HALF YEARLY MEETING SUPERGRID INSTITUTE, LYON, FRANCE

10-12 December 2018
HALF-YEARLY MEETING LYON

Place: Bibliothèque Marie Curie
Institut National des Sciences Appliquées (INSA) Lyon
20 avenue Albert Einstein, Villeurbanne.
Across from the “INSA Einstein” Tramway stop.

Date: 10 – 12 December 2018
13 December 2018 – PMG Meeting

Monday 10 December

Plenary Meeting
12:00 – 13:00 Lunch
13:00 – 13:20 Welcome by SGI
13:20 – 13:40 WP2
13:40 – 14:00 WP3
14:00 – 14:20 WP4
14:20 – 14:40 Break
14:40 – 15:00 WP6
15:00 – 15:20 WP7
15:20 – 15:40 WP9
15:40 – 16:00 Break
16:00 – 16:20 WP10
16:20 – 16:40 WP11
16:40 – 17:00 WP12
17:00 – 17:20 Break
17:20 – 17:40 WP13
17:40 – 18:00 WP15
18:00 – 18:20 WP16
19:30 - Late Dinner at "L'Avenue 45". Address: 45 Avenue Albert Einstein, 69100 Villeurbanne
Tuesday 11 December

Work Package meetings

<table>
<thead>
<tr>
<th>Work Package</th>
<th>Time</th>
<th>Room (will follow)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP2</td>
<td>09:00 – 12:30</td>
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<tr>
<td>WP3</td>
<td>09:00 – 12:30</td>
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<tr>
<td>WP4</td>
<td>09:00 – 12:30</td>
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<tr>
<td>WP6</td>
<td>09:00 – 12:30</td>
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<tr>
<td>WP7</td>
<td>11:00 – 12:30</td>
<td>13:30 – 16:00</td>
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<td>WP9</td>
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<td>WP15</td>
<td>09:00 – 12:30</td>
<td>13:30 – 16:00</td>
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<td>WP16</td>
<td>13:30 – 16:00</td>
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<tr>
<td>Lunch</td>
<td>12:30 – 13:30</td>
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</table>

Visit to SGI 16:15 departure of bus

Break Determined per WP

Wednesday 12 December

General Assembly (see sheets [https://service.projectplace.com/pp/pp.cgi/r1825831004](https://service.projectplace.com/pp/pp.cgi/r1825831004))

09:00 – 09:20  Amendment 7 update
09:20 – 12:30  Explanation of Vote 2-7
12:00 – 12:30  Vote 2-7
12:30 – 13:30  Lunch
13:30 – 14:30  Explanation of Vote 1 (excluding OEM vendors)
14:30 – 15:00  Vote 1 (excluding OEM vendors)
15:00 – 15:30  Break
15:00 – 17:00  PMG Meeting (WP leaders only)
WP2

Grid Topology & Converters

RWTH Aachen University ● Christina Brantl
• Timeline and Amendment
• Task 2.3
• Next steps
Objectives

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

Trade-off analysis of different topologies

Interconnection of VSC and DRC systems

Control concepts to ensure interoperability
2.1 Definition of model parameters, control objectives and operational assumptions

2.2 Adaptation of simulation models

2.3 Simulative investigation and functionality demonstration of interoperability by simulation

2.4 Define recommendations for minimum requirements on onshore and offshore power systems
### Timeline until 2nd reporting period

- **Kick-Off Task 2.2**
  - Brussels
- **Aberdeen Meeting**
- **Kick-off Task 2.3**
- **Glasgow Meeting**
- **Valencia Meeting**
- **Groningen Meeting**

<table>
<thead>
<tr>
<th>Month</th>
<th>Task/Event</th>
<th>Description</th>
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<tbody>
<tr>
<td>12</td>
<td>MS7</td>
<td>Model input from WP3</td>
</tr>
<tr>
<td>18</td>
<td>D2.2</td>
<td>Scenario and test case specification</td>
</tr>
<tr>
<td>19</td>
<td>MS9</td>
<td>Input on protection from WP4</td>
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<tr>
<td>20</td>
<td>MS10</td>
<td>Simulation models</td>
</tr>
<tr>
<td>24</td>
<td>MS11</td>
<td>Requirement cross-validation with WP1</td>
</tr>
<tr>
<td>30</td>
<td>MS13</td>
<td>Simulation benchmark</td>
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</tbody>
</table>

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

MS13  Simulation benchmark

Lyon Meeting

MS14  Coordination with WP4

Aachen Meeting

MS15  Recommendations on grid code extension

Define recommendations for minimum requirements on onshore and offshore power systems

D2.3  Report on simulation results and benchmark

Task 2.3

Month

30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
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46
47
48

Task 2.4

D2.4  Requirements for grid code extension
Status Update Progress

Task 2.3
- Change of task lead from Siemens to UPV
- Delay of work of several months
- Discussion on benchmark
- Agreement on Structure of D2.3
- Set-up of format from cross-validation with WP4
- Start of writing of D2.3

Task 2.4
- Kick-off: 11 September 2018
- Agreement on aligned way forward with all tasks and work packages related to grid codes
- Participation in WP11 workshop on Control and Protection
Proposed timeline in Amendment No.7

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

Lyon Meeting

Define recommendations for minimum requirements on onshore and offshore power systems

