Meeting 4: Berlin, 29 November 2016, 17 Participants
5. Meeting 5: DELFT, 23rd February 2017, 15 participants
6. Meeting 6: Aberdeen, 31st May 2017, 10 participants,
7. Meeting 7: Vasteras, 21st September 2017, 18 participants,
8. Meeting 8: Valencia, 20th November 2017, 15 participants,
9. Meeting 9: Arnhem, 10th April, 2018, 16 participants,
10. Meeting 10: Groningen, 07th June 2018, 10 participants,
11. Meeting 11: Croydon, 20th September 2018, 7 participants,
12. Meeting 12: Lyon, 11th December 2018, 8 participants,
13. Meeting 13: Stockholm, 03 April 2019, 11 participants,
14. Meeting 14: Aachen, 12 June 2019, 7 participants,
15. Meeting 15: DELFT, 26th September 2019, 10 participants,
16. Meeting 16: Roskilde, 02 December 2019, 9 participants,

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

2) WP6 Characterisation of DC CBs, contribution and conclusions, deliverables and journals

Deliverables:

- 6 submitted
- 4 in final stages

journals published:

1. *A. Jamshidifar and D Jovcic "Design, Modeling and Control of Hybrid DC Circuit Breaker Based on Fast Thyristors", IEEE Transactions on power Delivery, October 2017, DOI: 10.1109/TPWRD.2017.2761022*
2. *M. Hedayati and D Jovcic "Reducing Peak Current and energy in HVDC CB using disconnector voltage control", IEEE Transactions on power Delivery, February 2018, DOI: 10.1109/TPWRD.2018.2812713 ,*
3. *L. Lian, S. Liu, M. Popov: Optimized Algorithm of Active Injection Circuit to Calibrate DC Circuit Breaker, International Journal of Electric Power And Energy Systems 103, 369-376,*
4. *S. Liu, M. Popov: Development of HVDC System-level Mechanical Circuit Breaker Model, submitted to International Journal of Electric Power And Energy Systems 103, 159-167,*
5. *D. Jovcic, M. Zaja and M. Hedayati, "Bidirectional Hybrid HVDC CB with a single HV Valve" IEEE Transactions on Power delivery, early access, 2019,*
6. *D. Jovcic " Series LC DC Circuit Breaker" IET High Voltage, early access, 2019*
7. *Liu, S., Liu, Z., de Jesus Chavez, J., & Popov, M. "Mechanical DC circuit breaker model for real time simulations". International Journal of Electrical Power & Energy Systems, 107, 2019, 110-119.*
8. *S. Liu et al., "Modelling, Experimental Validation and Application of VARC HVDC Circuit Breakers," in IEEE Transactions on Power Delivery. doi: 10.1109/TPWRD.2019.2947544*
9. *Seyed Sattar Mirhosseini, Siyuan Liu, Jose de Jesus Chavez, Zhou Liu, Marjan Popov "Modeling Voltage Source Converter Assisted Resonant Current DC Breaker for Real Time Studies", International Journal on Electric Power and Energy Systems, accepted*

2 further papers in review stategе.

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

2) WP6 Characterisation of DC CBs, contribution and conclusions, deliverables and journals

conferences published:

1. *D Jovcic and M.H. Hedayati "DC Chopper based test circuit for high voltage DC circuit breakers" IET ACDC Power transmission, Manchester, February 2017, DOI: 10.1049/cp.2017.0030*
2. *A. Jamshidifar and D Jovcic "Modelling of Hybrid DC Circuit Breaker Based on Phase-Control Thyristors", IEEE PES GM, Chicago, July 2017.*
3. *F. P. Page at all. "Mechanical Circuit Breaker Modelling for System-level, Real-time Protection System Simulations" CIGRE B4 colloquium, Winnipeg 2017,*
4. *M.H. Hedayati and D Jovcic "Low Voltage Prototype Design and Testing of Ultra-Fast Disconnector (UFD) for Hybrid HV DC CB" CIGRE B4 colloquium, Winnipeg 2017,*
5. *A. Jamshidifar, D Jovcic and A. Hassanpoor "Control methods for fault current limiting using hybrid HV DC Circuit Breakers", CIGRE Paris 2018.*
6. *A. Jamshidifar, D Jovcic. M Popov and S. Liu " Modelling and Comparison of Common Functionalities of HVDC Circuit Breakers" IEEE PES GM 2018.*
7. *M.H. Hedayati and D Jovcic "500A, 900V, Mechanical DC CB Demonstrator for HVDC applications", ISGT, Sarajevo, October 2018*
8. *D Jovcic "1200V, 200A Laboratory prototype for series LC DC Circuit Breaker" CIGRE Alborg, June 2019,*
9. *M. Wang, D. Jovcic, W. Leterme, D. Van Hertem, M. Zaja, I. Jahn "Pre-standardisation of Interfaces between DC Circuit Breaker and Intelligent Electronic Device to Enable Multivendor Interoperability", CIGRE Alborg, June 2019,*

Panels:

1. *WP6, Characterisation and testing of DC CBs for future DC grids, IEEE PES GM, Portland, August 2018,*
2. *WP6 and WP4, DC Grid protection, IEEE ISGT, Sarajevo, October 2018,*
3. *WP6 and WP4, DC grid protection equipment and methodologies, IEEE PES GM, Montreal, August 2020,*

Workshops:

1. *WP6 and WP4, DC Circuit breakers and DC protection, Brussels, September 2019,*

Promotion newsarticle:

1. *Two newsarticles from WP6*

1 patent.

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

Task 6.1 Develop system-level model for hybrid DC CB

1. DC Circuit breakers in DC grids,
2. Modelling IGBT based hybrid DC Circuit Breaker
3. Modelling Thyristor based hybrid DC Circuit Breaker

Models include:

- All key components,
- Detailed controls including self-protection
- Thermal models,

Modelling IGBT based Hybrid DC CB:

- Load Branch (Load switch and Ultrafast disconnector),
- Breaker Branch (Commutation switch),
- Energy Absorption Branch (Surge arresters),
- Residual current breaker,
- Series inductor,

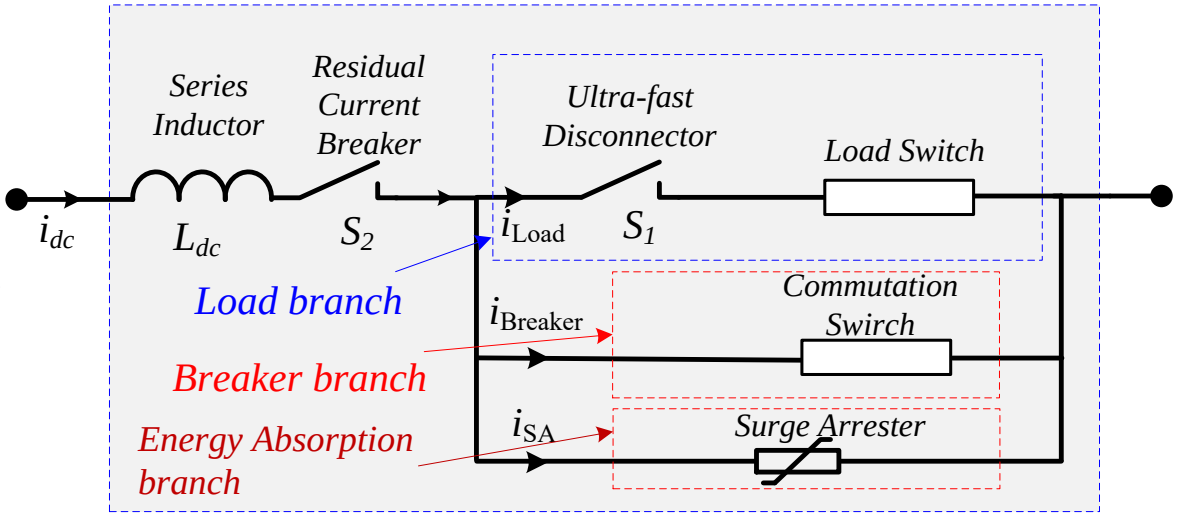

Figure 1. Structure of IGBT based hybrid DCCB

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Task 6.1 Develop system-level model for hybrid DC CB

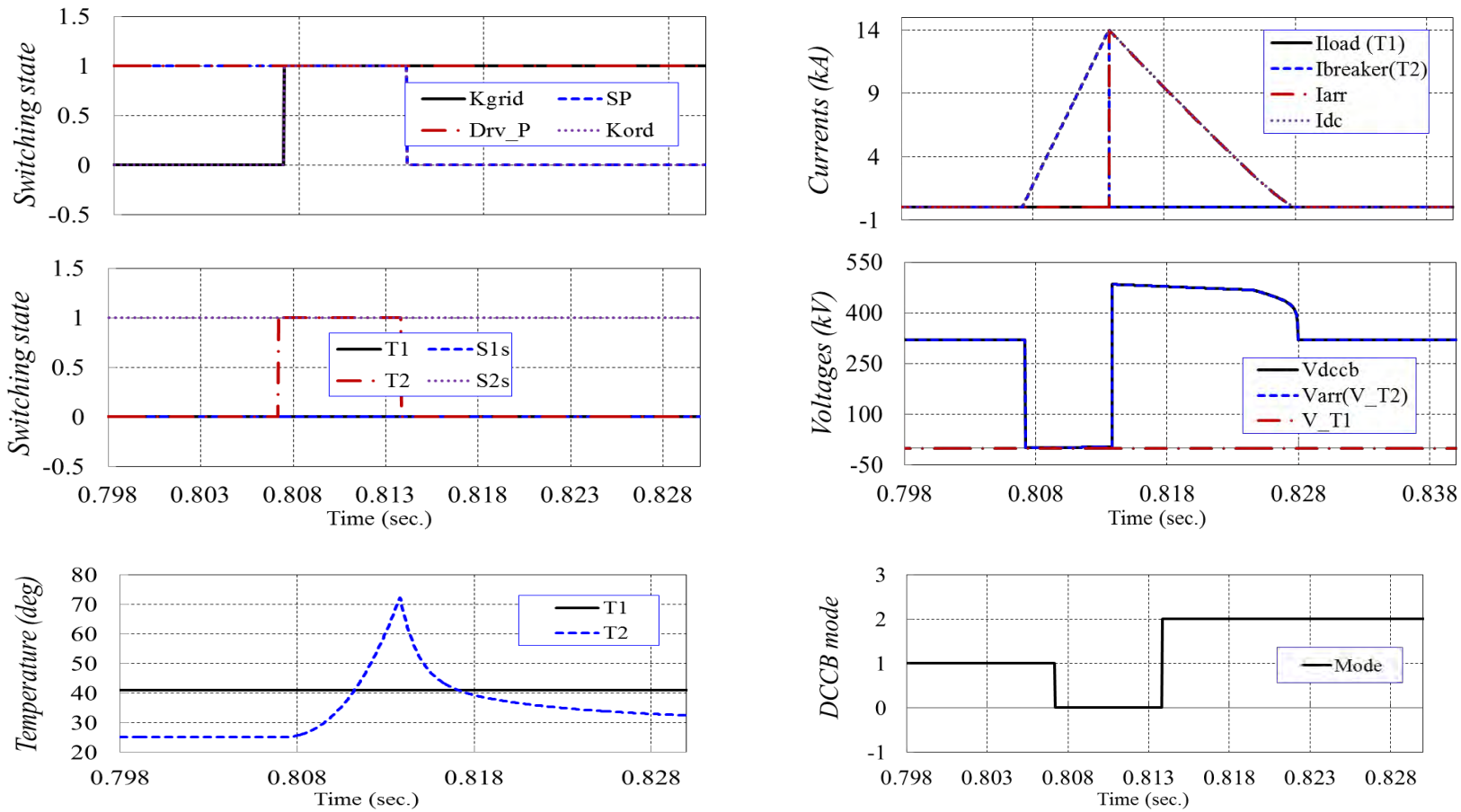

Figure 2. IGBT based Hybrid DC CB Simulation results for reclosing in fault

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Task 6.1 Develop system-level model for hybrid DC CB

Modelling thyristor based hybrid DC CB:

- Load Branch (Load switch and Ultrafast disconnector),
- Breaker Branch (Time delaying branches with thyristors),
- Energy Absorption Branch (Surge arresters),
- Residual current breaker,
- Series inductor,

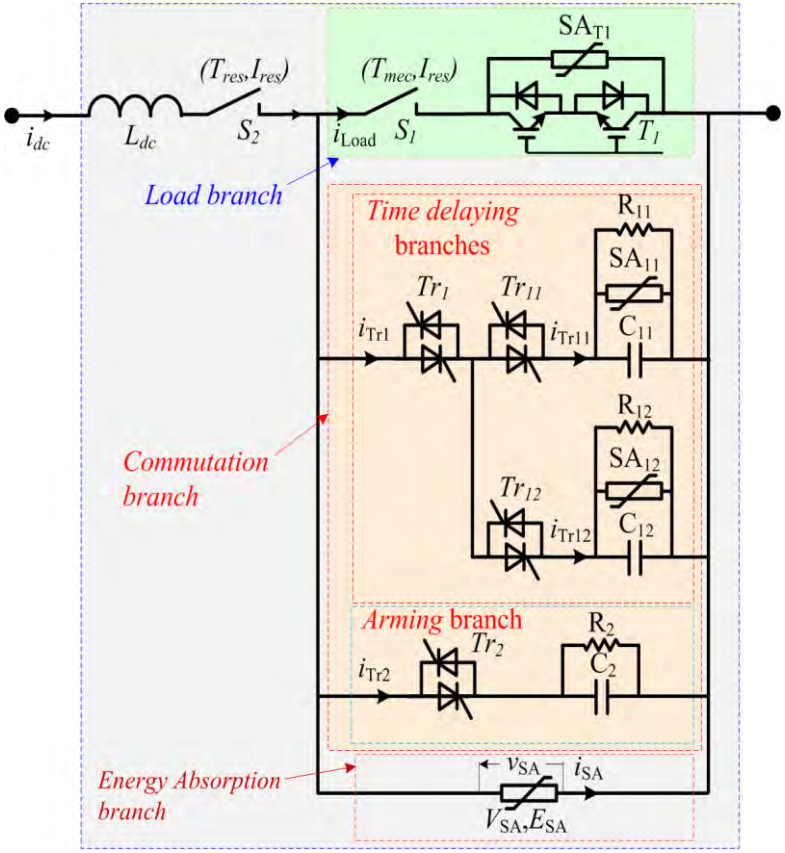

Figure 3. Structure of Thyristor based Hybrid DC CB

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Task 6.1 Develop system-level model for hybrid DC CB

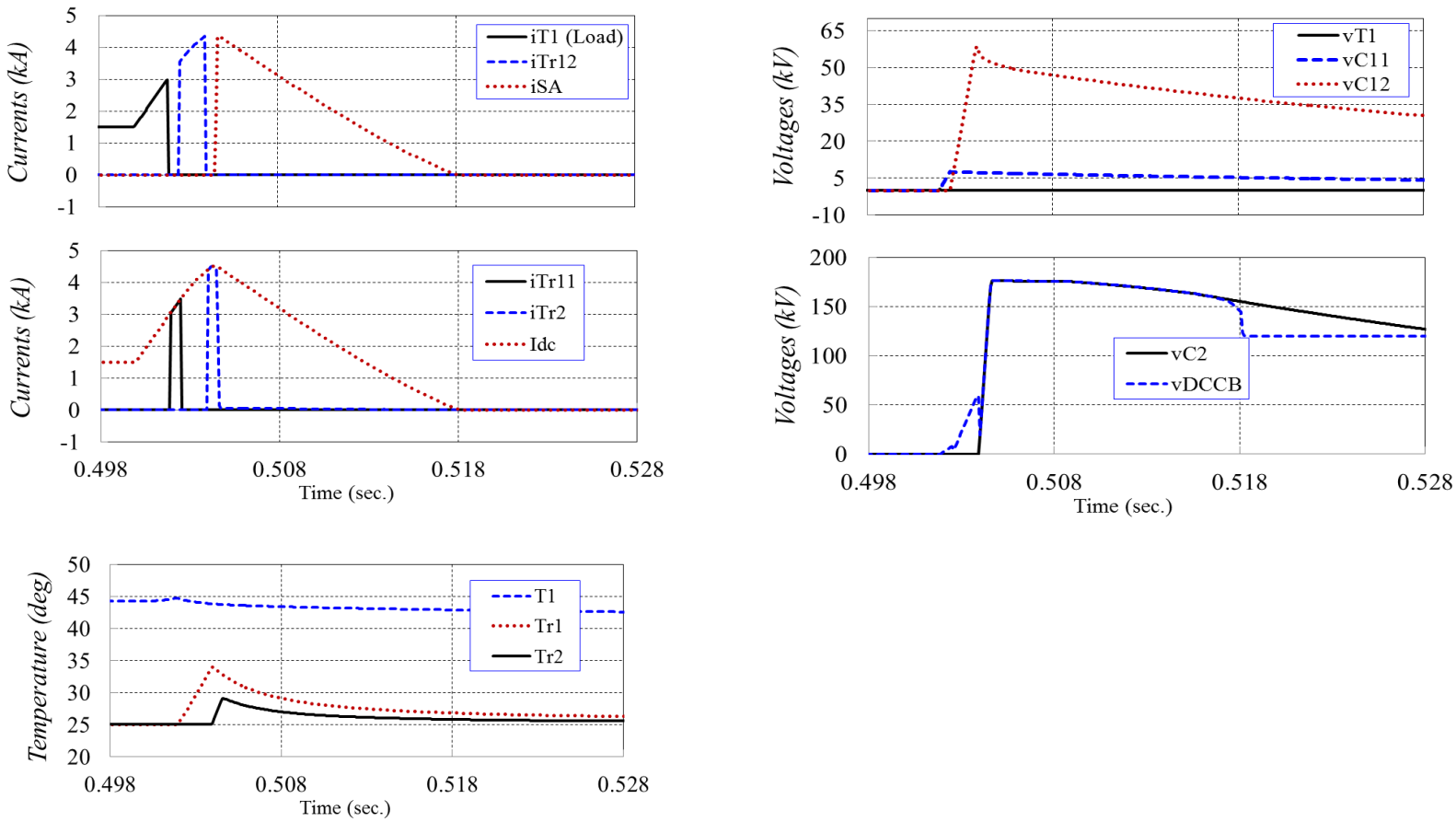

Figure 4. Thyristor based Hybrid DC CB Simulation results for opening

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

Task 6.2 Develop system-level model for mechanical DC CB

1. Mechanical DC Circuit Breakers,
2. Modelling mechanical DC Circuit Breakers
3. Simulation results

- Ideal switches
- Modelling of 3kHz resonant circuit
  - As Lc circuit
  - As series capacitor
- Detailed controller model,

Modelling mechanical DC CB:

- Main branch (main interrupter),
- Current injection branch (high speed making switch, capacitor, inductor),
- Energy Absorption Branch (Surge arresters),
- Residual current interrupter,
- Series inductor,

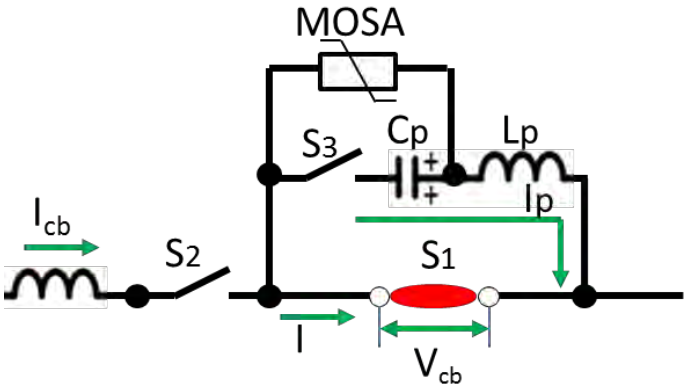

Figure 5. Structure of mechanical DCCB with active resonance.

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Task 6.2 Develop system-level model for mechanical DC CB

Modelling mechanical DC CB

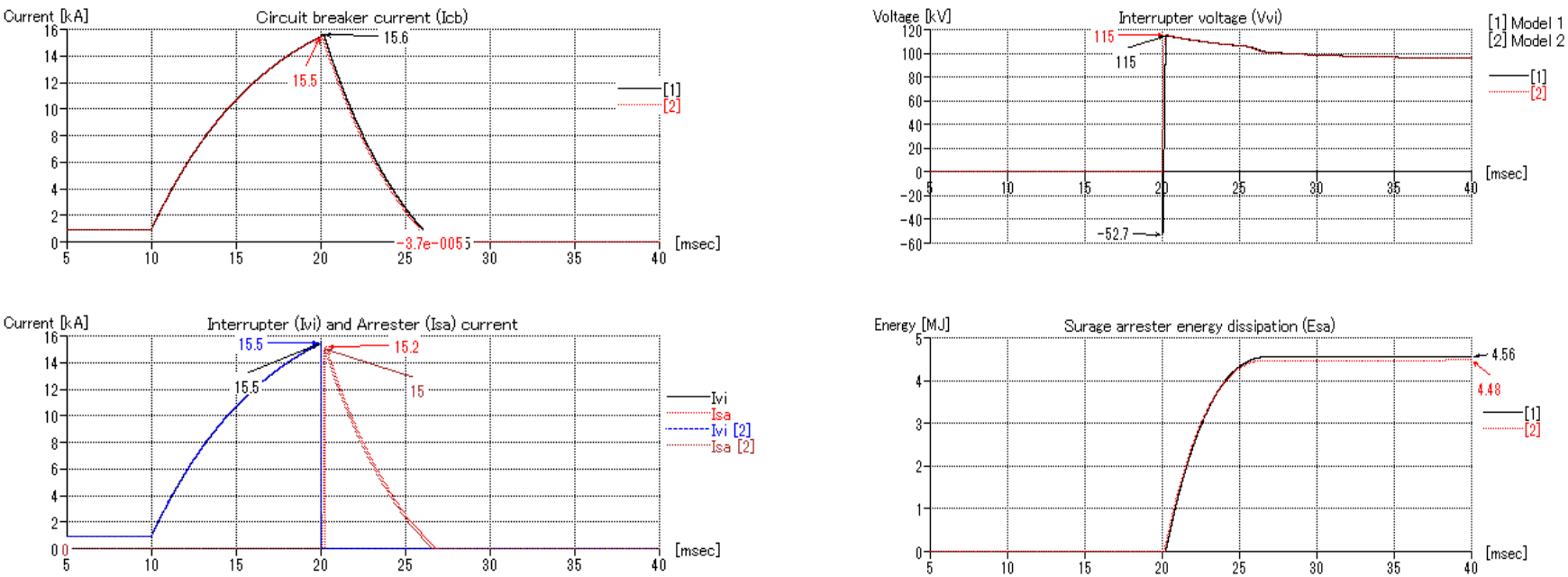

Figure 6. Simulation comparison of model 1 and model 2 for mechanical DC CB.

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Task 6.3 Develop component-level model for hybrid DC CB

1. DC CB Thermal stress,
2. Hybrid DC CB Electrical Stress,
3. Failure mode analysis of hybrid DC CB,
4. Fault current limiting and proactive breaking,
5. Ultrafast disconnector detailed model,
6. Voltage control of Ultrafast disconnector

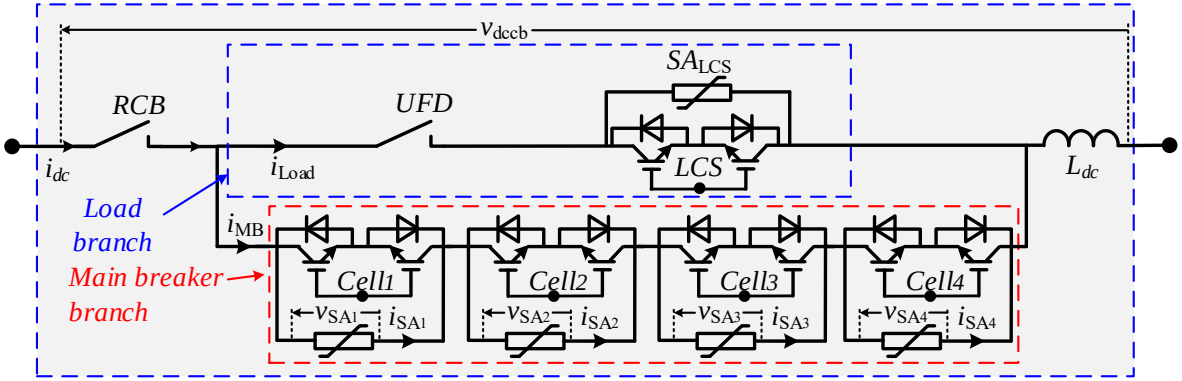

Figure 7. IGBT-based hybrid DC CB model with 4 modules.

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Task 6.3 Develop component-level and real-time model for hybrid DC CB

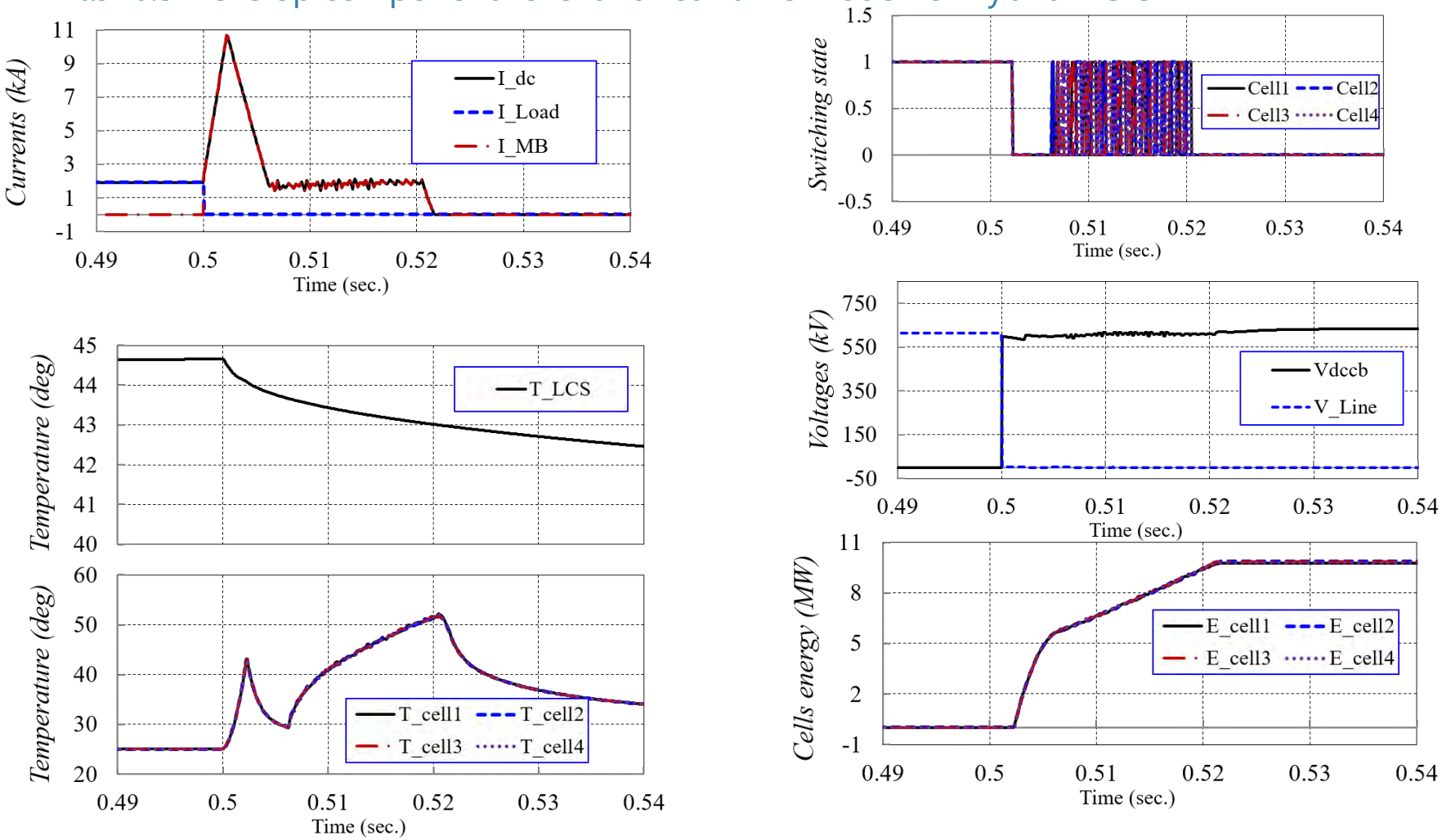

Figure 8. Simulation of fault current limiting mode.

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Task 6.3 Develop component-level and real-time model for hybrid DC CB

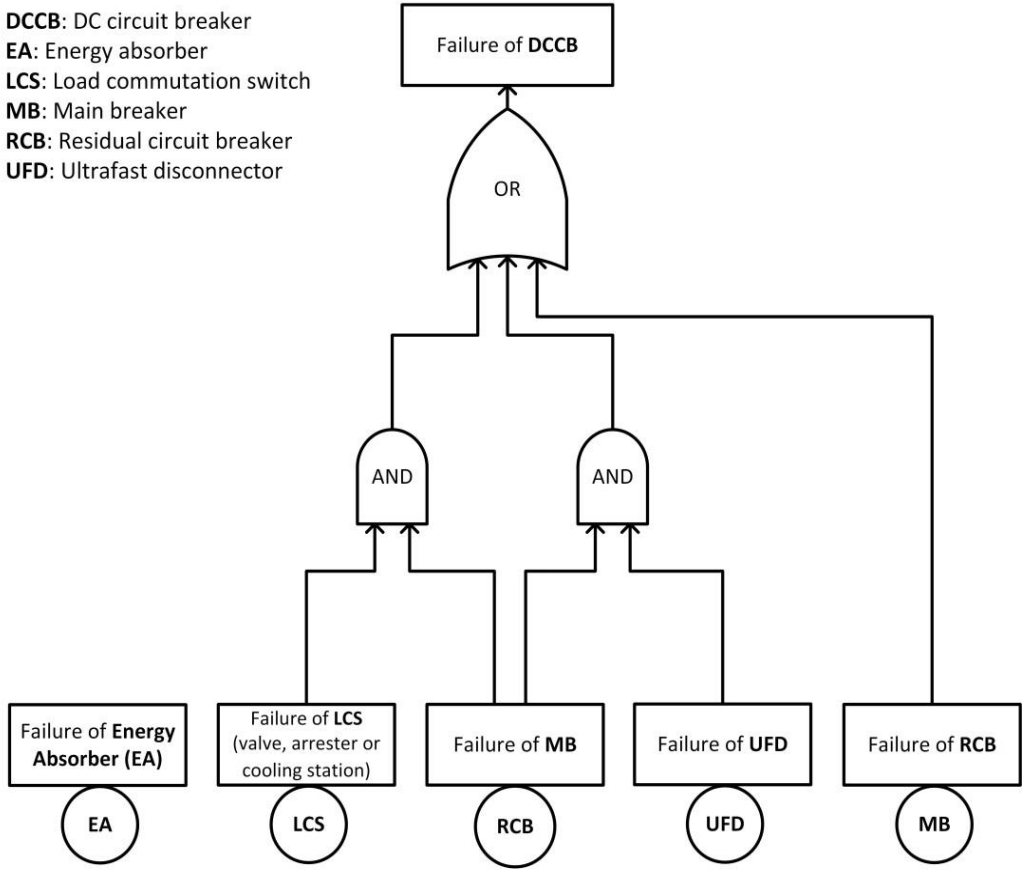

Figure 8. Failure tree diagram for hybrid DCCB in closed state.

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Task 6.4 Develop component-level and real-time model for mechanical DC CB

1. Thermal modelling of Surge Arresters,
2. Determination of suitable parameters of an active current injection DCCB,
3. Injection switches, time control and related stress on components,
4. Investigation on DCCB performance during a current interruption failure at first current zero,

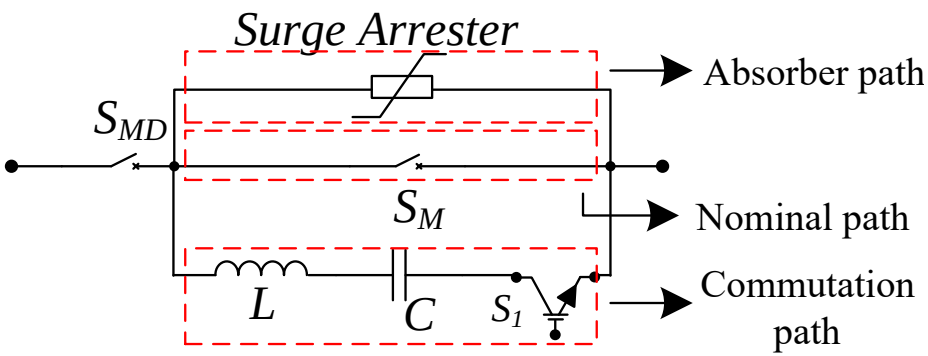

Figure 10. Typical configuration of mechanical DC CB.

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Task 6.4 Develop component-level and real-time model for mechanical DC CB

1. Finite element Thermal modelling of Surge Arresters,

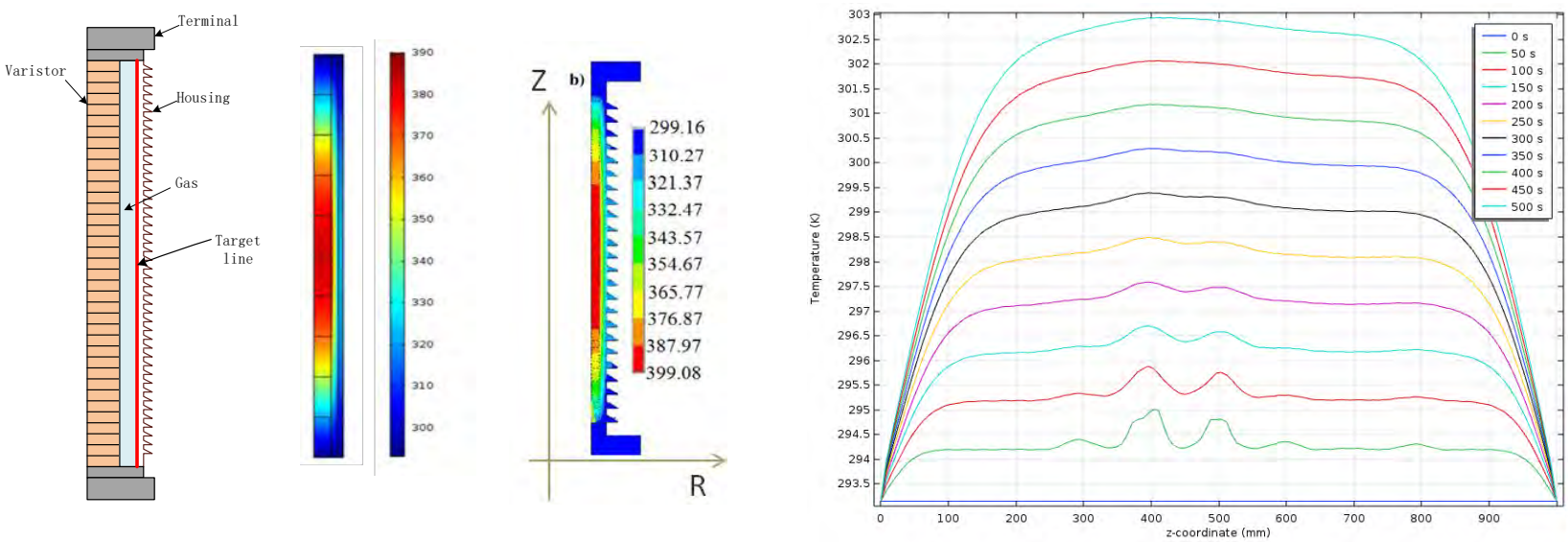

Figure 11. Temperature profiles on the border of SA housing and gas.

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Task 6.5 Develop kW-size hardware prototypes for hybrid and mechanical DC CBs

1. Test Circuit design and implementation,
   - 900V, 500A
   - Upgraded to 5kV, 2kA,
2. IGBT based Hybrid DC CB, 500A, 900V
3. Mechanical DCCB Demonstrator , 500A, 900V

Figure 12. Hardware DC CB and test circuit.

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Task 6.5 Develop kW-size hardware prototypes for hybrid and mechanical DC CBs

Voltage control of Ultrafast disconnector in Hybrid DC CB

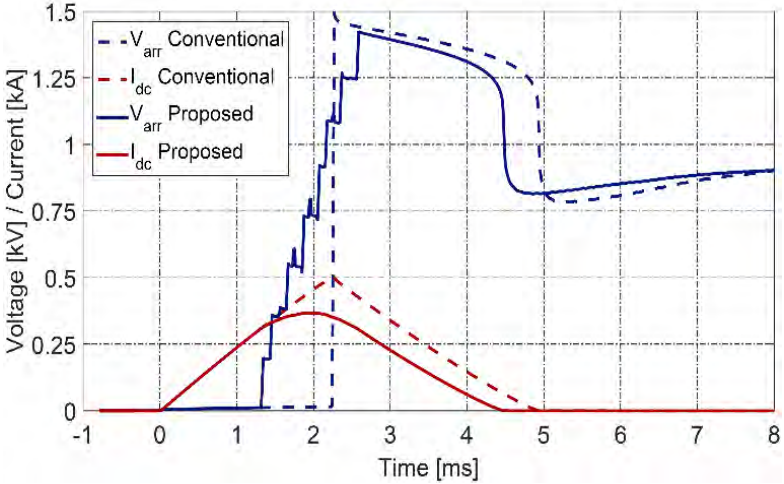


Figure 13. Voltage and current with UFD voltage control.

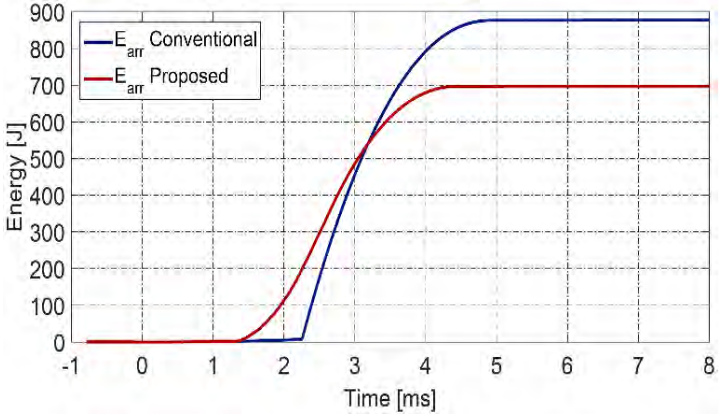
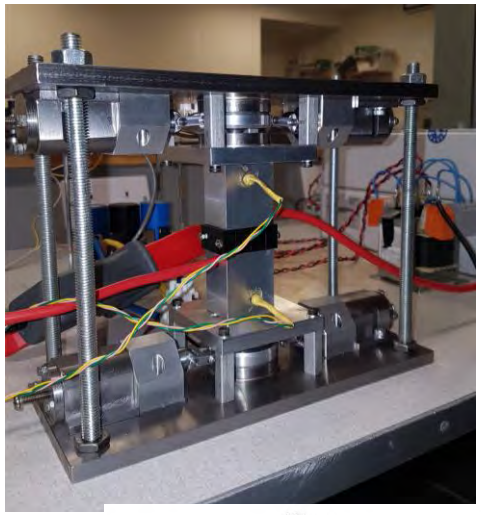


Figure 14. Energy with UFD voltage control.



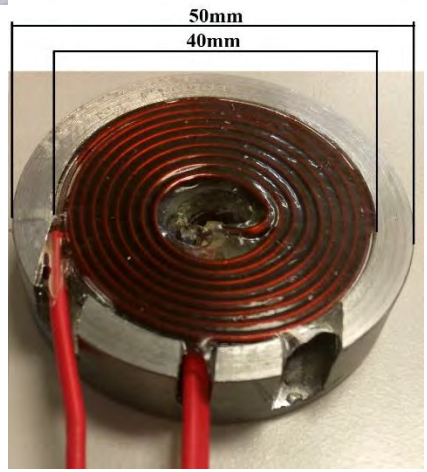


Figure 15. 3mm, 2ms Ultrafast Disconnector.

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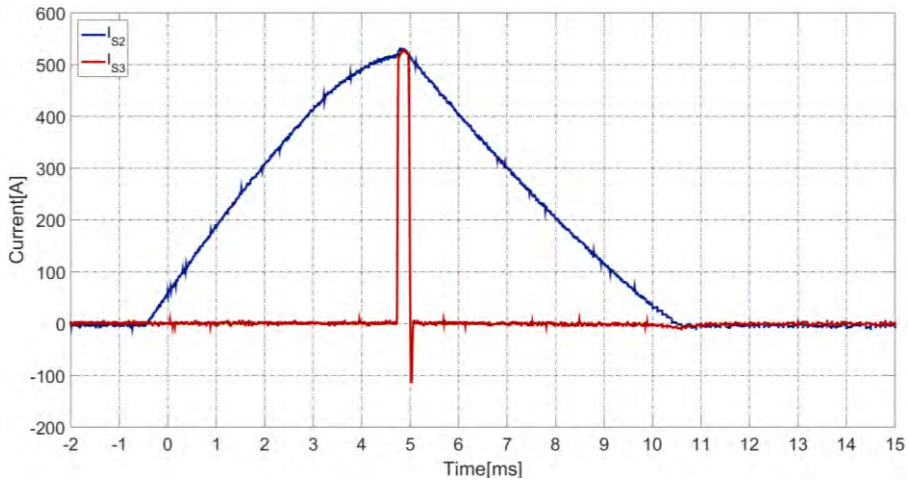
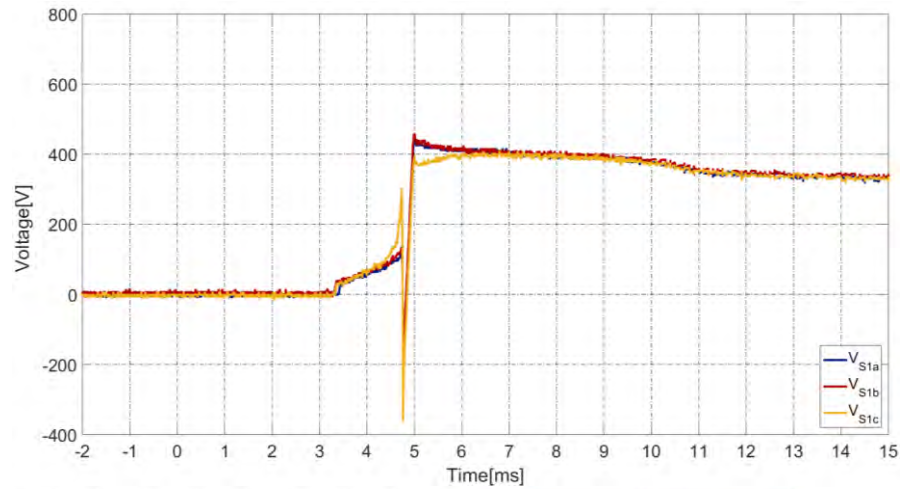
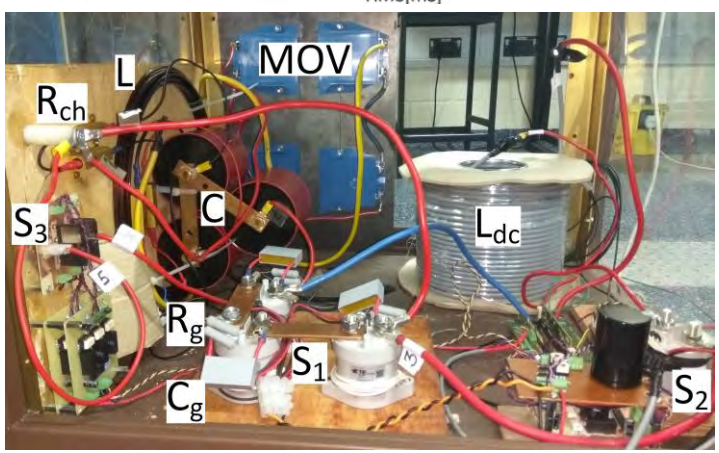
Task 6.5 Develop kW-size hardware prototypes for hybrid and mechanical DC CBs







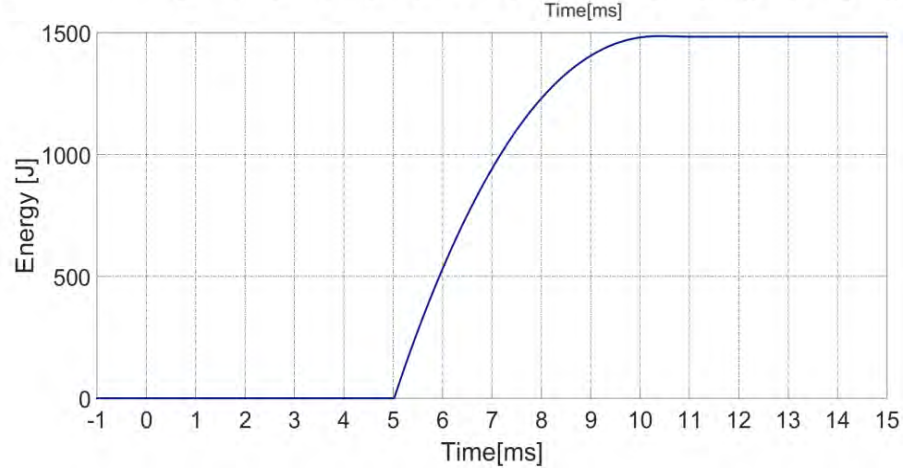


Figure 16. Successful interruption with mechanical DCCB (Vdc=750V)

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

Task 6.6 Demonstrate DC CB failure modes on kw-size hardware prototypes

1. Failure mode analysis of hybrid DC CB,
    1. Failure tree diagram
    2. Failure of Load commutation switch,
    3. Failure of ultrafast disconnector,
    4. Failure of main breaker
    5. Failure of energy absorber
    6. Failure of Residual current breaker
2. Failure mode analysis of hybrid DC CB,
    1. Failure tree diagram
    2. Failure of main breaker
    3. Failure of injection circuit,
    4. Failure of energy absorber,
    5. Failure of Residual current breaker

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Task 6.6 Demonstrate DC CB failure modes on kw-size hardware prototypes