Aachen Meeting

Task 2.3

Task 2.4

Month

30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48

MS13 Simulation benchmark

MS14 Coordination with WP4

D2.3 Simulation results and benchmark

MS15 Recommendations on grid code extension

D2.4 Requirements for grid code extension
Status Task 2.3
Overview D2.3

- Operational Strategies for Multi-terminal HVDC systems
- Operation of DRU in HVDC Systems
  - Radial DRU connection
  - DRU with AC meshing – parallel connection to AC and VSC links
  - DRU in meshed HVDC systems
- Investigations on AC Side Faults and Contingencies
  - AC FRT for meshed DC systems
  - Frequency Support
  - Impact of MMCs on the AC protection
- DC side faults and contingencies
  - Impact on the DC cables
  - DC FRT of the wind power plants
  - Impact on the AC system
- Benchmark
HVAC || HVDC || DRU:

1. AC interconnections

Tap changer required to minimize HVAC grid losses
HVDC - DRU Multiterminal

2. DRU Multi Terminal combined interconnector
HVDC - DRU Meshed:
all HVDC stations (including DRUs) must be coordinated to control HVDC power flow.
Impact of MMCs on the AC protection

- Analysis focused on the distance protection

- Impact divided into two categories:
  - Topological Impact
  - Control Impact

Impact of load-flow on impedance measurement

Double-sided infeed

Intermediate infeed
Fault Studies in VSC systems
Complimentary to WP4

FRT of Offshore Windfarms for DC faults
• DC breaker based fault clearing
  • Without blocking
  • With blocking
• Back-up fault clearing using AC breakers
• Full-bridge based fault clearing

Aim:
• Ensure FRT of WPP without violating constraints of the WPP
• Ensure fast resume of power transfer after DC fault clearing
Next Steps
Next steps

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

Lyon Meeting

Define recommendations for minimum requirements on onshore and offshore power systems

Aachen Meeting

Finalisation Task 2.3

- Complete Benchmark (MS13)
- Call with WP4 on cross-validation (MS20)
- Consolidate results
- Summarise results and findings in D2.3

Task 2.4

- Objective: Define recommendations for minimum requirements on onshore and offshore power systems
- Summary of results for harmonization catalogue in WP11
Thank you for your attention!
WP3
Wind Turbine Generator – Converter Interaction
DTU ● Ömer Göksu
10 December 2018, Lyon, France
Work Packages

WP1 ∙ Requirements for Meshed Offshore Grids ∙ TenneT

WP2 ∙ Grid Topology & Converters ∙ TenneT

WP3 ∙ WTG – Converter Interaction ∙ DTU

WP4 ∙ HVDC Grid Protection Systems ∙ KU Leuven

WP5 ∙ Test Environment for HVDC CB ∙ DNV GL

WP6 ∙ HVDC CB Performance Characterisation ∙ UniAberdeen

WP7 ∙ Regulation & Financing ∙ TenneT

WP8 ∙ Test Environment for HVDC CB ∙ DNV GL

WP9 ∙ Protection System Demonstration ∙ SHE Transmission

WP10 ∙ HVDC Circuit Breaker Demonstration ∙ DNV GL

WP11 ∙ Harmonisation Towards Standardisation ∙ DTU

WP12 ∙ Deployment Plan for Future European Offshore Grid ∙ TenneT

WP13 ∙ Dissemination ∙ SOW

WP14 ∙ Project Management ∙ DNV GL
Planning

2nd reporting period

WP1 · Requirements for Meshed Offshore Grids · TenneT
WP2 · Grid Topology & Converters · RWTH Aachen
WP3 · WTG – Converter Interaction · DTU
WP4 · HVDC Grid Protection Systems · KU Leuven
WP5 · Test Environment for HVDC CB · DNV GL
WP6 · HVDC CB Performance Characterisation · UniAberdeen
WP7 · Regulation & Financing · TenneT
WP8 · DRU demo · Siemens
WP9 · Protection System Demo · SHE Trans
WP10 · HVDC Circuit Breaker Demo · DNV GL
WP11 · Harmonisation Towards Standardisation · DTU
WP12 · Deployment Plan for Future European Offshore Grid · TenneT
WP13 · Dissemination · SOW
WP14 · Project Management · DNV GL
WP15 · HVDC GIS Demo · ABB
WP16 · MMC Test Bench Demo · RWTH Aachen

2016 2017 2018 2019 2020
**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

---

Diagram: HVDC link and control algorithms for grid forming WPP.
Task Structure

WP3

3.1 Functional requirements to WPPs

3.2 General control algorithms

3.3 Compliance evaluation procedure

3.4 Compliance evaluations based on detailed numerical simulations

WP1

WP2

WP16
Milestones & Deliverables

WP3 meeting & Siemens DRU Lab Visit
Aberdeen Meeting
Valencia Meeting
T3.4 Kick-off
Groningen Meeting

Task 3.2
- Planned: D3.2
- Delay: MS17
- Converter models and grid topologies received from WP1 and WP2
- Specifications of the control strategies and the simulations test cases

Task 3.3
- Planned: D3.3
- Delay: D3.4, D3.5
- Models for control of WT/WPP connected to DR-HVDC
- Operation of WPPs connected to DR-HVDC
- Performance of ancillary services provision from WPPs connected to DR-HVDC

Task 3.4
- Planned: MS19
- Delay: D3.6
- Compliance evaluation procedures specified and approved
- Report with the compliance test procedures for DR and VSC connected WPPs
D3.3 Models for Control of WT/WPP Connected to DR-HVDC

Confidential - only for members of the consortium

- Aggregated single WT
- Ideal onshore DC voltage
- Ideal WT DC voltage

- Offshore AC start-up
- Voltage & frequency control
- Active power setpoint control
- Offshore AC fault ride-through
- Intentional islanded operation
Ongoing Work