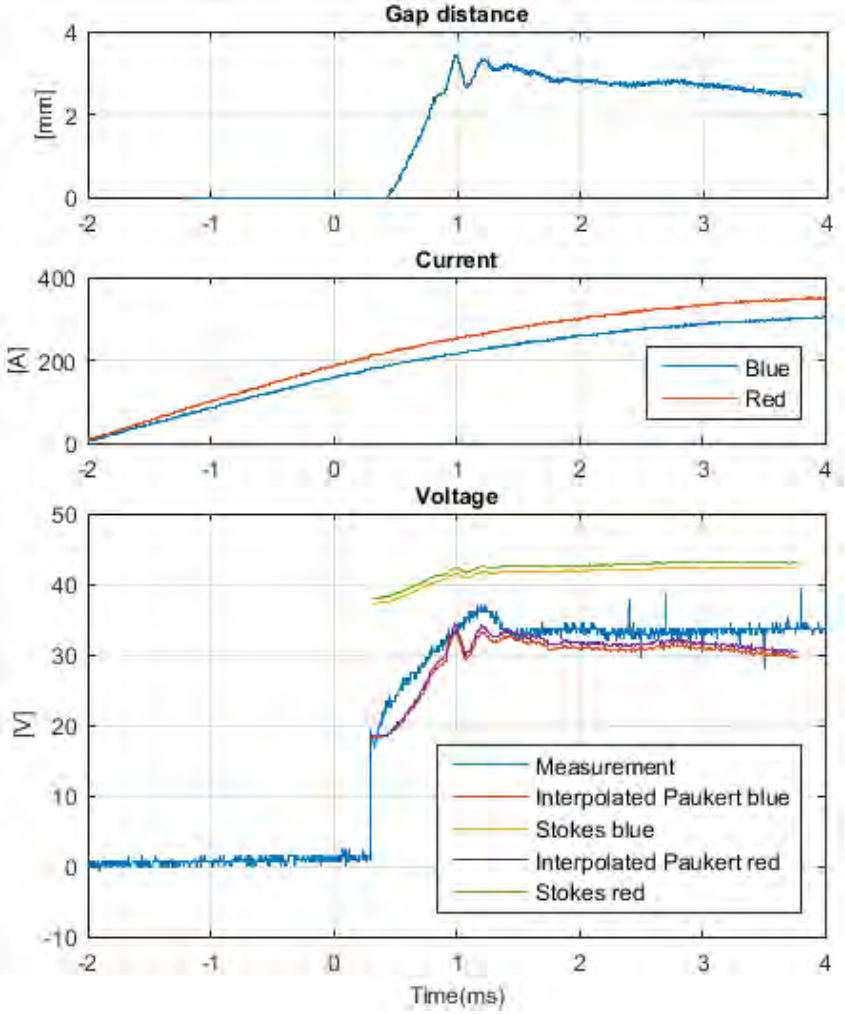

Figure 17 – Fitted arc models versus experimental data for high current

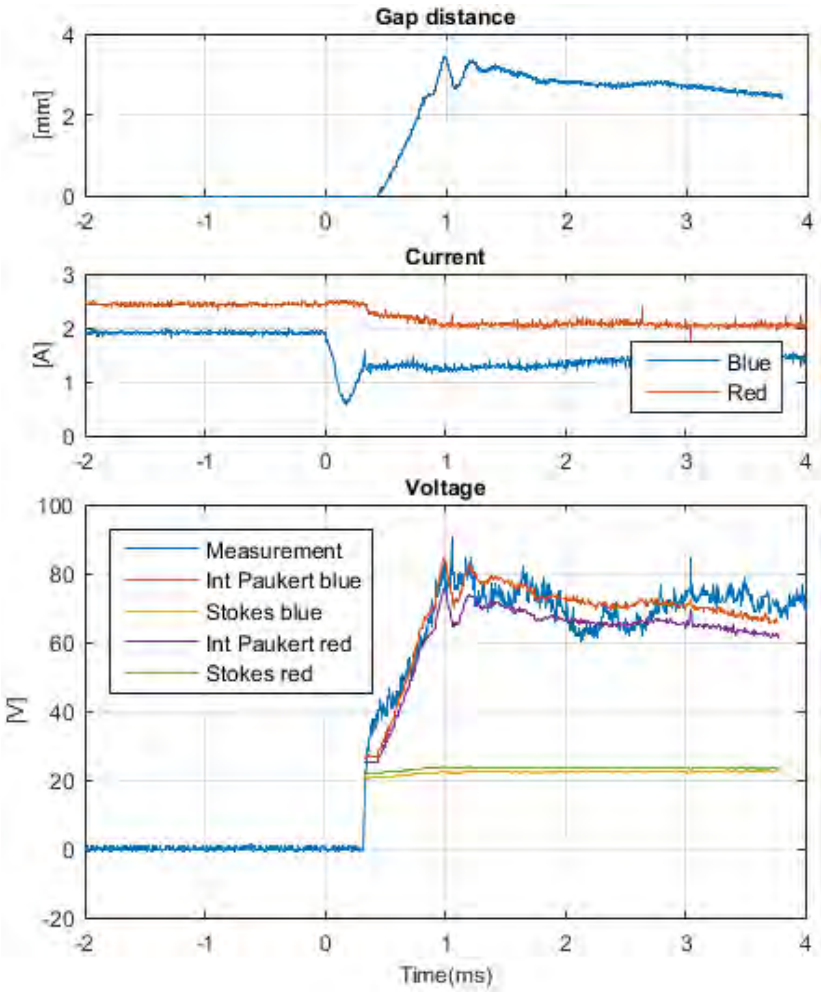

Figure 18 – Fitted arc models versus experimental data for low current

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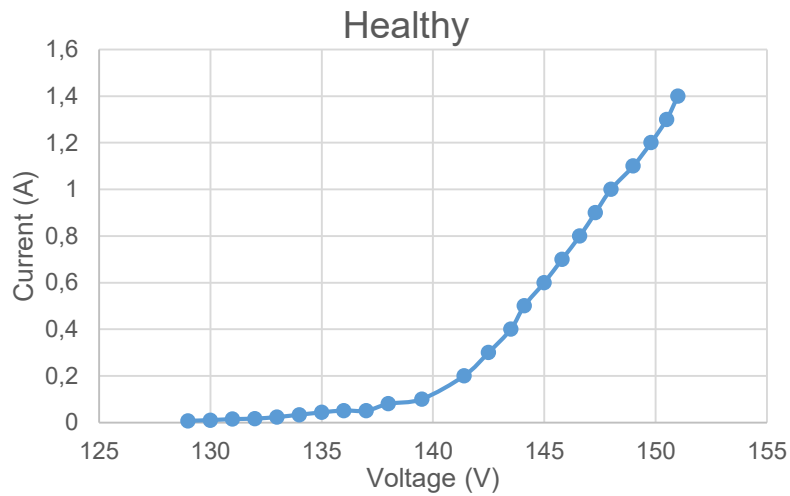
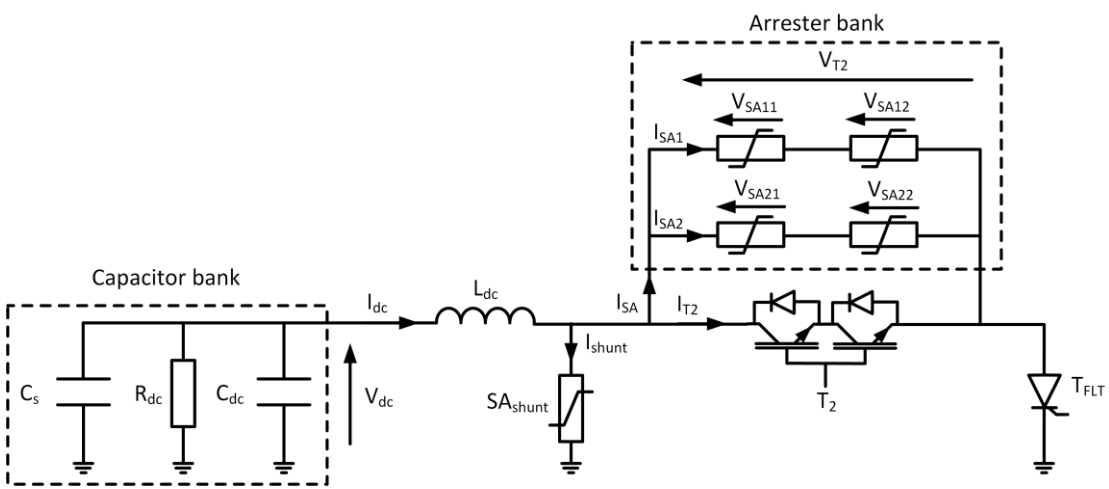
Task 6.6 Demonstrate DC CB failure modes on kw-size hardware prototypes

Component-level failure of surge arresters:

- Healthy arrester has variable resistance between 100 and 20k ohm in the observed range
- Failed arrester has constant resistance of around 2 ohms





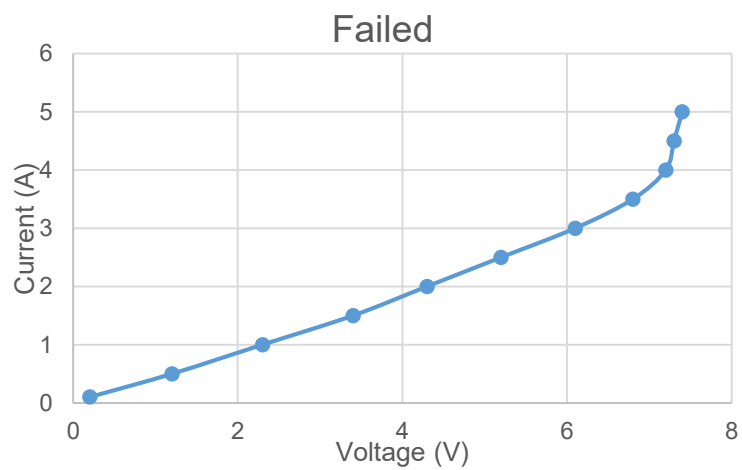


Figure 19 – Test circuit schematic for SA failure study.

Figure 20 – Healthy and failed arrester's I-V characteristic

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Task 6.6 Demonstrate DC CB failure modes on kw-size hardware prototypes

Cascaded failure of the main arrester bank

- One arrester in 2x2 bank failed,
- In the next interruption the second arrester in the sae branch fails – cascaded failure.
- Faulted branch takes the full DC current with very little counter voltage – breaker remains a closed circuit

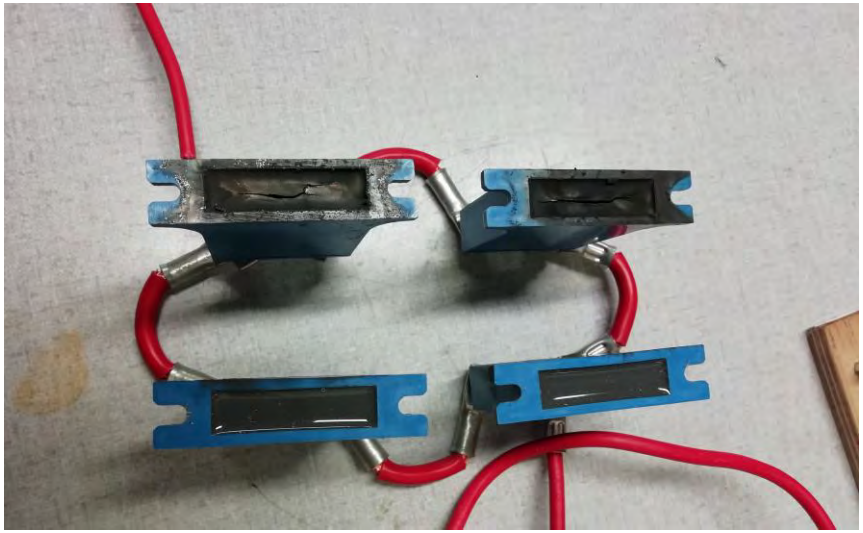


Figure 21– Arrester bank after failure (bottom)

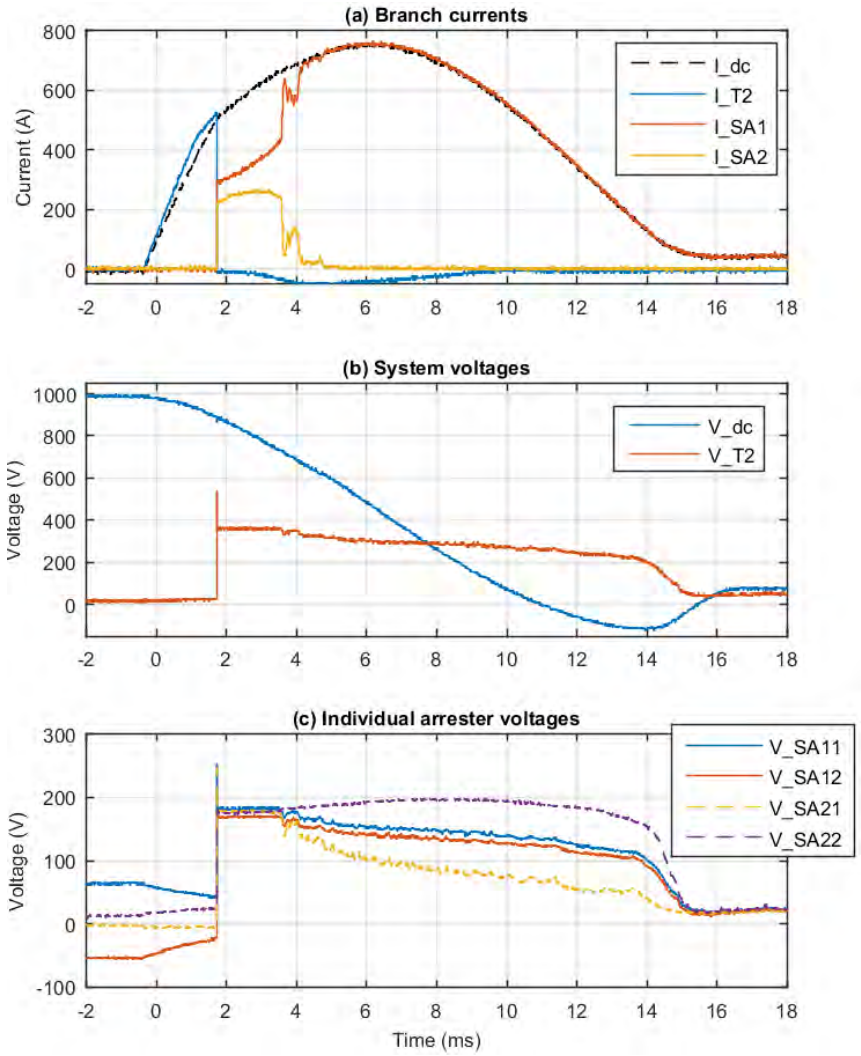


Figure 22 – Arrester bank failure during breaker opening

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

Task 6.6 Demonstrate DC CB failure modes on kw-size hardware prototypes

Failure of arrester at Load Commutation Switch

- UFD fails to open.
- LCS arrester takes full line current because of its low voltage rating. The arrester overloads and ruptures
- An arc ignites between the arrester's ruptured contacts which maintains low voltage across T1
- The breaker remains a closed circuit but T1 survives

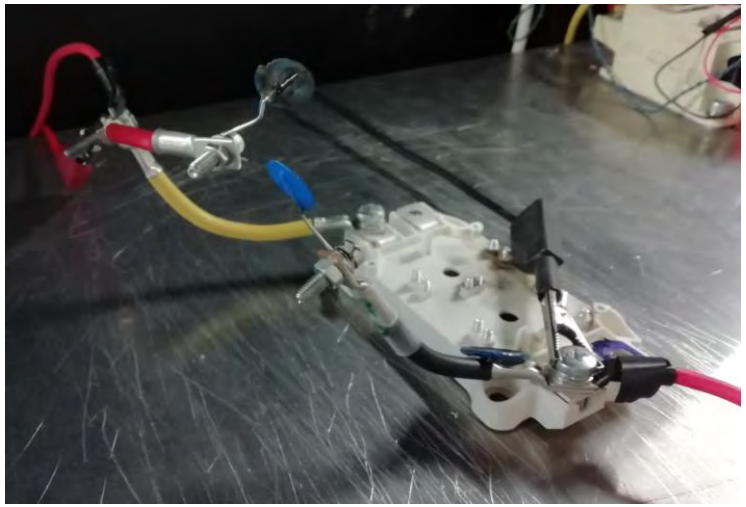


Figure 23 – T1 with arrester after failure

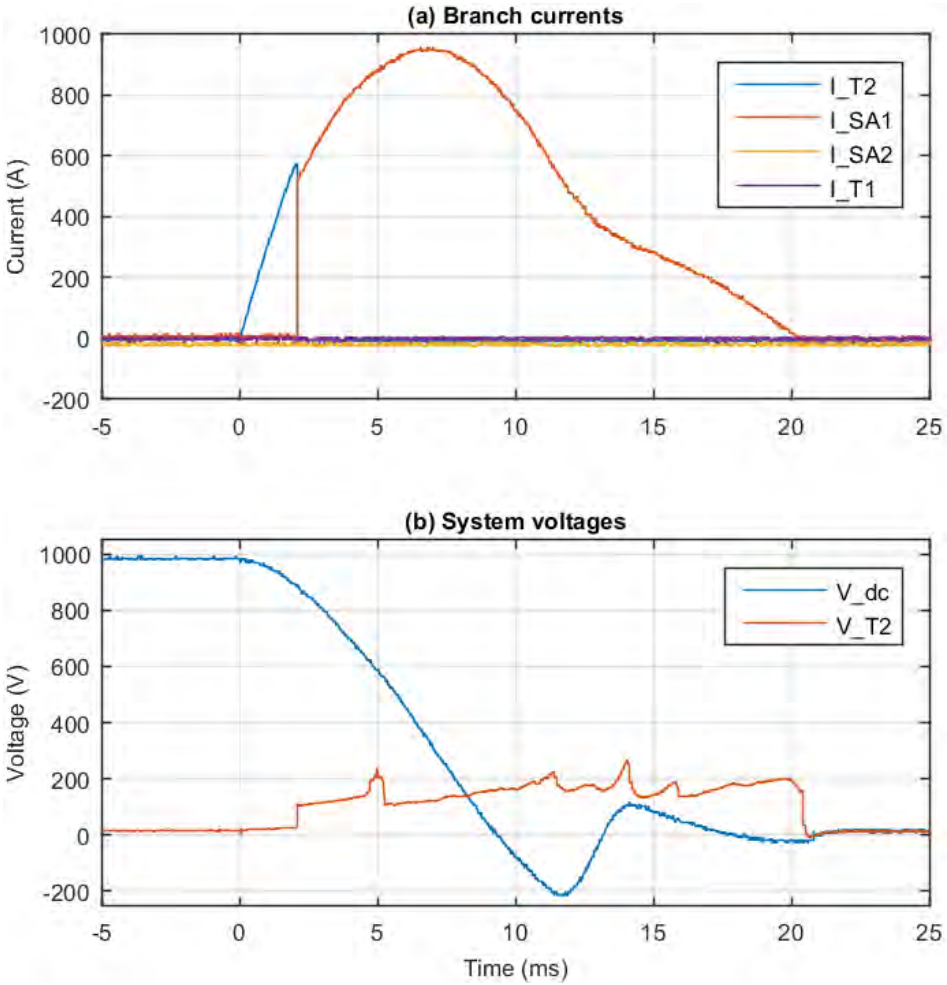


Figure 24 – Test results for LCS arrester failure

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

Task 6.7 Analyse hybrid DC CB integration into EHV DC grid

1. Scaling the hybrid DC circuit breaker to extra high voltage
2. Integration of a hybrid DCCB in a DC grid
3. Simplified hybrid DC CB modelling for grid-level studies
4. Advanced DC CB topologies

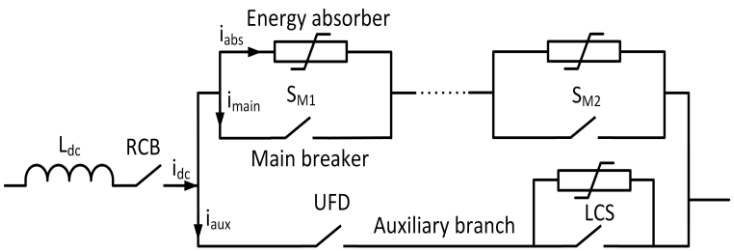


Figure 25 – Simplified hybrid DCCB model,

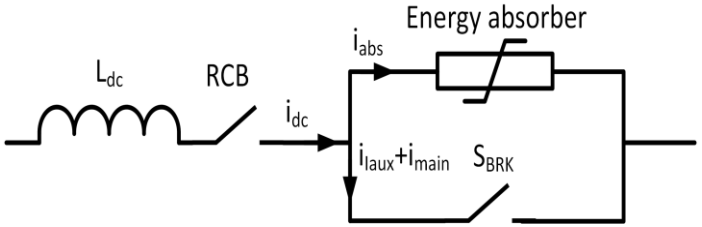


Figure 26 – Generic DCCB model,

Table 1– Simulation effort with different DCCB models

Topology	Detailed	Simplified	Generic
Hybrid DC CB	690 min ~ 11.5 h	25 min	2.5 min
Active-resonant	6.0 min	2.5 min	2.5 min
VARC	197 min ~ 3.3 h	2.5 min	2.5 min

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

Task 6.7 Analyse hybrid DC CB integration into EHV DC grid

DC grid integration of hybrid DCCB

a) DC grid model from WP4,
b) Common test plan (T6.7, T6.8 and T6.10),
c) Common variables of interest (T6.7, T6.8 and T6.10),

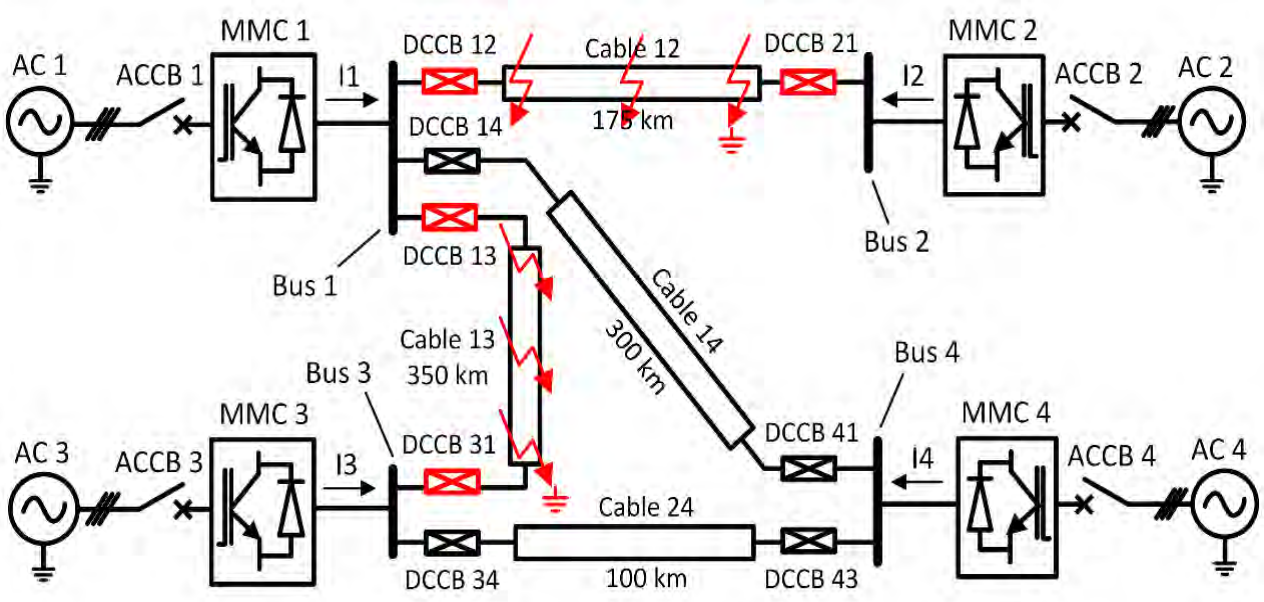


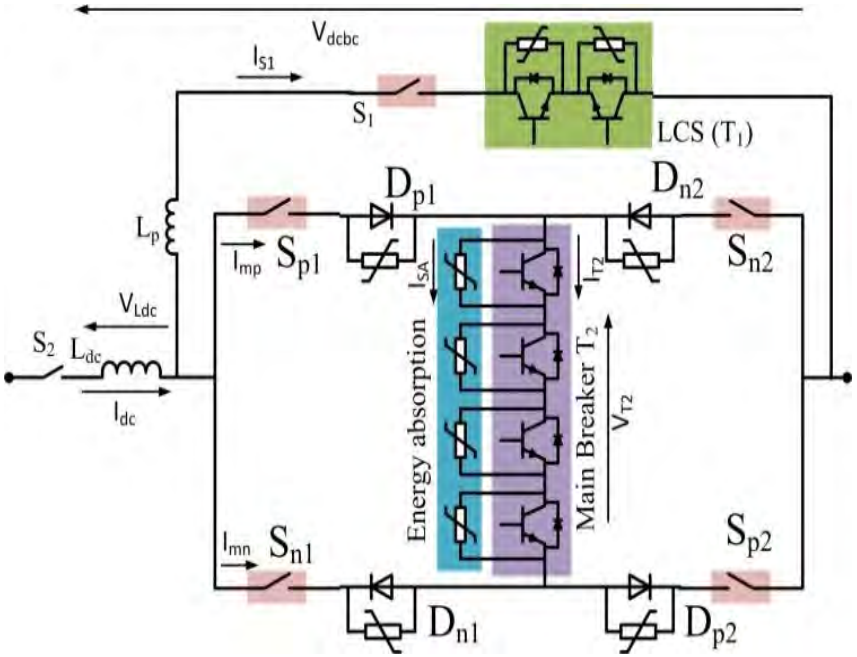
Figure 27 – Four terminal DC grid employed in T6,7, T6.8 and T6.10,

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

Task 6.7 Analyse hybrid DC CB integration into EHV DC grid

Advanced topologies:

a) Bidirectional breaker with unidirectional valve,
b) LC DC Circuit Breaker,



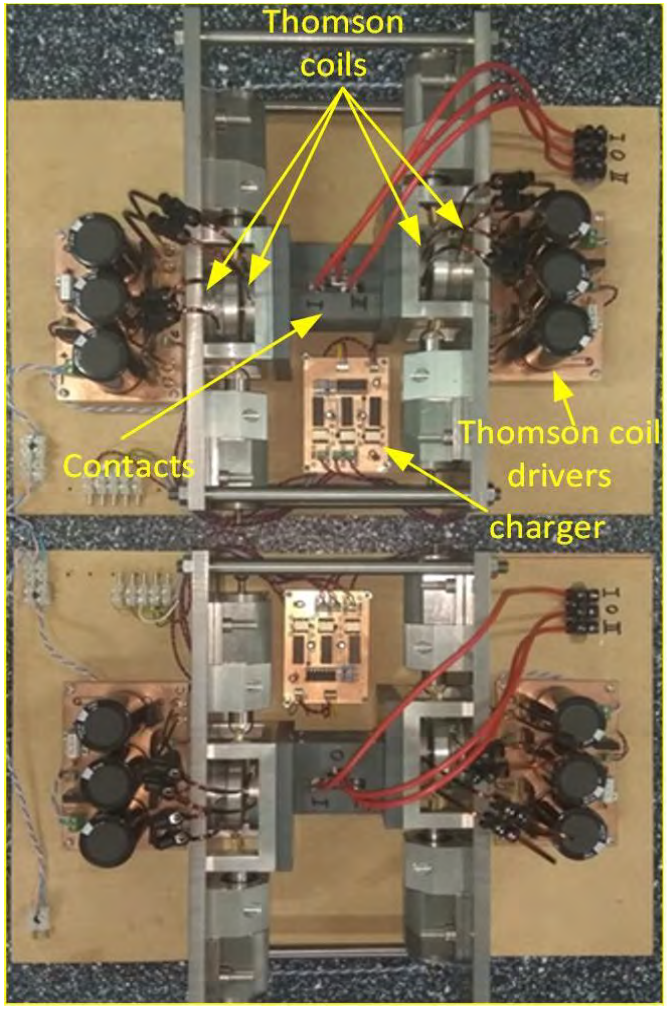


Figure 28 – Bidirectional DC CB with unidirectional valve and two double-throw disconnectors,

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

Task 6.8 Develop roadmap for VARC DC CB scaling to EHV DC voltage

1. Modelling and Experimental Verification of VARC HVDC Circuit Breakers
2. Scaling of VARC DC CB to EHV
3. The Implementation of VARC DC CB in TenneT grid
4. Implementation of VARC DC CB in a 4-terminal MTDC grid (as developed in wp4)

L

VARC DC CB

(a)

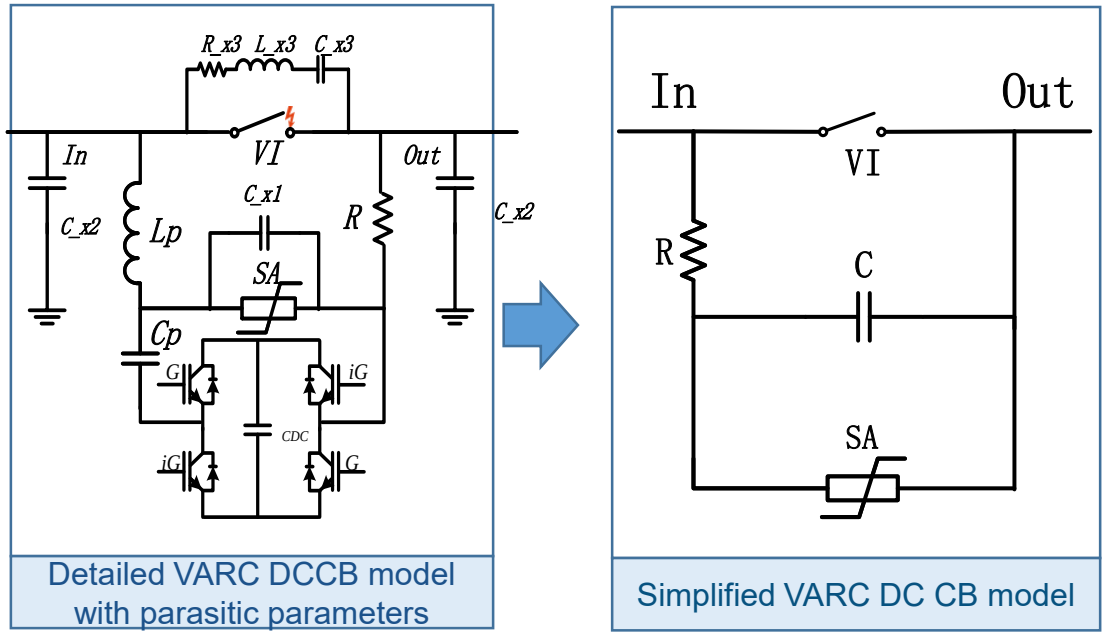


Figure 29 – Detailed and simplified VARC DCCB model,

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

Task 6.9 Develop standard DC CB verification plan and RTDS models

1. General DC CB model verification plan (including self protection)

2. Verification of IGBT-BASED Hybrid DC CB model

3. Verification of Thyristor based Hybrid DC CB model

4. Verification of mechanical DC CB model

5. Verification of VSC assisted mechanical DC CB model

6. RTDS modelling and verification of IGBT based hybrid DCCB

7. RTDS modelling and verification of mechanical DCCB

Models will be verified against WP10 test measurements

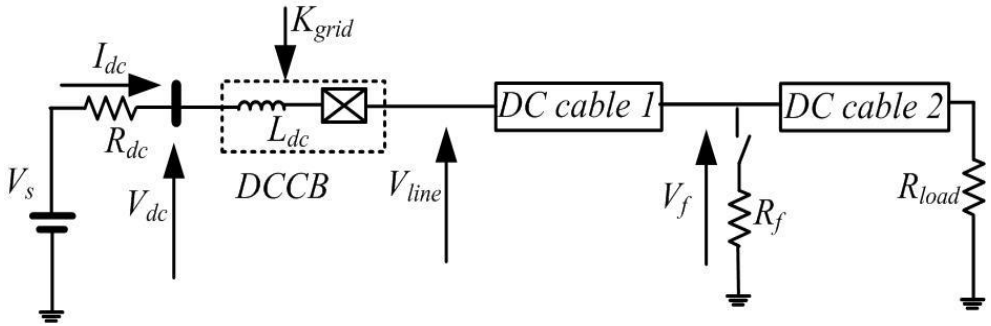


Figure 30. Test circuit for DC CB model verification.

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

Task 6.9 Develop standard DC CB verification plan and RTDS models

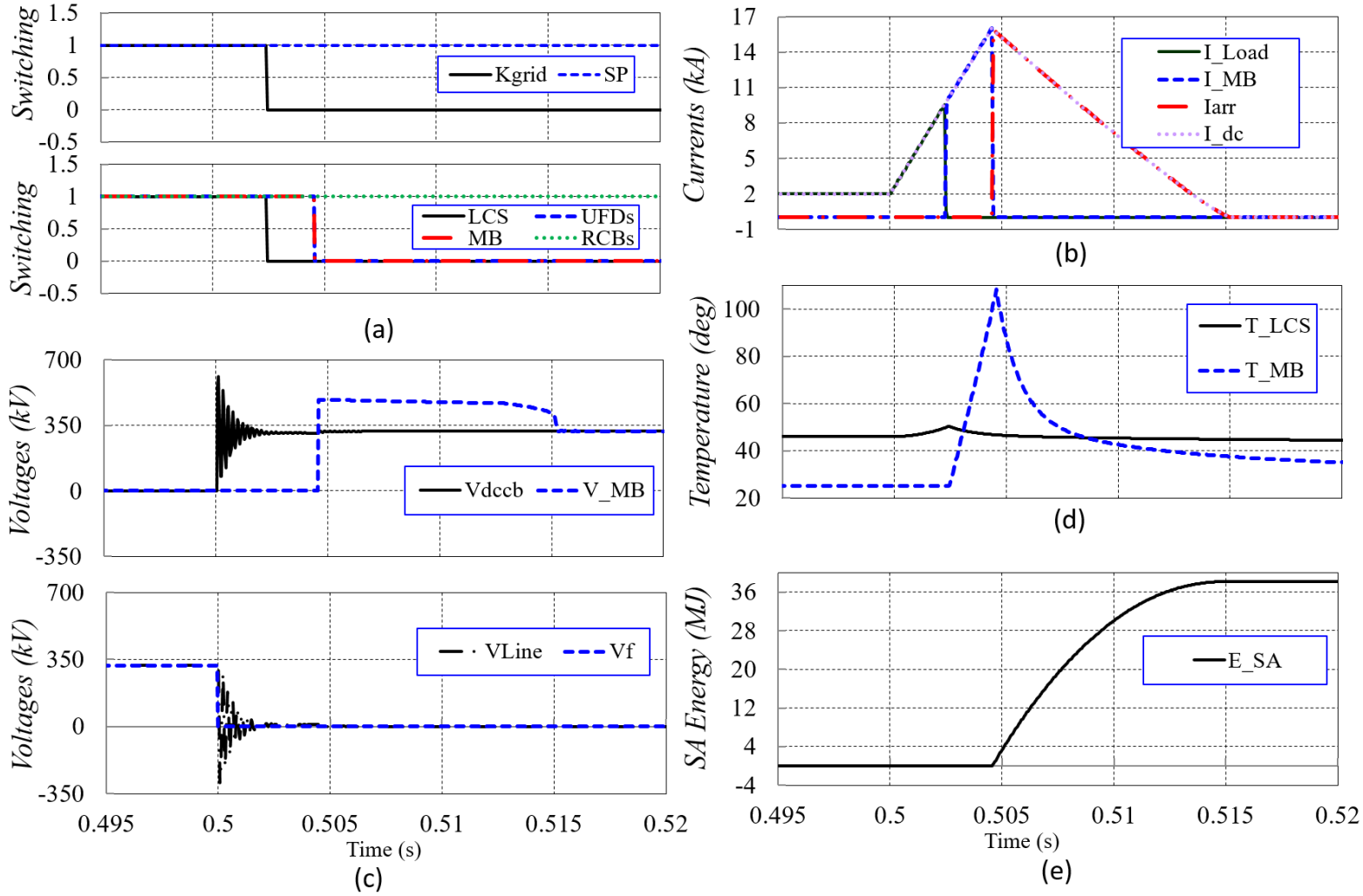


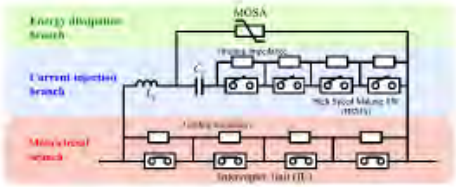
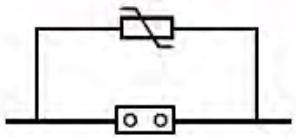
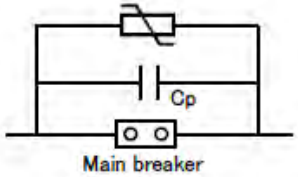
Figure 31. High current interruption IGBT DC CB model testing.

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

Task 6.10 Develop roadmap for mechanical DC CB scaling to EHV DC voltage

1) STUDY OF SCALING TO EHV ON DETAILED MODEL
2) MECHANICAL DCCB INTERACTION WITH GRID
3) VERIFICATION OF SYSTEM-LEVEL MODEL

Table 4 Comparison of DC BUS voltage between models

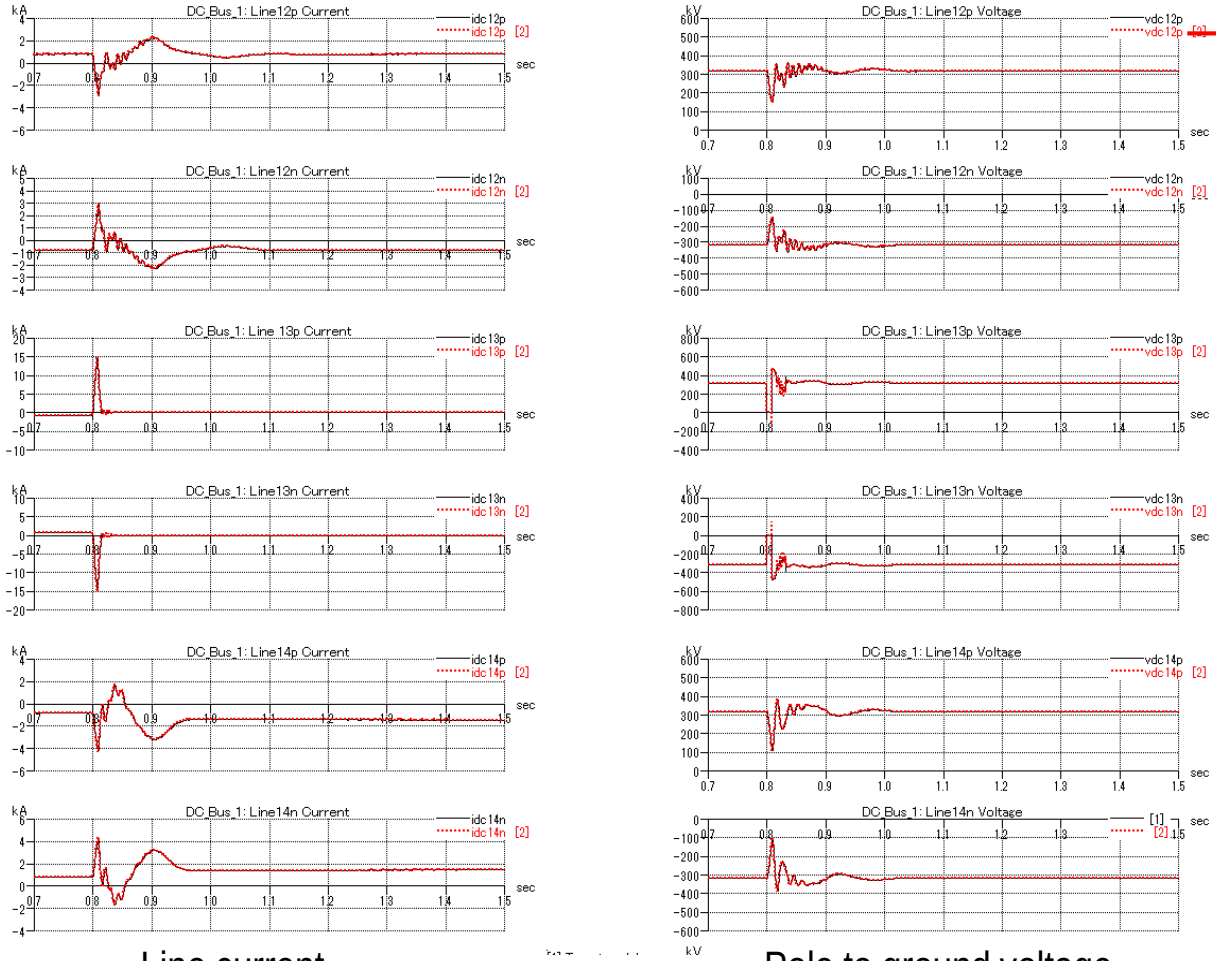
MODEL		TIV RISING POINT	MMC RESTARTING POINT
Detailed		308.7 kV (100%)	267.6 kV (100%)
Generic		312.1 kV (101%)	223.5 kV (83.5%)
Simplified		311.1 kV (101%)	260.4 kV (97.3%)

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

Task 6.10 Develop roadmap for mechanical DC CB scaling to EHV DC voltage

Simple DCCB model (System level model)

MEU DCCB detailed model



Line current

Pole to ground voltage

Figure 32. The simulation results show examples of waveforms at the DC BUS 1 current/voltage close to the operated DCCB.

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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.

3) WP6 Characterisation of DC CBs, Contribution towards objectives, WP12 and WP11,

1 'To establish interoperability between different technologies and concepts by providing specific technical and operational requirements, behaviour patterns and standardization methods for different technologies ' – WP12

3 Different DC CB technologies are considered and for all technologies:

- Models (detailed, simplified) delivered on common platform (PSCAD),
- Real time modes delivered on common platform (RTDS),
- Demonstrated on scaled hardware 900V, 500A DC CB demonstrator (except VARC DC CB),
- Common simplified and generic DC CB model developed,
- Common verification plan for DC CB models,
- Generic input/output DC CB interface developed (jointly with WP4),

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

3) WP6 Characterisation of DC CBs, Contribution towards objectives, WP12 and WP11 ,

2. 'To develop interoperable, reliable and cost-effective technology of protection for meshed HVDC offshore grids and the new type of offshore converter for wind power integration' –WP12

- Multiple studies on improved and advanced DC CB technologies (Lower costs, smaller/simpler, faster DC CB),
- Evaluated and demonstarted failure modes for DC CB and components, (understanding and improving reliability),
- Proposed interface between DC CB and protection system (jointly with WP4), (enhancing interoperability),

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

3) WP6 Characterisation of DC CBs, Contribution towards objectives, WP12 and WP11,

5. *To facilitating the harmonization of ongoing initiatives, common system interfaces and future standards by actively engaging with working groups and standardization bodies and actively using experience from the demonstrations' - WP11*

- Models (detailed, simplified) for 3 DC CB technologies delivered on common platform (PSCAD),
- Real time modes for 3 DC CB technologies delivered on common platform (RTDS),
- 2 DC CB technologies demonstrated on scaled hardware 900V, 500A DC CB in Universiy laboratory,
- Common simplified and generic model developed applicable to all 3 DC CB topologies,
- Common verification plan for DC CB models,
- Generic input/output DC CB interface developed (jointly with WP4),
- DC CB model common verification plan,
- Engagement in professional community:
- Dissemination at professional conferences and in journals (9 conferences and 9 journals),
- 3 panels at professional events (IEEE conferences),
- Particpation in CIGRE JWG A3/B4.80,
- (Small) cntribution to CENELEC.

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

Conclusions

1. WP6 status
   a. 6 deliverables completed
   b. 4 deliverables in final stages
   c. 16 meetings,
2. WP6 Outputs
   a. PSCAD models for 3 DC CB topologies – publicly available
   b. Generic/simplified DC CB model and model verification method, - publicly available,
   c. RTDS models for 3 DC CB topologies,
   d. DC CB low power demonstrators and DCCB test circuit,
   e. 9 journal articles,
   f. 9 conference articles,
   g. 3 panels,
   h. 1 workshop,
   i. 2 newsletter articles,
3. Proposed improvements to DC CB and new topologies,
   a. UFD voltage control,
   a) Bidircetional DC CB with unidiercational valve,
   b) DC CB with parallel capacitor,
4. Contribution to project objectives,
5. Contrbution to WP11,
6. Contribution to WP12,

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

WP10: HVDC CIRCUIT BREAKER PERFORMANCE DEMONSTRATION

PROMOTioN Half-Yearly Consortium Meeting, Roskilde, Dec. 2, 2019

René Smeets / Nadew Belda / Roy Nijman KEMA Labs, DNV GL

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

- Document status
- MEU‘s 160 - 200 kV breaker testing + demo
- Results and lessons learnt
- Evaluation of component stresses
- Standards development
- 2020 HVDC breaker demos

PROMOTioN research work on HVDC breaker stresses @ KEMA labs

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

Deliverables to come

• D10.1 – D10.4	Submitted	
• D10.5	Failure modes of HVDC breakers - final draft	confidential
• D10.6	Testing of HVDC circuit breakers (details, incl. all tests)	confidential
• D10.7	Demonstration of HVDC circuit breakers (performance)	public
• D10.8	Initialization of standardization	public
• D10.9	Reporting	public

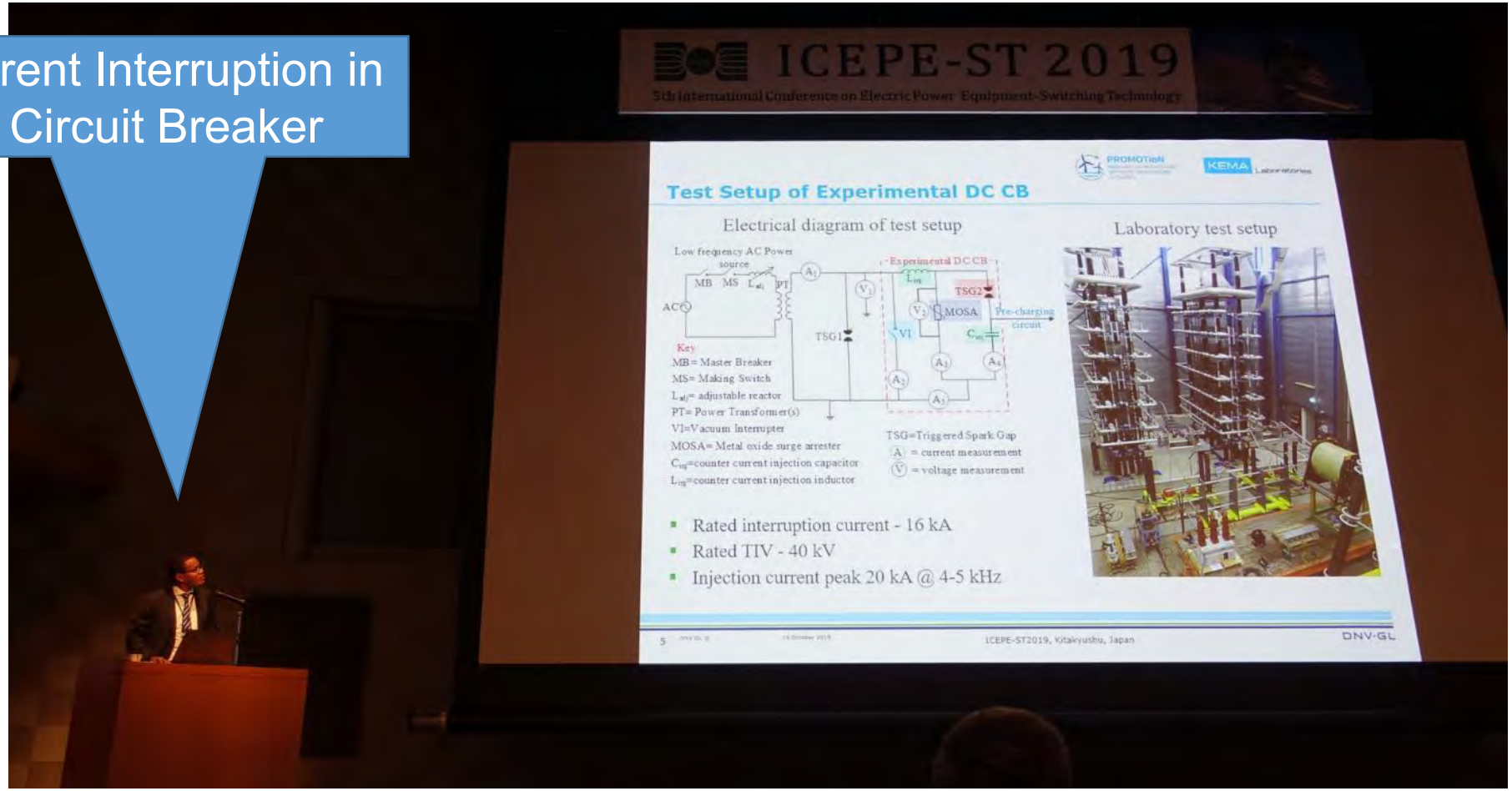
- Deadline: June 30, 2020

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

Nadew Belda wins *Wang Jimei Young Investigators Award* at ICEPE-ST conference in Japan, Oct.16, 2019

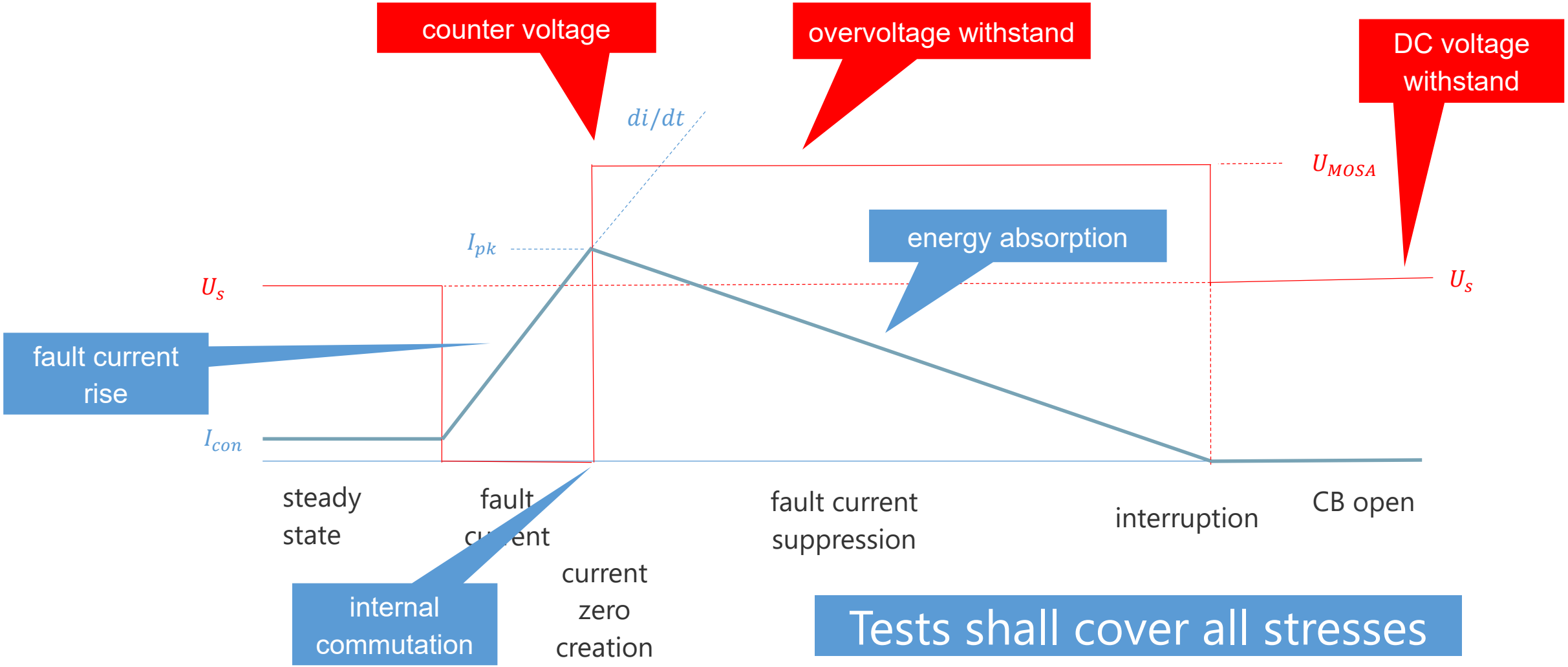
High-Frequency Current Interruption in an Experimental DC Circuit Breaker

- 40 papers on DC switching
- One invited lecture
- One panel session with PROMOTioN and Chinese manufacturers



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

The critical stresses on HVDC circuit breakers



Tests shall cover all stresses

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

Proposed breaking test requirements – Test program agreed WP10

Name	Current	Breaking test	#
TC10+	10% of rated continuous current	2 tests in positive current direction	2
TC10-	10% of rated continuous current	2 tests in negative current direction	2
TC100+	100% of rated continuous current	2 tests in positive current direction	2
TC100-	100% of rated continuous current	2 tests in negative current direction	2
TF100+	100% of peak fault current	2 test at specified energy absorption*, positive current direction	2
TF100-	100% of peak fault current	2 test at specified energy absorption*, negative current direction	2
TDT+	TBD	2 test at rated fault current suppression time**, positive current direction	2
TDT-	TBD	2 test at rated fault current suppression time**, negative current direction	2
	*: Specified energy absorption based on specified value of energy absorption (MJ) of the test-object delivered **: Rated fault current suppression time based on *Us, UMOSA, ΔTic, Ipk*, as would be present in service condition		
	All tests are single opening operations		
	In all tests, *Us* (considering 10-15 % overvoltage) will be supplied during 300 ms after main current interruption		

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

MEU demo test June 20

11:30	**Registration**
12:00 – 13:00	**Lunch**
12:40 – 13:00	**Welcome (starts during lunch)** Shankar Subramany DNV GL – KEMA High Power Laboratory
13:00 – 13:30	**Progress on Meshed Offshore HVDC Transmission Networks** Cornelis Plet DNV GL – PROMOTioN Coordinator
13:30 – 14:00	**Mechanical HVDC Circuit Breaker with Active Current Injection** Ito Hiroki Mitsubishi Electric Co.
14:00 – 14:30	**Testing Methods for HVDC Circuit Breakers** Nadew Belda DNV GL – KEMA High Power Laboratory
14:30 – 15:00	**Transport to laboratory (incl. safety briefing)**
15:00 – 16:00	**Demonstration of DC fault current interruption**
16:00 – 17:00	**Tour through high power and high voltage laboratory**
17:00 – 17:30	**Transport to Haarhuis hotel and Central station**

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

MEU 160 - 200 kV / 16 kA HVDC breaker under test

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

Full-power testing of 160-200 kV active current injection breaker

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

Combination of different sources

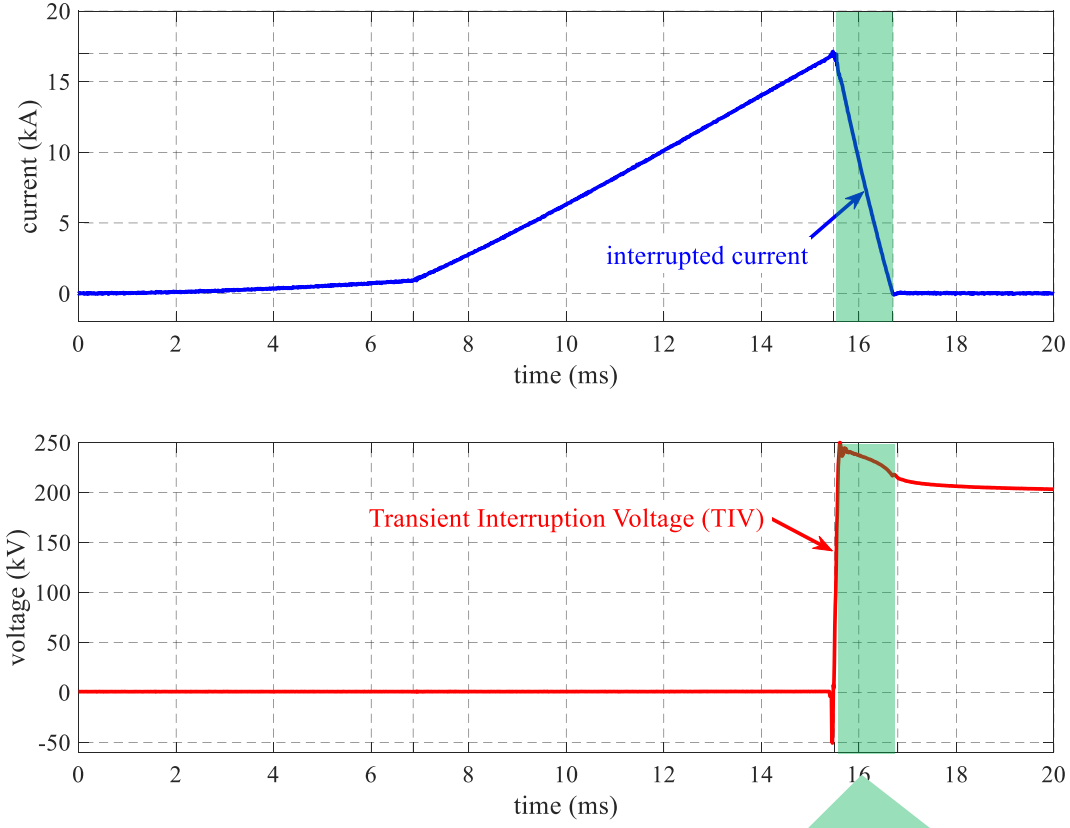
AC power generators

Test laboratory and DC sources

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

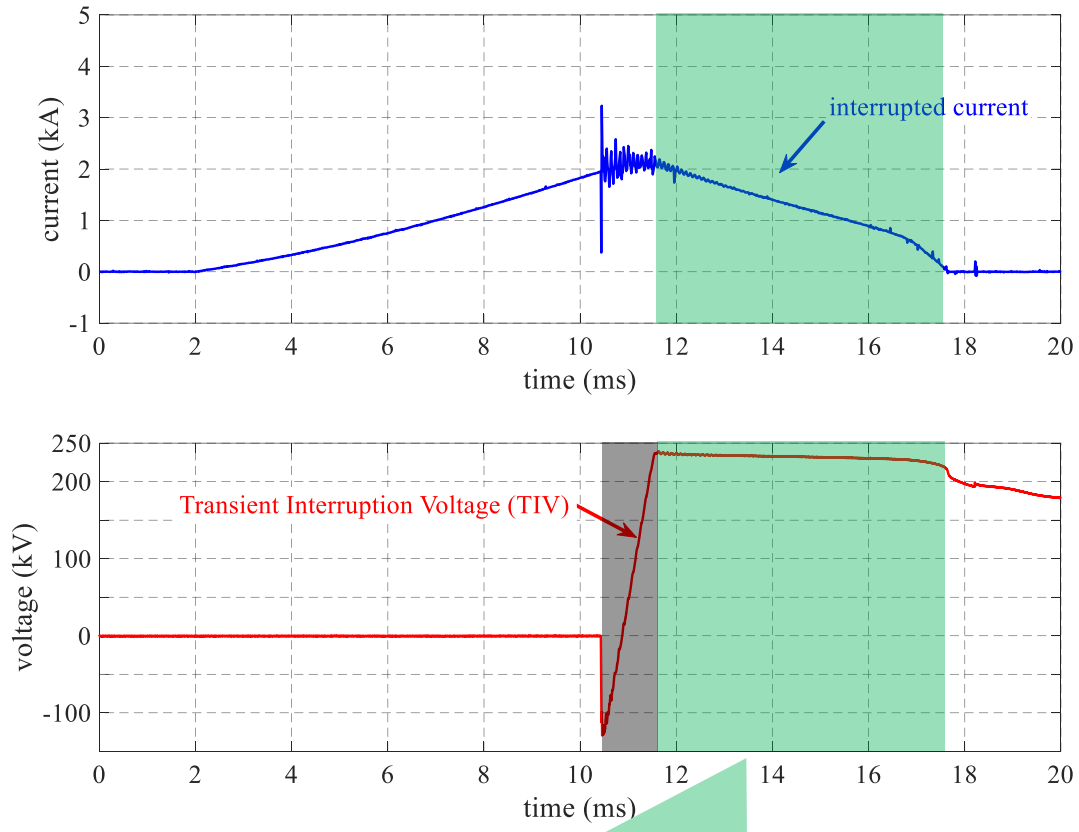
Application of adequate stresses in tests with limited MOSA

Fault current interruption with energy limitation



1.2 ms overvoltage duration

Load current interruption incl. TIV overvoltage stress



> 6 ms overvoltage duration

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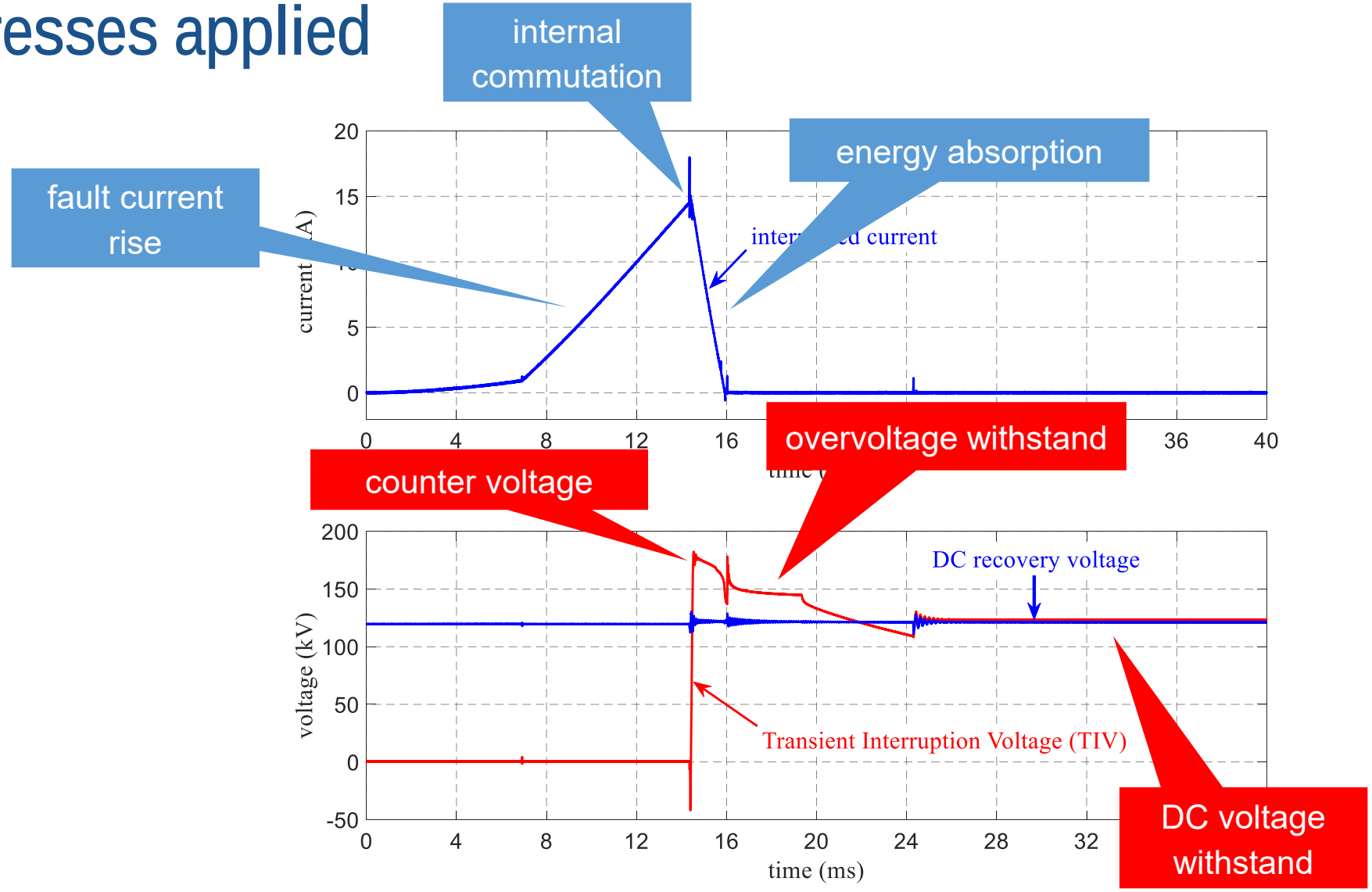
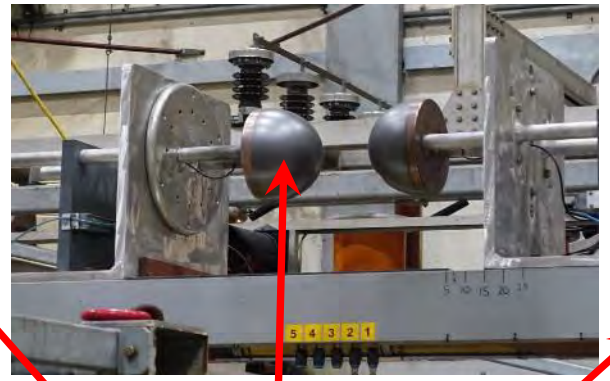
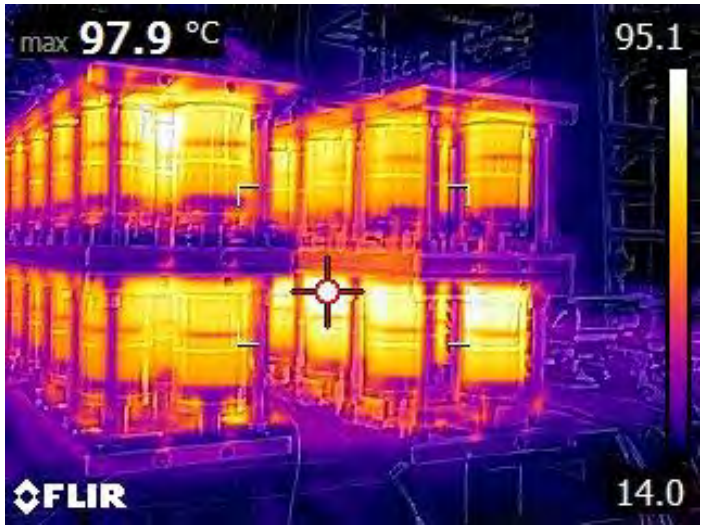
Six stresses applied

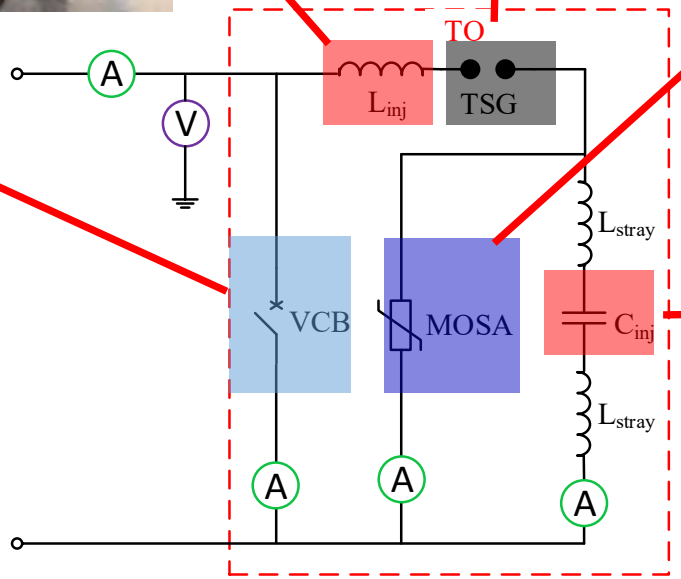


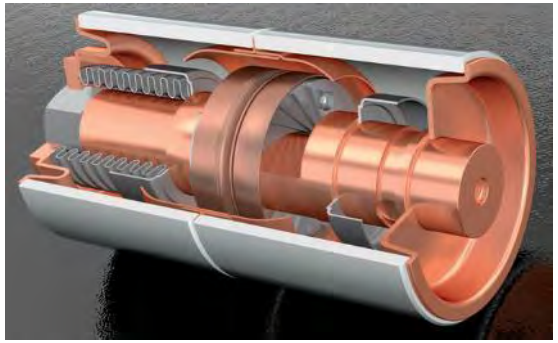
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

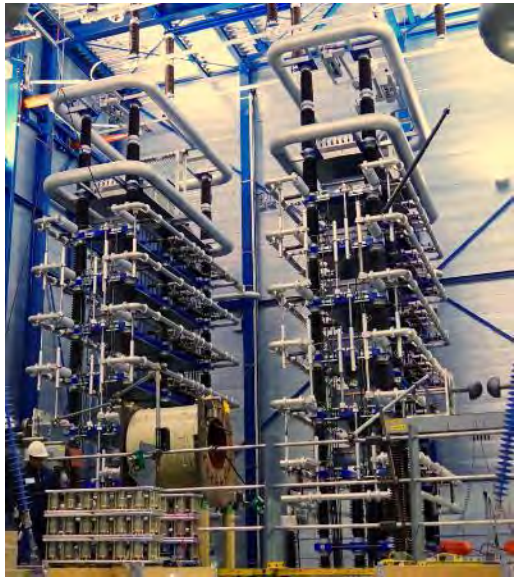
Getting to know the internal critical stresses by power experiments









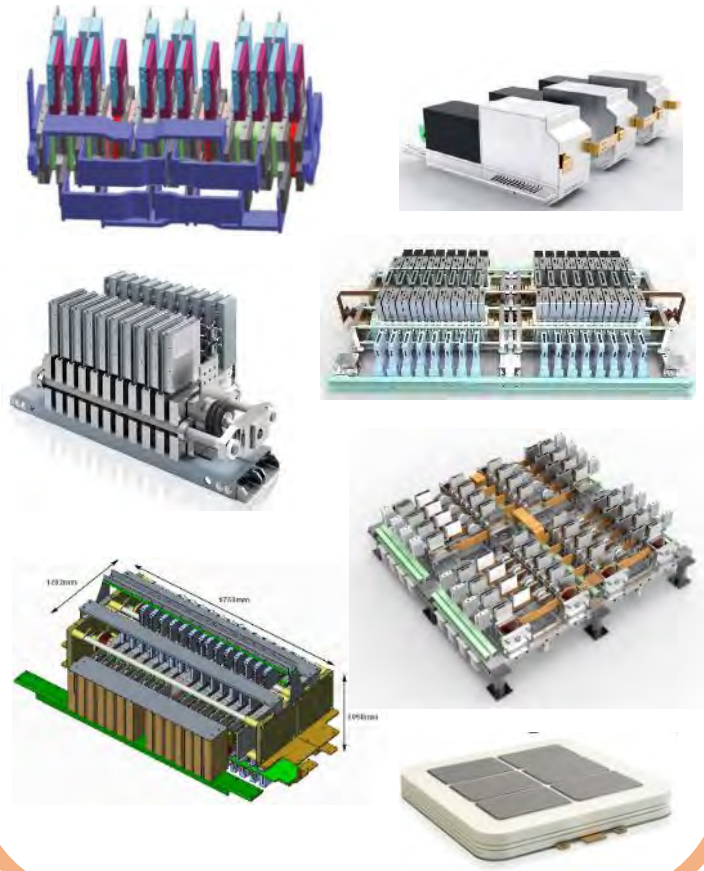


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

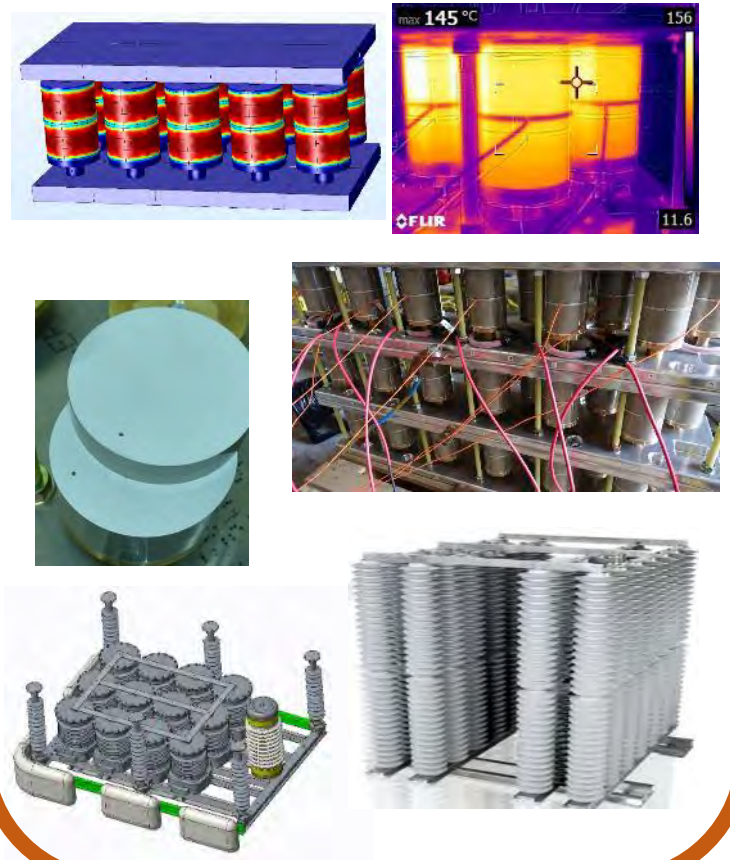
Standard components used in a non-standard application

switching gaps and drives

semiconductor switches

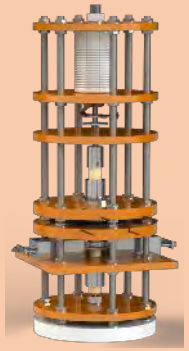
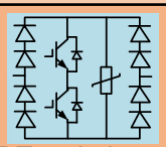
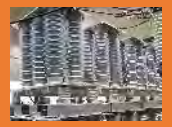


metal oxide surge arresters



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

Risk mitigation by defining proper verification methods

subcomponent		normal operation	HVDC CB application	potential issue?
 mechanical switches	(Multiple) electrodynamic actuator(s) for mechanical switching device	Speed 1 – few m/s	Ultra-high speed, high impact force Electronics onboard	Mechanical reliability Compatibility with equipment attached (bellows of vacuum interrupters) EMI sensitivity
	Power supply to actuator(s)	On earth potential	On high potential	Non-galvanic power supply
	Vacuum interrupters for interruption	Power frequency AC current interruption	HF current and / or interruption, isolation at small gap length	HF current interruption
	Vacuum interrupters for insulation	AC voltage insulation	DC voltage applied	DC voltage withstand capability
	High-speed (vacuum, PE) making switches	Capacitor bank inrush current making	Injection current making above highest IEC standardized value	Contact welding
	Multiple vacuum breakers in series	Not applied; vast majority of VCB is single break	Several / many in series	Grading for transients and DC Redundancy Mechanical synchronicity
	SF6 gap(s) for insulation (ultra-fast disconnector)	Very low opening speed in GIS AC application	Ultra-high contact separation speed	Shall not switch any current Dynamic DC voltage withstand capability Mechanical consistency over time
 PE switches	Semiconductors in continuous current path (load commutation switch function)	Semiconductors switch with high frequency	Conduct continuously and switch only occasionally	Thermal stability
	Semiconductors in commutation path (main breaker function)	Semiconductors switch with high frequency	Never conduct and switch only occasionally	Reliability after long idle time
 MOSA	MOSA consisting of multiple columns	Overvoltage protection	Significant energy absorption	Thermal overload Current sharing between columns
	MOSA columns	Always under (AC) voltage	Occasionally stressed by voltage	Conditioning

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

Standardization initiatives 2019

With WP10 participation:

- CIGRE WG A3.40: MVDC circuit breakers and systems (Heinrich, DE)
  Meeting Xi'an, Oct. 2019; Darmstadt, Feb. 2020
- CIGRE JWG B4A3.80: HVDC circuit breakers (Cao, CN)
  Meeting Lyon, Nov. 2019; Ningbo, Apr. 2020 -> draft technical brochure
- IEC HVDC Transfer switches (Ren, CN) - meeting Xi'an, Feb. 2020
- IEC HVDC Circuit breakers (Jia, CN) - meeting Xi'an, Feb. 2020

Other:

- IEC HVDC Bypass switches
- IEC HVDC Earthing and disconnecting switches
- IEC HVDC General clauses
- IEC HVDC GIS assemblies

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

Demo tests 2020

February 2020

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29

Thursday, Feb 27th 2020

ABB 320 kV 16 kA breaker
320 kV GIS

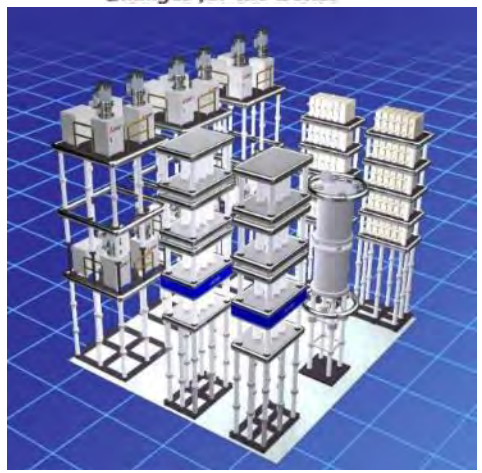
April 2020

M	T	W	T	F	S	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

Thursday 30th Apr 2020

SciBreak 80 kV 16 kA

MITSUBISHI ELECTRIC
Changes for the Better

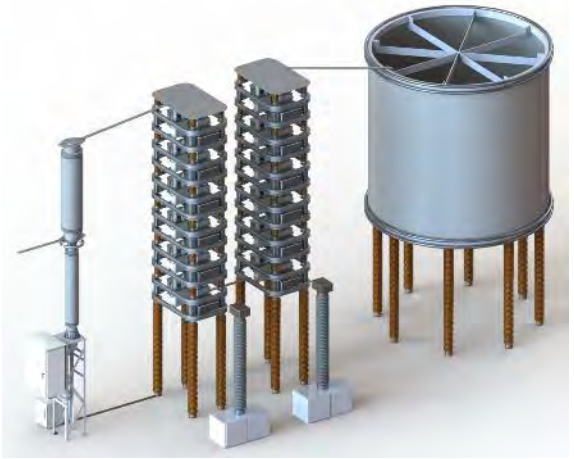


525 kV 16 kA

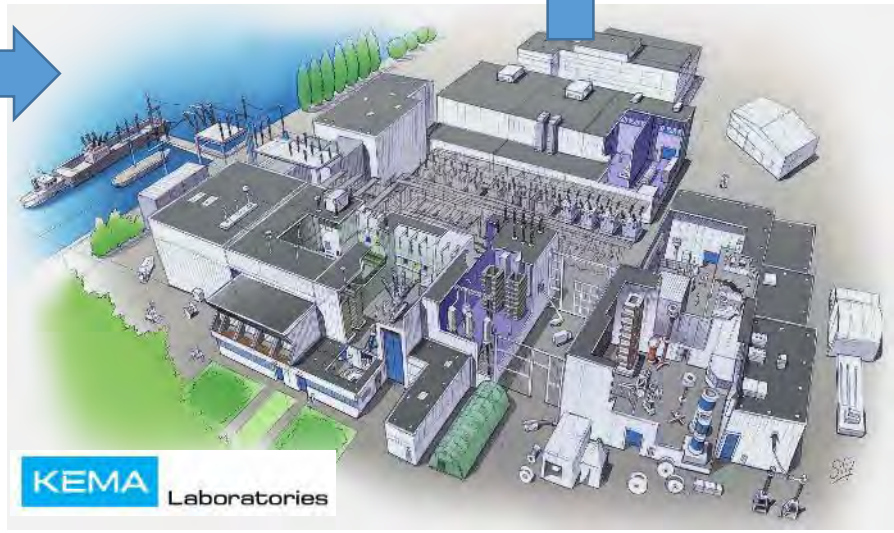
ABB

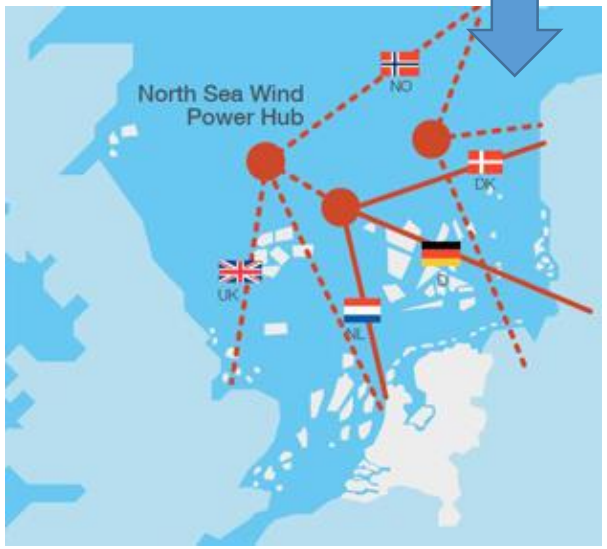
320 kV 16 kA

SC*i*Break



320 kV 16 kA





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APPENDIX

DISCLAIMER & PARTNERS

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

WP4 status report

Dirk Van Hertem (KU Leuven)
Serge Poullain (Supergrid Institute)

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

Presentation outline

- WP4, where we are
- D4.5 status
- Preparation of cost- benefit analysis from a protection point of view
  - D4.7 status
  - Reminder on key performances indicators
  - Reminder on implemented case studies
  - Key takeaways from case studies
  - Some recommendation proposals
- Final message

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

WP 4: DC Grid protection system development

Partners: KU Leuven (WP Leader), DNV GL, ABB, KTH, EIRGRID, SGI, MEU, SvK, RTE, Statoil, TenneT, Siemens, RWTH, Tractebel, Iberdrola, SHE Trans

Objectives:

↗Develop a set of functional requirements for a set of representative DC grids
↗Analyse a wide range of DC grid protection philosophies on a common set of metrics
↗Identify the best performing methods for each identified DC grid
↗Develop detailed protection methodologies for the selected methods
↗Develop configurable multi-purpose HVDC protection IEDs to allow testing of the methodologies
↗Investigate the key influencing parameters of protection systems on the cost-benefit evaluation

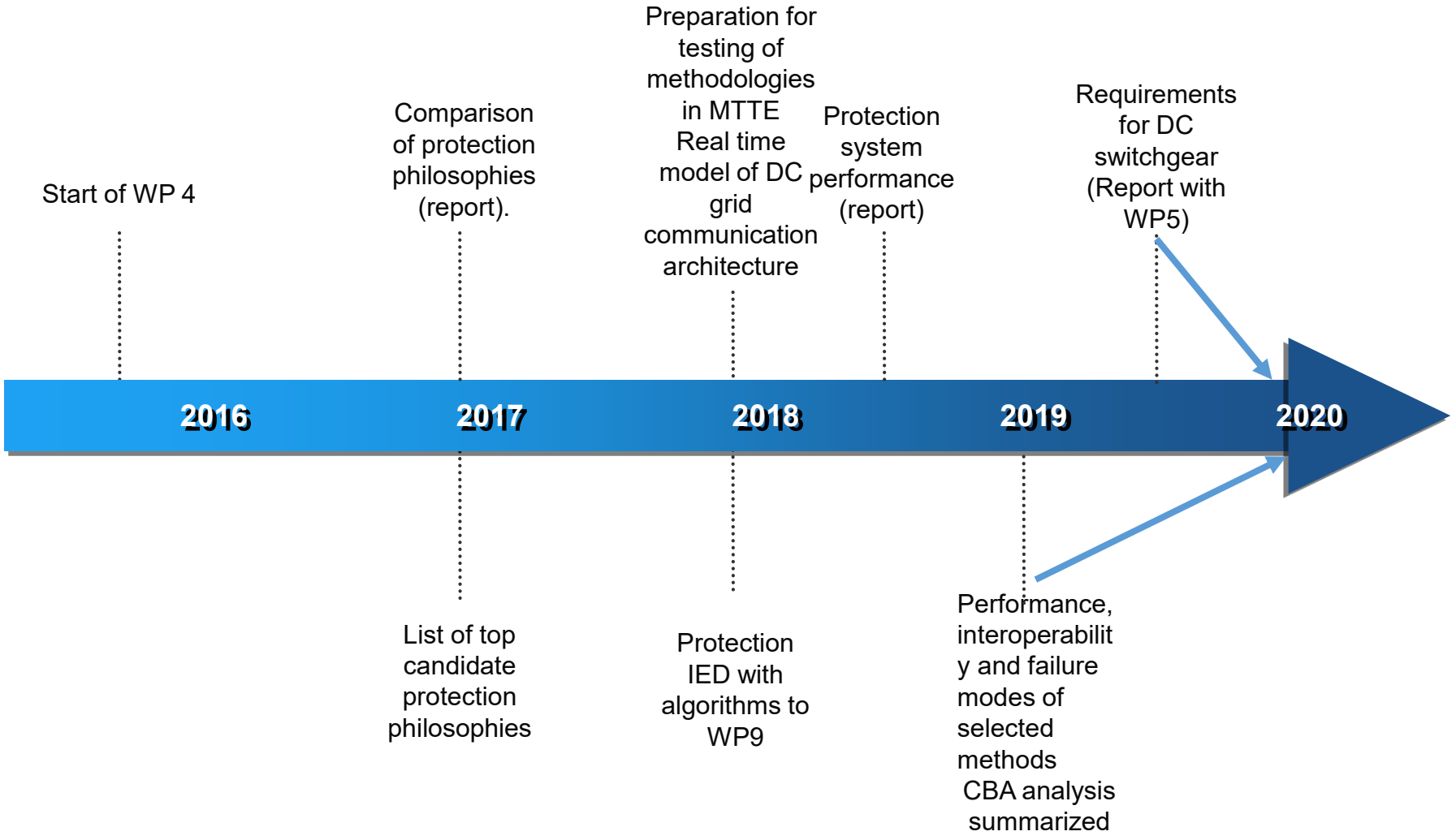
WP 4: DC Grid protection system development

Partners: KU Leuven (WP Leader), DNV GL, ABB, KTH, EIRGRID, SGI, MEU, SvK, RTE, Statoil, TenneT, Siemens, RWTH, Tractebel, Iberdrola, SHE Trans

Deliverables and Milestones:

- **Reports:**
  - **D4.1: Definition of test cases and functional requirements for DC grid protection methodologies**
  - **D4.2: Broad comparison of protection methodologies for identified grid topologies**
  - **D4.3 Performance, interoperability and failure modes of implementation of selected methodologies**
  - **D4.5: Requirements for DC switchgear (joint deliverable with WP 5) (M48)**
  - **D4.6: Functional HVDC protection IED**
  - **D4.7: Impact of protection system design factors on CBA of a system (M47)**

WP 4: DC Grid protection system development



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Requirements for DC switchgear

D 4.5

02 December 2019

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Objectives of D4.5

- Classify DCCBs into different types based on results obtained in WP4, WP5 and WP6
- Specify general requirements of DCCBs with the intention of contributing to standardization and interoperability
- Focus is on breakers, not switches
- What are the
- Bringing work together rather than new ideas
  - Executive summary

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DCCB Types (or Classes) based on application scenarios

Application scenarios	DCCB types	Parameter ranges			
		Operation speed ($t_{br,o}$)	Breaking current ($I_{br,pk}$)	Inductor size (L_{line})	Energy absorption capability (E)
Fully selective protection strategy	Type-I	*Dealing with pole-to-pole and pole-to-ground faults*			
		High (< 10 ms)	High (> 10 kA)	High	High
Fully selective strategy (Cable-based symmetrical monopolar HVDC grids)	Type-II	Only dealing with pole-to-ground faults			
		Slow (~ 20 ms)	Low (few kA)	Medium/high	Medium (few MJ)
Non-selective protection strategy (Converter + DCCB)	Type-III	Line/Converter DCCB			
		Slow (20 ms)	High (20 kA)	Zero	Low/medium (< 1MJ/7MJ)

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General requirements of Type-I DCCBs in a fully selective protection strategy

Constraints or requirements from HVDC grid system and components

- **Converter DC fault-ride-through (DCFRT)** requirements [1]
- Selectivity requirements
  - Inductors are used for separating protection zones, and have to be large enough to allow for discrimination of internal and external faults [2][3]
- **Protection coordination** requirements [4]:
  - Hybrid DCCB auxiliary functions: DCCB-level protection and internal failure detection
  - System-level (IEDs) protection should act before triggering DCCB-level protection
    - Breaker opening time
    - Inductor size
- HVDC grid stability requirements:
  - The choice of main circuit parameters has to result in a stable system [5].
- Multivendor interoperability requirements:
  - DCCB sizing should consider a range of parameters as they differ from one vendor from another.

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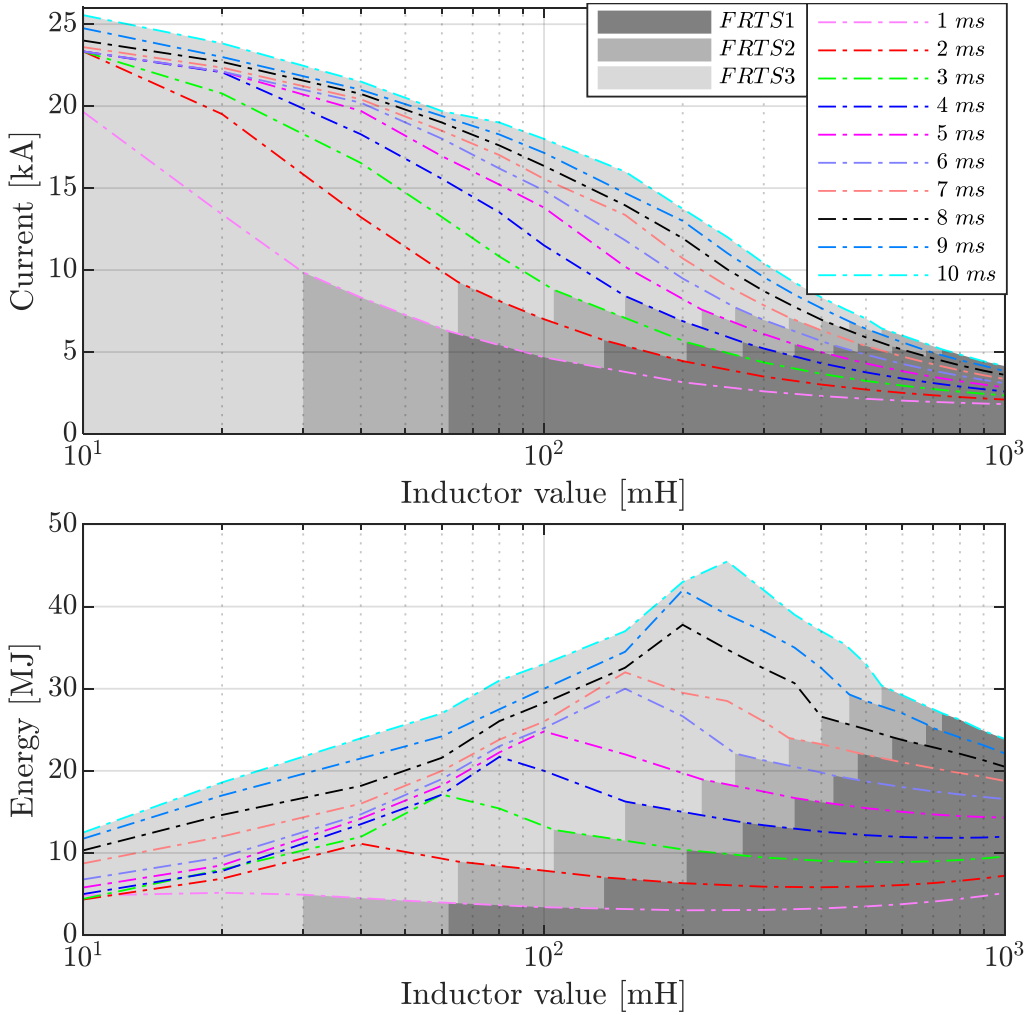
Converter DCFRT requirements

HVDC Grid Fault Ride Through Scenarios:

- **DC-FRTS1** leads to high values of line inductors for the given HVDC grid test system, which may be impractical towards real applications.
- **DC-FRTS2** reduces the requirements for the line inductors in the grid for all DCCB operating times. However, it shows higher line inductor values for longer DCCB operating times in combinations with low converter ratings.
- **DC-FRTS3** can be used for any HVDC grid with any DCCB technology, and the DCCB operating time and line inductor value can be determined depending on the allowable fault level in the grid.



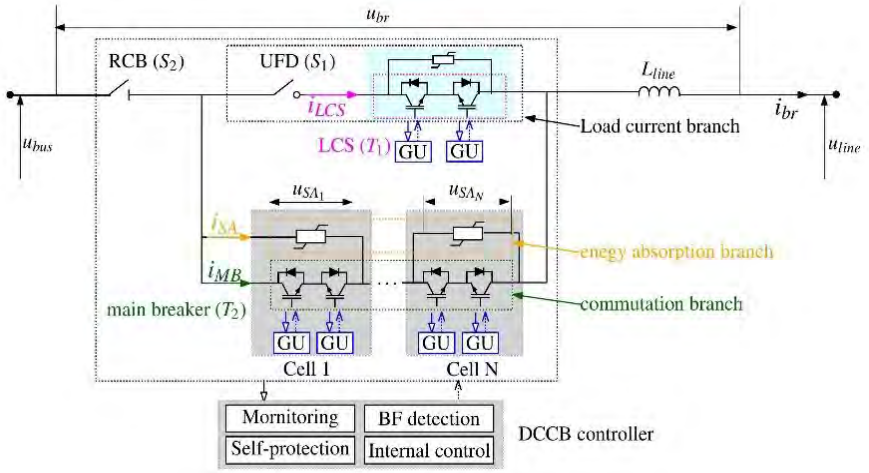
M. Abedrabbo, W. Leterme and D. Van Hertem, "Systematic Approach to HVDC Circuit Breaker Sizing," in IEEE Transactions on Power Delivery.

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

Protection coordination requirements in case of hybrid DCCBs

Self-protection: trip DCCB on internal command without receiving a trip order from the IED(s).

Driver-level protection: block semiconductor switches at the gate driver unit without receiving an order from the DCCB controller.