WP3 • WTG – Converter Interaction

Ongoing Work

- **WP3 Roskilde**
  - Task 3.4
    - **MS20** Recommendations on requirements to existing grid codes provided to WP11
      - An internal deliverable with the recommendations
    - **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, academic and industrial
        - Black start capability assessment
    - **D3.8** List of requirement recommendations to adapt and extent existing grid codes
      - Paradigm shift from grid following wind turbines to grid forming
      - 100% converter-based AC grid
      - Assessment of Grid Code recommendations based on WP16 results

- **Lyon Meeting**

- **Aachen Meeting**
Progress Towards Demonstration

Outside PROMOTioN
Energinet performs Black Start field test with Skagerrak 4 (SK4) HVDC interconnector

WP3 Performs Black Start Simulation Test with Offshore WPP
To energize:
• 3 buses
• Overheadline & underground cable
• Shunt reactor & transformer
• Step MW++ load
  • Load changes
  • Frequency & voltage setpoint changes
  • Load disconnection

Results to be compared against HVDC field tests by Energinet
Scenarios – Self-Energization & Black Start

HVAC-connected OWPP

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

HVDC-connected OWPP(s) directly (66kV) connected to the HVDC
Preliminary Findings – Self-Energization & Black Start

- Self-energization of the WTs – feasible & achievable
  - Availability of wind still investigated

- Hard-switching of large transformers and long export cables
  - might be a challenge for the WT converters

- Soft-start (voltage ramp-up) by the WTs
  - Feasible for the HVDC offshore AC network
    (HVDC onshore handles the onshore AC network switchings)
  - Fast energization of onshore AC network regions
    e.g. energizing the network and allowing conventional to take over
Preliminary list - Recommendations for Requirements

- Grid forming WTs
  - Capabilities
  - Operational ranges (V, f, df/dt)
  - Control gains (e.g. droop, reserve)

- Fault response in 100% converter-based grids

- Black Start contribution by OWPPs
  - Soft (voltage ramp-up) but very fast start
Progress Towards Demonstration in WP16

WP3 controls → WP16 setups

• Offshore AC and DC faults
• Grid forming OWPP cluster
• Fault Handling with Grid-Forming WTGs
• Black start capability of HVAC and DRU-connected offshore wind farms
• Frequency Support and Power Oscillation Damping by OWPP Cluster
• Cluster Control of Two/Three OWPPs Connected to the Same HVDC Converter
## Risk Management

<table>
<thead>
<tr>
<th>Risks</th>
<th>Effects</th>
<th>Measures</th>
<th>P(Risk)</th>
</tr>
</thead>
</table>
| • Compliance evaluation procedures are not confirmed by the simulations | • Delay or impossibility in defining and testing compliance evaluation procedures | • **P**: defined as milestone and will be monitored  
• **C**: compliance procedures redefined based on the initial simulation results | Medium |

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Any Questions?
Budget Use

Person-month usage of most partners on track
• Especially the major partners with large budgets

FGH had substantial commitment in 2018 Q3
• This will be observed in the next period

Most of the industrial partners’ commitment has been increasing due to increased focus on Self-Energization & Black Start by 2018 Q2
• This will be observed in the next period
Task 4.3
Main results from D4.3

WP4
Alberto BERTINATO
Structure of the document

Title: D4.3 – Performance, interoperability and failure modes of selected protection strategies
Due Date: M36
Part 1
Methodologies for protection strategy development

- Failure mode analysis
- Key Performance Indicators
- Interoperability
- AC system impact
- Overvoltage management
Methodologies for protection strategy

- Failure mode analysis of protection strategy

For each step in the protection strategy the following questions are asked:

- Which of the defined failure modes can happen during a step?
  - DCCB failure
  - Dependability failure...
- Which are the impacts of this failure mode?
- Development of consistent backups
Methodologies for protection strategy

• KPI for protection strategies
  - Fault interruption time
  - DC voltage restoration time
  - Active power restoration time
  - Reactive power restoration time
  - Transient energy imbalance

• KPI for protection algorithms
  • Speed
  • Protection margin (for non-unit algorithm)
  • Dependability

Key Performance Indicators:
- Efficiency Indicators:
  - Fault interruption time
  - DC voltage restoration time
  - Active power restoration time
  - Reactive power restoration time
  - Transient energy imbalance

- Failure Indicators:
  - Primary sequence failure probability
  - Protection strategy failure probability

- Cost Indicators:
  - To be defined in T4.5

Graph:
- Operation Time [s]
- Voltage Derivative
- Traveling Wave
- Current Derivative
- Max. Time

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Meeting Lyon
Methodologies for protection strategy

- **Interoperability approach:**

  - **Interoperability among key elements**
  - **Interoperability among protection strategies**
  
  - **Functional interoperability**
    (define functional requirements at component or system level)
  
  - **Syntactic and Semantic interoperability**
    (ability to exchange data and to use the exchanged data)
  
  - **Electrical interface interoperability**
    (related to voltage and current withstand capability)
Methodologies for protection strategy

- AC system impact: depending on its magnitude and duration, temporary loss of DC grid could effect
  - Frequency stability
  - Rotor angle stability
  - AC Voltage stability

Power loss in per-unit relative to the AC system power

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Meeting Lyon
Methodologies for protection strategy

- **Overvoltage management** during pole-to-ground fault in a symmetric monopolar system