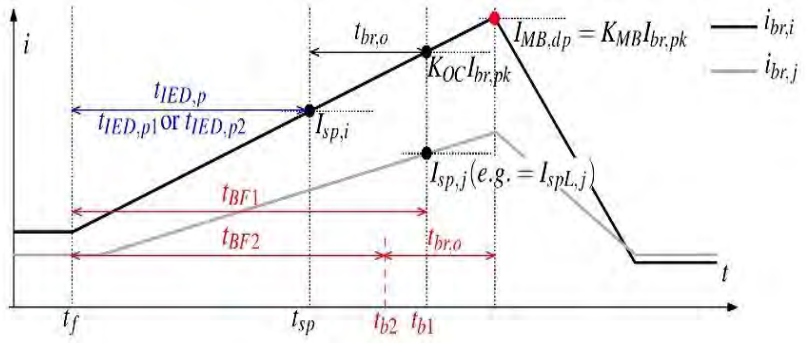
Without DCCB-level protection:

$$\begin{cases} i_{MMC} < I_{diode,MAX}\ (DCFRTS3) \\ \tau_{eq,i}\left(t_{IED,p} + t_{br,o}\right) + I_{DC,n} \leq\ I_{br,pk} \end{cases} \qquad (3)$$

Protection coordination:

- Primary IED operates before self-protection:
- Breaker failure backup IEDs operates before driver-level protection (of the failed DCCB):

$$\begin{cases} \tau_{eq,i}\left(t_{IED,p} + t_{br,o} + t_{mgn,sp}\right) + I_{DC,n} \leq I_{br,pk} \\ \tau_{eq,i}\left(t_{BF2} + t_{br,o} + t_{mgn,dp}\right) + I_{DC,n} \leq I_{MB,dp} \end{cases} \qquad (4)$$



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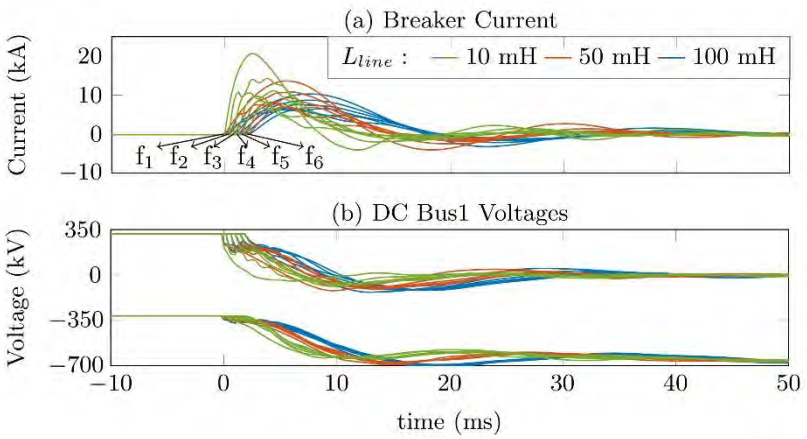
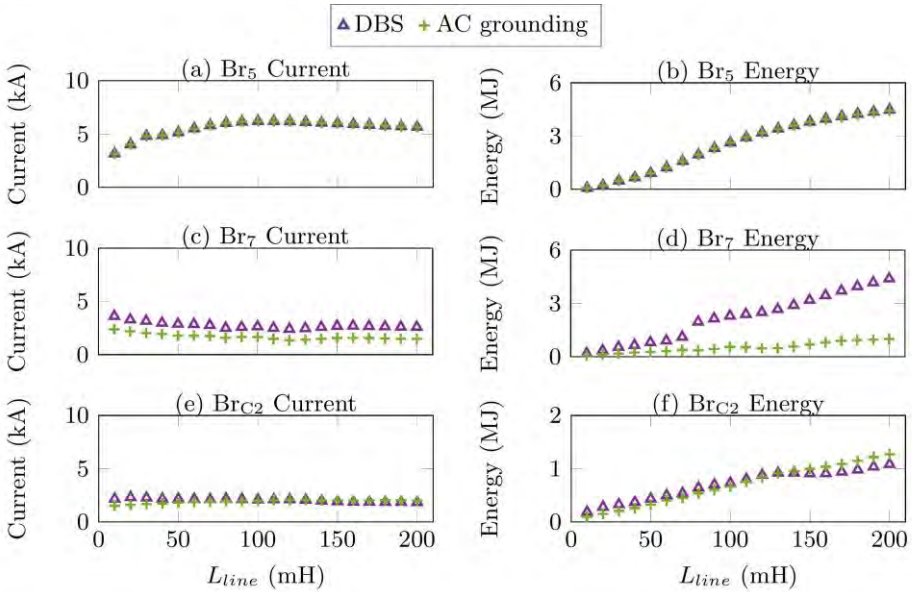
General requirements of Type-II DCCBs in a fully selective protection strategy for cable-based symmetrical monopolar system

DCCB requirements [6]:

- Opening time: slow ~ 20 ms
- Breaking current: few kA
- Energy: few MJ





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Status of D4.5 (Due M48)

Submission to reviewers: this week
Final submission, not after M49

Chapters	Responsible partner	Completion percentage (writing)
1. Executive summary	KUL	95%
2. Introduction	KUL	100%
3. DC circuit breaker	KUL	100%
4. Fully selective strategy		
4.1 Type-I DCCB	KUL	85%
4.2 Type-II DCCB	KUL	100%
5 Non-selective strategy (Type-III DCCB)	SGI	100%
6 Summary	KUL	100%

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Preparation of cost- benefit analysis from a protection point of view

WP 4.5

02 December 2019

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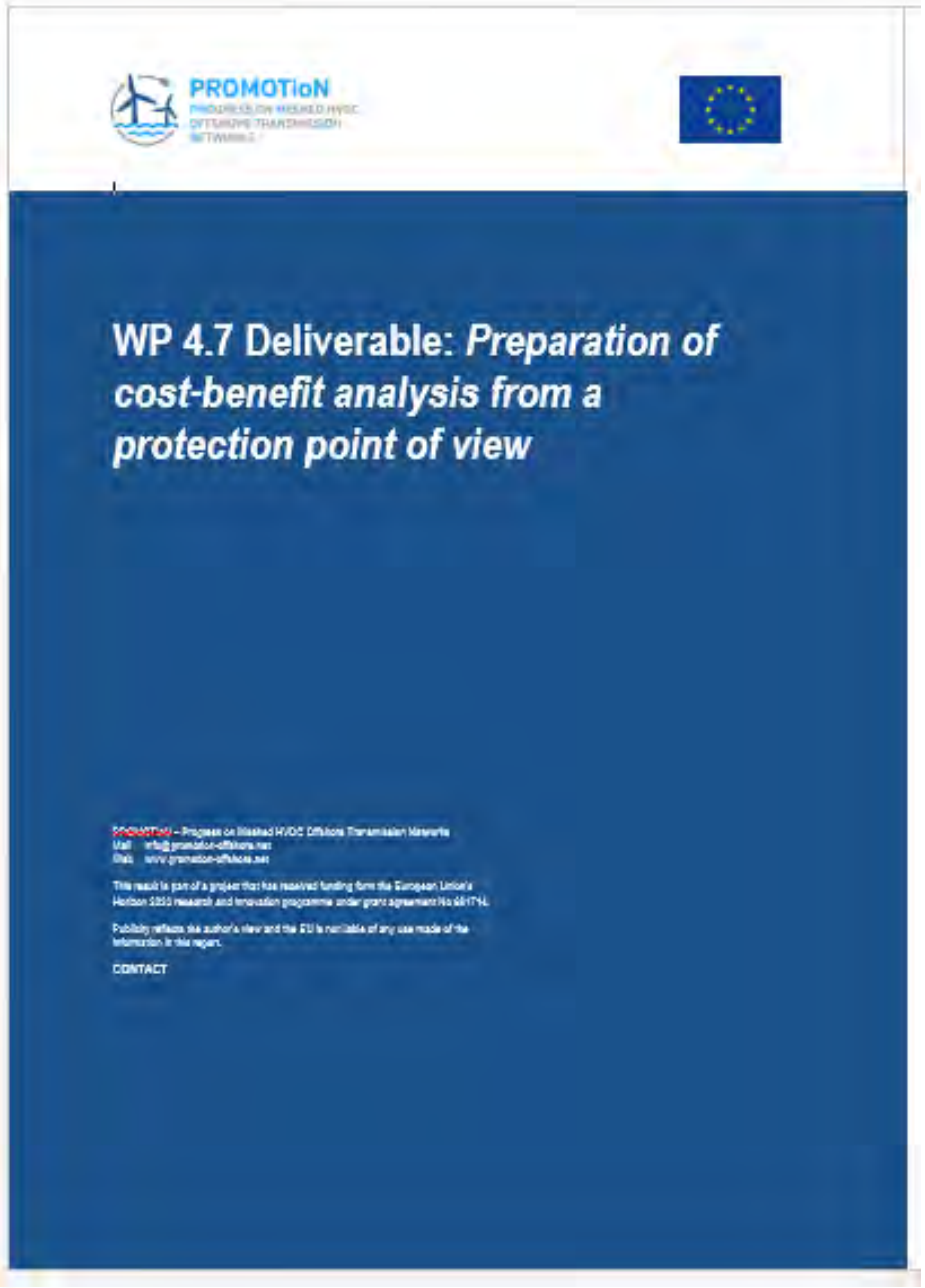
Deliverable D4.7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WP 4.7 Deliverable: *Preparation of cost-benefit analysis from a protection point of view*

CONTACT

Sent to Reviewers by 30 November

John Moore (TenneT)

Nicoloas Cutululis (DTU)

Due date M47

Considered Key Performance Indicators within WP4.5

Economic KPIs

Capital Expenditures (CAPEX)

Operational expenditures (OPEX)

- Losses
- Maintenance
- Expected Energy Non Transmitted (EENT)

Technical KPIs: Efficiency & reliability (from works of WP4.2 and WP4.3)

Efficiency Indicators

- Voltage restoration time
- Active power restoration time
- Reactive power restoration time
- Transient energy unbalance

Reliability Indicators

- Backup Probability
- Non-cleared fault probability

Technical KPIs: AC grid impact indicators

Frequency deviation

- Frequency Reserve Requirement
- ROCOF

Generation dispatch costs

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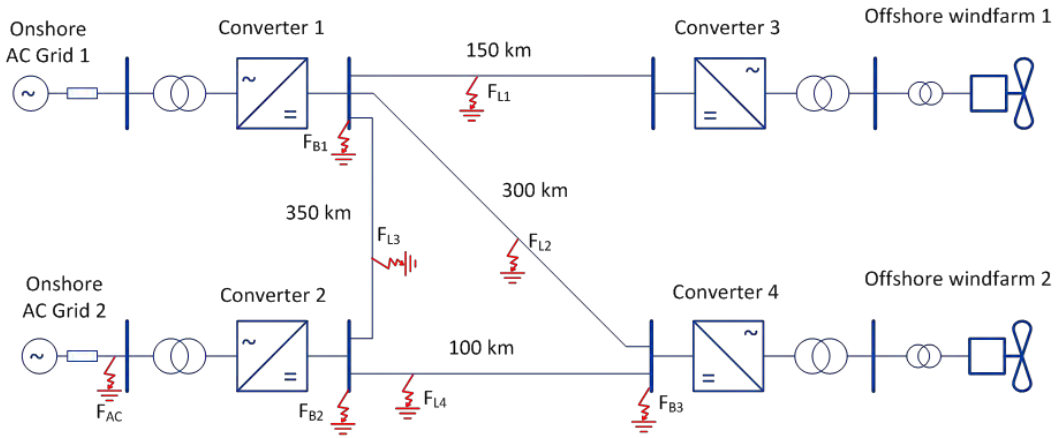
Case studies



Small 4 terminal meshed DC grid

(WP 4.2, WP4.3)

Four protection strategies

A full selective with fast DC CB

A full selective with slow DC CB

A non-selective with DC CB at converter output

A non-selective with fault blocking capability converter

Grid splitting with non-selective with DC CB at converter output

Large 35 terminal radial DC grid (WP 12)

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

Methodologies and tools for supporting a CBA assessment relative to protection systems of DC grids have been proposed and developed

Indicators have been demonstrated as relevant to discriminate protection systems from both costs and performances analysis.

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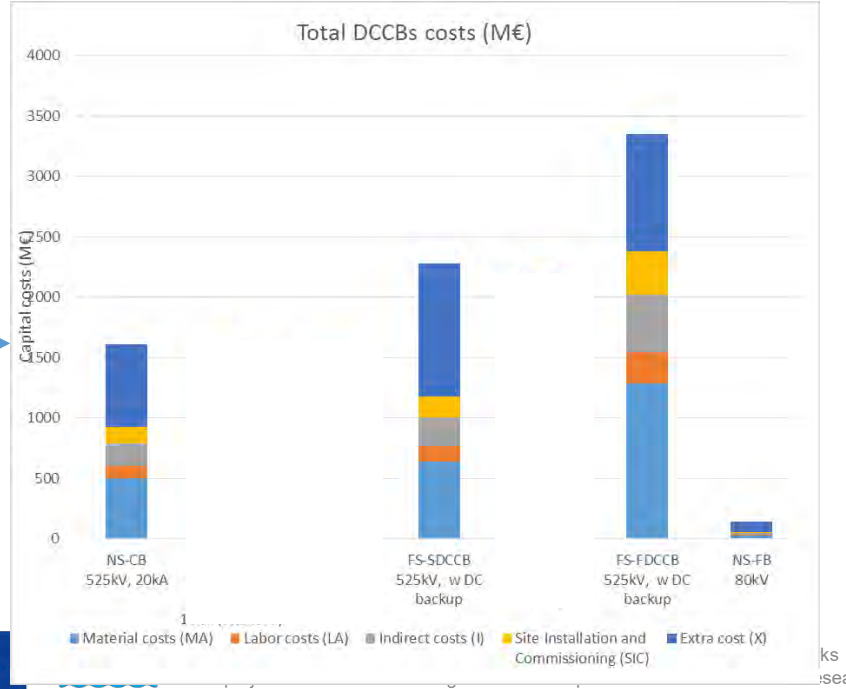
Key Takeaways : CAPEX

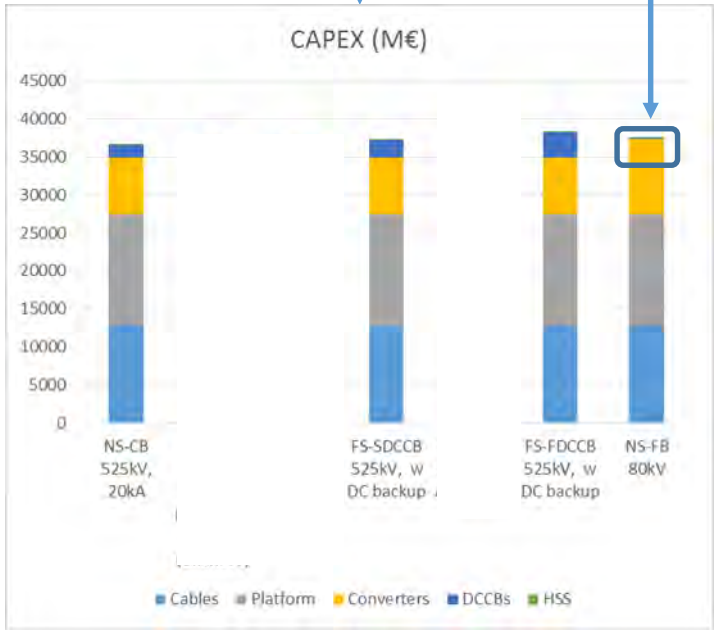
Dominated by DC circuit breakers costs

Lower CAPEX is associated to non-selective protection strategy using DC CB at converter output, whereas higher CAPEX is related to full selective protection strategy with fast DC CB (ratio of two)

CAPEX relative to non-selective fault blocking converter based protection strategy needs to consider additional costs incurred by such converters

Protection system CAPEX lies between 4% and 8% of DC grid total CAPEX





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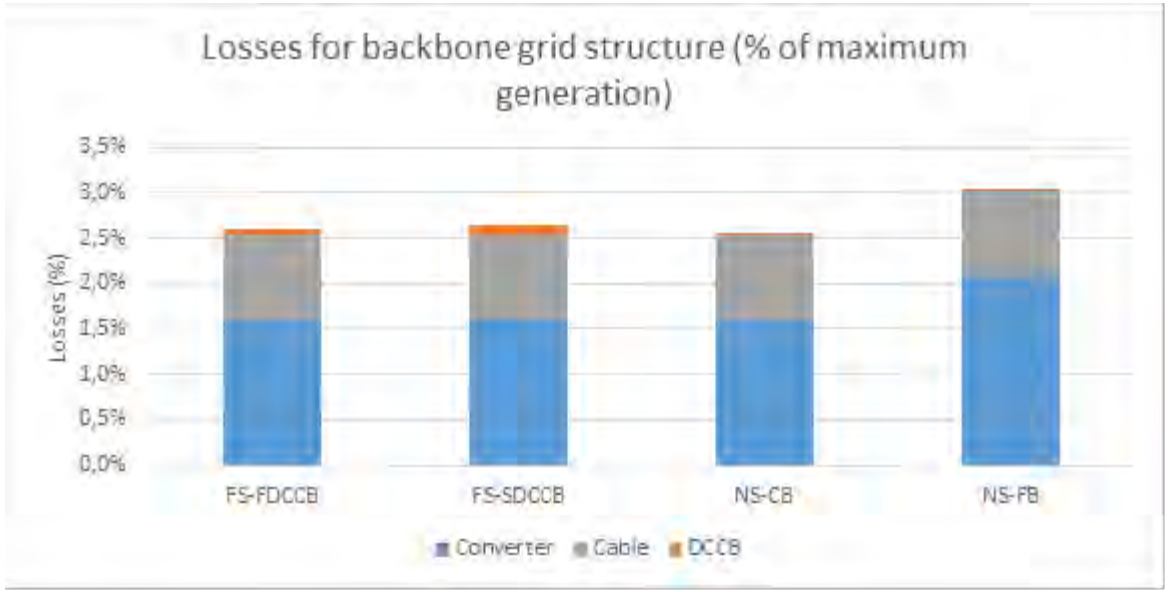
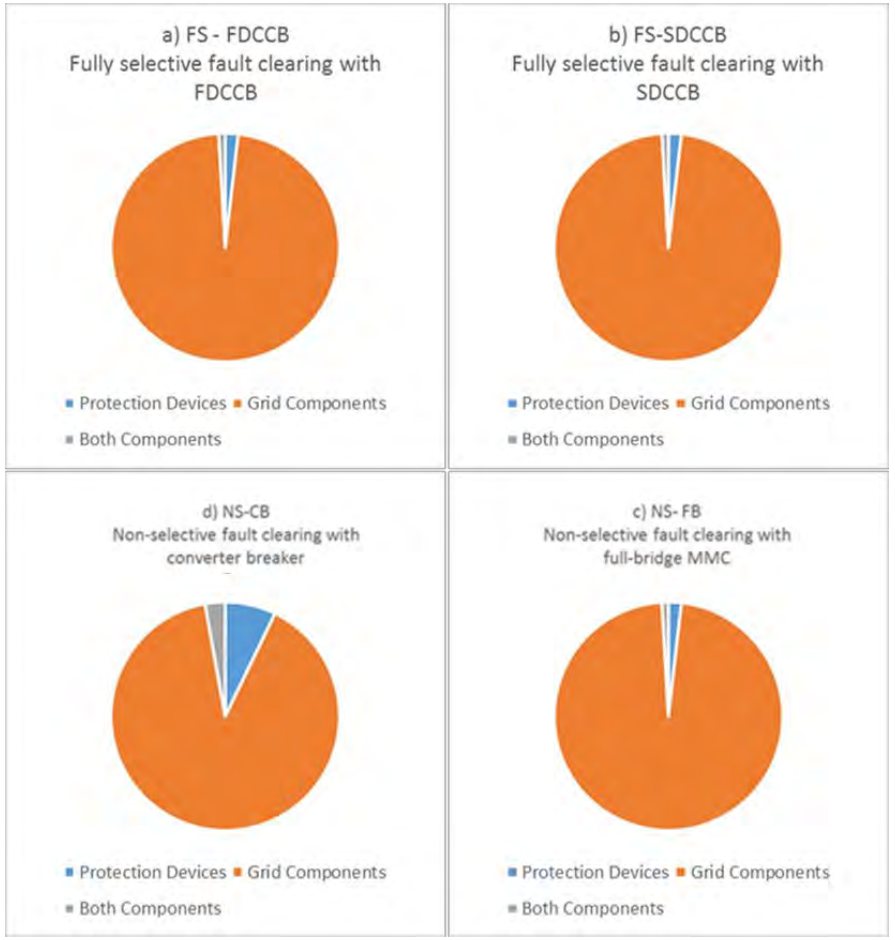
esearch and innovation programme under grant agreement No 691714.

Key Takeaways : OPEX



Observed maximal EENT due to protection systems does not exceed 10 % of total EENT

EENT due to non-selective protection strategy using DC CB at converter output is slightly higher than for other protection strategies



Contributions of protection system to total losses are observed as less that 6%. Fault blocking converters additional losses needs to be considered

Contributions of protection system to total maintenance costs is between 4% and 8% (modeled as a coefficient of CAPEX)

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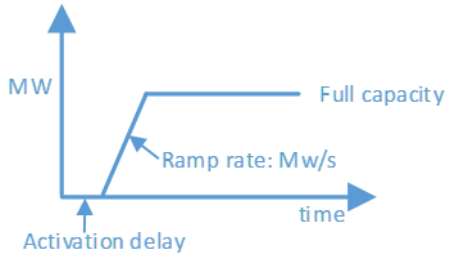
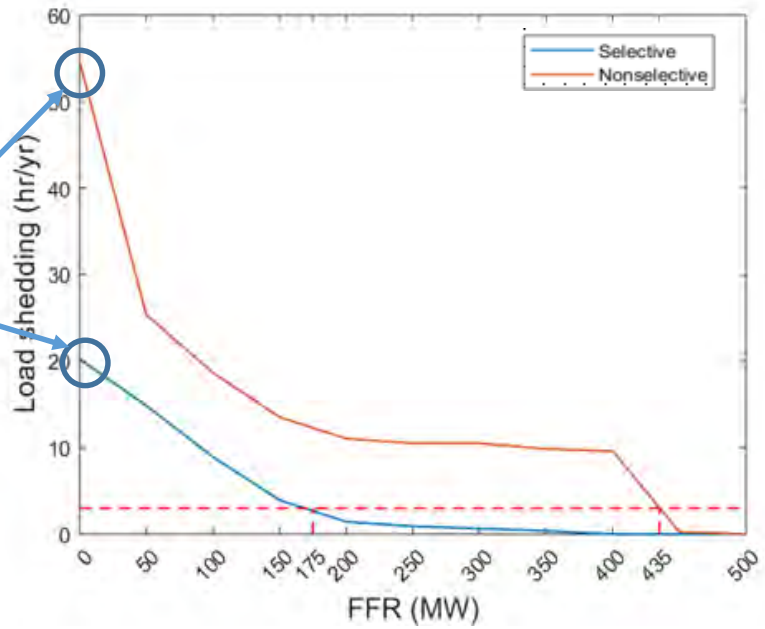
Key Takeaways : OPEX: Frequency reserves

WP12 case study: Used ENTSO-e model of frequency response for the Nordic grid

Assuming hydro power plants as the main frequency containment reserves (FCR)



With no additional reserves, the load shedding duration is 20 hr/annum and 54 hr/annum for selective and nonselective strategies respectively



FFR activation = 0.1 sec

Nonselective strategy needs faster and higher amount of reserves

There is no difference in load shedding/reserve requirement among selective and nonselective groups of strategies

Transient frequency constraint violations incurred during DC fault clearing and DC grid restoration processes can be counterbalanced by using fast frequency reserves (FFR)

Slower protection strategies could require more FFR and would then incurred some additional OPEX

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Key Takeaways : Total Costs

Considering CAPEX and OPEX: The range of protection system cost contribution to total grid cost varies from approximatively 4% to approximatively 8%

While not negligible, protection system cost is not seen as determining in respect to total grid cost

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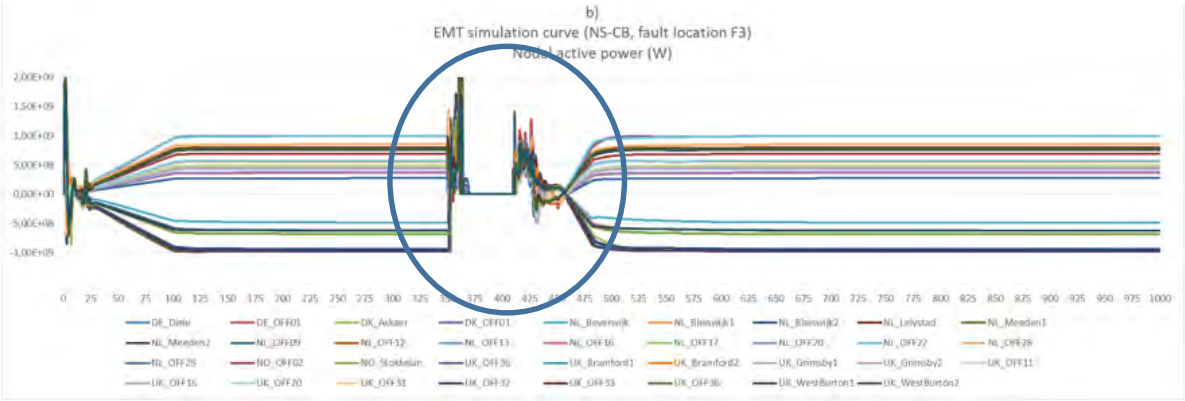
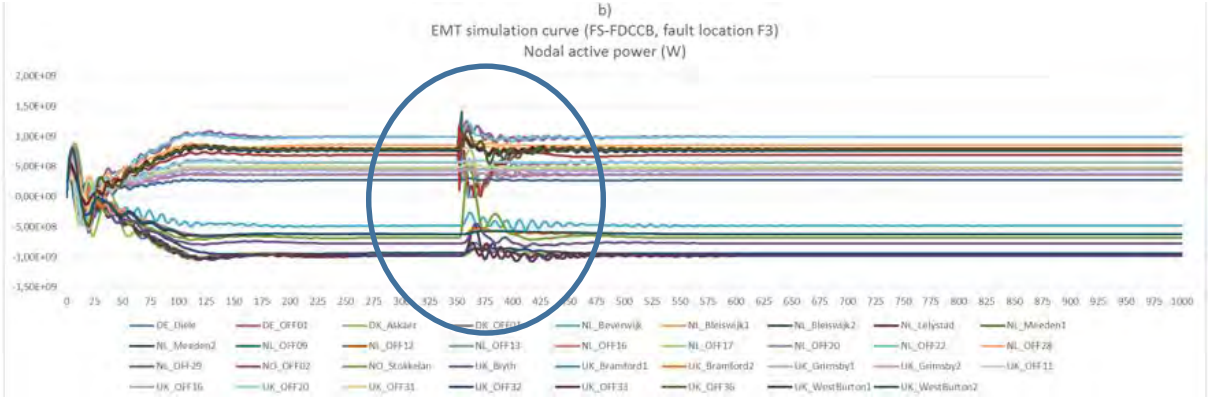
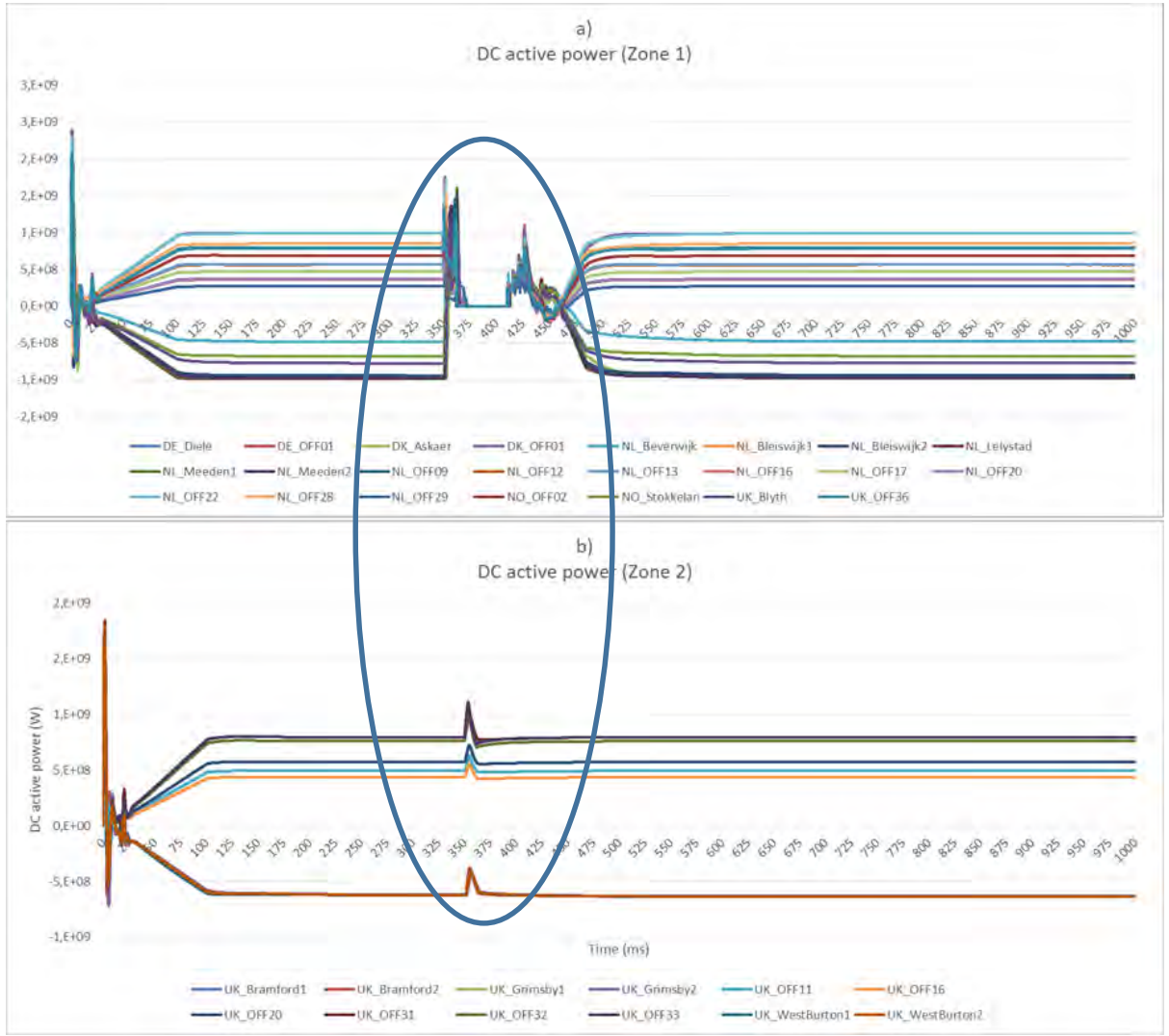
Key Takeaways : Technical Efficiency KPIs



Non selective with converter breaker protection strategy



Full selective with fast DCCBs protection strategy



Grid splitting with non selective with converter breaker protection strategy

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Key Takeaways : Technical KPIs

	Strategy	Active power restoration time	Energy Imbalance
Not affected converters (%)	NS-CB	0	0
	FS-FDCCB	75	0
	FS-SDCCB	55	0
Range (lowest/highest values) (ms or MJ)	NS-CB	[120,200]	[10,150]
	FS-FDCCB	[0,100]	]0,30]
	FS-SDCCB	[0,150]	]0,40]

	Strategy	Active power restoration time	Energy Imbalance
Not affected converters (%)	NS-CB	0	0
	Grid splitting	22	0
Range (lowest/highest values) (ms or MJ)	NS-CB	[120,200]	[10,150]
	Grid splitting	[0,220]	[0,150]

Computation of technical KPIs has demonstrated that impacts on both DC and AC grids are dependent on protection strategies. As such, computation of technical KPIs is fundamental when assessing the performances of protection systems

In the case of the large size radial backbone DC grid, it is shown that, if well-adapted converter controls are implemented, full selective protection strategies will have less grid impact (DC and AC grids)

For large DC grids, grid splitting design has been shown as an applicable and efficient solution to reduce grid impact when implementing non-selective protection strategies

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A large set of protection strategies are technically applicable to small size and large size DC grids

The performances of protection system do not only depend on DC circuit breakers and protection equipment performances but also highly rely on converter control behavior. With low control performances, significant increase of time to restore the grid can be observed

There are no preferred protection strategies suitable for all DC grid systems

There is not a unique way to protect DC grids and the selection of protection system will depend on many parameters. First objective of protection system is to ensure system security as well as allow system stable operation during and after fault clearing process. Cost considerations are then addressed

From case studies, it seems that full selective or non-selective strategies based on grid splitting would be preferable for large size DC grids. As such, grid splitting design is a good way to use non-selective protection strategies for large grids

Although not investigated in detail in the deliverable, the authors do not see a reason why a mix of protection systems cannot exist (potentially requiring some additional engineering)

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Protection system design needs a full assessment and no short cut to design a protection system can be applied.

Both technical performances and costs have to be addressed and relevant key performance indicators need to be defined and used to perform a full assessment of protection system

Designing protection systems will then result in protection system components specification. Specification of DC circuit breakers will play a central role regarding cost of protection systems as it has been shown that costs are mainly DC CB driven.

Cost of DC circuit breakers can vary in a large range

It has been observed that the cost of DC CBs vary approximately with a factor of two, depending on breaker requirements.

Additional costs due to installation of DC CB on offshore platform are not negligible

From cost considerations, the general transmission system (DC grid) layout is not so much affected by the selection of protection system. As a consequence, it seems that no protection system is impossible due to excessive cost

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The end of WP4

02 December 2019

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Output of WP4

- Regular invitation to participate in workshops and conferences
- Organized a workshop in Brussels with WP6 on 30/9
- Developed testing protocols for DC IEDs:
  - Applied to both Promotion and Melco IED (successfully)
- Interfacing with WP9 and transferring ideas from WP4 to WP9
  - First outcomes confirm our work
- Scientific output:
  - 14 conference papers (more to come)
  - 5 papers (more to come)

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High level conclusions of WP4

- ↗HVDC grid protection is realistic: from academic to (near) industry grade implementation
- ↗Different approaches are possible, with different advantages and disadvantages
- ↗HVDC grid protection equipment (IEDs) are available: academic and industrial
- ↗IEDs are tested
- ↗Interfaced with WP9 for validation at higher TRL
- ↗HVDC grid protection is not blocking technically nor economically

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

Thank you to all WP4 contributors!

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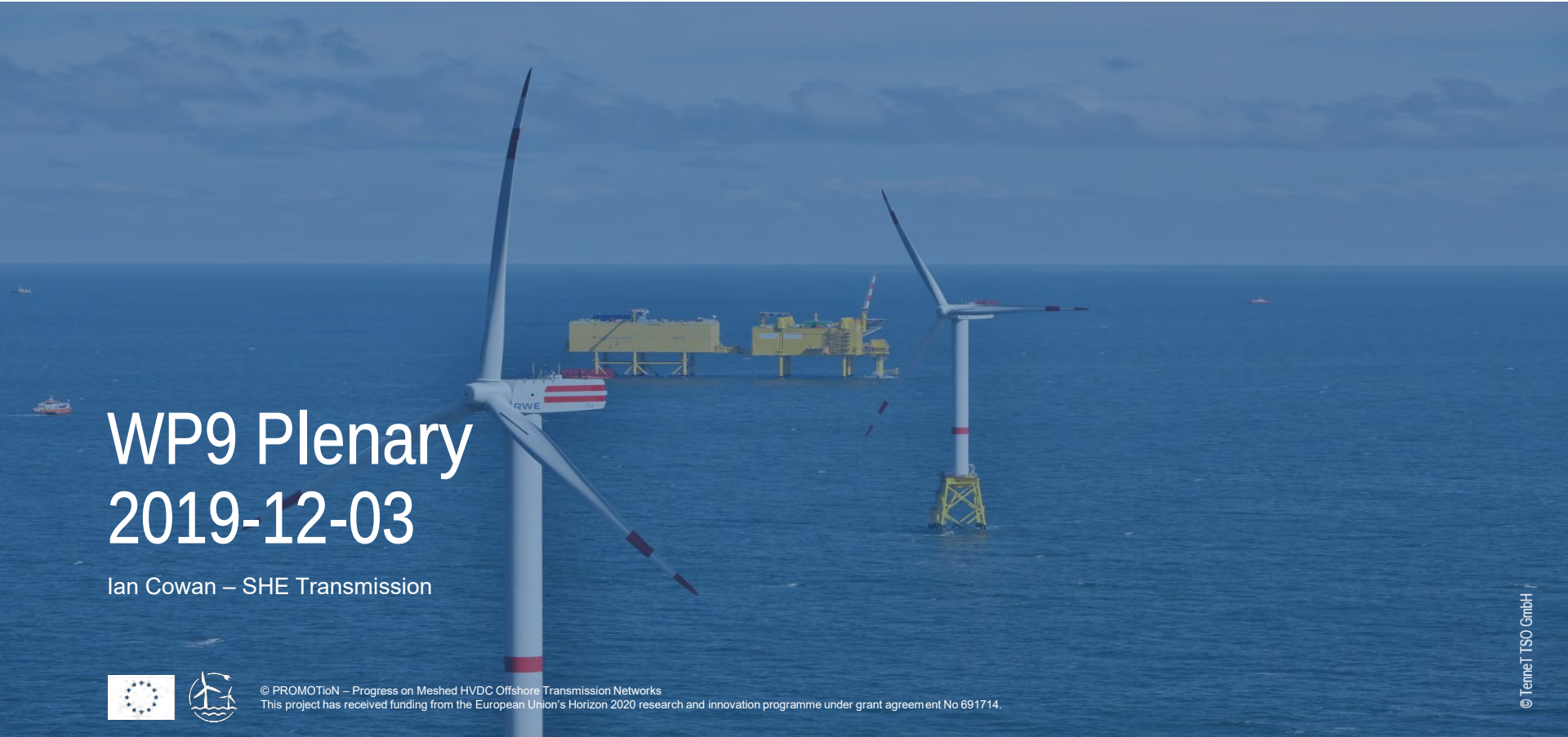
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS



WP9 Plenary 2019-12-03

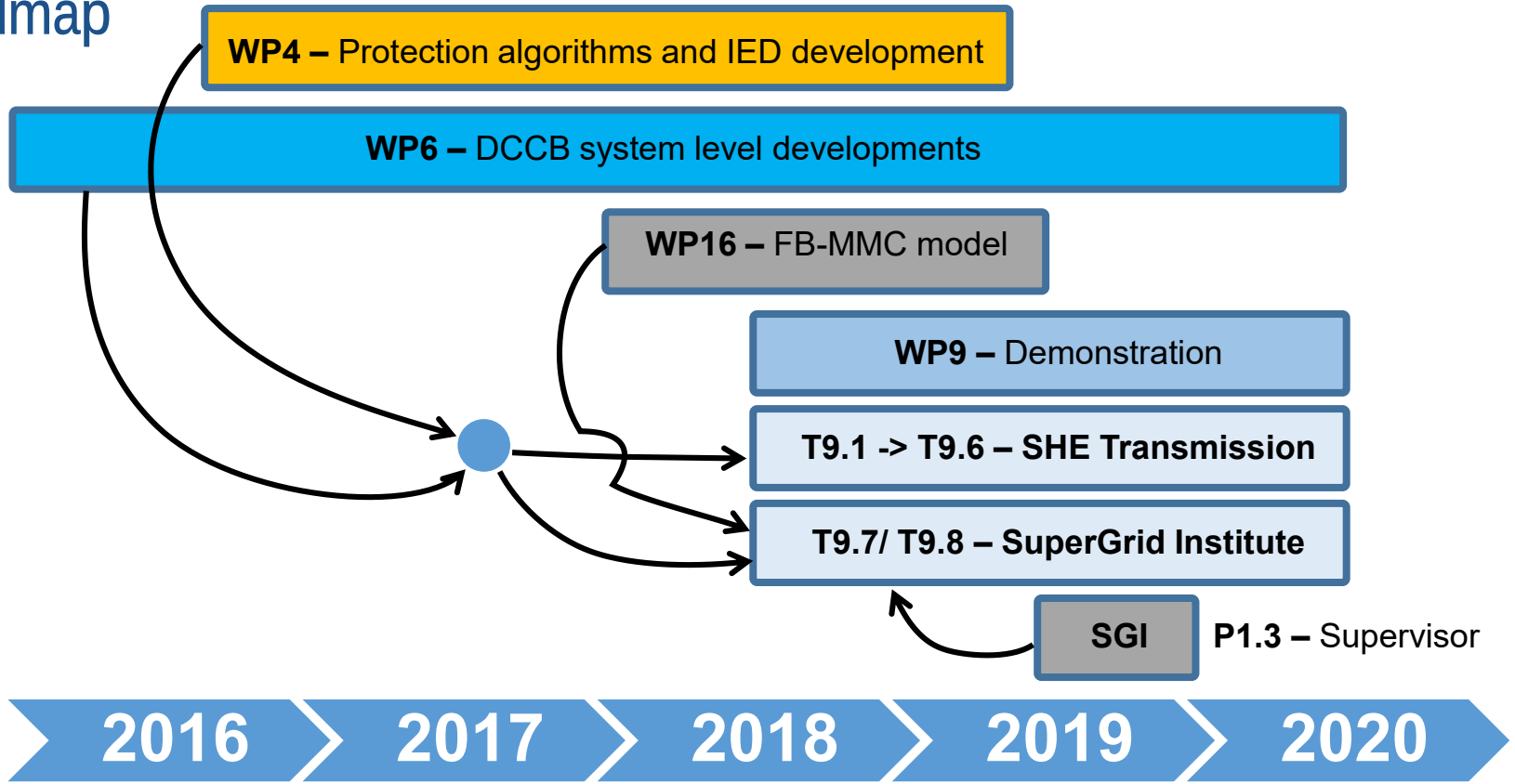
Ian Cowan – SHE Transmission

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

Reminder

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

Roadmap



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WP9 Scope

HIL demonstration of fault clearing strategies (real system)

Partially selective

Symmetrical monopole configuration

Fully selective

Symmetrical monopole configuration

HIL demonstration of **Non-selective** fault clearing strategies (IEC61850)

Converter-breaker strategy

HB-MMC: Bipole configuration

Full-Bridge based converter strategy

FB-MMC: Symmetrical monopole configuration

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Progress Update

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Progress Update – Task 9.1 through 9.6

- **Deliverables**
  - D9.1 Real-time models for benchmark DC grid systems (KUL M38)
  - D9.2 DC grid protection testing guidelines (TU Delft M36) – Delivered M36
  - D9.3 Protection system demonstration (SHET M42[44]) – Delivered M44
  - D9.4 Demonstration of protection system interoperability and primary and back-up protection (SHET M46[51-TBC])
  - D9.5 Hardware-in-the-loop test environment and guidlines for non-selective protection systems demonsrtations (SGI M48[49])
  - D9.6 Demonstartion of non-selective protection systems interoperability and primary and back-up protection (SGI M54)
- **Milestones**
  - MS42 DC grid and CB models are delivered (SHET M30) - ?Completed
  - MS43 Relays and grid models successfully integrated in RTDS, and project moves to testing (SHET M38[40])
  - MS44 Protection system successfully demonstrated (SHET M42[44])
  - MS45 Interoperability successfully demonstrated (SHET M46[51])
  - MS81 Full bridge converter models are developed (SGI M38)
  - MS82 Relays and grid models successfully integrated in real-time simulation environment, and project moves to testing(SGI M41[49])
  - MS83 Supervisor prototype for HVDC system restoration ready (SGI M48[49])
  - MS84 Non-selective protection systems successfully demonstrated (open-loop system restoration) (SGI M48[49])
  - MS85 Non-selective protection systems successfully demonstrated (closed-loop system restoration) (SGI M54)

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D9.3 Protection System Demonstration Summary

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

D9.3 Overveiw

- Purpose of D9.3: Demonstration of protection system
  - Protection systems will be tested using hardware in the loop real-time approach
  - Integration of:
    - WP6 DCCBs
    - WP4 IED
    - MELCO IED
    - detailed ‘realistic’ real time models

Demonstration of HVDC protection system - Agenda

Location & Registration: The National HVDC Centre, Cumbernauld, G68 0FQ, UK

Agenda, 22nd August 2019[1]

09:00 – 09:30	Registration & Welcome
09:30 – 09:50	Safety Induction and Introduction – *Ian Cowan (SHET)*
09:50 – 10:20	DC Grid Protection philosophy – *Geraint Chaffey (KUL)*
10:20 – 10:50	DC circuit breakers - *tbc*
10:50 – 11:20	*Break*
11:20 – 11:45	Technical description of IED-1 - PROMOTioN IED – *Ilka Jahn (KTH)*
11:45 – 12:10	Technical description of IED-2 - MELCO IED – *Frederick Page (MELCO)*
12:10 – 12:50	Description of test set up and walking tour – *Various WP9 Members*
12:50– 13:50	*Lunch*
13:50 – 15:20	Demonstration of selected fault cases – *Various WP9 Members*
15:20 – 15:45	Presentation of past test results and discussions - *Various WP9 Members*
15:45 - 16:10	WP9 future test plans - *Ian Cowan (SHET) and William Leon Garcia (SGI)*
16:10 – 16:30	Close out session including Q&A - *Ian Cowan (SHET)*
	End of Event

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D9.3 Attendees

Registration list
D9.3 Demonstration of HVDC Protection Systems – SHE Transmission

22 August 2019, The National HVDC Centre (Cumbernauld, UK)

Nr.	Name	Affiliation	Signature
1	Bharath Ponnalagan	The National HVDC Centre (SHE Tranmission)	
2	Daniel Oluwole	The National HVDC Centre (SHE Tranmission)	
3	Dirk Van Hertem	KU Leuven	
4	Dragan Jovcic	University of Aberdeen	Dragan Jovcic
5	Frederick Page	Mitsubishi Electric Europe	
6	Geraint Chaffey	KU Leuven	
7	Ian Cowan	The National HVDC Centre (SHE Tranmission)	
8	Ilka Jahn	KTH Royal Institute of Technology	
9	Kamran Sharifabadi	Equinor ASA	
10	Lie Xu	University of Strathclyde	
11	Linash Kunjumuhammed	Mitsubishi Electric Europe	
12	Nicolaos A. Cutululis	DTU	

Nr.	Name	Affiliation	Signature
13	Rory Shanahan	The Carbon Trust	
14	Rui Li	University of Strathclyde	
15	Sertkan Kabul	TenneT TSO B.V.	
16	Simon Marshall	The National HVDC Centre (SHE Tranmission)	
17	Willem Leterme	KU Leuven	
18	William Leon Garcia	SuperGrid Institute	

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Partially and Fully Selective Testing

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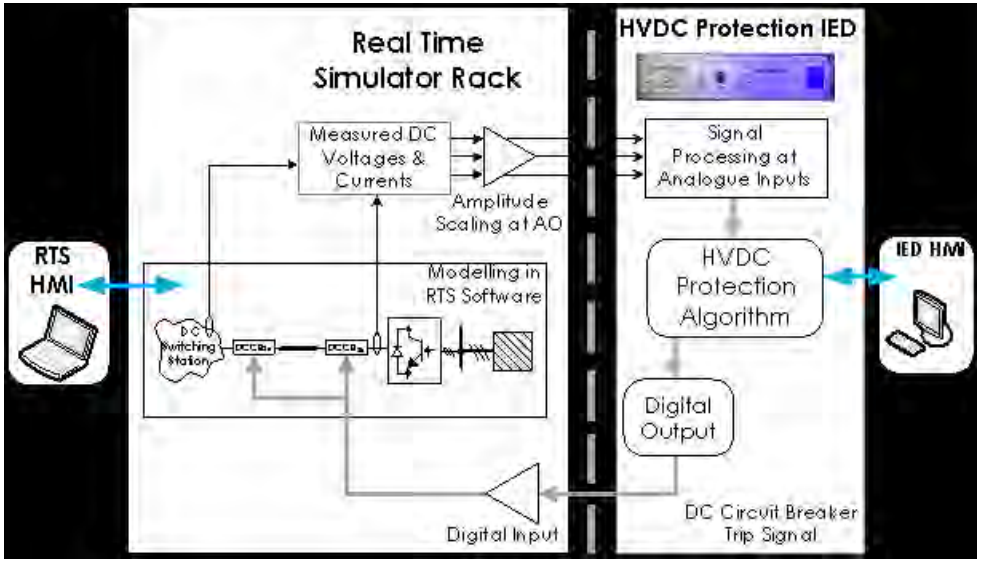
Real time Simulation test setup.



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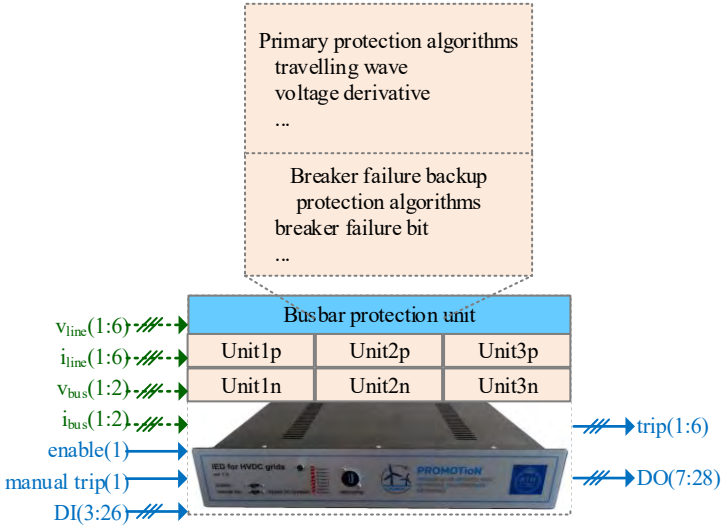
HVDC grid protection IEDs – hardware prototypes

- KTH IED
  - Off-the-shelf System-on-Chip development platform (Zedboard)
  - Six independent function unit
    - Inputs: line voltage(1) and current (1)
    - Outputs: trip out
  - Implemented protection functions:
    - Primary protection: travelling wave, dudt..
    - Breaker failure backup: breaker failure bit
    - Busbar protection
- MELCO IED
  - State-of-the-art, industrial-grade hardware
  - High speed input measurement sampling and computation
  - Outputs: flexible applicable in variety of network topologies
  - Implemented protection functions [1][2]



(a)

(b)

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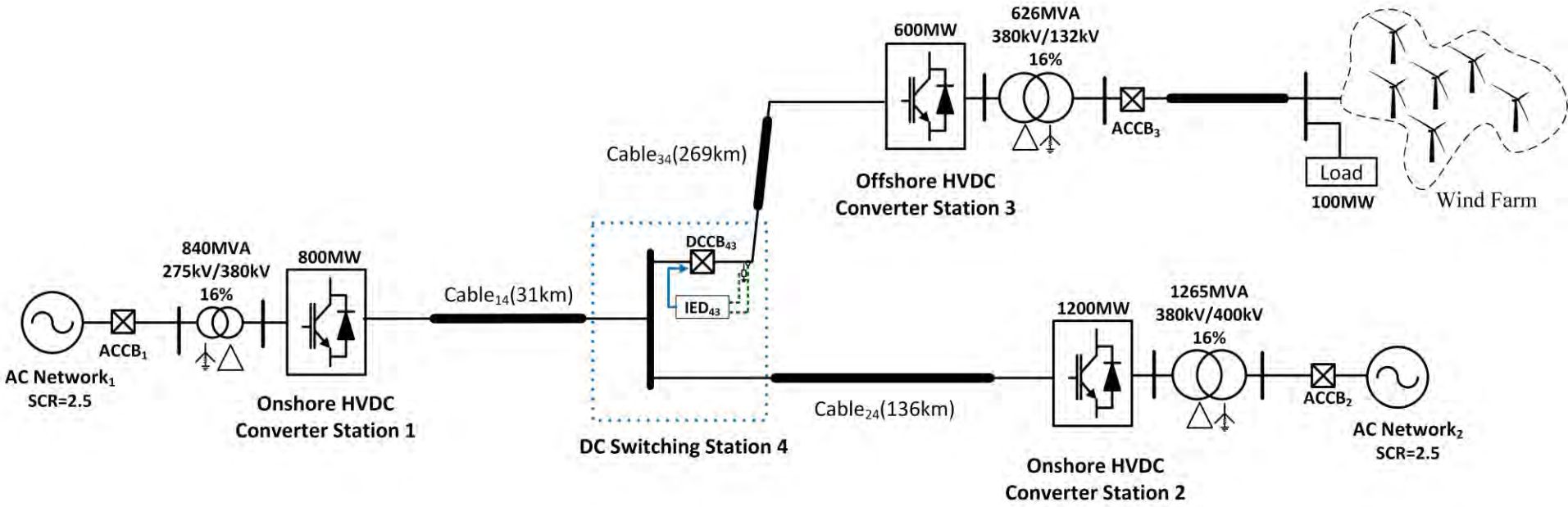
System model



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System Parameters

Table 1: Parameters of 3-Terminal HVDC System

	Station 1	Station 2	Station 3
	Converter		
Topology	HB-MMC	HB-MMC	HB-MMC
Arm inductance	13%	13%	13%
No. of cells per arm	350	350	350
Cell capacitance	7.2mF	10.8mF	5.4mF
Av. cell capacitance	20.55μF	30.83μF	15.4μF
Rated power	840MVA	1265MVA	626MVA
Rated active power	±800MW	±1200MW	±600MW
DC voltage		640kV (±320kV)	
AC voltage	380kV	380kV	380kV
	Transformer		
Rating	840MVA	1265MVA	626MVA
Voltage ratio	275/380kV	400/380kV	132/380kV
Reactance	0.16pu	0.16pu	0.16pu
	AC Grid		
Voltage	275kV	400kV	132kV
Nominal frequency	50Hz	50Hz	50Hz
SCR	2.5	15	-
X/R ratio	10	10	-
Local load	-	-	100MW
	Wind Farm		
Rated power	-	-	626MVA
Rated active power	-	-	±600MW
VSC DC Voltage	-	-	1.2kV
VSC AC Voltage	-	-	0.69kV
Trans. rated power	-	-	840MVA
Trans. voltage ratio	-	-	132/0.69kV
Trans. reactance	-	-	0.16pu

Table 2: Cable Parameters of 3-Terminal HVDC System

Item	Cable 1	Cable 2	Cable 3
Type	Underground	Subsea	Subsea
Conductor	Aluminium	Copper	Copper
Insulation	XLPE	XLPE	XLPE
Length	48km	267km	113km

Table 3: Additional inductance required to meet specified fault ride through scenario for each circuit breaker topology

	DCCB topology 1	DCCB topology 2
FRTS3	25 mH	105 mH

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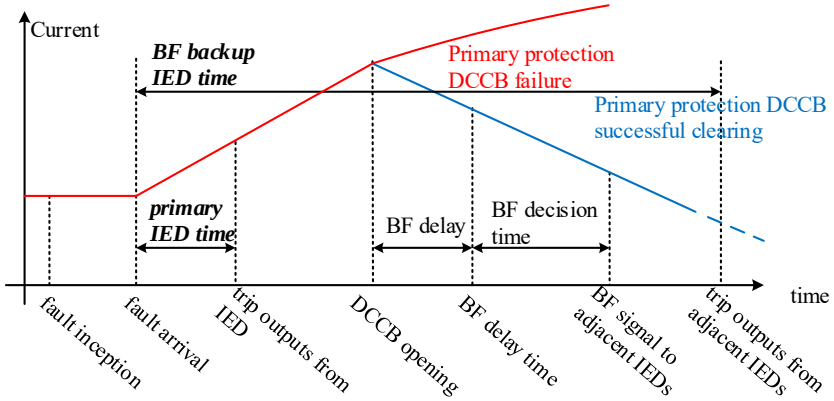
Test conditions

- Pole-to-pole faults every 5 km
- Three repetitions at each fault location
- IED operating time (mean time of 3 repetitions):
  - Primary protection: from fault arrival to the IED issues a trip outputs
  - Backup protection: from fault arrival to the backup protection IED issues a trip outputs



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Performance and Results for Hybrid Breaker

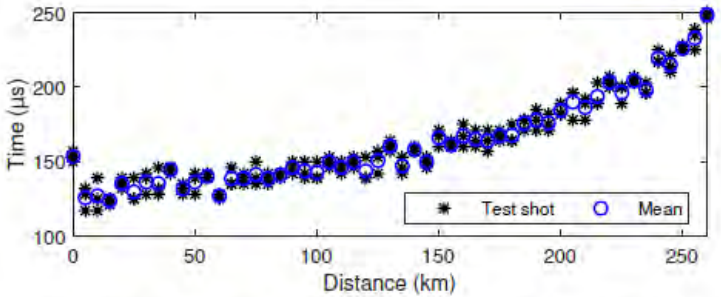

Fig. 5: IED Operating Time for PROMOTioN IED when Utilising Hybrid DCCB

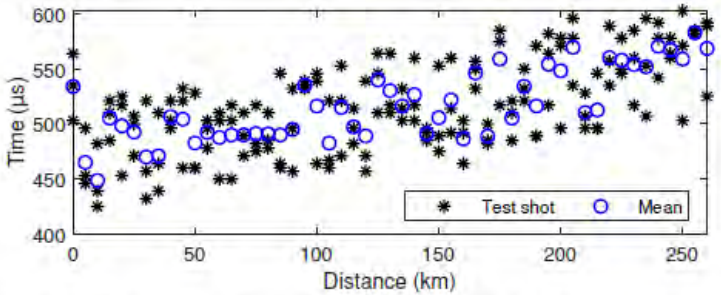

Fig. 6: IED Operating Time for MELCO IED when Utilising Hybrid DCCB

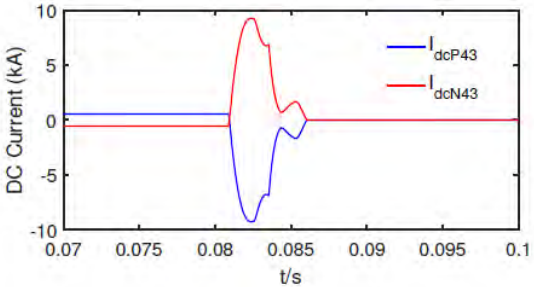

Fig. 7: DC Current Measured at the IED Location when Utilising Hybrid DCCB for Mid-Cable Pole-to-Pole Fault (MELCO IED Under Test)

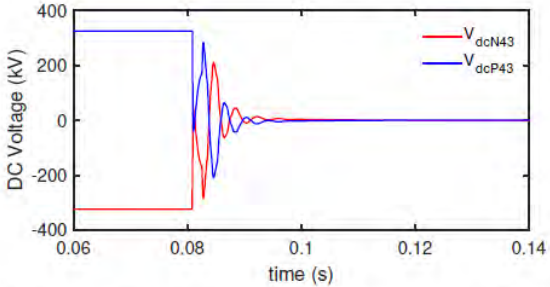

Fig. 8: DC Voltage Measured at the IED Location when Utilising Hybrid DCCB for Mid-Cable Pole-to-Pole Fault (MELCO IED Under Test)

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Performance and Results

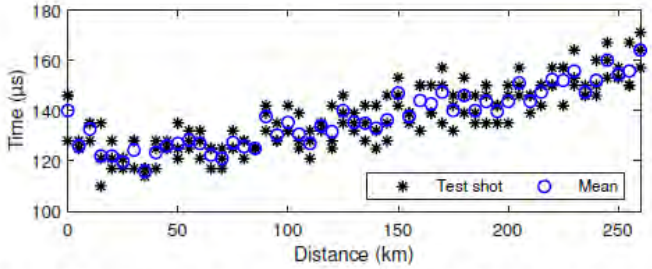

Fig. 9: IED Operating Time for PROMOTioN IED when Utilising Mechanical DCCB

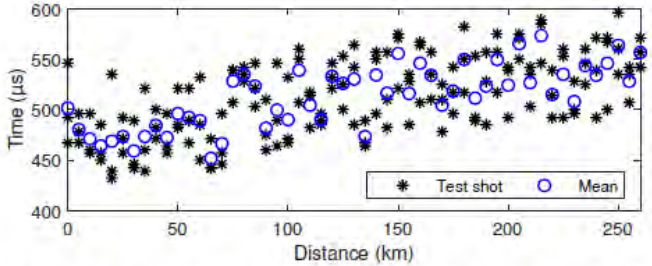

Fig. 10: IED Operating Time for MELCO IED when Utilising Mechanical DCCB

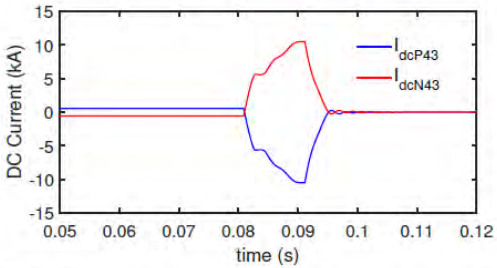

Fig. 11: DC Current Measured at the IED Location when Utilising Mechanical DCCB for Mid-Cable Pole-to-Pole Fault (PROMOTioN IED Under Test)

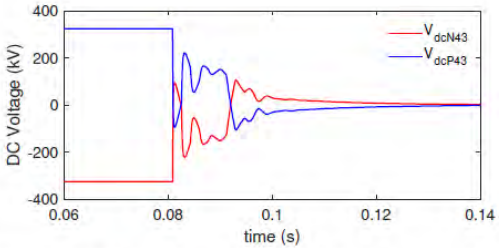

Fig. 12: DC Voltage Measured at the IED Location when Utilising Mechanical DCCB for Mid-Cable Pole-to-Pole Fault (PROMOTioN IED Under Test)

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Multi-vendor interoperability of IEDs

- Interoperability of IEDs from multiple vendors is one of the essential aspects to achieve a successful fault clearing.
- How to evaluate multi-vendor interoperability
  - Step 1: evaluate IED performance in a **single-vendor** setup
  - Step 2: evaluate IED performance in a **multi-vendor** setup
  - Step 3: comparison

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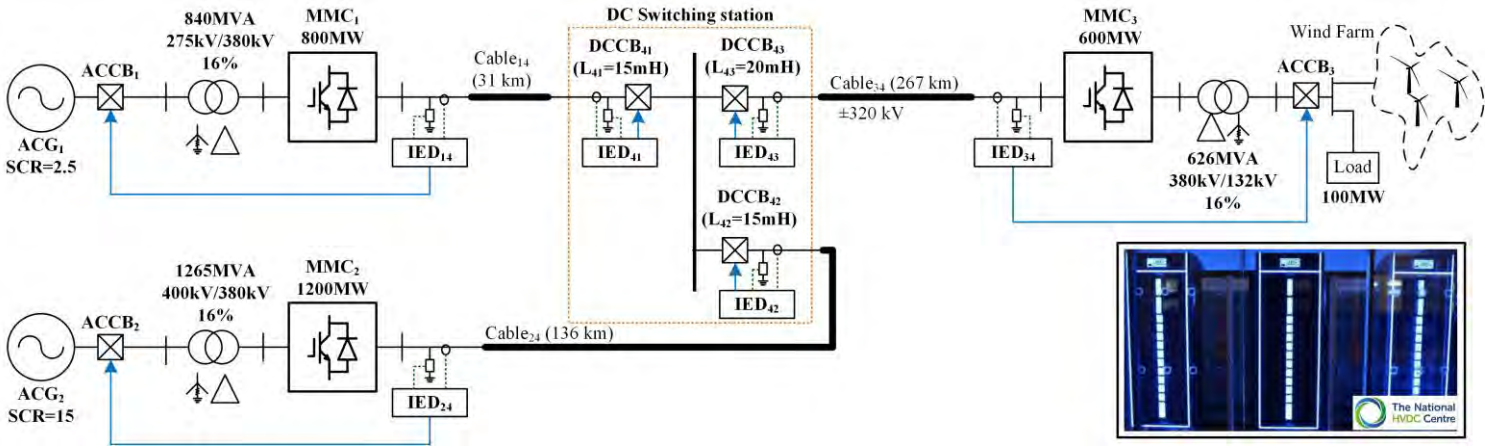
Multi-vendor interoperability test setup

- Fully selective strategy
  - IEDs are placed at both ends of a cable
  - DCCBs are placed at the DC switching station: inductors are chosen to allow breaking current to fall within the capability of hybrid DCCBs (2 ms/16 kA)
  - ACCBs at the converter side



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Test Cases

Case No	Vendor	Type	IED					
			41	42	43	14	24	34
C1	Single-vendor	Primary	SW	KTH	SW	SW	KTH	SW
C2		Primary	SW	MELCO	SW	SW	MELCO	SW
C3		Breaker failure	MELCO	MELCO	MELCO	SW	SW	SW
C4	Multi-vendor	Primary	SW	KTH	SW	SW	MELCO	SW
C5		IED failure	SW	KTH	SW	SW	SW	SW
			SW	MELCO	SW	SW	SW	SW
C6		Breaker failure	KTH	MELCO	KTH	SW	SW	SW

IED types:

- KTH and MELCO: Hardware IEDs; SW: Software IEDs modeled in RTDS

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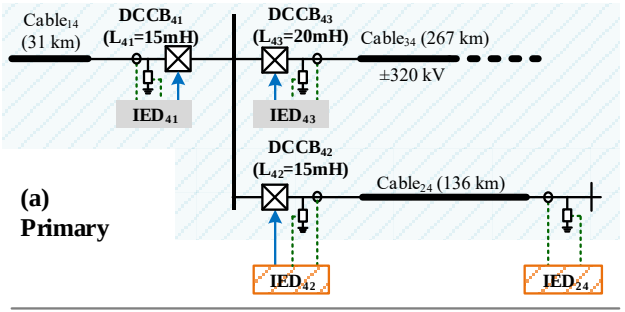
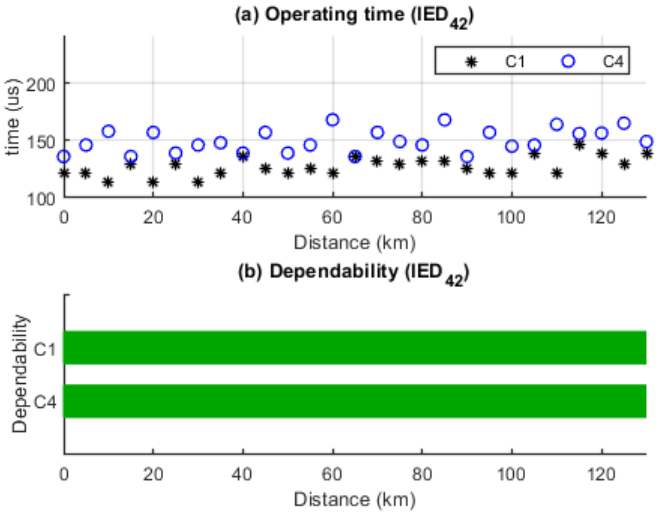
Primary protection

- IED configuration:
  - Single-vendor setup:
    - C1: KTH IED functional units connected to IED_{42} and IED_{24}
    - C2: MELCO IED functional units connected to IED_{42} and IED_{24}
  - Multi-vendor setup:
    - C4: KTH IED: IED_{42}, MELCO IED: IED_{24}
- Example results (KTH IED):
  - Mean operating time: less than 200 μs
  - Single-vendor and multi-vendor cases:
    - Comparable operating time (Multi-vendor case is slightly higher → needs further investigation)
    - 100% dependable along the 136 km cable





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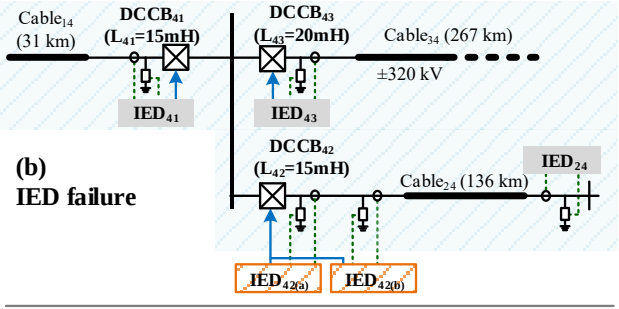
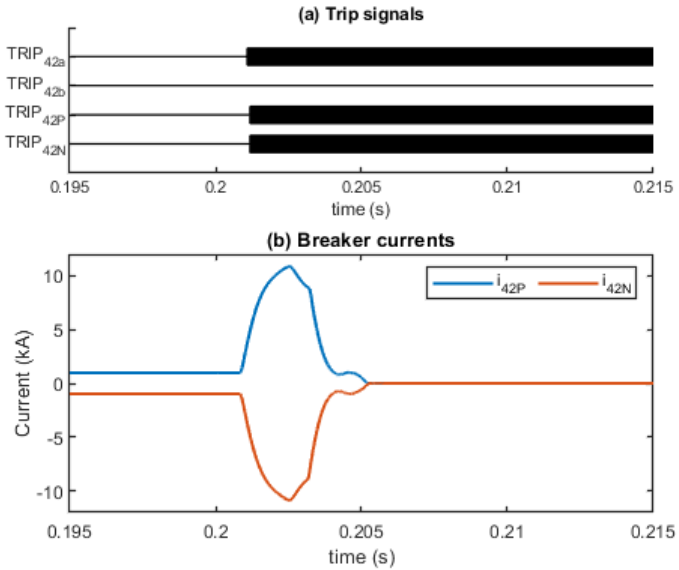
IED failure backup protection in a dual redundant setup

- IED configuration (multi-vendor setup (C5)):
  - KTH IED as IED_{42a}, MELCO IED as IED_{42b} with separate measurement inputs, and independent trip outputs
  - One of the hardware IEDs is disabled to simulate a failure





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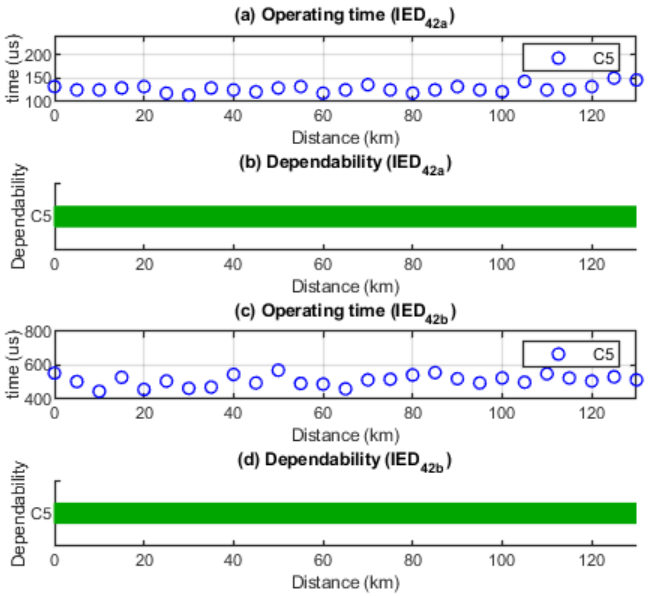
IED failure “backup” protection in a dual redundant setup

↗IED performance:

- ↗Operating time: few hundreds μs
- ↗100% dependable



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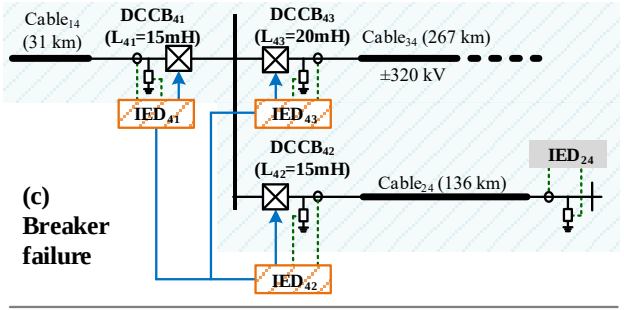
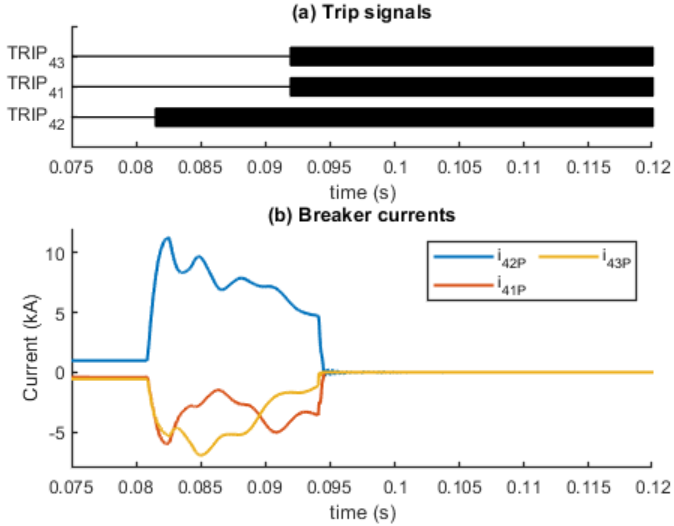
Breaker failure backup protection

- IED configuration:
  - Single-vendor setup (C3):
    - MELCO IED functional units are connected to IED_{42}, IED_{41} and IED_{43}.
  - Multi-vendor setup (C6):
    - MELCO IED: IED_{42}
    - KTH IED: IED_{41} and IED_{43}
    - MELCO and KTH IED: directly connected with a wire
- Tests:
  - $DCCB_{42}$ is disabled
  - IED_{42} detects a fault and issues a trip order
  - IED_{42} detects a breaker failure and send a trip order to IED_{41} and IED_{43}
  - IED_{41} and IE_{43} trip the backup DCCBs





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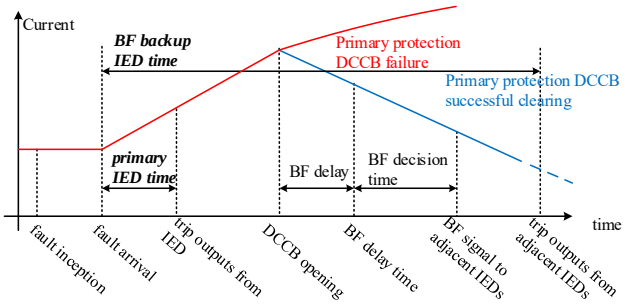
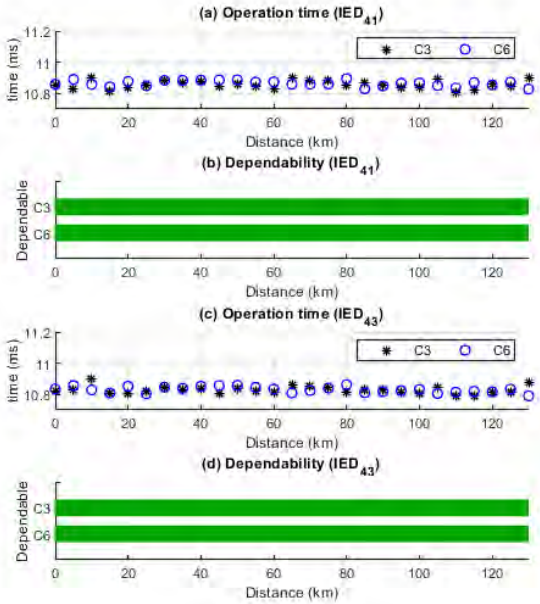
Breaker failure backup protection



- ↗ IED performance:
  - ↗ BF delay setting: 10.42 ms
  - ↗ Single-vendor and multi-vendor cases:
    - ↗ BF backup IED time: comparable
    - ↗ BF decision time: few hundreds μs
    - ↗ 100% dependable



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Use of CMS Control and Protection Replcias

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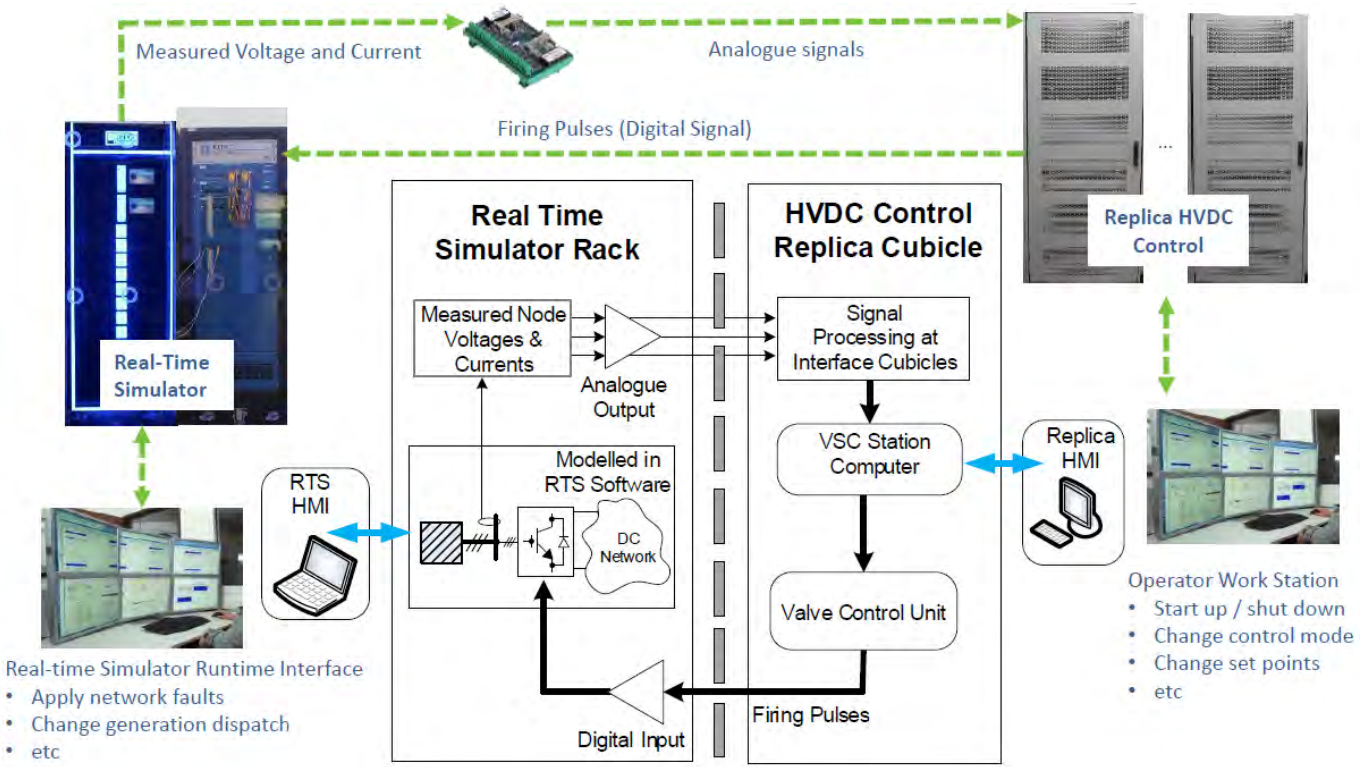
Replica Setup



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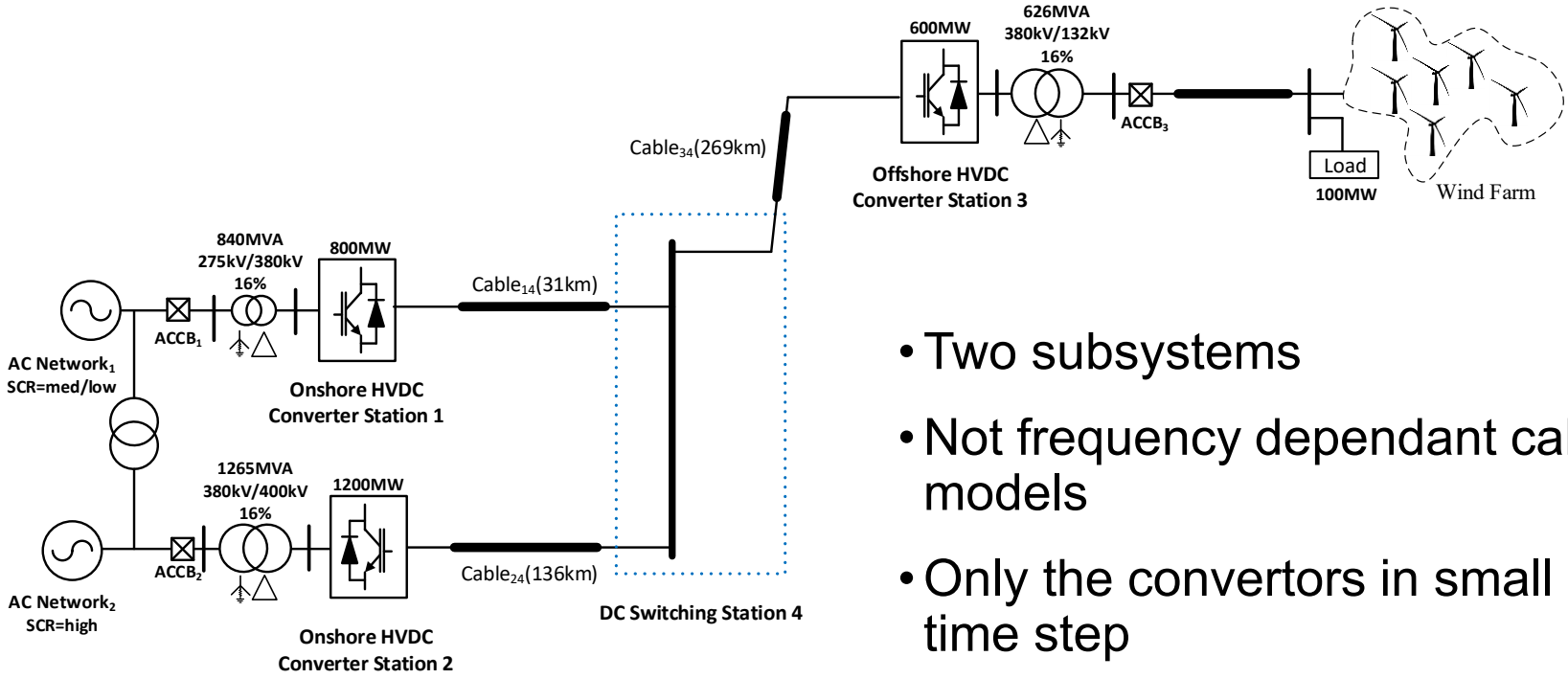
Base Model



- Two subsystems
- Not frequency dependant cable models
- Only the convertors in small time step

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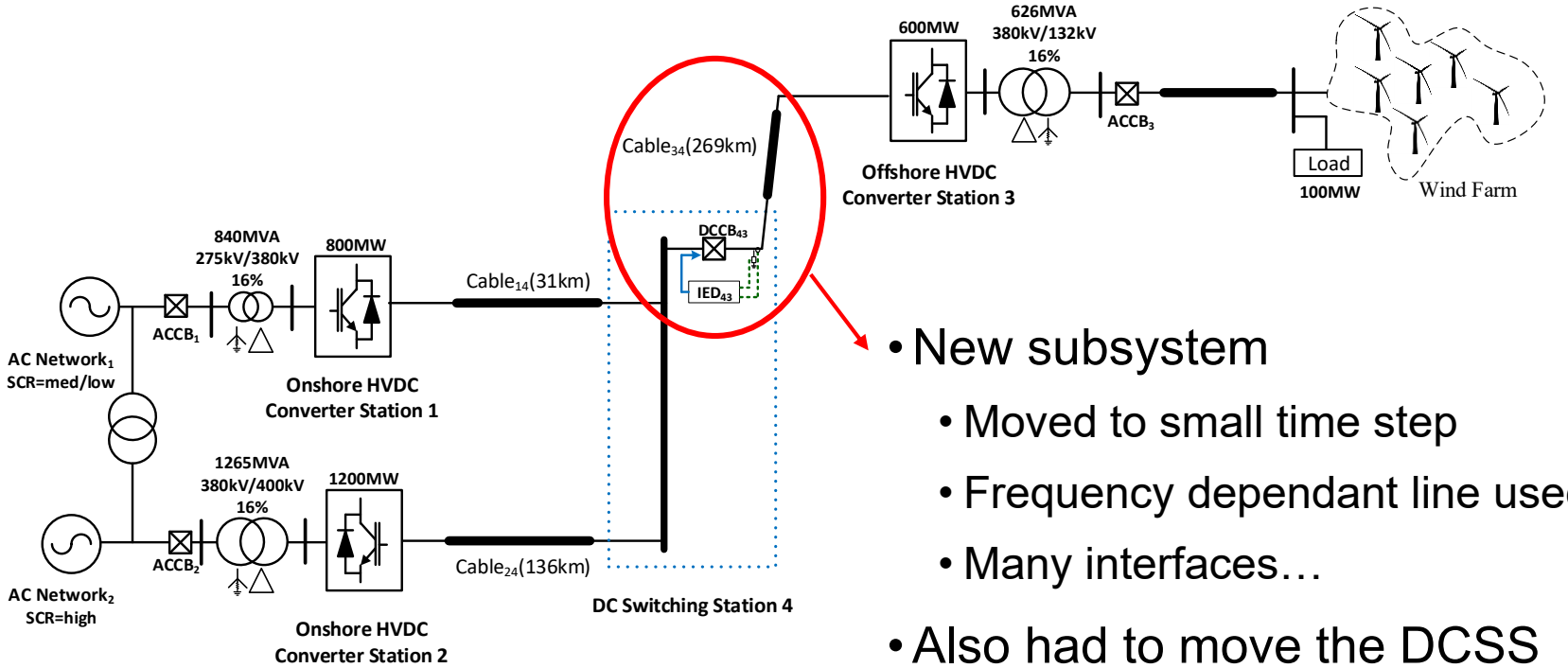
Updated Model



- New subsystem
  - Moved to small time step
  - Frequency dependant line used
  - Many interfaces…
- Also had to move the DCSS

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Partially and Fully Selective Testing Summary

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SUMMARY

PROGRESS

- Two hardware IEDs are tested in a realistic three-terminal network for primary, IED failure backup and breaker failure backup protection. The test results demonstrate
  - Single-vendor and multi-vendor cases: comparable performance
  - Multi-vendor HVDC grid protection system: feasible and a viable option
- Initial steps to test with CMS Control and Protection Replicas undertaken

NEXT STEPS

- Further testing with different combinations of DCCB models and IED locations
- Extend model to 4T system
- Add in pole rebalancing to allow move to system level testing
- Further testing including the CMS Control and Protection Replicas
- Prepare for the next Demonstation
  - (Probably the second week in May)

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Non-selective Testing

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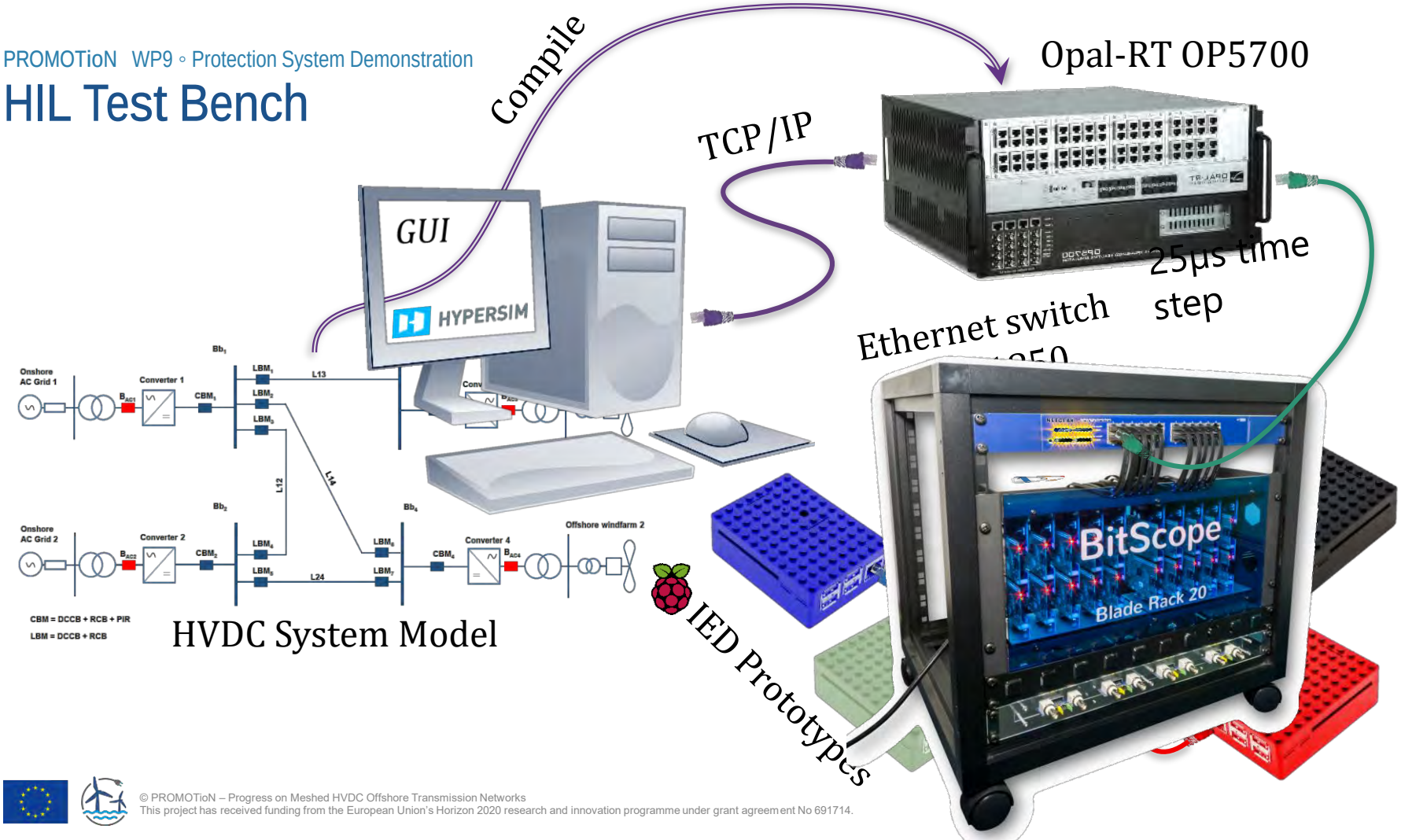
HIL Test Bench



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Benchmark network 1

Bipole HVDC

- System and IEDs from SuperGrid Institute

In simulation (25µs):

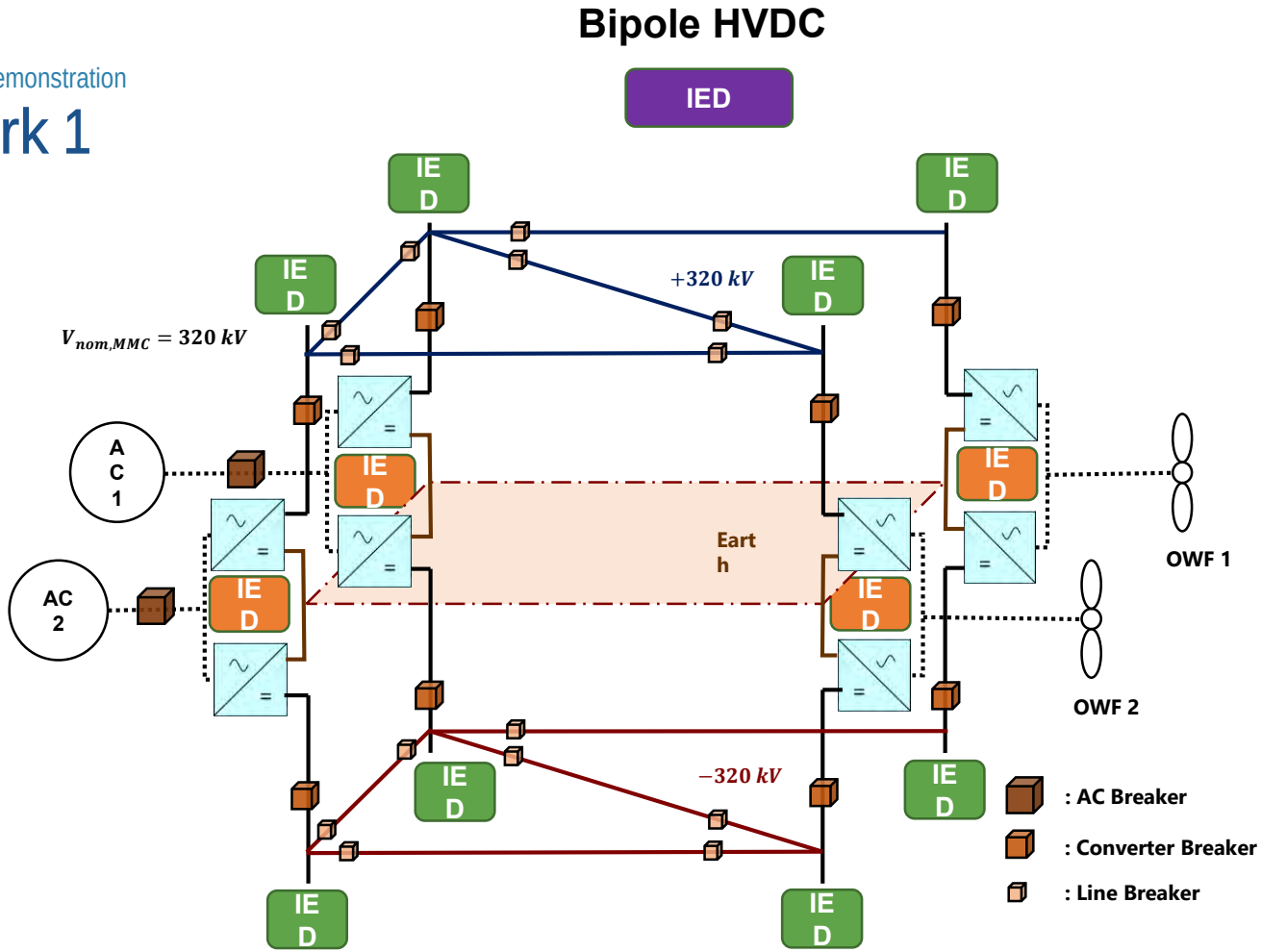
- Ground return
- AC side (Thevenin equivalent)
- HB-MMC average model
- Wideband cable moldel

HIL:

EDs (1 pole)

- Relays x11 (11 IEDs)
- Station supervisor (4 IEDs)
- Grid supervisor (1 IEDs)

16 IEDs



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Benchmark network 2

Monopole HVDC

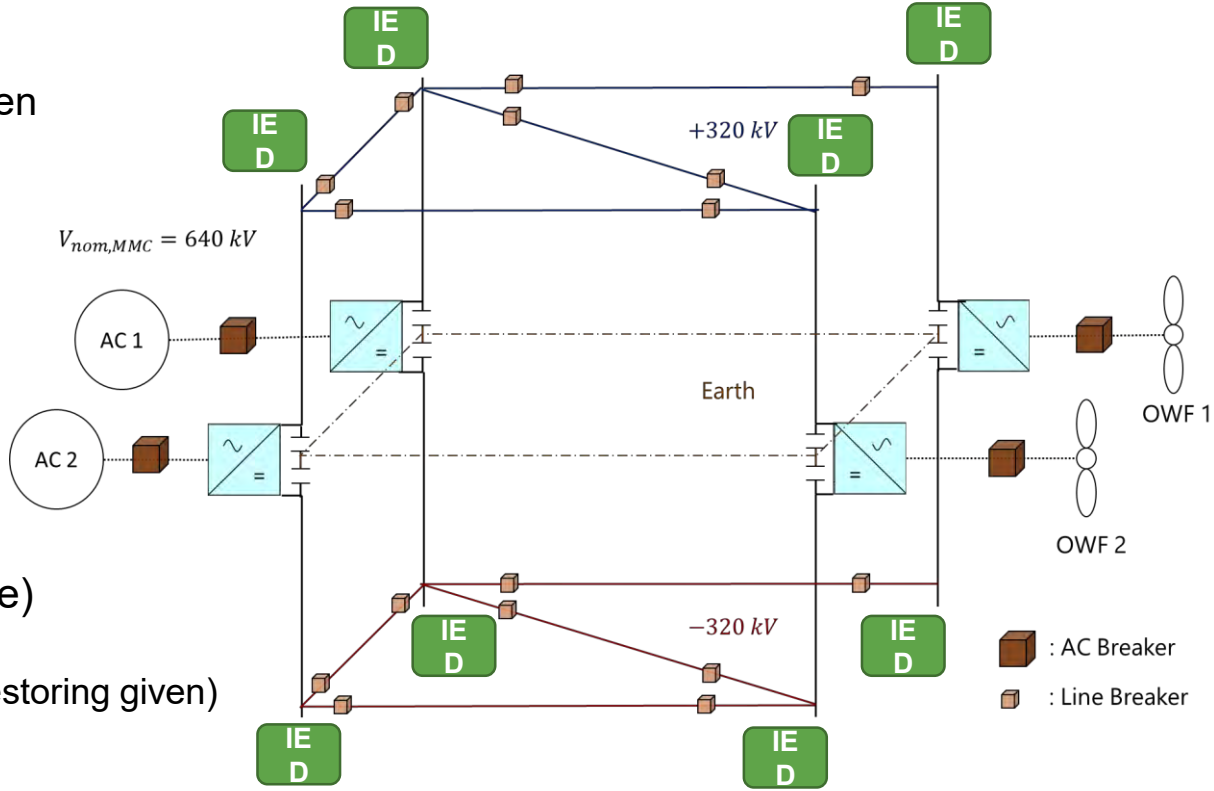
- System provided by RWTH Aachen
- IEDs from SuperGrid Institute

In simulation (40µs):

- Star point reactor
- FB-MMC average model
- Wideband cable model
- AC side (Thevenin equivalent)

HIL:

- IEDs (2 poles because monopole)
  - Relays x16 **16 IEDs**
  - No station supervisor (FB-MMC restoring given)
  - No grid supervisor



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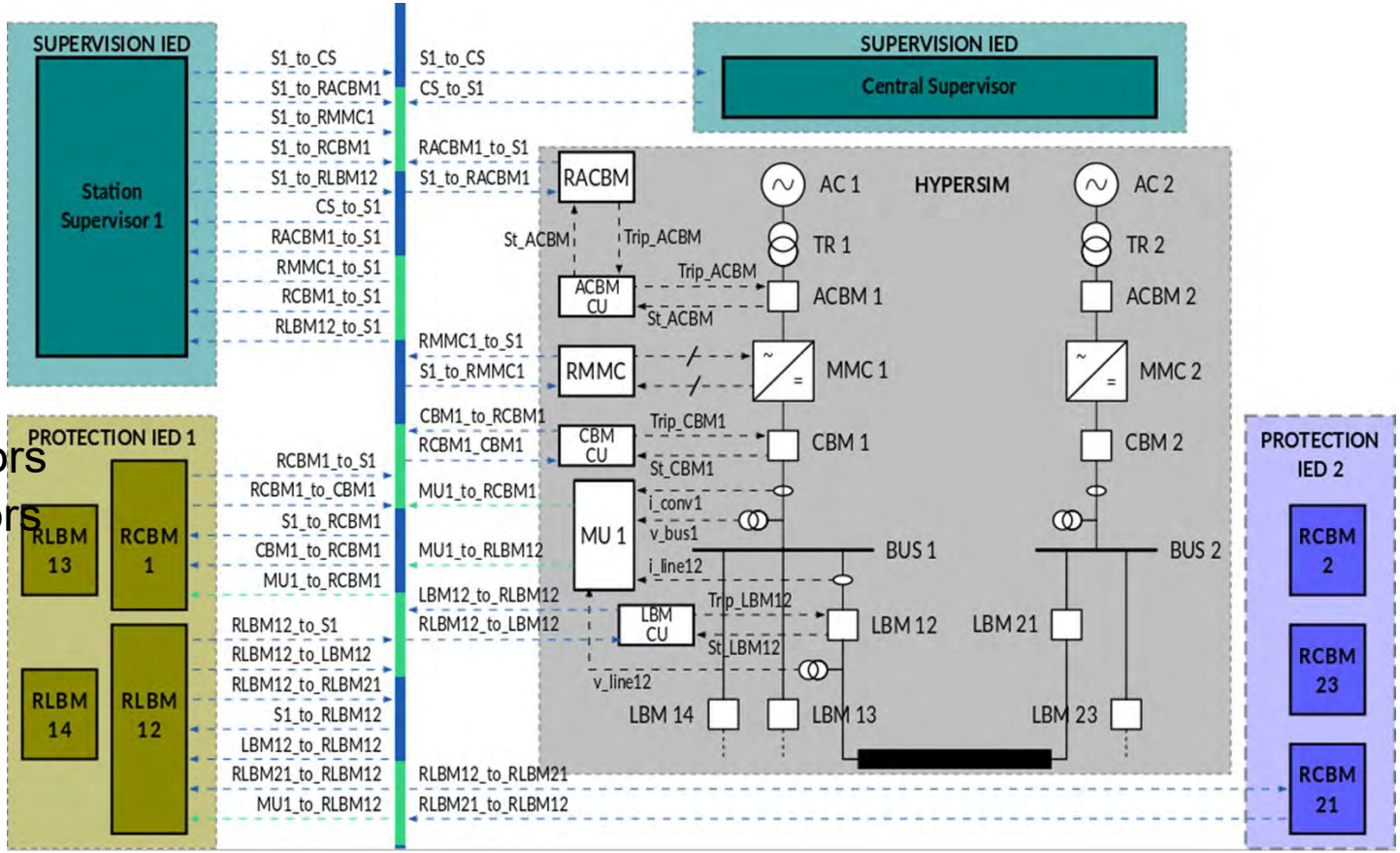
Protection and supervision architecture

Vision from SuperGrid Institute

- Interoperable
- Central supervisors
- Station supervisors
- Modes:
  - Start-up
  - Short-circuit fault
  - Voltage recovery
  - Power recovery



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Non Selective Testing Summary

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Non Selective Testing Summary

PROGRESS

- Hypersim models
  - MMC-HB
  - MMC-FB
  - Mechanical DC CB
- Pre-validation tests of a 4T
  - Start-up
  - DC fault (open-loop)
- Validation tests of the FB-MMC model in a 3T grid (symm. Monopole).
  - Start-up
  - DC fault (closed-loop with simulated IEDs)
- Improvement of IED prototypes
  - Developpment (C code)

NEXT STEPS

- Pre-validation tests of the 4T including SuperGrid IEDs (bipole).
- Pre-validation tests of the 4T including SuperGrid IEDs (symm. monopole).
- Validation tests of the FB-MMC model in the 4T grid (bipole) using simulated relays.
- First version of supervisor for the 4T grid in Hypersim.
- Prepare for the Demonstation
  - Aligned with SuperGrid Institute TO event May/June

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Thank you!