Investigated solutions

- Pole Rebalancing Reactor (AC side)
- Zig Zag transformer (AC side)
- Neutral grounded transformer (AC side)
- Dynamic Braking System DBS (DC side)
Part 2
Protection Strategy Development
Protection Strategy Development

- Protection strategy development (in-depth analysis)

- Protection Strategy description
- Failure mode analysis
- Off line virtual mock-up development
  - PSCAD
  - EMTP-RV
- Main components technical specifications
- Interoperability analysis
- KPI calculation

Backups development
Protection Strategy Development

• Selected protection strategies

Full-selective fault clearing strategies
- Full selective with Mechanical-DCCB
- Full selective with Hybrid-DCCB

Non-selective fault clearing strategies
- Full Bridge MMC based strategy
- Converter breaker strategy

Investigated architecture and type of fault
- Symmetric Monopolar
  - Pole-to-ground fault
- Bipolar
  - Pole-to-ground fault
  - Pole-to-pole fault
Protection Strategy Development

- Main results for pole-to-pole fault in a symmetric monopolar system

Full-selective fault clearing strategies

- Hybrid DCCB (2ms / 50mH)
- Mechanical DCCB (8ms / 100mH)

Non-selective fault clearing strategies

- FB MMC based strategy

- Converter Breaker Strategy

- Primary sequence
- Backup sequence

- HSS counter voltage
  - 0 kV
  - 40 kV
  - 80 kV
Task 4.5
Nominal pole to ground DC voltage  
Transient Interruption Voltage (TIV) peak value (Maximum voltage between the two terminals during the breaking process)  
Maximum DC breaking current  
Maximum DC permanent / operating current  
Breaker opening time at maximum DC breaking current (Time from breaker trip signal to current diversion to energy dissipators)  
Maximum Energy Dissipation (Maximum electromagnetic energy that can be dissipated during one cycle of the breaking process)  
Current limiting DC reactor  
Uni-directional vs Bi-directional  
Opening/closing cycle (O vs OCO)  
Onshore vs Offshore

WP 4.5: DC CB cost model development: Methodology / Main parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
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<tbody>
<tr>
<td>Nominal pole to ground DC voltage</td>
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<tr>
<td>Transient Interruption Voltage (TIV) peak value</td>
<td>( U_{brM} )</td>
</tr>
<tr>
<td>Maximum DC breaking current</td>
<td>( I_{brM} )</td>
</tr>
<tr>
<td>Maximum DC permanent / operating current</td>
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<tr>
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<td>( T_o )</td>
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<tr>
<td>Maximum Energy Dissipation (Maximum electromagnetic energy that can be dissipated during one cycle of the breaking process)</td>
<td>( E )</td>
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<td>( L_{dc} )</td>
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<td>Uni-directional vs Bi-direction</td>
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<tr>
<td>Onshore vs Offshore</td>
<td></td>
</tr>
</tbody>
</table>
WP 4.5: DC CB cost model development: Organization & Contributions

**Sept. 2017**
- DC CB main specifications
- SuperGrid Institute (from D 4.2 report)

**Feb. 2018**
- DC CB’s component breakdown parametric models
- Univ Aberdeen Review SGI

**Nov. 2018**
- Estimation of material direct cost models
- SuperGrid Institute Review DNV-GL
- Shallow estimation of other costs (Labor, indirect, SIC)
- Review and validation process

**Jan. 2019**
- DNV-GL WP 12 Project Partners
- SuperGrid Institute Review DNV-GL

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**Task 4.5 – Subtask 2**
Components breakdown and parametric model for DC Circuit Breakers

**DCCB Cost model – Draft report v1.5**

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WP 4.5: DC CB cost model development: Further steps and uses

Make the Component breakdown report available to project partners

Make the DC CB cost model report available for Project Partner feedback/validation (step 5 of proposed process)

Is a contribution to Cost Data Collection report from WP 12

Will be used for cost-benefit analysis in both WP 4.5 and WP 12

What about confidentiality?
   Diffusion outside PROMOTioN Consortium? Write a publication?
Meeting with WP 4.5, WP 7 and WP 12 about CBA activities within PROMOTioN on 02 October 2018 in Lyon

CBA studies within PROMOTioN:
WP 12 is in charge of grid CBA studies. These studies will be mainly performed by FHG and Carbon Trust
WP 4.5 is in charge of Protection system CBA.

AC grids models and data from WP 12 to support WP 4.5 CBA studies
Tractebel could provide some AC Grid Data to perform a simplified DC Power Flow on AC side.
AC Grid models and data could also be provided by FGH, from TYNDP data.

Organization and roadmap of support from WP 4.5 to WP 12
Lot of HVDC grid case studies (several concepts, wind scenario and system configurations, busbar configurations)
Four protection strategies to be considered (from WP 4.3)
Need to define a suitable methodology with 3 phases
Would require a WP 4.5 extension from M42 to M48

<table>
<thead>
<tr>
<th>Phase</th>
<th>Main contributors</th>
<th>Due time</th>
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</thead>
<tbody>
<tr>
<td>Methodology set-up and validation through application to a first case study (8 GW DC Hub)</td>
<td>SGI, KUL</td>
<td>March 2019</td>
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<tr>
<td>Definition of other HVDC grid option (other grid case studies)</td>
<td>WP 12</td>
<td>March 2019</td>
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<tr>
<td>Application of the methodology to all grid case studies</td>
<td>SGI, KUL</td>
<td>Oct. 2019</td>
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<tr>
<td>Main outcomes synthesis for WP 12 deployment plan</td>
<td>SGI, KUL</td>
<td>Dec. 2019</td>
</tr>
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</table>
WP 4.5: DC CB cost model development: Methodology / Main parameters