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Minutes of Meeting

Event: PROMOTioN Half-yearly meeting
Location: Roskilde
Date: 3rd of December 2019
Session: Plenary session

WP13 – Sebastian Menze (SOW)
Cees Plet: DG RTD mentioned during visit to the booth that in the Horizon Europe program he will put particular focus on ensuring the results of research projects are exploited. Hence please participate with intent in the exploitation of results initiative led by DNV GL

WP11 – Poul Sørensen (DTU)
Lorenzo Zeni: The cost axes on the figure refers to the cost of a test. It is not easy to compute the cost of a bad model

Cees Plet: What are you doing to ensure active uptake of our recommendations such writing CIGRE WG ToR proposals?

Poul Sørensen: we are carefully looking at where this is of value, as starting a new WG is not always addressing the issue in the most effective way and can even cause confusion. It is therefore also important to make sure existing initiatives are strengthened by ensuring PROMOTioN results are transferred to them.

Cees Plet: The creation of a grid code on the DC side was seen as a key requirement for the development of a DC grid during the WP12 meeting. What is WP11 doing to kick-start the formation of such a grid code?

Poul Sørensen: This is the task of TSOs. As PROMOTioN we can provide the input and a first draft but we cannot start the activity.

WP15 – Uwe Riechert (ABB)
Rene Smeets: With regards to the presented additional test (SF6 alternative AirPlus long term test) are you planning to also include alternative gases from other manufacturers, as is done with other technologies in PROMOTioN?

Uwe Riechert: In principle open to do so, but it requires more time which is no longer possible within the project.

Cees Plet: Are there any other OEMs that are interested in showcasing there are alterative gases in a similar way?
- No response

WP2 – Christina Brantl (RWTH Aachen)
Dragan Jovcic: Why are deliverables confidential if no vendor-specific models were used?

Kanstantsin Fadzeyeu: Models in WP2 were all derived from publicly available CIGRE models. WP2 models were benchmarked by OEMs and the dynamic response was

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deemed reasonable. The enhanced models of WP2 have been delivered back to the public domain (e.g. CIGRE).

Christina Brantl: PSCAD model will be available on ProjectPlace. Other university internal models will also be made available. Commercial software e.g. Eurostag will not be made available.

Cees Plet: supports making all deliverables in WP2 publicly available as not OEM specific info was used. Should be discussed in WP2 and PMG, also to make library of models of all HVDC grid components available publicly as a project.

Ramon Blasco: supports making it open, but we need to think about what to publish as some material in deliverables is probably not of interest for general public.

Karim Karoui: Can we recommend values for the limits on our CG requirement recommendations

Christina Brantl: can be done, but it should be done by ENTSO-E

Cees Plet: We should provide numbers based on state of art and PROMOTioN understanding, including argumentation and disclaimer that of course final values should be determined by ENTSO-E

Niklas Svensson: How much of the WP2 results are applicable to point-point HVDC links?

Christina Brantl: in principle everything, as point-point can be regarded as a special case of HVDC grids, so eventhough all requirements are applicable, they may not be relevant.

WP3 – Nikolaos Cutululis
Kanstantsin: Were models Matlab or PSCAD

Nikos: Models were provided in PSCAD

Kanstantsin Fadzeyeu: How do industry and academia see perspective of self-energisation and black start and how does this translate to requirements of custoemrs and when do you think this might happen?

Nikolaos Cutululis: Industry was not very much involved in that part, so can't comment on that. OEMs have provided vendor specific models with black-start functionality. There is a lot of interest, but a lot of engineering and details still need to be defined. PROMOTioN has developed basics and fundamentals. Push is coming from TSOs

Ramon Blasco: depends on when technology is available, e.g. Siemens Gamesa has been working on it. Need to convince TSO's that black start from offshore wind can work, as there is a drive to close down coal plants who often have black start duty. This drive is happening, and in latest bidding for blackstart by national grid, wind farms were included. It looks like it might happen in medium term

Philipp Ruffing: do we ave any actions like the STP planned for DRUs to demonstrate that it can be done.

Nikolaos Cutululis: do what promotion originally set out to do

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Dirk van Hertem: It seems that DRU is dead, even though technically feasible there are no next steps in industry. A STP should be included in WP12 to create this push

Cees Plet: WP3 output should include requirement for validation of models used for grid code compliance evaluation. WP3 and WP16 should create joint message on this topic

WP16 – Philipp Ruffing
Dragan Jovcic: Will results from WP16 demo using Chinese OEM equipment be shared? Will deliverable be reviewed by Chinese partner? Will they be available for questions?

Cees Plet: Other OEMs in the project were contacted but were not willing to rent out control & protection replicas for this purpose. Hence the equipment was rented from Chinese OEMs where it was possible. The Chinese vendors are only suppliers to the work package and are not partners of the project. As such they do not review deliverables for example. If there are specific questions, then these can be forwarded to the OEM.

WP6 – Dragan Jovcic
Cees Plet: As a suggestion to add to the failure mode analysis is to create reliability block diagrams which relate the failure rates (mean time between failure) of individual components to the overall failure rate, or reliability, of a DCCB as a system. This figure is typically used in grid planning and availability studies. Even though MTBFs for new components in DCCBs are not yet known, the logical relationship between the failure rates can already be derived.

Dragan Jovcic: WP6 will look into this.

WP10 – Rene Smeets
Dirk van Hertem: How many people will be able to attend the demo test?
Rene Smeets: Lab is limit of about 30 people, tests are open to anyone in the consortium, date is fixed, invitation will come soon

Cees Plet: will multi-part testing in which different stresses are tested in separate tests be sufficient for qualifying HVDC circuit breaker technology?

Rene Smeets: Yes, it has to be, since other commercial labs will not be able to carry out one-stop-shops in the way KEMA Labs can. This is the topic of the Cigre B4.80 WG on HVDC circuit breakers.

WP4 – Dirk van Hertem (KU Leuven) & Serge Poullain (Super Grid Institute)
John Moore: in contrary to claim, protection design must be thought of a priori to reserve space on platforms etc. So how to choose between different protection strategies
Dirk van Hertem: not necessary during basic grid design, but later, before platform FEED, toold provided by promotion can provide insight in which method is best

Cees Plet: how do we select what is best strategy in a specific project?

Dirk van Hertem: Prob fully selective but this cannot be said without exact information on costs and reserve benefits

Christina Brantl: What are EENT pie charts based on? Should be clear if this is used to support external message.

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Serge Poullain: only part of cost. Includes cabels, transformers and protection contribution to total EENT. This is topology specific

Karim Karoui: At the beginning of PROMOTioN the question was if fully or non-selective protection strategies would be best, now it emerges that the conclusion is that probably a mix of both will be best.

WP9 – Ian Cowan (SHE Transmission)
Philipp Ruffing: It seems supergrid topology is not the same as the one used in Aachen, can we align?

SGI: Yes

Cees Plet: Are the real ABB control & protection replicas going to be used?

Ian Cowan: Yes

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Deployment considerations for HVDC Meshed Offshore Grids in the Northern Seas

TenneT ● John Moore

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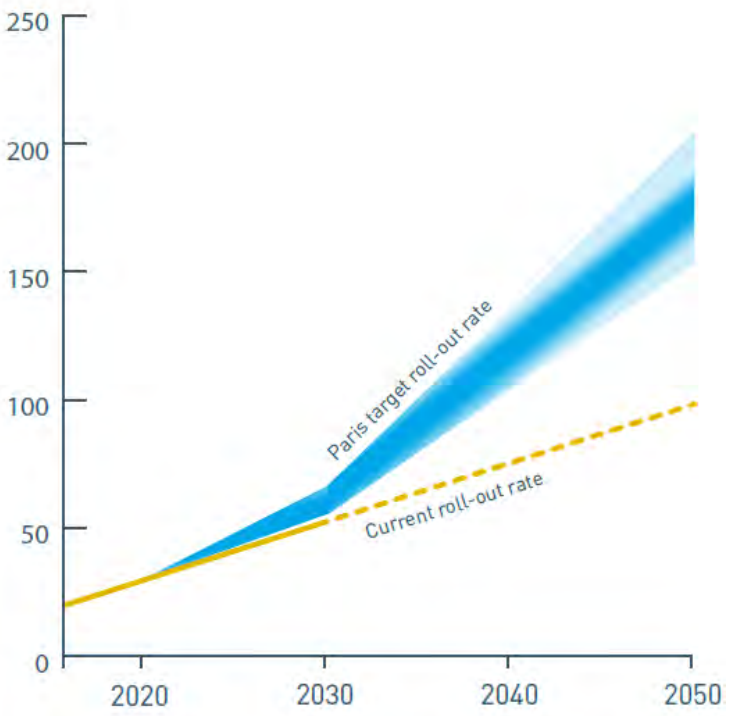
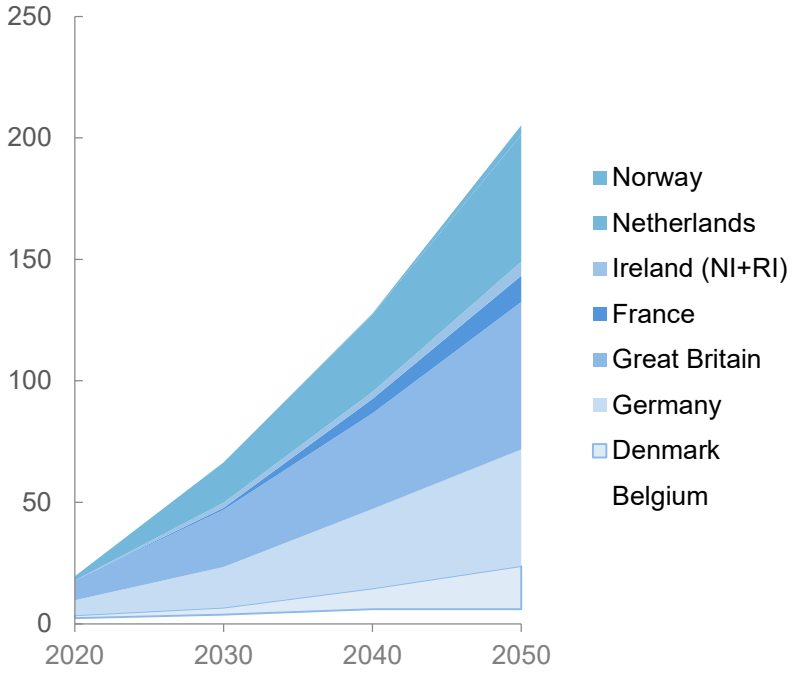
What is the challenge for transmission operators?

Current roll-out rate of offshore wind is insufficient to meet Paris target.

Projected installed offshore wind capacity range in the North Sea [GW]



PROMOTioN worked together with different stakeholders to balance national ambition and top down targets



- To hit 2050 Carbon targets we need to accelerate the build of Offshore Wind
- Distance to shore increases as near shore locations filled and resistance increases: 55km today to >100km
- Preparation time increases
- Uncertainty as to technological change and need
- A consistent Legal & Regulatory environment is required to facilitate more efficient evacuation and anticipatory investment
- The infrastructure requires to adopt and provide flexibility options at scale and interact with the onshore grid

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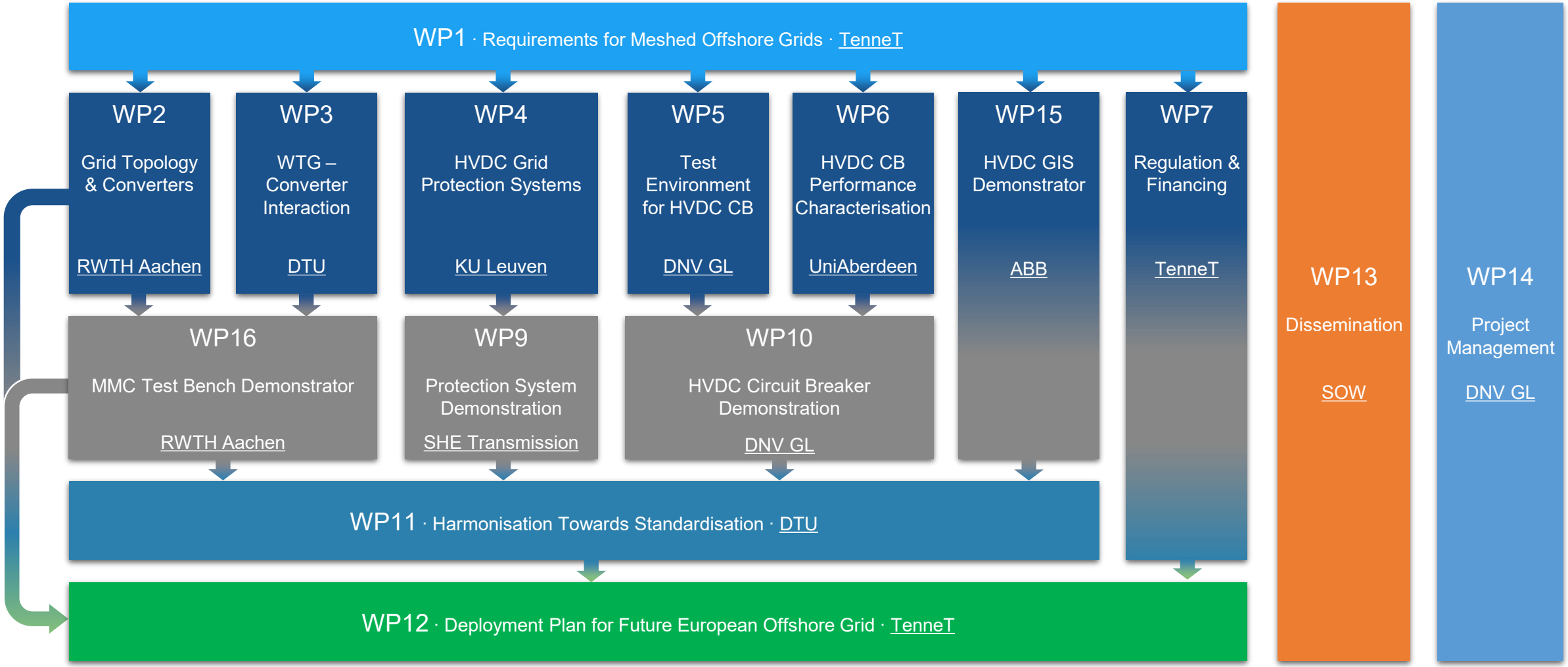
PROMOTioN researches into technology and broader issues



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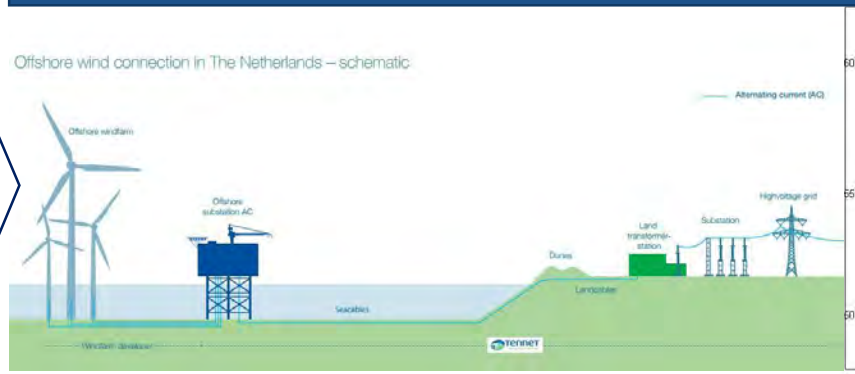
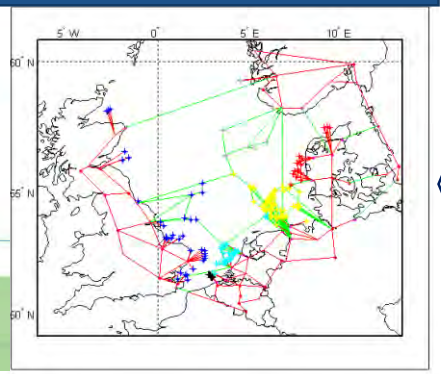
To produce a Deployment Plan for European future offshore grid development.

- Technical
- Governmental
- Financial





- Economic
- Market
- Legal & Regulatory

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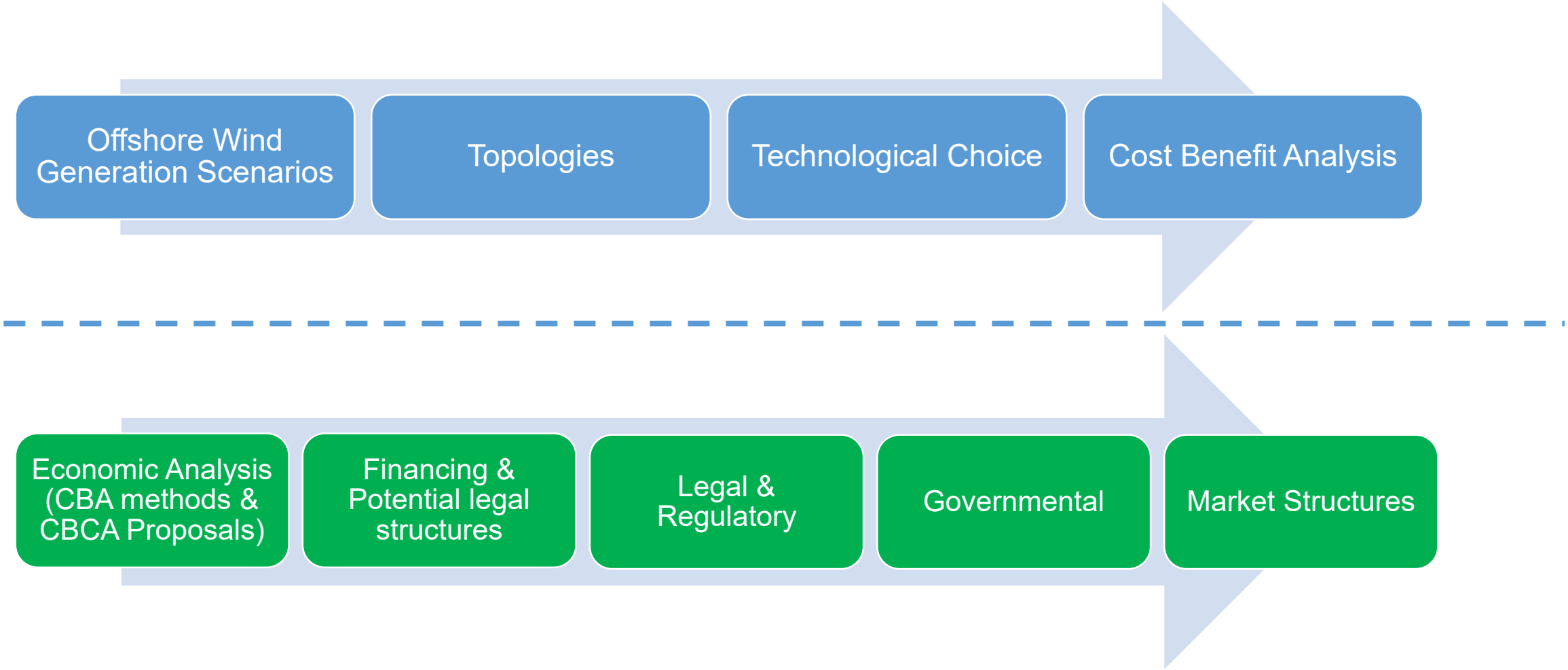
Two parallel paths to a Deployment plan:



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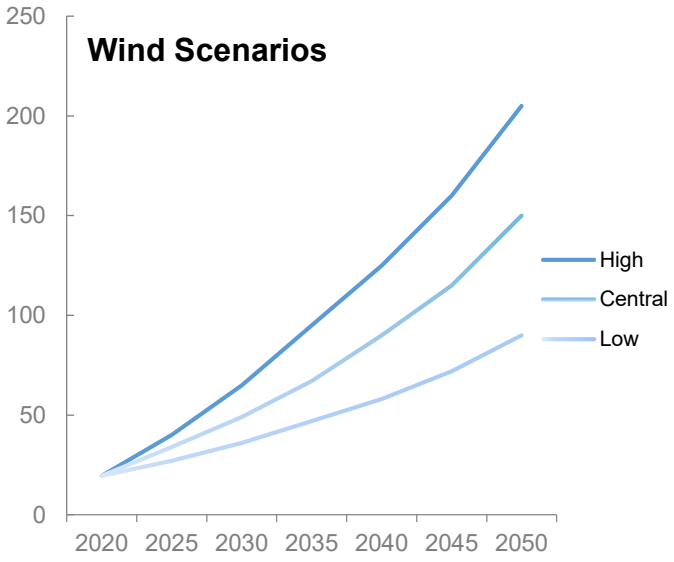
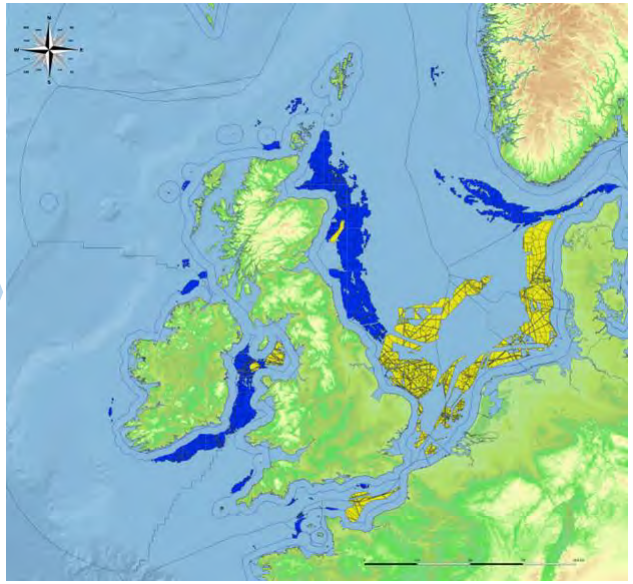
Offshore Wind Generation Scenarios → Topologies → Technological Choice → Cost Benefit Analysis

1. Top down market
2. GIS mapping studies
3. Country Allocation



PROMOTioN Projected Locations



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Offshore Wind Generation Scenarios → Topologies → Technological Choice → Cost Benefit Analysis

PROMOTioN recommendations

- PROMOTioN High scenario projects higher growth than current ENTSO-e scenarios in order to reach 2050 Carbon reduction targets,
  - Our high scenario is not the highest we have seen in parallel studies.
  - Be aware of space constraints and ability to deliver.

- Optimising offshore wind potential is subject to political influences and does change, e.g. new governing trends shift towards an increased emphasis on RES
  - Positive increase in Wind potential (e.g. DK – greater ambition) can lead to use of better locations for generation. EU Clean Energy Package encourages cooperation.
  - Use local powers for more rational allocation of spatial planning (e.g. NL rationalises spatial planning).

- High development of offshore wind leads to some utilisation of Nature 2000 areas
  - Prioritise and coordinate spatial planning for offshore wind
  - We fixed wind development, but could be optimised more per concept.

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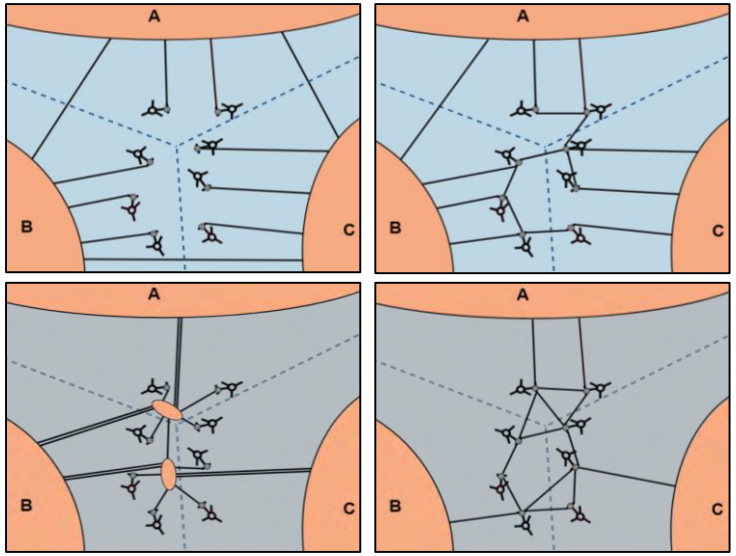
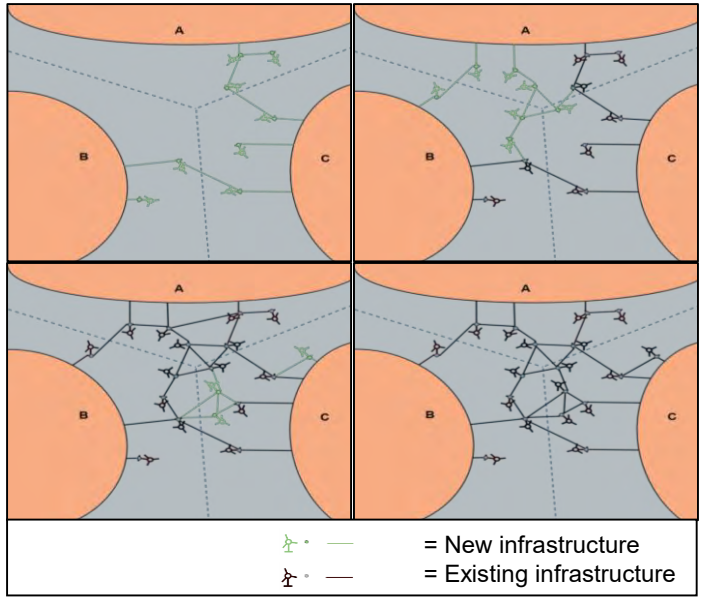
Offshore Wind Generation Scenarios → **Topologies** → Technological Choice → Cost Benefit Analysis

1. Concepts
2. Temporal development
3. Optimisation





Step 1: Primary Optimization (Minimization of the investment cost to evacuate offshore wind energy)

Step 2: Secondary Optimization (Optimization of the interconnection capacity between countries)

Step 3: Technical feasibility of the proposed grid

Setup of a detailed grid model

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Offshore Wind Generation Scenarios | **Topologies** | Technological Choice | Cost Benefit Analysis

PROMOTioN recommendations

- Islands planned and built early on in the period (2025 – 2030)
  - PROMOTioN assumes a current status quo that concentrates energy into (small) hubs as Business as Usual
  - For maximum Cost-Benefit, the optimiser suggests a benefit in the use of islands.
  - This is a theoretical model, and requires feasibility and further optimisation.
- Meshing and multi-terminal connections are important and should be used where appropriate
  - Technical choice of bipole architecture and N-1 security criterion reduces benefit of redundant paths
  - Cable maximum power is matched to onshore infeed constraints.
  - The optimisation does not have large amounts of meshing, but it does provide material cost savings in some cases.
- Early planning facilitates meshing later in the period (2040 onward)
  - As distance to shore increases, meshing of offshore wind clusters becomes more cost effective
- Adopt standards to facilitate meshing, but we anticipate ‘stacked’ meshed systems rather than an entire meshed offshore grid
- Interconnection between windfarms of different countries in order to save on cable costs and increase cable utilisation

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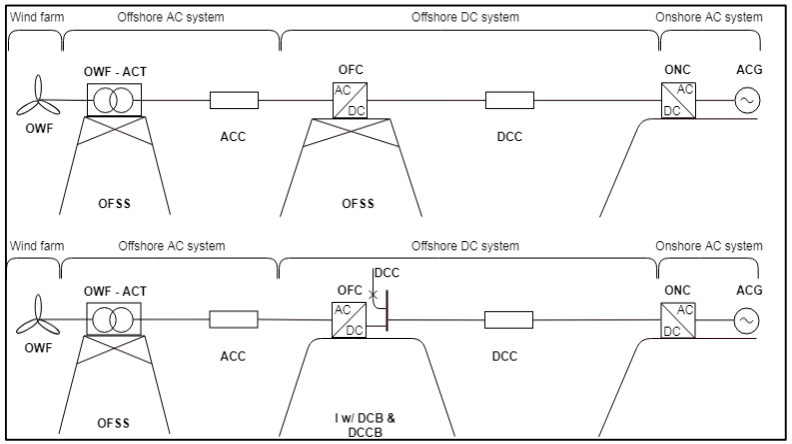
Offshore Wind Generation Scenarios → Topologies → **Technological Choice** → Cost Benefit Analysis

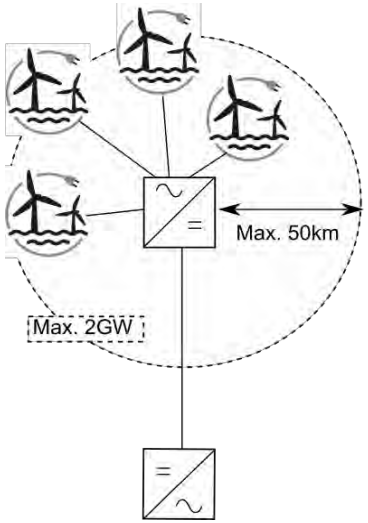
1. Cost data / inputs
2. Clustering
3. Hub design: bare bones and Protection
4. Costing the network

Cost Data Collection

Standard voltages, e.g.525 KV
Standard configuration: Bipole with fixed return
Standard cable sizes – current Max 2 GW
No onshore load shedding – N-1



Different Hub structures per Concept with different components (standard architectures depend on distance/power flows)
Protection Strategies determined by WP4



Costs Analysis

Investments	Protection Costs (where required)	Operating Costs
- AC equipment & cables - DC Hub Equipment - cables		

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Offshore Wind Generation Scenarios | Topologies | **Technological Choice** | Cost Benefit Analysis

PROMOTioN recommendations

- Design standard Platforms that can be either modular or built out for multi-terminal use.
  - Protection equipment requires increased space on platforms such that costs increase quickly
- Plan early and anticipate future capacity needs to minimise cable costs.
  - Small changes to the topology can have major costs impact
  - Direct connection of AC inter-array cables saves high AC platform costs
- Shorter distance connections will still be in AC, and therefore utilise (cheaper) AC meshing where large power concentrations (Hub model)
- HVDC protection costs dependent on choice of fault clearing strategy
  - Protection may be done fully selective which requires many expensive DC Circuit Breakers
  - Smart protection using grid splitting may significantly reduce protection costs

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Offshore Wind Generation Scenarios → Topologies → Technological Choice → **Cost Benefit Analysis**

1. Network Costs
2. Benefits Analysis
3. Non Quantitative analysis
4. KPIs - LCoT

Costs Analysis

Investments	Protection Costs (where required)	Operating Costs
- AC equipment & cables - DC Hub Equipment - cables		

#	NAME	METHOD
B1	Socio Economic Welfare	Quantitative
B2	RES Integration	Quantitative
B3	CO2 Variations	Quantitative
B4	Societal Well-being	Qualitative
B5	Grid losses	Quantitative
B6	Security of Supply – Adequacy	Quantitative
B7	Security of Supply – Flexibility	Qualitative
B8	Security of Supply – Security	Qualitative
B9	Security of Supply – Resilience	Qualitative
S1	Environmental	
S2	Social	
S3	Other	

Cost-Benefit Report per Concept-Scenario

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Offshore Wind Generation Scenarios → Topologies → Technological Choice → Cost Benefit Analysis

PROMOTioN recommendations

- Where sufficient generation concentration use European Hub concept to deliver significant savings in costs for support structures
- Multi-terminal connections depend on anticipatory investment, therefore steer deployment through organised and structured planning.
- Cooperate across Europe to build grid infrastructure (connect hubs in country A to country B if shorter distance)
- Mesh where appropriate not for meshing's sake
  - Meshing leads to lower curtailment and higher security of supply, but at high costs for additional infrastructure
- Different grid goals may lead to additional benefits of the different topologies per region – but overall quite similar. Optimise on grid elements
  - PROMOTioN constraints on onshore load shedding result in retaining 2GW cables. This results in partial redundancy and therefore lower benefits compared to BAU.
- Environmental and social impact of concepts different but none more impactful than the others

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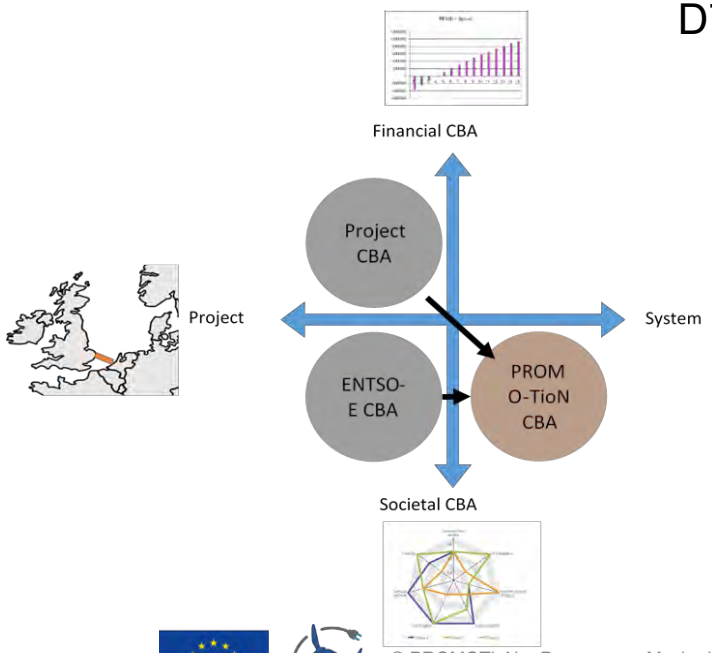
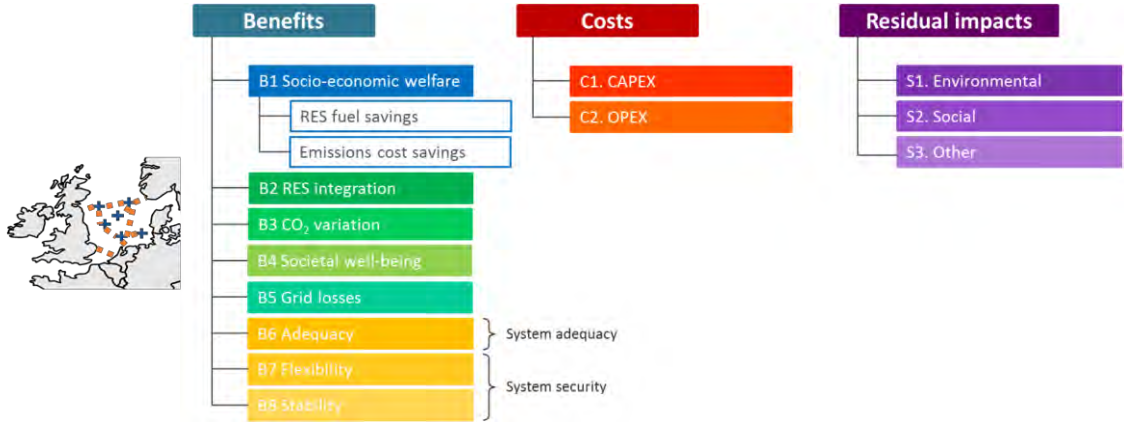
1. Application of improved and standardised (ENTSO-E) CBA techniques
2. Formal and standard Cross Border Cost Allocation

D7.2 analyses how to best allocate cross border costs

D7.11 Cost Benefit Analysis - Method





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Economic Analysis (CBA methods & CBCA Proposals) → **Financing & Potential legal structures** → Legal & Regulatory → Governmental → Market Structures

1. Financing Investments
2. Potential structures for transmission owners/operators

1. A clear definition of responsibilities and liabilities of investors, constructors and managers of the meshed HVDC offshore grid is advisable, to allow institutional investors, debt and equity providers the clarity needed to make an assessment of the investment risk. Offshore grid asset ownership should be designed to ensure the participation of multiple funding sources to support the challenging volume of required investments.
2. Grid ownership when meshed is likely to become more "blurred":
    1. e.g. with North Sea Wind Power Hub, we already see a consortium ownership. Incumbents are likely to see a dilution in ownership, and need similar controls/management to cross border interconnectors.
    2. PROMOTioN recommends clear rules for Cross Border Cost Allocation, in order to clarify the discussion, but we also accept pragmatism in the eventual finance of new grid infrastructure.

NSG TSO	Co-operation of national TSOs/third parties	Tenders before construction	Tenders post construction
• System operation, asset operation (O&M), ownership, construction • Owned by National TSOs or national TSOs & private investors, or private investors	• Extension of the current national structures • Each actor applies their current approach within its own EEZ	• Asset operation (O&M), ownership and construction • Private or public investors/ national or international/ public-private consortia	• Construction carried out by national TOs or a single TO • Assets tendered to third parties (private investors) for ownership, maintenance and asset operation

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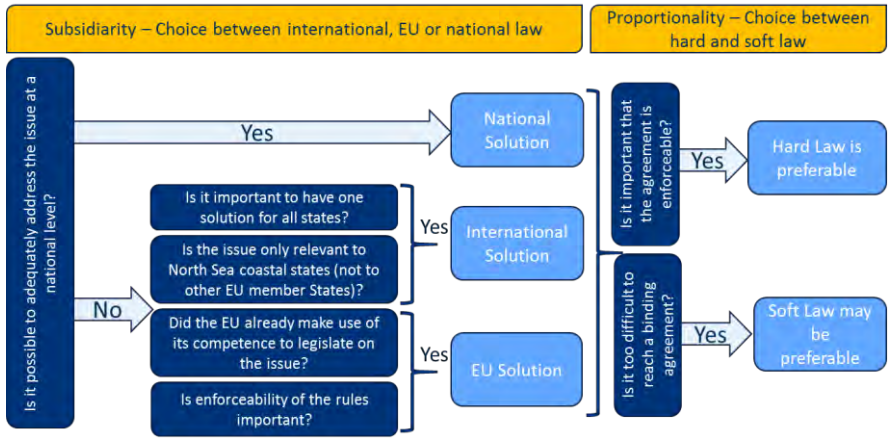
Economic Analysis (CBA methods & CBCA Proposals) | Financing & Potential legal structures | **Legal & Regulatory** | Governmental | Market Structures



1. Cooperation – Develop a mixed partial agreement

North Sea coastal states should work to develop a multilateral mixed partial agreement (a North Sea Treaty) which can serve as a framework for formalising the rules of a meshed offshore grid.

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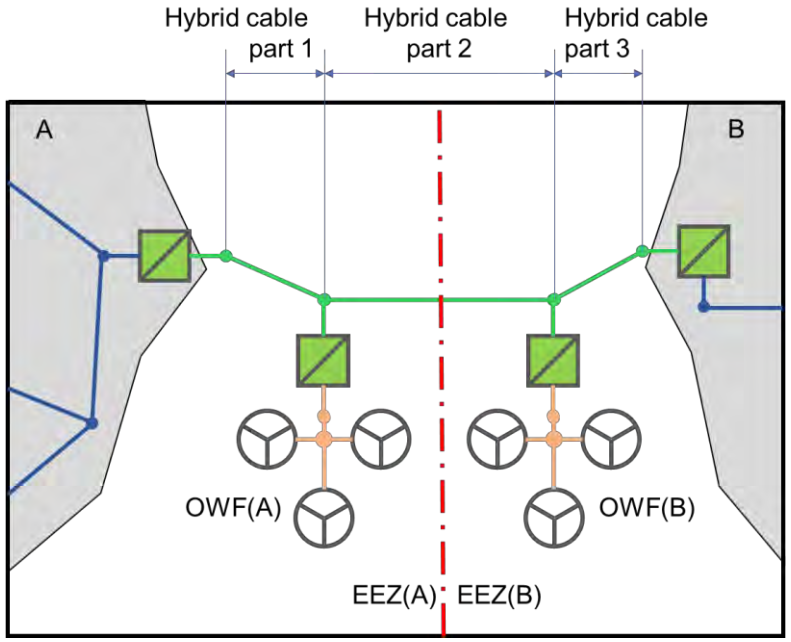
Economic Analysis (CBA methods & CBCA Proposals) | Financing & Potential legal structures | **Legal & Regulatory** | Governmental | Market Structures

1. Cooperation – Develop a mixed partial agreement
2. A robust Legal definition of an Offshore Hybrid Asset



North Sea coastal states should adopt a common interpretation of the law of the sea regarding hybrid assets within the MOG, by taking a broad interpretation of UNCLOS terminology. This definition of hybrid assets should be set out in a multilateral (mixed partial) agreement that is used for the governance of the MOG.

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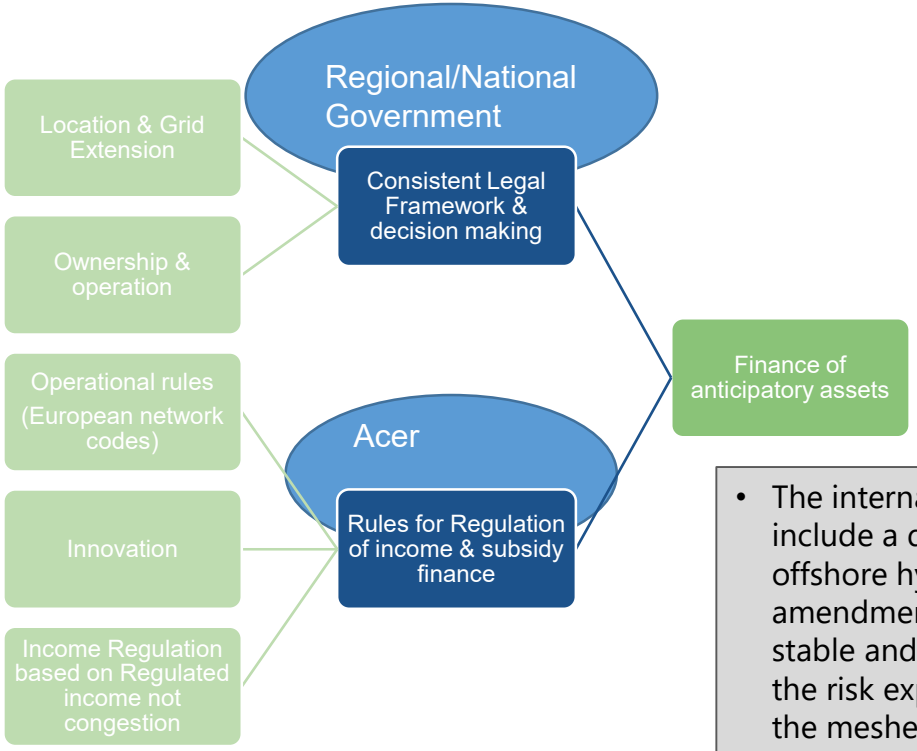
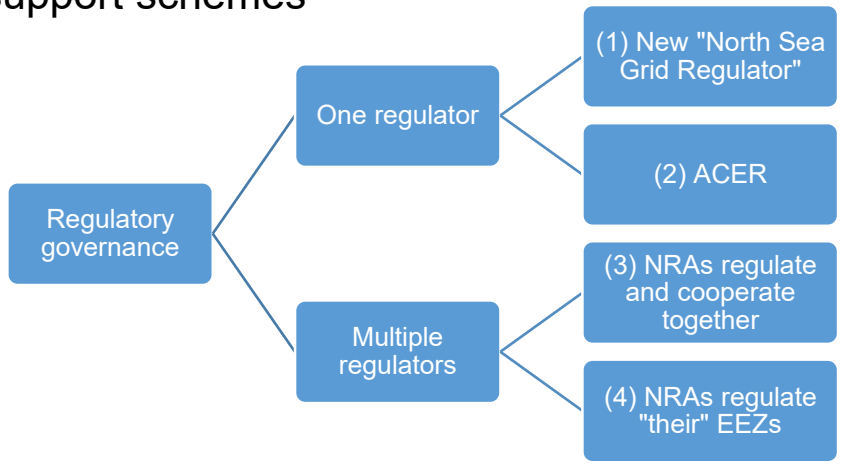


1. Cooperation – Develop a mixed partial agreement
2. A robust Legal definition of a Hybrid Asset
3. Agreement on approach to regulating the grid (who and how)
   1. Finance of Anticipatory assets
   2. Transmission owner income regulation
   3. Coordinated offshore wind support schemes

- The internal market regulation should be amended to include a definition and a substantive provision on how offshore hybrid assets should be regulated. The amendments should be designed to support a long-term, stable and predictable regulatory framework, so to reduce the risk exposure on capital in relation to investments in the meshed offshore grid.
- It is recommended that NRAs organise themselves in a specific regulatory coordination group to oversee grid development and operations through strong, mutual cooperation.



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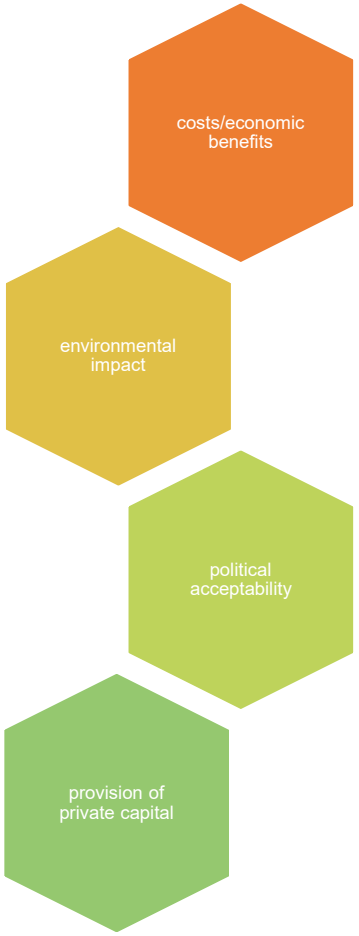

1. Cooperation – Develop a mixed partial agreement
2. A robust Legal definition of a Hybrid Asset
3. Agreement on approach to regulating the grid (who and how)
    1. Finance of Anticipatory assets
    2. Transmission owner income regulation
    3. Coordinated offshore wind support schemes
4. Decommissioning regulation

The internal market regulation should be amended to include a definition and a substantive provision on how offshore hybrid assets should be regulated. The amendments should be designed to support a long-term, stable and predictable regulatory framework, so to reduce the risk exposure on capital in relation to investments in the meshed offshore grid.

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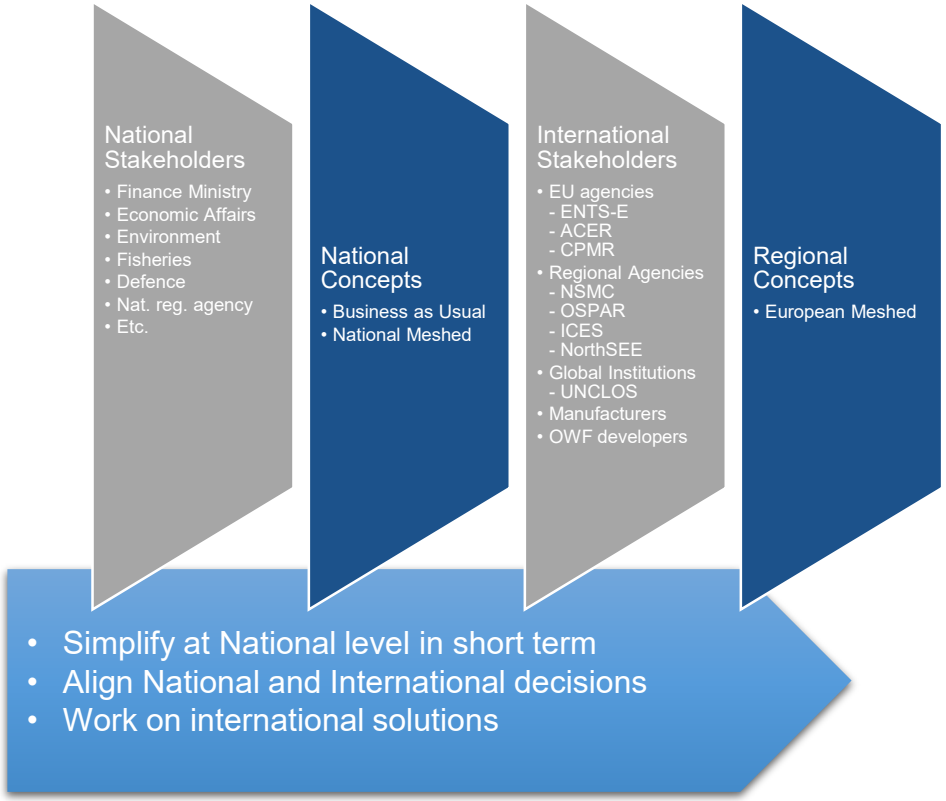

1. Planning & permit Processes alignment/simplification
2. Stakeholder participation and Consultation

- Streamline the permitting process to reduce the risk of legislative change during the permitting phase. Legislative changes should not retroactively impact projects already approved. Once granted, permits/licenses will remain valid for the duration of the construction and operation phase.
- A central approach for grid planning and strong coordination of grid development plans in terms of timing and location is recommended to increase the transparency of future network investments requirements and their cross-border impact.

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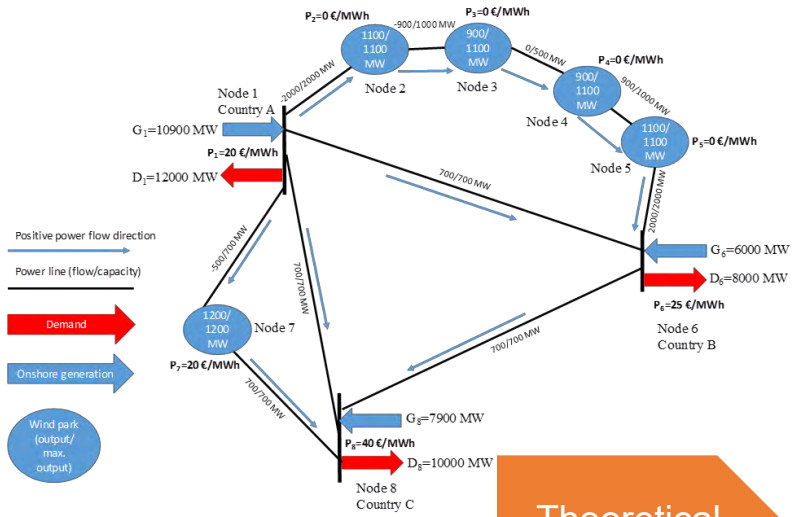
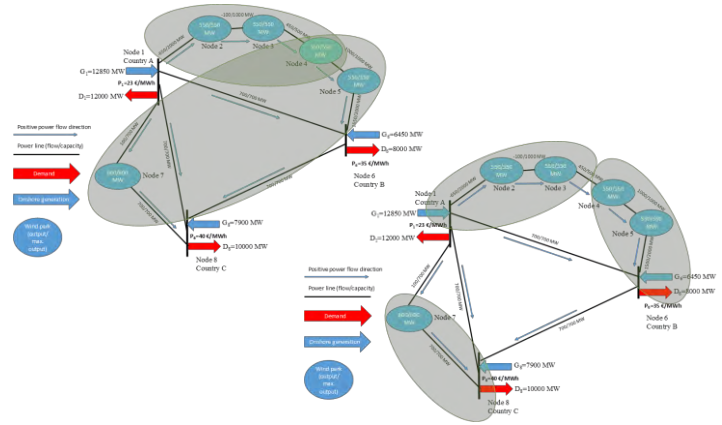
Economic Analysis (CBA methods & CBCA Proposals) → Financing & Potential legal structures → Legal & Regulatory → Governmental → **Market Structures**





1. Market structures from extension of country bidding zone into EEZ to small zones models
2. Market models where meshing exists

Theoretical example grid → Test for different Mkt models → Test for different Wind loads

- In the short term, current practice of extending the National Bidding zones to the country EEZ is sufficient
- With an increase in development and meshing, then a small zones approach may be more appropriate.
- Market management and organisation has not been studied, but new trading tools could be implemented to support this proposal

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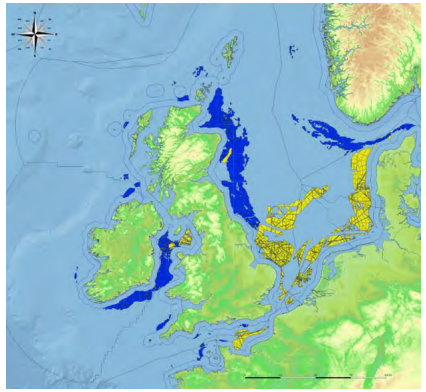
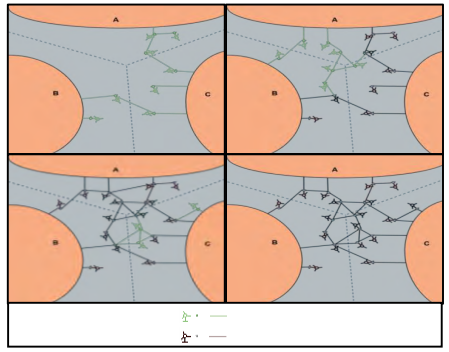
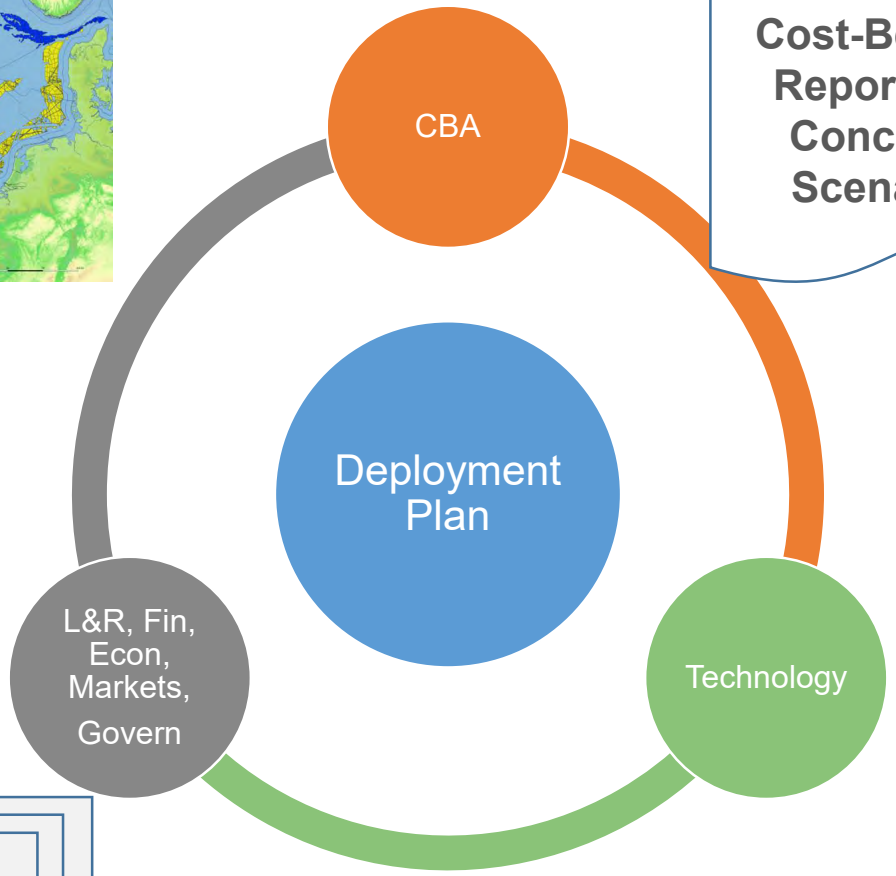




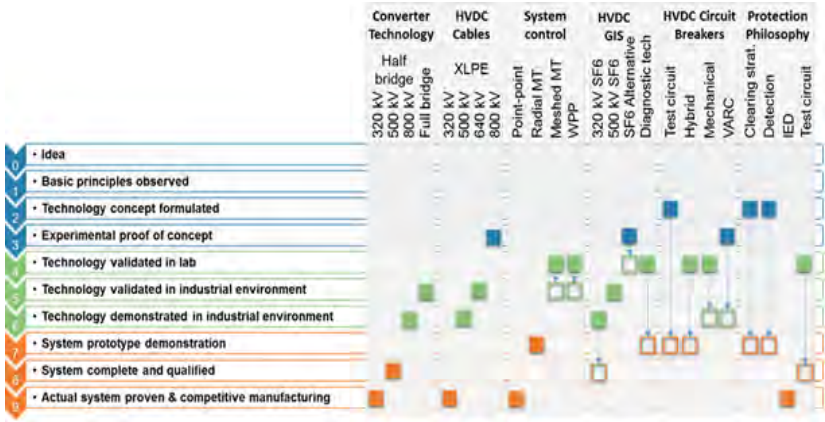
Cost-Benefit Report per Concept-Scenario

- Hybrid Assets
- CBCA
- Planning
- Environment
- Finance
- Small Zones



- Procurement

Short term Projects



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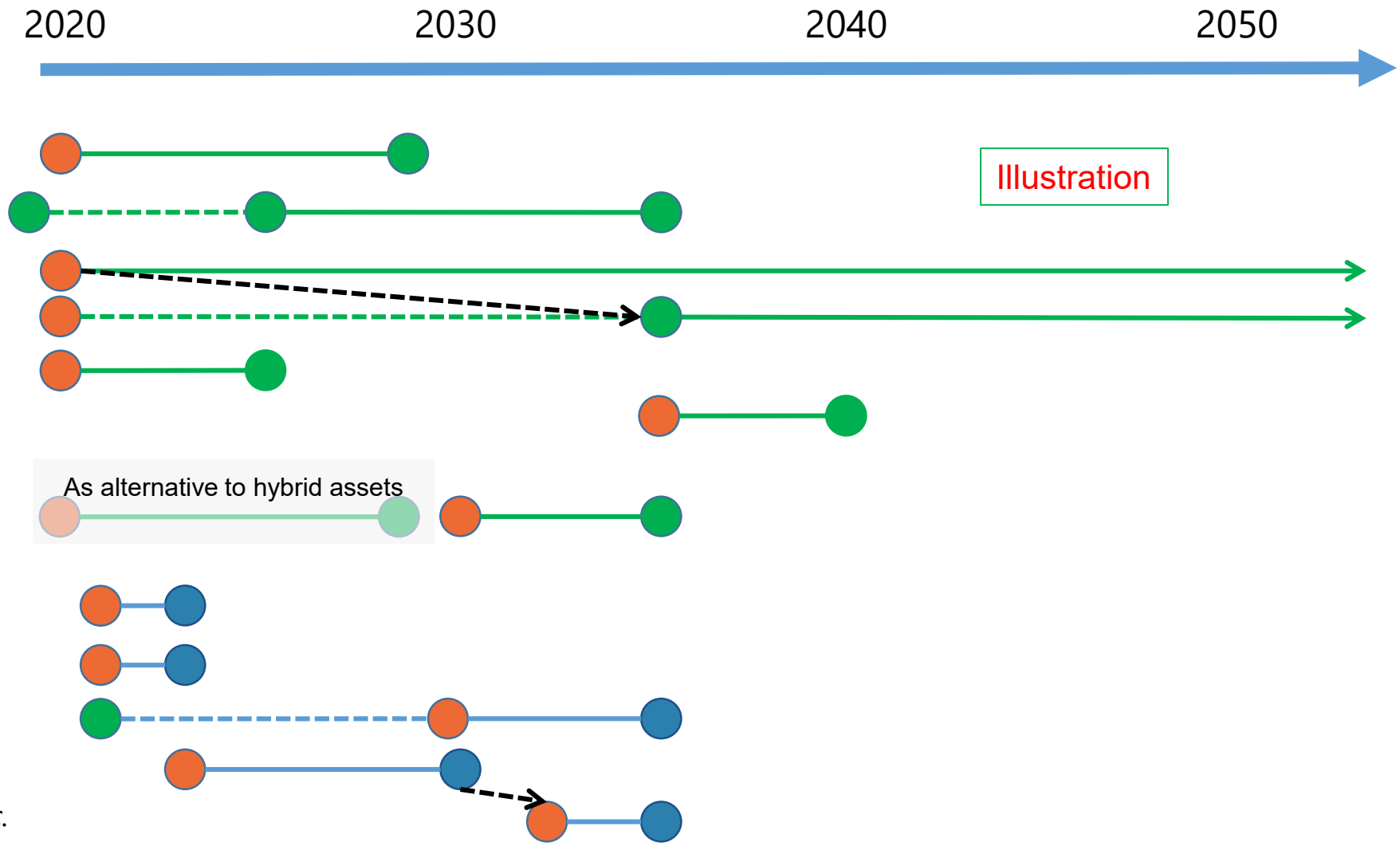
Deployment plan gives direction and says what is needed
– we suggest ground rules for potential development and interoperability



Legal & Regulatory

- *Hybrid Asset*
- *Mixed partial agreement*
- *Coordinated planning*
- *Supply chain*
- *DC Grid Code*
- *Decommissioning*

Market Models

- *Small Zones Bidding Zone*

Technology

- *Anticipatory investments*
- *Interoperability*
- *Island solution*
- *(Multivendor) pilot projects*
- *Application of DCCBs/GIS etc.*

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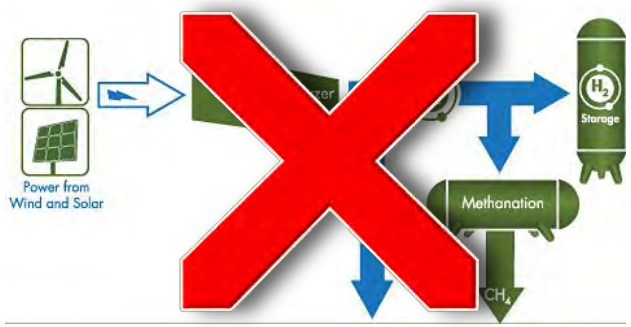
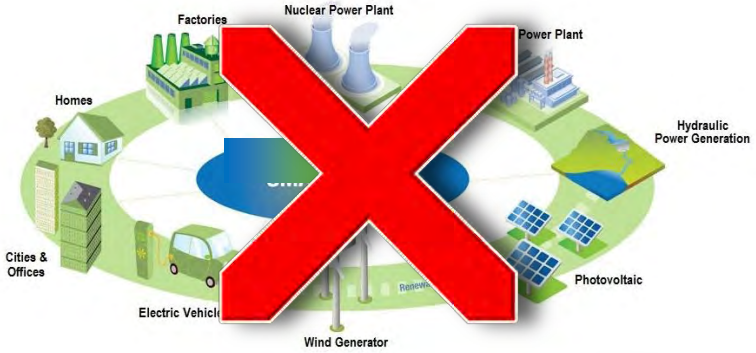
Boundaries of the deployment plan
- what we propose as the best solution will never be built

Power to Gas

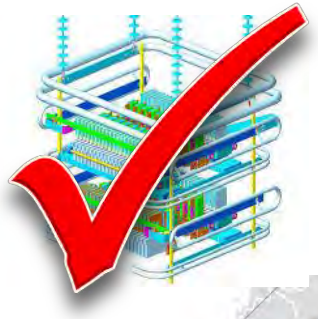


Power to Consumption

Distributed Storage

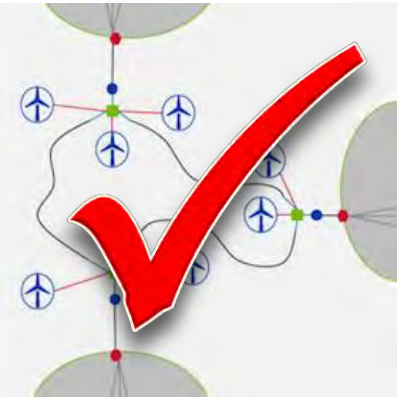


Primary Goal:
Efficient, secure evacuation of offshore generated wind energy to shore



New Technology

Grid Reinforcement



Aggregated viewpoint

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Any Questions?

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Results benefit analysis

Felix Rudolph (FGH), 03.12.2019

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CONTENT

- Introduction to benefit analysis
- Results B1: Socio-economic welfare
- Results B2: RES integration
- Results B3: CO_2 variation
- Results B6: Adequacy - Loss Of Load Expectation
- Conclusion

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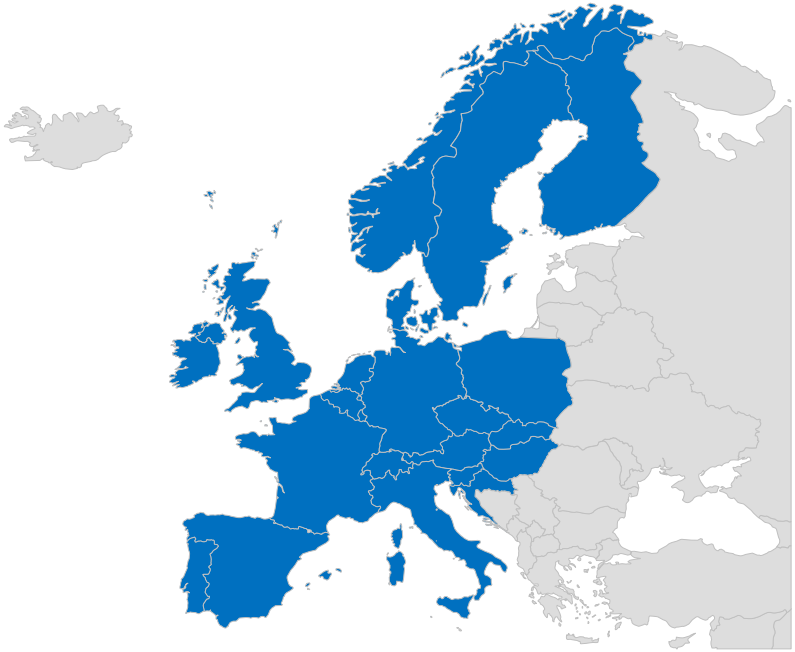
Introduction benefit analysis

- Operational dispatch simulation with hourly resolution
  - BAU / NAT / EUR / HUB concepts
  - Scenario years 2025 – 2050
  - Including most ENTSO-E bidding zones as node model
  - Offshore topologies in detail
  - Time-coupling simulation (hydro)
  - Input data mostly from TYNDP2018 and ENTSO-E Transparency Platform (extrapolated to 2050)
- Output as KPIs (D7.11)



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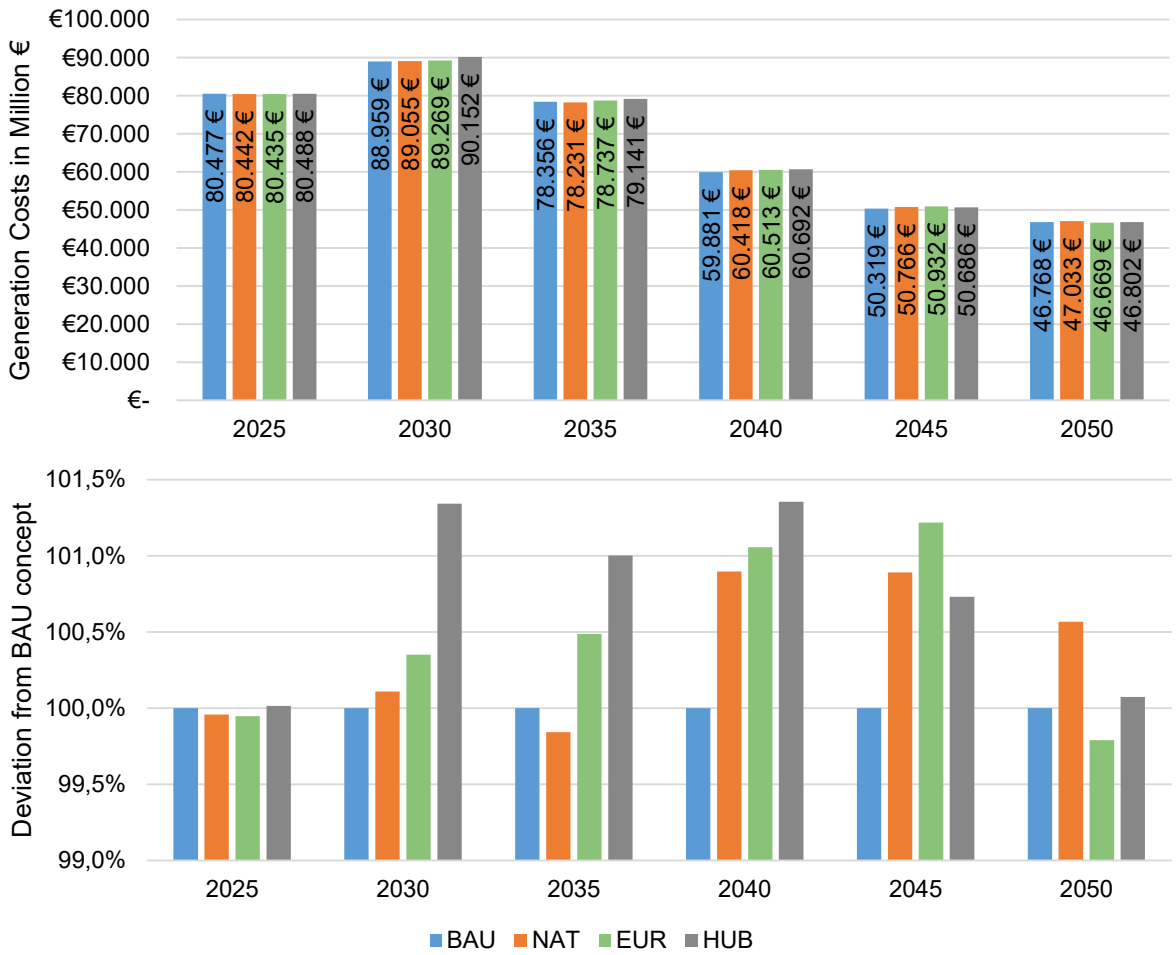
Results B1: Socio-economic welfare of all simulated bidding zones

- Generation Costs:
  - Includes only fuel type specific marginal costs
  - No distinction between markets
- Increase in costs in 2030:
  - High CO_2 price results in a sharp rise of marginal costs
  - Not offset by RES
- Small differences between concepts with less than 2 %

- EUR concept with best socio-economic welfare in 2050



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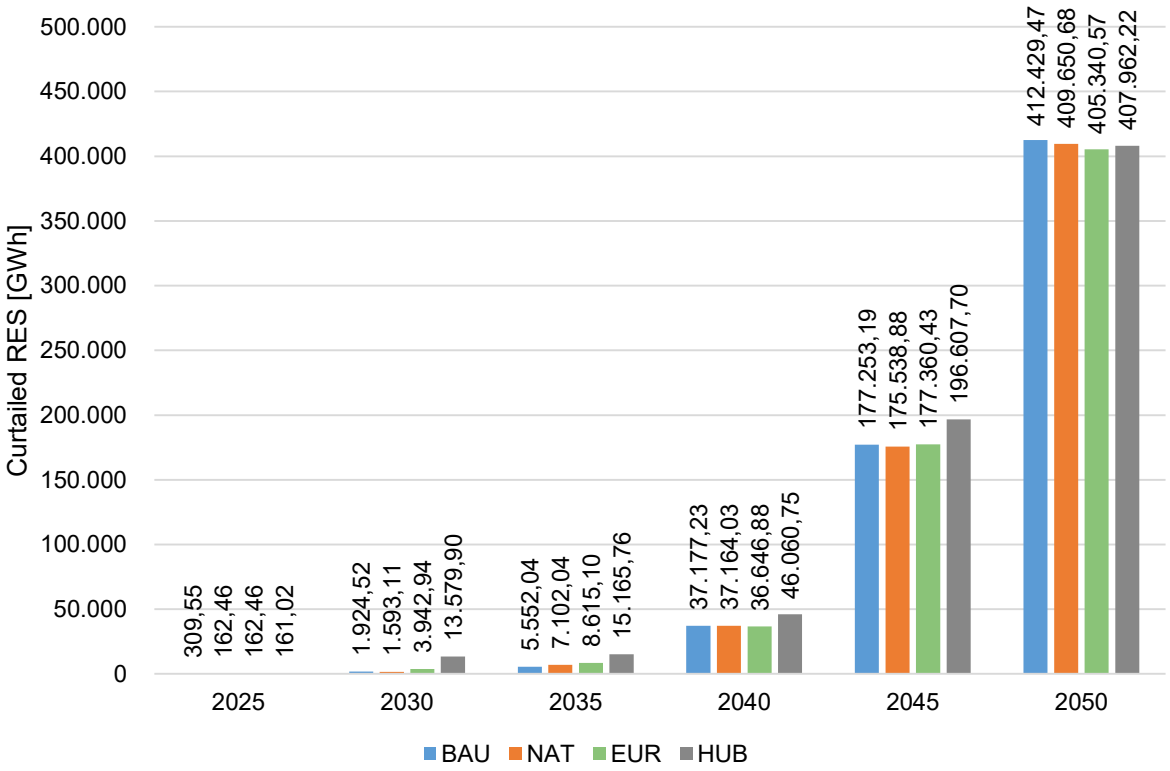
Results B2: RES integration of all simulated bidding zones

- Curtailment of PV and Wind (onshore / offshore / OWF)
- Missing flexibility leads to curtailment in times of low load – high RES generation
- OWFs are only source of curtailment until 2035

- Additional IC could improve RES integration
- Flexibility (e.g. storage units, DSM, P2X) could improve RES integration
- Not always cost-effective



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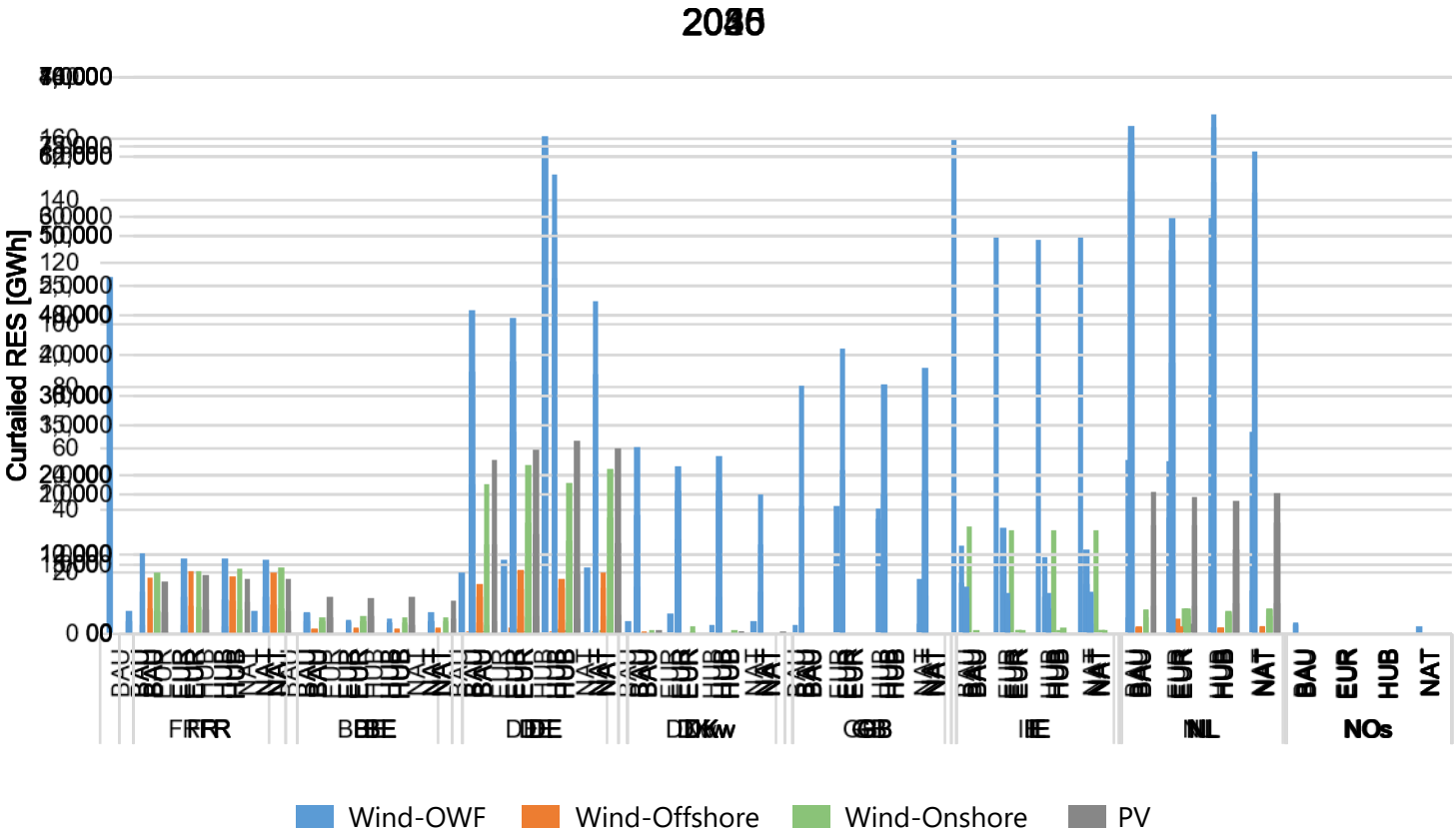
Results B2: RES integration of North Seas countries



→ Flexibility needed to fully integrate the high amount of offshore generation

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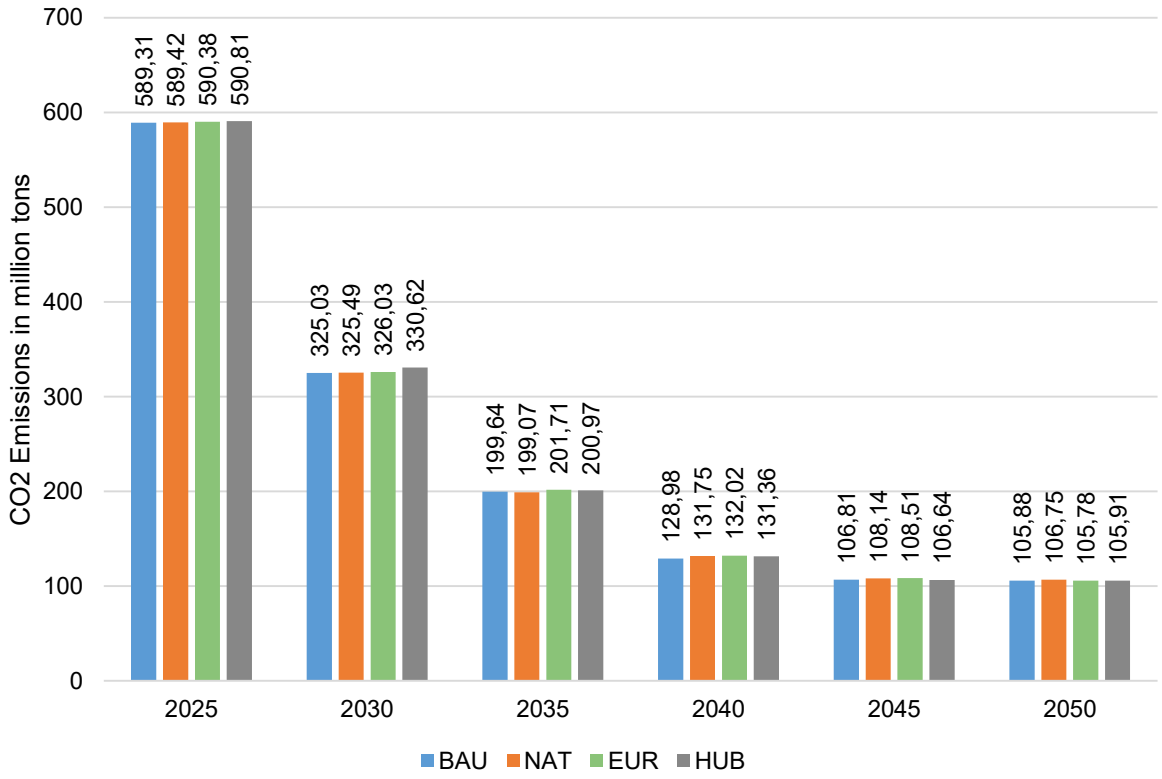
Results B3: CO_2 variation of all simulated bidding zones

- CO2 emissions in all four concepts similar
- 2040-2050: dispatch of thermal generation (mostly gas turbines) when low wind and solar radiation

- Additional IC could improve hydro integration
- Flexibility (e.g. storage units, DSM, P2X) could improve CO_2 emissions
- Not always cost-effective



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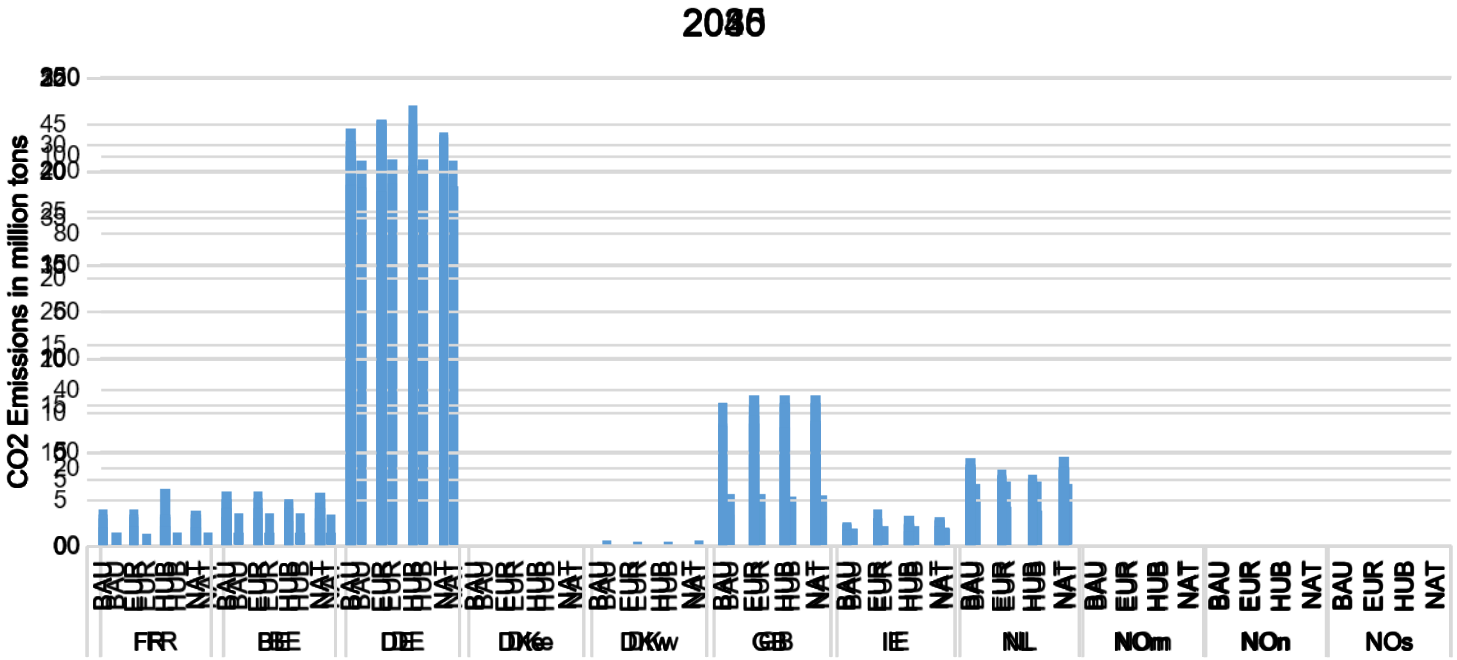
Results B3: CO_2 variation of North Seas countries



Variations of CO2 emissions between the concepts in bidding zones

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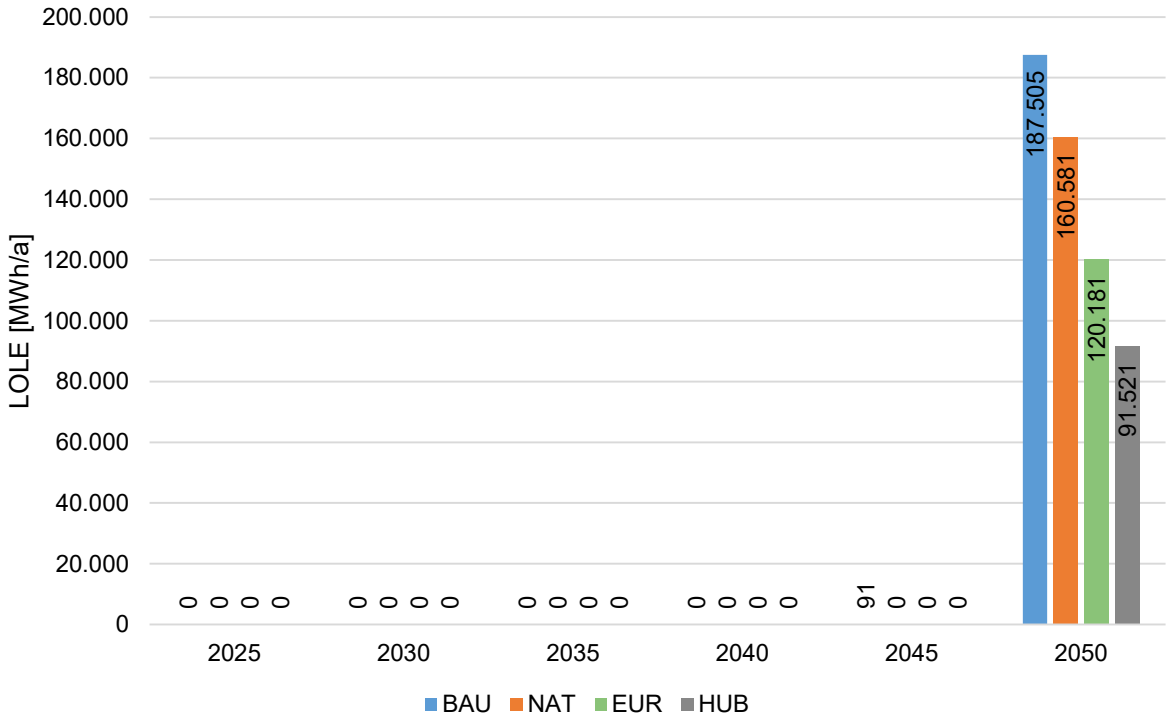
Results B6: Security of Supply - Adequacy of North Seas countries

- Loss Of Load Expectation (LOLE): Expectation that the available generation capacity cannot meet the load
- Expected Energy Not Supplied (EENS): Expected amount of electricity that cannot be delivered per year

- Markets: DE, DK, NL



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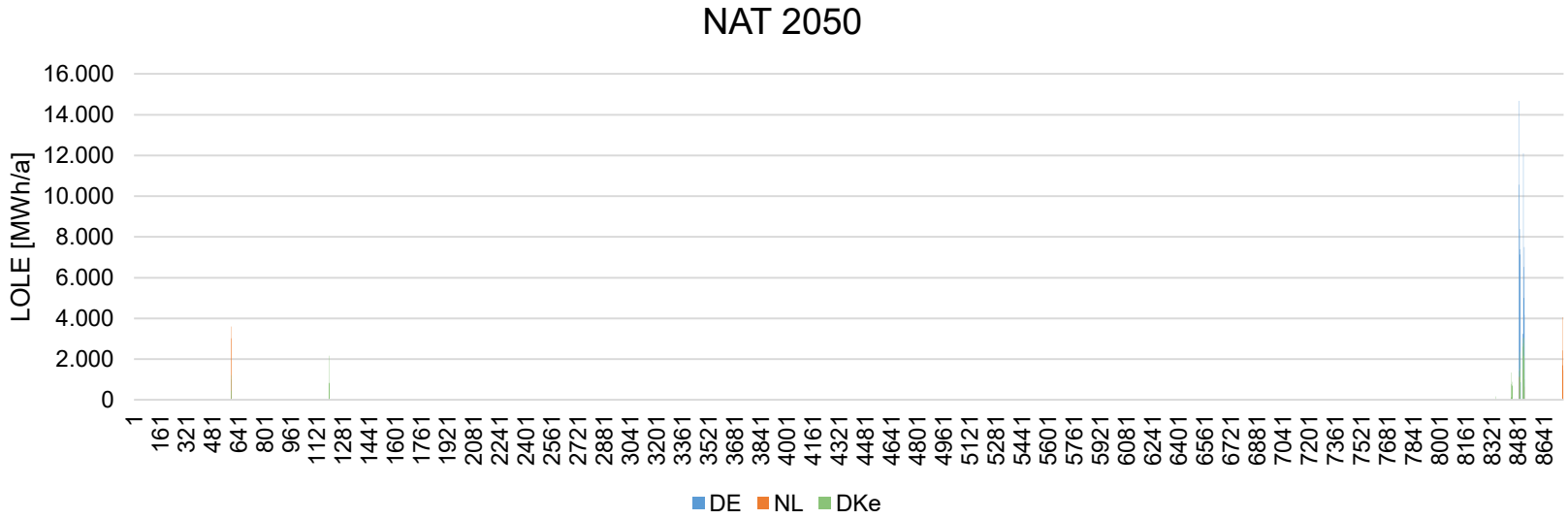
Results B6: Security of Supply - Adequacy of North Seas bidding zones