- Nominal pole to ground DC voltage: $U$
- Transient Interruption Voltage (TIV) peak value: $U_{brM}$
- Maximum DC breaking current: $I_{brM}$
- Maximum DC permanent / operating current: $I_n$
- Breaker opening time at maximum DC breaking current: $T_o$
- Maximum Energy Dissipation: $E$
- Current limiting DC reactor: $L_{dc}$
- Uni-directional vs Bi-directional
- Opening/closing cycle (O vs OCO)
- Onshore vs Offshore

DCCB Costs

Capital Costs (CAPEX) & Operational costs (OPEX)

Direct costs, Indirect costs, Installation & Commissioning costs, Platform extra cost

Material costs, Labor costs
WP 4.5: DC CB cost model development: Organization & Contributions

Sept. 2017

DC CB main specifications

SuperGrid Institute
(from D 4.2 report)

Feb. 2018

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Univ Aberdeen
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SuperGrid Institute
Review DNV-GL

Shallow estimation of other costs (Labor, indirect, SIC)

SuperGrid Institute
Review DNV-GL

Review and validation process

Nov. 2018

SuperGrid Institute
Review DNV-GL

DNV-GL WP 12
Project Partners

Jan. 2019

Task 4.5 – Subtask 2
Components breakdown and parametric model for DC Circuit Breakers

DCCB Cost model –
Draft report v1.5
WP 4.5: DC CB cost model development: Further steps and uses

Make the Component breakdown report available to project partners

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<tbody>
<tr>
<td>Methodology set-up and validation through application to a first case study (8 GW DC Hub)</td>
<td>SGI KUL</td>
<td>March 2019</td>
</tr>
<tr>
<td>Definition of other HVDC grid option (other grid case studies)</td>
<td>WP 12</td>
<td>March 2019</td>
</tr>
<tr>
<td>Application of the methodology to all grid case studies</td>
<td>SGI KUL</td>
<td>Oct.. 2019</td>
</tr>
<tr>
<td>Main outcomes synthesis for WP 12 deployment plan</td>
<td>SGI, KUL WP 12</td>
<td>Dec. 2019</td>
</tr>
</tbody>
</table>

Organization and roadmap of support from WP 4.5 to WP 12
Lot of HVDC grid case studies (several concepts, wind scenario and system configurations, busbar configurations)
Four protection strategies to be considered (from WP 4.3)
Need to define a suitable methodology with 3 phases
Would require a WP 4.5 extension from M42 to M48
Characterisation of DC Circuit Breakers

December 2018
Dragan Jovcic, University of Aberdeen

PROgress on Meshed HVDC Offshore Transmission Networks
CONTENT

- WP6 overview,
- Tasks 6.5 and 6.6, DC CB Demonstrator and failure modes,
- Task 6.7, Hybrid DC CB grid integration and scaling,
- Task 6.8, VARC DC CB grid integration and scaling,
- Task 6.10, Mechanical DC CB grid integration and scaling,
### 1) Characterisation of DC CBs, WP6 overview

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Lead</th>
<th>partners</th>
<th>timeframe</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Develop system-level model for hybrid DC CB</td>
<td>UAbdn</td>
<td>ABB, SGI, DNV-GL</td>
<td>M1-M11</td>
</tr>
<tr>
<td>6.2 Develop system-level model for mechanical DC CB</td>
<td>DELFT</td>
<td>MEU, DNV-GL</td>
<td>M1-M11</td>
</tr>
<tr>
<td>6.3 Develop component-level and real-time model for hybrid DC CB</td>
<td>UAbdn</td>
<td>DELFT, ABB, DNV-GL</td>
<td>M18-M30</td>
</tr>
<tr>
<td>6.4 Develop component-level and real-time model for mechanical DC CB</td>
<td>DELFT</td>
<td>MEU, DNV-GL, UAbdn</td>
<td>M18-M30</td>
</tr>
<tr>
<td>6.5 <em>Develop kW-size hardware prototypes for hybrid and mechanical DC CBs</em></td>
<td>UAbdn</td>
<td>ABB, DELFT, DNV-GL</td>
<td>M1-M36</td>
</tr>
<tr>
<td>6.6 Demonstrate DC CB failure modes on kW-size hardware prototypes</td>
<td>UAbdn</td>
<td>DELFT</td>
<td>M31-M48</td>
</tr>
<tr>
<td>6.7 Analyse hybrid DC CB integration into EHV DC grid</td>
<td>UAbdn</td>
<td>DELFT, TenneT</td>
<td>M31-M48</td>
</tr>
<tr>
<td>6.8 Develop roadmap for VARC DC CB scaling to EHV DC voltage</td>
<td>DELFT</td>
<td>SciBreak, TenneT</td>
<td>M31-M48</td>
</tr>
<tr>
<td>6.9 Develop standard DC CB verification plan and RTDS models</td>
<td>UAbdn</td>
<td>ABB, DELFT, MEU, DNV-GL, SGI, SciBreak</td>
<td>M12-M24</td>
</tr>
<tr>
<td>6.10 Develop roadmap for mechanical DC CB scaling to EHV DC voltage</td>
<td>MEU</td>
<td>DNV-GL, TenneT, UAbdn</td>
<td>M31-M48</td>
</tr>
</tbody>
</table>
1) Characterisation of DC CBs, WP6 overview

conferences published:

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

panels:
1. Characterisation and testing of DC CBs for future DC grids, IEEE PES GM, Portland, August 2018,
2. DC Grid protection, IEEE ISGT, Sarajevo, October 2018,
2) Tasks 6.5 and 6.6, 900V, 500A DC CB Demonstrators, development and failure mode study

Overview of work:

1. 320kV UFD
   a. Detailed modelling: Dynamics, Thomson coils,
   b. Cassie – Meyer arc model (SF6 medium),

2. Hybrid DC CB failure mode study

3. 900V UFD
   a. DC arc modelling in air,
   b. Reducing opening time

4. 900V mechanical DC CB
   a. Series connection of interrupters,
   b. Failure analysis
2) Tasks 6.5 and 6.6, 900V, 500A DC CB Demonstartors, development and failure mode study

1. 320kV UFD: Detailed modelling: Dynamics, Thomson coils,

Figure 1. Simulation results on PSCAD model of 320kV UFD.
2) Tasks 6.5 and 6.6, 900V, 500A DC CB Demonstrators, development and failure mode study

1. 320kV UFD: failure modelling
   - Open signal is received while UFD conducts large current.
   - Cassie arc model for SF6 medium.
   - Entry and exit from arcing mode. Positive and negative current.

\[
\frac{dg_c}{dt} = \left(\frac{g_c}{\theta_c}\right) \left[\left(\frac{U_a}{U_0}\right)^2 - 1\right]
\] (5)

Figure 2. 320kV UFD model structure.

Figure 3. 320kV UFD arc model for positive current.
2. 320kV UFD: failure modelling

- Open signal is received while UFD conducts large current.
- Cassie-Mayr arc model for SF6 medium.
- Entry and exit from arcing mode. Positive and negative current.

\[
\frac{dg_c}{dt} = \left( \frac{g_c}{\theta_c} \right) \left[ \left( \frac{U_a}{U_0} \right)^2 - 1 \right]
\]

(5)

Figure 2. 320kV UFD model structure.

Figure 3. 320kV UFD arc model for positive current.
2) Tasks 6.5 and 6.6, 900V, 500A DC CB Demonstartors, development and failure mode study

2. 320kV DC CB failure mode study
• Failure in closed state.
• Failure in open state.
• Failure while opening.
• Impact of failure of each of 5 components are studied:
  • LCS
  • UFD
  • Main breaker
  • Residual Breaker
  • Energy absorber
• Failure tree diagram,
• assumptions:
  • primary protection operates within 10ms,
  • back up protection operates within 200ms

Figure 4. 320kV hybrid DC CB.
2. 320kV DC CB failure mode study
In closed state DC CB fails if
a) RCB fails or,
b) Any other two switches fail

Figure 5. Failure tree diagram for closed state.
2) Tasks 6.5 and 6.6, 900V, 500A DC CB Demonstrators, development and failure mode study

3. 900V UFD improvements and failure mode
   a) Opening time reduced to 1ms,
   b) DC arc model in air

Figure 6. 900V UFD (Air) arc model verification.
3) Task 6.7 Hybrid DC CB Grid intergation and scaling to high voltage

1. DC grid integration of hybrid DCCB
   a) DC grid model from WP4,
   b) Tenet is working on finalising parameters,
   c) Same DC grid will be used in T6.7, T6.8 and T6.10,

2. Pre-standardisation of DC CB inputs and outputs
   a) Connection with IED (coordination with WP4)

---

Figure 7. DC grid test system.
3) Task 6.7 Hybrid DC CB Grid integration and scaling to high voltage

1. DC grid integration of hybrid DCCB
   a) DC CB model influence,

![Hybrid DCCB models](image)

   a). Detailed hybrid DC CB model.
   b). Switched hybrid DC CB model.
   c). Generic hybrid DC CB model.

Figure 8. Hybrid DCCB models.
3) Task 6.7 Hybrid DC CB Grid integration and scaling to high voltage

1. DC grid integration of hybrid DCCB
   a) At system level response of three DCCB models is very similar,

![Figure 9. Comparison of hybrid DCCB models.](image)
### 3) Task 6.7 Hybrid DC CB Grid intergation and scaling to high voltage

#### 1. DC grid integration of hybrid DCCB

Table 1. Properties of Hybrid DCCB models .

<table>
<thead>
<tr>
<th></th>
<th>Detailed</th>
<th>Switched</th>
<th>Generic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current breaking</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fault current limiting</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Individual branch currents</td>
<td>All</td>
<td>All</td>
<td>Some</td>
</tr>
<tr>
<td>Power loss estimation</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Switch temperature estimation</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Arrester energy estimation</td>
<td>All arresters</td>
<td>All arresters*</td>
<td>Main branch only, no FCL</td>
</tr>
<tr>
<td>LCS voltage estimation</td>
<td>Yes</td>
<td>Yes*</td>
<td>No</td>
</tr>
<tr>
<td>Self-protection</td>
<td>Full</td>
<td>Full</td>
<td>Limited</td>
</tr>
<tr>
<td>Failure modes</td>
<td>All</td>
<td>Most</td>
<td>Few</td>
</tr>
</tbody>
</table>

1s real time, 10 us time step:

- Generic DCCB: 2.5 min
- Switched HDCCB: 25 min
- Detailed HDCCB: 690 min ~ 11.5 h
3) Task 6.7 Hybrid DC CB Grid integration and scaling to high voltage

1. DC grid integration of hybrid DCCB
   a) study of different fault location on line 13.

Figure 10. Peak DC CB current and energy dissipation for different fault location.
3) Task 6.7 Hybrid DC CB Grid integration and scaling to high voltage

2. Pre-standardisation of interfaces between hybrid DCCB and protection

a) 3 DC CB inputs.
b) 4 DCCB outputs

Figure 11. Input and output connection between IED and DC CB.

- Mechanical CB:
  - TRIP_BRK: 1/0→open/close order
  - BRK_L_REF: not used
  - TRIP_RCB: not used
  - Breaker monitoring:
    - ST_BRK: include VI and RCB
    - BRK_READY: ready to operate, including all components in the mechanical DCCB
4) Task 6.8 VARC DC CB Grid integration and scaling to high voltage

1. Detailed Simulation of VARC DC CB including RTDS modelling
2. Stress study for HV scaling
3. Series connection of units
4. Energy absorber thermal modelling and model verification (with WP10)

Figure 12. VARC DC CB schematic and RTDS model.
4) Task 6.8 VARC DC CB Grid intergation and scaling to high voltage

1. Detailed Simulation of VARC DC CB including RTDS modelling

Figure 13. Verification of PSCAD model using experimental results.
4) Task 6.8 VARC DC CB Grid integration and scaling to high voltage

1. Detailed Simulation of VARC DC CB including RTDS modelling

Figure 14. Verification of RTDS model.
4) Task 6.8 VARC DC CB Grid integration and scaling to high voltage

Stress study for HV scaling

Figure 15. VARC DC CB insulation strength modelling.

a) Successful interruption

b) Failed interruption because of early injection
4) Task 6.8 VARC DC CB Grid integration and scaling to high voltage

Series connection of units

4 modules in series

5 modules (with 1 redundant module) in series

An extra surge arrester connected in parallel with 5 modules

Extra surge arresters connected in parallel with each modules

Additional SAs

Figure 16. VARC scaling to HV using series connection of modules.
4) Task 6.8 VARC DC CB Grid integration and scaling to high voltage

Series connection of units

Figure 17. Comparison of VARC DC CB with 3, 4, and 5 modules.

CB cannot interrupt the fault with 3 modules

≈ 300A. Residual breaker does not interrupt.

Energy keeps dissipating
4) Task 6.8 VARC DC CB Grid integration and scaling to high voltage

Series connection of units

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>• If all modules work well, the external SA will dissipate all energy. In this case, the design of SAs inside the module is not affected by the energy.</td>
<td>Additional SAs;</td>
</tr>
<tr>
<td>• If one module fails to operate, the external SA will dissipate the energy with the SAs inside the module.</td>
<td>Additional SAs;</td>
</tr>
<tr>
<td>• Possible issues from the SA capacitance inside the breaker module can be mitigated.</td>
<td>Additional SAs;</td>
</tr>
<tr>
<td>• If one SA fails to operate, the other SAs can still dissipate the energy.</td>
<td>If one module fails to operate, the corresponding parallel SA may fail as well, the other four external SAs need to withstand more voltage than expected</td>
</tr>
</tbody>
</table>

The equivalent clamping voltage across the DC CB is set to $1.5 \cdot 320$ kV

Figure 18. Comparison of options for location of additional arresters.
5) Task 6.10 Mechanical DC CB Grid integration and scaling to high voltage

1) Study of scaling DC CB to EHV (ongoing)
2) Analysis of DC grid integration of mechanical DC CB, (just started)
3) Verification of system level model, (not started)
5) Task 6.10 Mechanical DC CB Grid integration and scaling to high voltage

1) Study of scaling DC CB to EHV
   Topology 1

   • This configuration uses a common current injection circuit.
   • A number of series-connected interrupter units are used to withstand the required voltage imposed by the MOSA.
   • Voltage grading networks are required to ensure distribution of voltage stress across the interrupters during static and transient conditions.

Figure 19. Mechanical DC CB for 320kV. Topology 1.
5) Task 6.10 Mechanical DC CB Grid integration and scaling to high voltage

1) Study of scaling DC CB to EHV
   Topology 1

![DCCB Model (Type 1)](image)

Individual control over interrupter operation time is possible

Figure 20. Model of mechanical DC CB for 320kV. Topology 1.
5) Task 6.10 Mechanical DC CB Grid intergration and scaling to high voltage

1) Study of scaling DC CB to EHV
   Topology 2

   • This configuration circuit series connected modules
   • Each module contains the key elements of an individual DC breaker: current injection circuit and MOSA;
   • Modules are connected in series to generate the required counter-voltage to interrupt fault current

Figure 21. Mechanical DC CB for 320kV. Topology 2.
5) Task 6.10 Mechanical DC CB Grid integration and scaling to high voltage

1) Study of scaling DC CB to EHV
   Topology 2

The multi-break DCCB PSCAD component contains all electrical elements and control blocks.