- LOLE only in Winter
  - Low solar radiation
  - Low wind capacity factors
- Interconnector capacity and generation capacity of available flexibilities not sufficient to fully avoid LOLE

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Conclusion

- All results quite close to each other with marginal differences
- EUR concept always slightly the best, followed by BAU and HUB

➔Recommendation for EUR concept from operational benefits standpoint

- Installing interconnections earlier could benefit RES integration
- Increasing NTCs would increase RES integration
  - Onshore between (continental) Western ⇔ Eastern Europe, Western ⇔ South Europe
  - For hydro pump-storage integration: NO ⇔ DE/DK, DE ⇔ AT/CH

- Flexibility needed to integrate these amounts of offshore generation
- Further research and simulations with flexibility necessary, especially for horizon 2035 and beyond
  - Not scope of the project PROMOTioN, as battery storage, DSM and P2X are researched within other European projects
  - Flexibility should be developed in parallel with offshore topologies

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Deployment considerations for HVDC Meshed Offshore Grids in the Northern Seas

TenneT ● John Moore

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

Overview of costs

		2025	2030	2035	2040	2045	2050
CAPEX(bn€)	*BAU*	25.9	28.5	23.2	50.3	41.4	39.3
	NAT	28.1	31.1	25.3	50.6	46.6	41.7
	HUB	33.2	23.6	27.5	52.4	40.2	36.9
	EUR	25.9	30.8	24.8	51.6	45.3	43.0
Cum. CAPEX(bn€)	*BAU*	25.9	54.5	77.6	128.0	169.4	208.7
	NAT	28.1	59.1	84.5	135.1	181.7	223.4
	HUB	33.2	56.8	84.3	136.7	177.0	213.8
	EUR	25.9	56.7	81.5	133.2	178.5	221.5

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Where is the difference? - NAT

Figures in billion

	BAU	NAT	NAT - BAU
Offshore converters, transformers and platforms (AC, DC, *sub-total*)	€ 37.96	€ 33.82	-€ 4.15
	€ 80.79	€ 93.69	€ 12.90
	€ 118.76	*€ 127.51*	*€ 8.75*
Protection equipment	€ 0.00	€ 7.20	€ 7.20
Cabling	€ 58.95	€ 56.28	-€ 2.67
Point-to-point interconnection	€ 3.33	€ 3.32	€ 0.00
Onshore stations	€ 27.65	€ 29.10	€ 1.45
Total	**€ 208.7**	**€ 223.4**	**€ 14.73**

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Where is the difference? - HUB

Figures in billion

	BAU	HUB	HUB - BAU
Offshore converters, transformers and platforms (AC, DC, *sub-total*)	€ 37.96	€ 56.38	€ 18.42
	€ 80.79	€ 50.66	-€ 30.13
	€ 118.76	*€ 107.04*	*-€ 11.72*
Protection equipment	€ 0.00	€ 0.40	€ 0.40
Cabling	€ 58.95	€ 74.07	€ 15.12
Point-to-point interconnection	€ 3.33	€ 4.80	€ 1.47
Onshore stations	€ 27.65	€ 29.73	€ 2.08
Total	**€ 208.7**	**€ 216.0**	**€ 7.36**

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Where is the difference? - EUR

Figures in billion

	BAU	EUR	EUR - BAU
Offshore converters, transformers and platforms (AC, DC, *sub-total*)	€ 37.96	€ 33.49	-€ 4.48
	€ 80.79	€ 96.59	€ 15.79
	€ 118.76	*€ 130.07*	*€ 11.32*
Protection equipment	€ 0.00	€ 5.28	€ 5.28
Cabling	€ 58.95	€ 55.57	-€ 3.37
Point-to-point interconnection	€ 3.33	€ 1.71	-€ 1.62
Onshore stations	€ 27.65	€ 28.83	€ 1.18
Total	**€ 208.7**	**€ 221.5**	**€ 12.78**

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Conclusions that we may tie to these figures

- Meshing will increase the need for DC technologies
- These DC technologies drive costs upwards through replacement of AC components

- Decrease in cable length is minimal but present, but does not offset this cost increase

- Large hubs replace costs made for DC platforms to a large extent
- Cabling largely offsets this cost decrease, due to rerouting of cables

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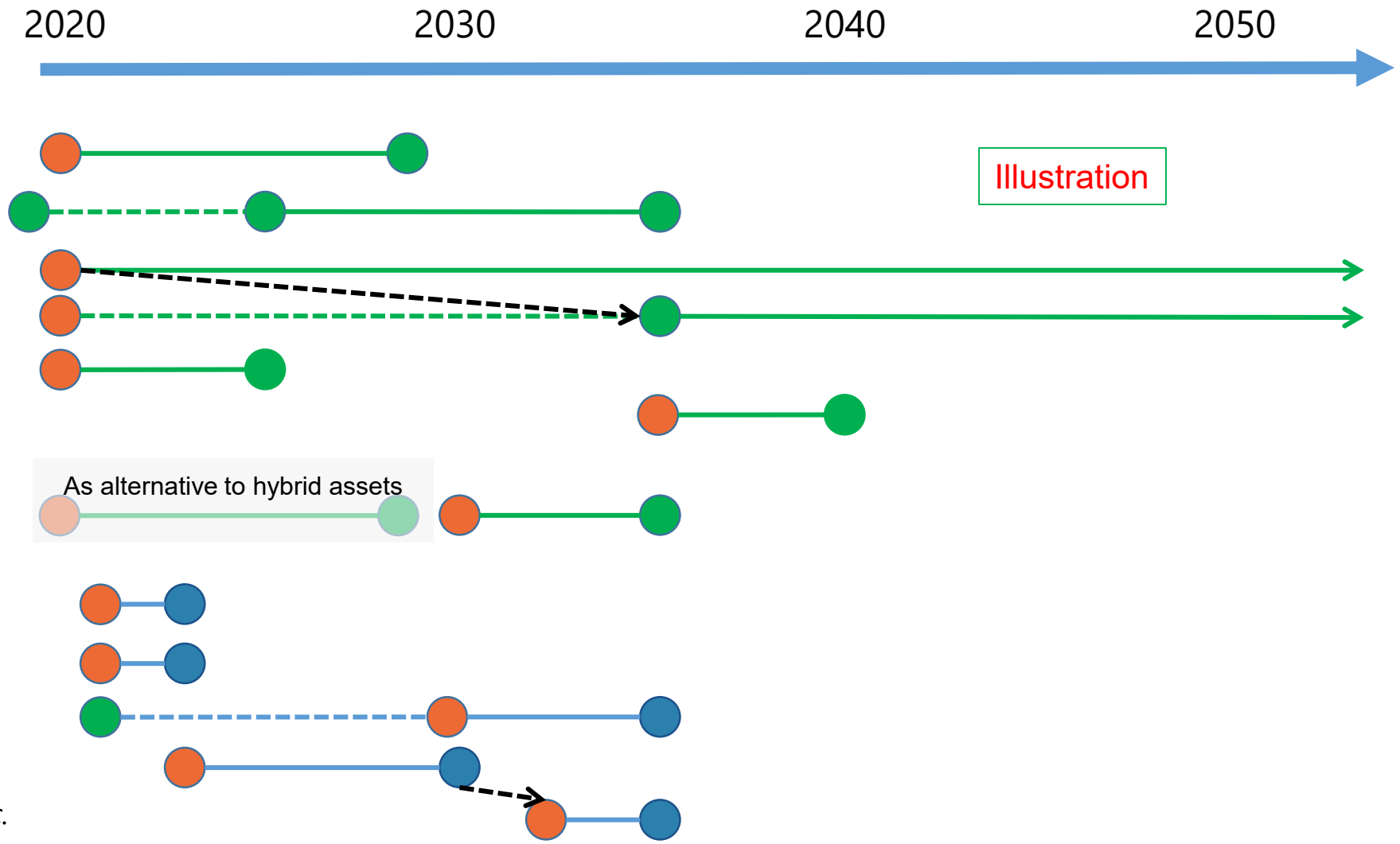
Deployment plan gives direction and says what is needed
– we suggest ground rules for potential development and interoperability



Legal & Regulatory

- *Hybrid Asset*
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PROMOTioN is a European Union funded Horizon 2020 project consortium, formed to address the technical, regulatory, financial and legal challenges for offshore HVDC transmission networks. It consists of 33 organizations including European HVDC manufacturers, Transmission System Operators (TSO), academic institutions, testing institutions and consultants. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

For more information please visit www.promotion-offshore.net

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

Any Questions?

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

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Minutes of Meeting

Event: PROMOTioN Half-yearly meeting
Location: Roskilde
Date: 3rd of December 2019
Session: General Assembly

Present: Refer to attendance register

Minutes:

WP12 – John Moore (TenneT), Felix Rudolph (FGH) & Jelle van Uden (TenneT)
Wei He: analysis shows meshing after 2035, but Doggerbank is already in full development will be ready before 2022. Unlikely to be 525 kV. Offshore loads may be connected (storage and capacity) and also floating solar might be connected.

Dirk van Hertem: Optimisation model looks at optimizing offshore wind efficiently to onshore system, and not necessarily the overall system flow. Dirk suggests that due to large wind resource, markets will change increasing the need for interconnection. Also, protection devices are not significant cost contributor as shown by WP4 and thus not stopping grid development. This should also be indicated as such in the end conclusion.

Olivier Antoine: estimation done in two steps, first offshore wind export and reducing cable length, second step TYNDP price scenarios and interconnector model candidates are selected based on market study.

Poul Sorensen: Did similar project that also came to conclusion for meshing. Hence results are credible from a markets optimization point of view. It seems national and European concepts they are very similar, and national concept is much easier to regulate.

Dirk van Hertem: are redispatch costs included in the model as this is a common complaint of TSOs?

Felix Rudolph: No, this may come in the flexibility analysis

John Moore: base assumptions of bipole gives natural redundancy which means availability benefit of meshing is not as obvious

Paul Neilson: Maps are not showing existing interconnectors and windfarms or the ones under construction. We need to be careful not to play in the hands of parties that are looking to avoid building grid, and continue radial build out.

John Moore: it is important to show that significant benefits can be realized if: basic technological harmonization can be achieved, planning of different projects can be coordinated. This requires political will in addition to pilots which show that benefit is real

Dirk van Hertem: if you look at cost of grid per person, then it is very low. This is what to tell the regulator

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Karim Karoui: investment looks big, but it is not very large compared to figures relating to other energy systems such as gas

Staffan Norrga: Was it considered to have hub interconnection on DC side?

Jelle van Uden: no, earlier feedback from PROMOTioN suggested that this was impossible

Cees Plet: we need to include the benefit of avoided losses (and avoided converter capex) for DC side connection of HUB conception

Everyone agrees that connection on DC side should be considered as this will significantly reduce costs

Ramon Blasco: HUB solutions show benefit over other solutions, but Tennet is also promotor of HUB concept. How to avoid that this looks like a TenneT push for the hub?

John/Jelle: TenneT concept is actually different and includes storage or conversion on island too. The approach in PROMOTioN assumes complete power export

Dragan Jovcic: Top down planning is not the way to go about grid build-out, it should grow organically and all pre-requisites should be in place to allow that to happen. E.g. Ijmuiden Ver platform offshore should have open connection on DC bus, allowing the market to determine the connections.

Ceciel van Nieuwenhout: coordinated planning does not necessarily refer to technical grid planning, but very much to spatial planning and permitting.

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

General Assembly

4th of December 2019 | Roskilde

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

Agenda

- Amendment 8
- Announce amendment 9
- Reporting
- D7.9 Regulatory and Financing principles for a Meshed HVDC Offshore Grid
  - Vote to approve the WP7 recommendations to be taken forward into WP12 - please prepare by reading the recommendations of D7.9

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

Amendment 8

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

Name change Tractebel

- As result of spin off TRACTEBEL ENGINEERING has requested to terminate the PROMOTioN contract and to add TRACTEBEL IMPACT in a new Partner in the project.
- With this amendment we effectuate the termination of TRACTEBEL ENGINEERING and want to add TRACTEBEL IMPACT as a new partner.
- The remaining budget of TRACTEBEL ENGINEEING is transferred to TRACTEBEL IMPACT.

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Budget transfer SHE Transmission

- We noticed a risk with the available resourcing in SHE Transmission to complete their task in WP9. As mitigation action KU Leuven and the University of Strathclyde will support SHE Transmission.
- 12 MM will go to KU Leuven, including the corresponding budget and some travel cost, in total a subsidy budget of € 100,750 will go to KU Leuven.
- The University of Strathclyde will support SHE Transmission with 4 MM. There is budget available in the own budget of the University for this.

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Budget transfer DNV GL

- DNV GL Netherlands BV has transferred an amount of € 220,537.50 from budget to the third party DNV GL Norway. On request of DNV GL NL, DNV GL Norway assisted in far more topics than originally foreseen.

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

SuperGrid Institute name use

- On request of SuperGrid Institute their acronym SGI will not be used anymore as they prefer to be addressed as SuperGrid Institute. Only the acronym is changed in SuperGrid Institute, but the work packages descriptions are not changed.

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

Additional work in WP6

- In support of the objective of achieving technology interoperability, in work package 6 two more HVDC circuit breaker topologies will be recreated in scaled versions in the laboratory to carry out characterisation tests which are not possible in the full scale demonstrations tests in WP10.
- The additional work is a collaboration of University of Aberdeen, KU Leuven and the tests will be held at RWTH Aachen's DC laboratory.
- To enable this meaningful extension, 30k of personal cost budget is transferred from RWTH Aachen to KU Leuven. Furthermore, RWTH Aachen needs to shift 27k from Other direct costs to Personnel costs budget.

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Vote

- Tractebel name change

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

Amendment 9

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KEMA Laboratories

- KEMA Laboratories was a linked 3rd party of DNV GL but has been sold to CESI
- Actual transfer still subject to regulatory approval
- All WP10 and WP15 and WP16 tests will go ahead as planned
- OEMs have already confirmed their continued commitment for the demonstrators
- KEMA Laboratories or CESI (depends on actual transfer date and type) will become full partner in PROMOTioN

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

Reporting

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

CONTENT

- Financial reporting January 2020
- Final reporting October 2020

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

Financial Reporting January 2020

- Reporting to the EC, but different format.
- Original for January 2020 the final reporting was planned,
  due to prolongation of the project the final reporting is postponed until October 2020
- Reporting period became > 18 months → interim financial reporting according art. 20.5
- Reporting is not in ECAS, but a table in a report
- Only Financial Reporting, but no payment will follow.

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Reporting format

Report on cumulative expenditure incurred
(Art 20.5 of the Grant Agreement)

Programme: Horizon 2020 Framework Programme
Grant Agreement: 691714 - PROMOTioN
Period covered: from 01/01/2016 to 31/12/2016/30/6/2018/31/12/2019

Cumulative expenditure incurred for the action

Beneficiary	Period		
	01 Jan 2016 – 31 Dec 2016	01 Jan 2016 – 30 June 2018	01 Jan 2016 – 31 Dec 2019
1. DNV GL	405,102.43*	1,898,014.23	
1.a DNV GL UK	4,086.24	16,127.70	
1.b DNV GL NORWAY	79,988.03	263,861.41	
1.c DNV GL SWEDEN	0.00	0.00	
1.d KEMA	0.00	0.00	
2. ABB	127,249.41*	260,911.90	
2.a ABB LTD	0.00	175,650.90	
3. KU LEUVEN	180,067.20*	816,678.61	
4. KTH	131,942.54*	428,804.42	
5. EIRGRID	14,097.12*	25,509.46	
6. SGI	142,232.69	562,818.94	
6.a UJF	0.00	0.00	
7. DWG	92,686.80	311,518.43	
8. MEU	143,342.28	475,166.41	
9. SVK	15,896.25	47,953.25	
10. GE GRID	18,387.04	29,671.39	
11. UNI ABDN	191,007.15*	745,819.53	
12. RTE	32,170.31	85,151.66	

- Only Total need to be reported, including 25% overhead
- First 2 columns filled in on basis of ECAS Please check
- Cumulative expenditure
- Now to report:
  period 01 Jan 2016 – 31 Dec 2019
- Calculate the period 01 Jul 2018 – 31 Dec 2019 and add that amounts earlier reported

- Format will be sent by e-mail next week
- Deadline for the reporting is 31 Jan 2020
- Send the reporting to marga.vandeelen@dnvgl.com

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

Final reporting October 2020

- The financial figures reported in Jan 2020 need to be reported again in October 2020
- The period will then be: July 2018 – Sept 2020
- Reporting in ECAS
- Financial reporting and Technical reporting
- Quite similar to the 2 earlier reporting to the EU, in Jan 2017 and Jul 2018
- Detailed instructions will come by e-mail next year

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

Certificates on the financial statements (CFS)

- A certificate is needed as the requested contribution from the EU is 325,000 EUR or more

- Start early with it, at least inform you accountant/auditor in time, so the audit can be planned for October

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

Cost for reporting at the end of the project

- In principle only cost made during the project are eligible cost
- One exception: costs for reporting at the end of the action, especially Certificate on the financial statement

- Explanation given by the EU

  Costs for reporting at end of the action — Costs related to drafting and submitting the periodic report for the last reporting period and the final report are eligible even if they are incurred after the action duration.
  Those costs include the cost of certificates on the financial statements (CFS) required by the GA and the cost of participating in a final review carried out by the Commission/Agency before the submission of the final reports. They may also include the cost of personnel necessary to prepare the periodic report for the last reporting period and the final report. However, they do NOT include research or innovation activities undertaken after the end date of the action.

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

QUESTIONS?

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APPENDIX

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APPENDIX

COLOR SUMMARY

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

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

WP7

Regulation & Financing principles for a Meshed HVDC grid

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

Scope of the report D7.9 “regulatory and financial framework”

- Summarise the findings from Deliverables:
  - D7.2 “Legal Framework”
  - D7.4 “Economic Framework”
  - D7.6 “Financing Framework”

- Analyse and make recommendations on additional cross-disciplinary aspects, not addressed in the three deliverables.

- Deliver a set of recommendations to define the Regulatory and Financing Framework for the project lifecycle of a meshed HVDC offshore grid

- Provide a high level indication of the parties responsible for implementing the recommendations

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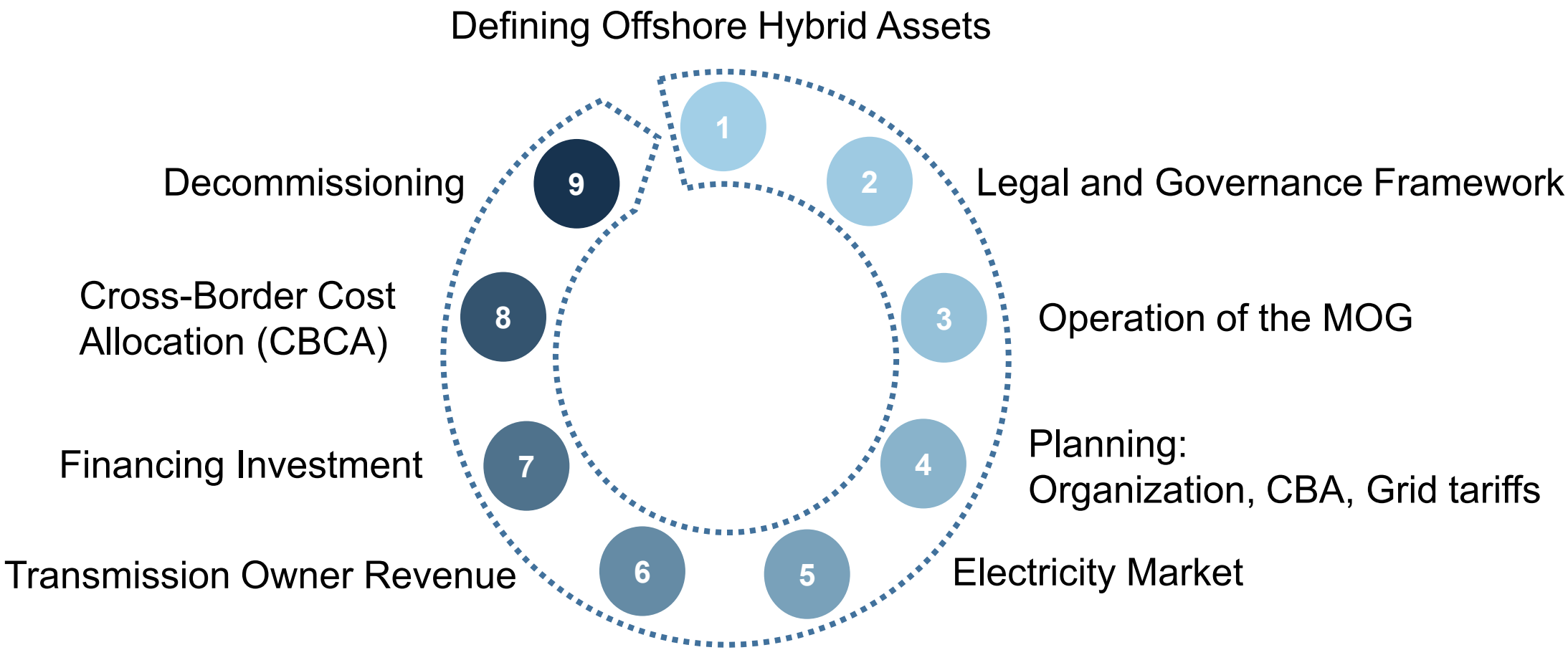
Content of the report



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1. Defining Offshore Hybrid Assets

Content addressed by the principles		
Problem	►►►	Recommendation
No legal definition of an “offshore hybrid asset” Uncertain regulatory framework hindering attractiveness of investments	►►►	Short-term recommendation: Adjustment of the Electricity Regulation to include Hybrid asset definition Long-term recommendation: common interpretation of UNCLOS by a multilateral agreement. Obstacle: long implementation time

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2. Legal and Governance Framework

Content addressed by the principles		
Problem	►►►	Recommendation
States currently coordinate their plans bilaterally and most coastal states cooperate with each other in the context of the EU. No international agreement (signatories: coastal states, EU) for the cooperation of the North Sea about MOG	►►►	Adopt a '**mixed partial agreement**' (signatories: states participating in the MOG, EU) to set out the objectives and high-level principles of the MOG National Regulatory Authorities (NRAs) to organize regulatory coordination group to: • oversee grid development and • gird operations.

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3. Operation of the MOG

Content addressed by the principles		
Problem	►►►	Recommendation
Significantly **increase in complexity for operating** a multi-connection meshed system connecting offshore windfarms to several countries in line with SOGL	►►►	North Sea Regional Coordination Centre for system operation governance. Staged approach to create operational knowledge base to master MOG operation and interface with onshore girds Balancing Mechanism design to remove barriers to entry for OWFs as BRPs/BSPs

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4. Planning: Organization / 1

Content addressed by the principles		
Problem	►►►	Recommendation
Planning and permitting procedures are perceived as a key risk in large infrastructure projects. Permitting issues become increasingly burdensome when the projects concerned span more than one jurisdiction, with the possibility of these risks materializing in two (or more) countries. Permitting can cause offshore infrastructure projects to be delayed by several years.	►►►	**Streamlined permitting process**. **Permits/licenses to remain valid for the duration** of the construction and operation phase. **Separate the process for the wind farm and cables** but **coordinate to align the projected commissioning dates** **Coordinated approach** for grid planning, strong coordination of grid development plans (timing, location) to **increase the transparency** **Simplify** them in number and interdependency

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4. Planning: Organization / 2

Content addressed by the principles		
Problem	►►►	Recommendation
Stakeholder objections to new OWF or transmission asset development could delay or prevent the deployment of the MOG	►►►	Wind farm developers should use the evidence and tools presented in the literature, to develop strategies for understanding public opinion and broadening active public participation.

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4. Planning: Cost Benefit Analysis (CBA)

Content addressed by the principles		
Problem	►►►	Recommendation
Dealing with interactions between (offshore) PCIs: Assessed CBA methodologies don't fully account for the interdependencies of meshed grid projects	►►►	• **Clustering projects**: Introducing clearer criteria on to consider projects part of a cluster for CBA • **Baseline definition**: compare a project against two baselines (TOOT and PINT) to identify potential synergies between new projects
Gaining trust and public acceptance: Lack of transparency about costs in decision making process for PCIs	►►►	• **Harmonize and disaggregate cost and benefits** reporting • **Open source CBA model** as target model
Reducing the politics in the valuation of PCIs: Decisions about PCI investments not always based on complete CBAs	►►►	• **Fully monetized CBA** of the value of project needed. • **Eligibility criteria** to be agreed upfront by all parties.

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4. Planning: grid tariffs

Content addressed by the principles		
Problem	►►►	Recommendation
Different regulatory handling of the grid connection costs of OWF between the North Sea countries	►►►	Develop **consistent approaches** about **selecting** • **wind farm locations**, • **onshore grid access responsibility and** • **grid connection charges**
The transmission charges paid by generators for access to the transmission network are not harmonized across Europe. For assets connected to more than one country there is no mechanism for calculating their transmission charges.	►►►	**Alignment of transmission** tariffs across North Sea countries (solution for OWF connected to multiple countries)

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5. Electricity Market

Content addressed by the principles		
Problem	►►►	Recommendation
Subsidies paid to RES are recognized only when electricity generation is effectively delivered from the EEZ into the respective country, thus preventing RES generation to move freely.	►►►	In the short term, decouple physical electricity flows from market flows when it comes to support for RES. In the longer term, **establish a joint fund** (or **joint support scheme**) and calculate each country's contribution ex-post, based on the principle '"beneficiary pays".

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6. Transmission Owner Revenue

Content addressed by the principles		
Problem	►►►	Recommendation
Regulatory framework undefined (undefined risk of the investment)	►►►	• **Long term stable regulatory framework** to increase assets 'bankability' • **Roles, responsibilities and liabilities** of investors, constructors and managers to support investment risk assessment

TSO restrictions on legal ownership and on balance sheet hindering
• private equity provision
• leverage on debt.
	►►►	• **Multiple funding sources** via design of offshore grid asset ownership
		• **Flexible access to private equity** to:
		  • overcome the TSOs' balance sheet constraints and
		  • optimize allocation of capital available from global investors.

Congestion rent as only investor income in case of MOG as merchant not viable for a long-term business model	►►►	• **Regulated income for OS hybrid assets** • Possible **regulatory grant of dedicated investment** for the additional risk (if offshore assets part of a RAB). • **Fixed revenue for Individually owned assets** depending on assets availability, performance and on market indicators

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7. Financing Investment

Content addressed by the principles		
Problem	►►►	Recommendation
National regulation with **no incentives for cross-border anticipatory investments** regarding hybrid assets	►►►	**EU public financing support** (CEF/EEPR funding) to remunerate **cross-border anticipatory investments** for the early phase of the MOG.
No **risk mitigations in construction phase** for: • technical problems and • delays from permitting/public consultation processes.	►►►	**Regulated revenues grant during construction**
Not common adoption of funding for innovation in the price controls across. Transmission networks legislation can hinder deployment of innovation in grid	►►►	• **Support for technological innovation through EU funding** at the early stage of the infrastructure development • **Regular review of the future developments** in the energy sector and its associated technologies

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8. Cross-Border Cost Allocation (CBCA)

Content addressed by the principles		
Problem	►►►	Recommendation
CBCA application for offshore to be improved. Key areas to be considered: - Use of significance threshold for CEF - Conducting Market tests - Incorporate binding contracts - Consider project interactions - Innovative approach to CBCA - Reach complete CBCA decisions	►►►	Ensuring **complete CBCA decisions**, costs allocation to national systems, with and without CEF contribution
		Single, coordinated CBCA agreement for a group of complementary projects (again: clustered approach):
		Binding, formal cooperation contract between the involved parties with specification of non-compliance penalties (commissioning dates, reduction stranded assets)
		Revisit **the interaction between the significance threshold and EU funding**, for more effective; - Cost allocation - CEF funding

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9. Decommissioning

Content addressed by the principles		
Problem	►►►	Recommendation
Rules for decommissioning offshore assets vary by country **Limited accounting of different technical lifespan** of offshore wind elements (e.g. lines technical life longer than OWF)	►►►	General process: **transmission cables left in place at the end of life of a wind farm**, unless otherwise needed **Case-by-case assessment of decommissioning requirements** by the relevant permitting agency. • Complete removal or • Foundation left in place **State takeover of responsibility of any assets in situ** after their useful life, with compensation for potential future costs (e.g. ring-fenced fund).
There are no guidelines supporting decommissioning of offshore assets	►►►	Guidelines for decommissioning should be agreed upon at an international level such as International Maritime Organization (IMO) or OSPAR.

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Conclusions

- The **legal** framework shall be integrated by the definition of hybrid assets, by the drafting of a mixed-partial agreement, by the creation of a joint fund for OWF support and by the framework for decommission of offshore assets
- The **governance** of all traditional roles for the design, permitting, planning, construction, operation, maintenance and decommissioning of the offshore assets must be defined and must be founded on a strong cooperation of involved nations
- From the **economic** point of view, processes and methodologies (permitting, CBA, CBCA…) should be more aligned and applied consistently to all projects, considering their costs interdependencies, so to increase the overall economic efficiency
- From **financing** perspective, key driver for investments in a MOG is a stable, long-term legal and regulatory framework with clear assignment of roles and responsibilities among involved parties, provides adequate remuneration to transmission owners, considers technology innovation risk and provides remuneration for agreed anticipatory investments.

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BACKUP

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

1. Defining Offshore Hybrid Assets

Number	Principle
2	North Sea coastal states should adopt a common interpretation of the law of the sea regarding hybrid assets within the MOG, by taking a broad interpretation of UNCLOS terminology. This definition of hybrid assets should be set out in a multilateral (mixed partial) agreement that is used for the governance of the MOG
3	The internal market regulation should be amended to include a definition and a substantive provision on how offshore hybrid assets should be regulated. The amendments should be designed to support a long-term, stable and predictable regulatory framework, so to reduce the risk exposure on capital in relation to investments in the meshed offshore grid.

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

2. Legal and Governance Framework

Number	Principle
1	North Sea coastal states should work to develop a multilateral mixed partial agreement (a North Sea Treaty) which can serve as a framework for formalizing the rules of a meshed offshore grid.
4	Grid governance should be designed to recognise the central role of states surrounding the North Sea in the decision making process: ministries should coordinate their actions with National Regulatory Authorities (NRAs) for long-term decisions in regular meetings, while favouring the centralisation of planning, technical and operational processes so to support a timely project delivery and a secure and reliable system operations.
5	It is recommended that NRAs organise themselves in a specific regulatory coordination group to oversee grid development and operations through strong, mutual cooperation.
29	Establish an offshore liability regime as part of the regulatory regime for the MOG. Clearly define and allocate the liabilities regarding asset operation and maintenance and liabilities related to the late delivery of transmission assets among the transmission owners.

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3. Operation of the MOG

Number	Principle
7	The governance of system operation should evolve towards a North Sea Regional Coordination Centre. A staged approach shall be followed to create an adequate knowledge base for any operator involved in the dispatching and operation of the MOG and its interfaces with onshore systems.
25	Changes to the Balancing Mechanism should remove barriers to entry for OWFs and should be cost-effective from an energy system perspective. Introducing a single price settlement rule, 15-minute settlement periods, scarcity pricing for capacity, and a liquid intraday market with gate closure as close to real time as possible would help to deliver a cost-effective balancing mechanism.

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

4. Planning: Organization

Number	Principle
8	Streamline the permitting process to reduce the risk of legislative change during the permitting phase. Legislative changes should not retroactively impact projects already approved. Once granted, permits/licenses will remain valid for the duration of the construction and operation phase.
9	A central approach for grid planning and strong coordination of grid development plans in terms of timing and location is recommended to increase the transparency of future network investments requirements and their cross-border impact.
10	National planning and permitting procedures should separate the process for the wind farm and cables but coordinate to align the projected commissioning dates.
11	National planning and permitting procedures should be simplified in terms of number and interdependency: this action can be supported by the creation of a one stop shop for key project permits.
15	A high level of public participation can have a positive impact on the public acceptability of offshore wind projects. Wind farm developers should use the evidence and tools presented in the literature, to develop strategies for understanding public opinion and broadening active public participation

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

4. Planning: Cost Benefit Analysis (CBA)

12	Interactions between offshore PCIs should be taken into consideration in CBAs. Improvements can be made to the clustering of projects and the baseline definition in the common CBA method. A project can be compared against two baselines (TOOT and PINT) in order to identify potential synergies between new projects
13	It is recommended to harmonize and disaggregate cost and benefits reporting to gain trust and public acceptance, with an ambition to move towards an open source CBA model.
14	To reduce the politics in the valuation of PCIs, it is important to carry out a fully monetized CBA of the value of project. To increase transparency of the process, the Regional Groups could to express their policy priorities at the start of the process via the eligibility criteria.

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

4. Planning: grid tariffs

16	Develop consistent approaches across North Sea countries to selecting wind farm locations (preferably zoned or single site), onshore grid access responsibility and grid connection charges (preferably super-shallow). Coordinating on these three aspects should enable stakeholders to successfully implement an integrated approach to offshore grid development in the North Sea
17	Work to align transmission tariffs across North Sea countries to prevent any negative impact on OWF development.

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

5. Electricity Market

Number	Principle
18	In the short term, decouple physical electricity flows from market flows when it comes to support for RES. In the longer term, establish a joint fund (or joint support scheme) and calculate each country's contribution ex-post, based on the principle "beneficiary pays".

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

6. Transmission Owner Revenue

Number	Principle
6	A clear definition of responsibilities and liabilities of investors, constructors and managers of the meshed HVDC offshore grid is advisable, to allow institutional investors, debt and equity providers the clarity needed to assess the investment risk. Offshore grid asset ownership should be designed to ensure the participation of multiple funding sources to support the challenging volume of required investments.
19	Offshore hybrid asset income should be based on regulated income (with appropriate incentives and adjustments to encourage good performance) rather than on congestion rent.
20	A long term and stable regulatory framework will increase the ‘bankability’ of offshore transmission assets. Where offshore assets are remunerated as part of a wider portfolio (RAB) additional dedicated investment incentives should be granted by the regulator where necessary. Where assets are owned individually, they should receive a fixed revenue subject to the availability and performance of the assets as well as market indicators (e.g. UK OFTO-regime).

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7. Financing Investment

Number	Principle
26	There should be flexibility regarding access to private equity in order to overcome the TSOs' balance sheet constraints and optimise allocation of capital available from global investors. Apply existing financing structures to the MOG that have proven to be successful in raising sufficient finance for other capital-intensive transmission infrastructures.
27	Given the importance of creating the MOG, it is essential to ensure public financial support by the EU for the remuneration of the necessary cross-border anticipatory investments. Using EU financial support (CEF/ EEPR funding) to fund anticipatory investment would reduce the risk of stranded assets for investors and bridge any financing gaps.
28	Support for technological innovation through EU funding at the early stage of the infrastructure development is a key enabler. It should be accompanied by a regular review of the future developments in the energy sector and its associated technologies.
30	Provide revenue during construction to reduce the risk to investors. This could make finance more readily available at lower interest rates during these riskier periods and reduce the interest accrued during construction

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8. Cross-Border Cost Allocation (CBCA)

Number	Principle
21	Coordination of CBCA decisions for complementary projects. This could be achieved by taking a clustered approach in which a CBCA agreement is reached for a group of projects. This would enable robust consideration of project complementarities and mitigate any distortions in the development of the projects.
22	Formalization of the CBCA as a binding contract between the involved parties with clear specification of non-compliance penalties, especially with respect to commissioning dates. In a multi-stakeholder environment, such a step can ensure greater commitment towards the project by all parties, thereby avoiding the construction of “bridges to nowhere”, also called stranded assets.
23	Revisit the interaction between the significance threshold and EU funding. This step would aid in more effective cost allocation by encouraging complete CBCA decisions as well as enable effective EU funding allocation.
24	Ensuring complete CBCA decisions. A complete CBCA is one which considers how costs would be allocated between nation states, both with and without a contribution from the EU’s Connecting Europe Facility (CEF). This is necessary as CBCAs are often carried out prior to a decision on whether CEF funding will be provided to a project. Having to revisit a decision in light of such funding being declined, can result in project delays.

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9. Decommissioning

Number	Principle
31	The decommissioning requirements for OWFs should be based on a case-by-case assessment by the relevant permitting agency, during the planning process. However, in general the standard process should be: • At the end of life of a wind farm, the transmission cables may be left in place unless in a sensitive area with high shipping or fishing activity, changeable sea bottom or areas such as the beach. Depending on the grid topology, these transmission assets could continue to be used as interconnectors or to connect a new wind farm built in the same place. • For wind farms, the permitting agency should decide whether removal of all wind farm assets are required, or whether the foundations can be left in place. This should be decided as early as possible to provide greater cost certainty to developers. • Any assets which remain in situ after their useful life (and after the owner has discharged their decommissioning responsibilities) should fall under the responsibility of the state provided that the state is compensated for potential future costs, for example through a ring fenced fund.
32	To provide consistency on guidelines for decommissioning of offshore wind assets (turbines and transmission assets), guidelines should be agreed upon at an international level such as International Maritime Organisation (IMO) or OSPAR. To inform this, further research into the environmental impact of decommissioning OWFs and offshore electricity cables is necessary.

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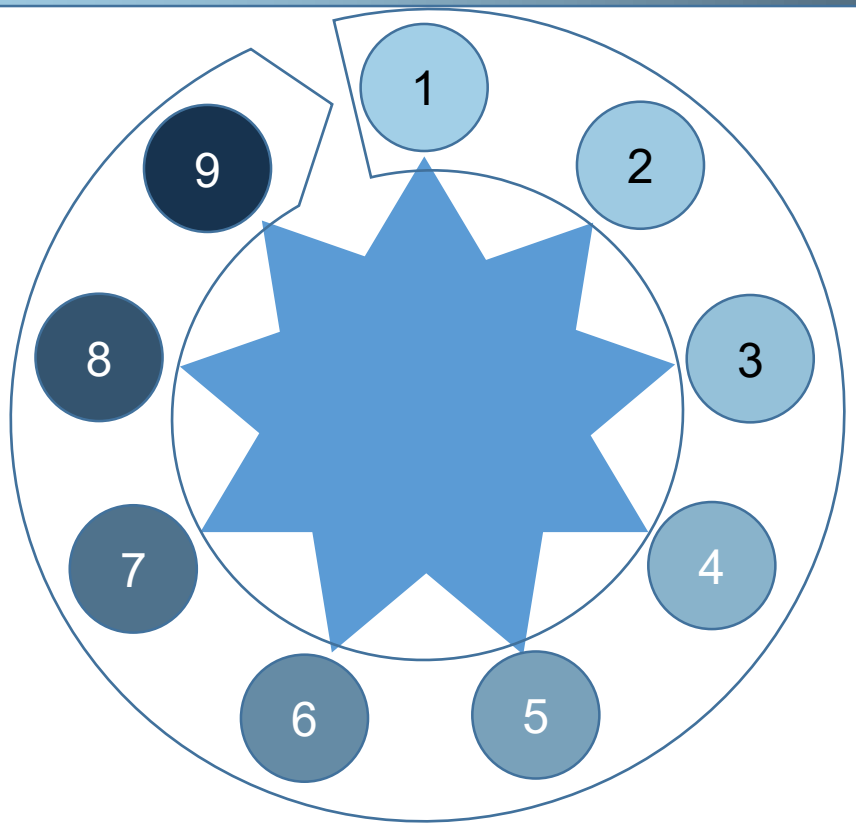
Content of the report



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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Minutes of Meeting

Event:	PROMOTioN Half-yearly meeting
Location:	Roskilde
Date:	4th of December 2019
Session:	General Assembly
Present	Refer to attendance register

27 partners present out of 33 → quorum reached

Minutes:

Amendment 8
[VOTE] → All in favour of Tractebel namechange

Amendment 9
The change of KEMA Laboratories from linked third party from DNV GL to full partner will mean that the PMG will also have an additional industrial partner.

It is announced that Amendment 9 will also include a namechange of ABB.

Reporting
Ramon: do you need some financial certificate from the administration?
Marga: No, just the number, in order to get an overview

John: TenneT changed auditor, new auditor will start next year (2020). Might have to get certificate for end of year.
Marga will look into it

Cees: will there be another review meeting?
Marga: not sure, but we will check it. In principle EC can request a meeting for 5 years after project meeting
AP Cees to check with Mariana

Final payment (10%) is done after final reporting October 2020, payment in principle 90 days after but can be postponed for several reasons
Financial certificate period is whole project

WP7

Vote 1 – 1 Hybrid asset classification
Antje: Why is definition needed? If we create separate bidding zones, everything should work without the need of new legislation.

Ceciel: This is right, and is a simple solution if all countries work together. However, bidding zone configuration offshore is a tricky point, so hence this is a work around which avoids bilateral difficulties

Dirk: This changes the responsibilities of the developers significantly. So it is a choice, not necessarily the best

Dragan: Hybrid implies dual purpose of export and interconnection, does this also allow for different uses such as offshore loads?

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Ceciel: Yes, the definition of hybrid should be sufficiently broad to cover this.

Antje: with bidding zones the link from the offshore wind farm to shore would also be interconnector. Also word hybrid is not specific enough, we should consider different wording

Paul: Offshore transmission is regardless of purpose. Perhaps the point is to more broadly define offshore transmission.

Ceciel: Should be careful to make broad definition that affects legal certainty of existing infrastructure, Separate definition of hybrid class avoids this issue. Term 'hybrid asset' has already been included as recital in clean energy package. Not recommended to change name.

John: The 70% rule on interconnector is causing problems for hybrid projects. Definition of hybrid asset should follow lines in clean energy package to open markets and reduce restrictions.

Ceciel: This rule is contradictive to offshore wind development as it would mean curtailing windfarms and why would these OWFs be build in the first place?

Antje: Summarizing the above, perhaps our message should be that a bidding zone configuration is the best and most simple solution but that - given the recital that already exists, - applying, a definition of a hybrid asset class might be the second best, but more cumbersome solution to move forward for countries that have an aversion against bidding zones.

Vote 2 – 2 Mixed partial agreement

Karim: How does framework deal with disagreement, and what is the role of the EU in this?

Ceciel: Intl agreement is mainly based on ensuring UK and Norway is included as EU law does not apply to them. EC is included in agreement, so necessary EU law principles will also be included in agreement. Conflict resolution clauses need to be put in the agreement, like it is currently described by NRAs, ACER, EC sequence in EU, but this may not be acceptable to UK after Brexit. Agreements like CETA can provide examples on how to do this.

Dirk: to what does the agreement apply? To all offshore assets or only multi-lateral projects? What should be the grand-fathering approach?

Ceciel: depends on agreement and the amount of trust one wants to build in.

Niklas: Can you explain offshore liability regime?
Alexandra: Refers to multi-actor grid to define how liabilities due to eg project delays are assigned, and to make it part of regulatory framework. This must be clearly defined, but we do not yet have specific details as this is part of the roadmap. Timing should be discussed in WP12, by when does framework need to be in place?

Vote 3 – 3 Operation of MOG

Dirk: This can be rewritten by integrating this in future grid codes, however, 15 min should not be specified by PROMOTioN, it could be less too

Prad: This is taken from EBGL

Dragan: The last recommendation is too restrictive as it should not be limited only to OWFs

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John: This will be amended in WP12

Vote 4 – 4 Planning / organization
John: please remove word central and replace by coordinated.

Dirk: One-stop shop approach should be build up starting at national level. Hard to achieve on European level

Vote 5 – 4 CBA
Antje: this is describing usual project risk which is also valid for every other project. Unlikely that more and deeper calculations will help, it might even further complicate and slow down processes

Prad: need to make sure it is made simplified as possible to reduce adverse impact. The CBA analysis needs to be seen from a system perspective, especially when considering an offshore grid, as any project will affect surrounding projects.

Antje: look at the ENTSO-E TYNDP's online project map: Everything which is requested by PROMOTioN is already published for each single project on ENTSO-E's homepage. You can find about 13 market- and network indicators per project, many of them monetized. Seems that the recommendation is outdated.

Dirk: what will be actual recommendation if these are already being done?

John: difference in PROMOTioN is that a system social economic welfare CBA is done for European consumer, rather social benefits for projects and developers. WP12 will take into account global perspective, but will not prescribe a method.

Antje: That's no difference – ENTSO-E's analysis *is* from a global system perspective analyzing benefits from a European perspective.

Vote 6 – 4 Grid tariffs
Dirk: change the word 'any' to something less restrictive.
Accepted

Vote 7 – 5 Electricity market
Ceciel: only applies to wind farms connected to hybrid grids

Paul: Should this not be covered by mixed partial agreement?

Ceciel: could be, but is not preferred as it may be more subject to change, so in terms of time required for changes it should be decoupled from the governance framework. This is only relevant whilst offshore wind is subsidized.

Dirk: we should not write anything that suggests subsidies will be required. Hence rewrite to include 'as long as required' and remove 2nd part.

Ceciel: 2nd part is required to increase political acceptance to ensure fair distribution of support

Vote 8 – 6 Transmission Owner Revenue
John: change wording to make sure third party investors are 'facilitated', and regulatory income 'may' be a source of income.

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Alexandra: in large meshed grid, merchant income may be hard to estimate increasing risk for investors, hence income should be regulated

Dirk: allow for small exceptions such as individual links to say offshore O&G platforms
John: it should not be definitive

Maksym: last statement needs to be changed as fixed revenue and market indicators are conflicting.

Alexandra: agreed, it will be reworded accordingly

Paul: cannot see how entrepreneurial or merchant initiatives are enabled by this.

Alexandra: can be for example through equity partnerships with TSOs

John: early links will be merchant, so this needs to be facilitated

Vote 9 – 7 Financing investment
Alexandra: Correction to slide: the 2nd point should be extended to meshed offshore grids

Paul: post Brexit EU members may not want to support UK investments. How can this be done?

Alexandra: this concerns cross-border invesments, so EU will have a say on it.

Paul how to deal with UK getting social welfare benefit

Prad could be done in same way as east west link, where UK also contributes, based on negotiation

Dirk: change 'TSO's balance sheet' to 'investors' balance sheet', because also developers may wish to build links

Alexandra: here really TSO's are meant due to the specific rules which may cause some TSO's to not be able to attract private financing. Wording will be adapted accordingly

Vote 10 – 8 CBCA
No questions

Vote 11 – 9 Decommissioning
Dirk: What does state responsibility take over mean in international environment?

Ceciel: This includes international waters on continental shelf

John: This may be part of commercial assets from a non-TSO country

Ceciel: situatons could arise were assets are left if removing them causes more damage than leaving it. This can change with changing seabed for example, so should be monitored, and removed if necessary

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