Figure 22. Model of mechanical DC CB for 320kV. Topology 2.
5) Task 6.10 Mechanical DC CB Grid integration and scaling to high voltage

1) Study of scaling DC CB to EHV

<table>
<thead>
<tr>
<th>Item</th>
<th>Topology #1: Common Current Injection Circuit</th>
<th>Topology #2: Module Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact of mechanical switch operation variation</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Grading unit for high speed switch</td>
<td>Necessary</td>
<td>Unnecessary</td>
</tr>
<tr>
<td>Design flexibility for higher voltage levels</td>
<td>Less flexible</td>
<td>More flexible</td>
</tr>
<tr>
<td>Capacitor charging sequence</td>
<td>Simple</td>
<td>Complicated</td>
</tr>
</tbody>
</table>

Items regarding electric circuit phenomena ➔ Reflected in the models
Items regarding operation
Conclusions

1. T6.5, T6.6 900V Demonstrator DC CB development and failure mode study
   a. 320kV UFD
   b. Hybrid DC CB failure mode study
   c. 900V UFD
   d. 900V mechanical DC CB

2. T6.7 Hybrid DC CB grid integration and scaling
   a. DC grid integration of hybrid DCCB
   b. Pre-standardisation of DC CB inputs and outputs (with WP4)

3. T6.8 VARC DC CB grid integration and scaling
   a. Detailed Simulation of VARC DC CB including RTDS modelling
   b. Stress study for HV scaling
   c. Series connection of units
   d. Energy absorber thermal modelling and model verification (with WP10)

4. T6.10 Mechanical DC CB grid integration and scaling
   a. Study of scaling DC CB to EHV
WP7
Regulation and Financing of a meshed offshore grid in the North Sea
Plenary Meeting | 10 December 2018 | Lyon
Intermediate Results

WP1 · Requirements for Meshed Offshore Grids · TenneT
WP2 · Grid Topology & Converters · RWTH Aachen
WP3 · WTG – Converter Interaction · DTU
WP4 · HVDC Grid Protection Systems · KU Leuven
WP5 · Test Environment for HVDC CB · DNV GL
WP6 · HVDC CB Performance Characterisation · UniAberdeen
WP7 · Regulation & Financing · TenneT
WP8 · DRU demo · Siemens
WP9 · Protection System Demo · SHE Trans
WP10 · HVDC Circuit Breaker Demo · DNV GL
WP11 · Harmonisation Towards Standardisation · DTU
WP12 · Deployment Plan for Future European Offshore Grid · TenneT
WP13 · Dissemination · SOW
WP14 · Project Management · DNV GL
WP15 · HVDC GIS Demo · ABB
WP16 · MMC Test Bench Demo · RWTH Aachen

Intermediate Reports

Financial
Legal
Economic

Conclusions
Stakeholder
CBA

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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.
Set of aspects, covering parts of the financial and regulatory framework

- Cross-border offshore grid ownership
- Cross-border offshore grid operation
- Remuneration of hybrid assets
- Grid connection costs (treatment of generation v load)
- Grid connection costs (super-shallow, shallow, deep)
- Priority dispatch
- Cross-border cost allocation method
- Locational planning of offshore wind farms
- Renewable energy supplies (RES) support schemes cooperation

Important elements have to be brought in the picture of WP7

- The adherence to the ENTSO-E technical regulation (network codes) about market access across all time frameworks (as indicated at least in FCA NC, CACM NC and EB NC)
- The regulatory governance: who should be the overarching regulatory
- Risk analysis and development of financial framework
- Offshore grid operations / balancing
- Legal classification of hybrid assets and support schemes for OWF
- Licensing & permitting and decommissioning
- Bidding zone design
Presentation of and discussion with the North Seas Energy Cooperation Support Group 2

- General introduction on work package 7: regulatory issues
- Balancing mechanisms
- Possible ownership and system operation governance models
- Barriers identified by Roland Berger

Working session on regulatory aspects with ministries, NRAs, developers, TSOs, wind associations

- Who should regulate a MOG? The regulatory governance structure
- Who should own and operate a MOG?
- The role and design of support schemes in a MOG
Our way towards a comprehensive framework

- Long term grid access according to the FCA and CACM NC requirements
- Market based grid access with the EB NC
- Cross-border offshore grid ownership
- Cross-border offshore grid operation
- Remuneration of hybrid assets
- Grid connection costs (treatment of generation vs load)
- Grid connection costs (super-shallow, shallow, deep)
- Priority dispatch
- The regulatory governance
- Renewable Energy Supplies (RES) support schemes cooperation
- Locational planning of offshore wind farm
- Cross-border cost allocation method

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10.12.2018 7
Next step: compile all options derived from the different tasks

- **Examples:**
  - **Parameter: Cross-border offshore grid ownership**
    - **Options:**
      - Model A: North Seas grid (NSG) transmission system operator (TSO)
      - Model B: Cooperation of national TSOs (from continental Europe) and offshore transmission owners (OFTOs) (in the UK)
      - Model C: Third parties (tendered before construction)
      - Model D: NSG TSO builds, then tenders ownership to third parties
      - Model E: National TSOs build, then tender ownership to third parties
  - **Parameter: Remuneration of hybrid assets**
    - **Options:**
      - Only regulated income
      - Regulated income plus congestion rents
      - Congestion rents only

- **Need to consider the full list for legal, economic, and financial frameworks – and in particular identify options from different parameters which need to be selected in combination**
Next step: identify the criteria to review the different options

- Our criteria should include all characteristics of the legal, economic, and financial frameworks for a MOG that are important to the Commission *(collectively exhaustive)*. These could include:
  - Least cost for a given outcome (e.g. energy delivered via offshore wind in Europe by 2050).
  - Simplest/fastest/least disruptive to implement.
  - Lowest risk/most stable/predictable regime to minimise uncertainty and the cost of capital.
  - Most socially and politically acceptable, to maximise North Seas countries’ buy in.
  - Most likely to facilitate provision of private capital, given investment needs.
  - Technically feasible/easy to implement.

- Ideally **mutually exclusive** so we’re not counting the same thing twice in different criteria e.g. there is a conceptual overlap between ‘least risky’ and ‘most likely to facilitate provision of private capital’.

- Has to **show differences** between options – i.e. criterion is not useful if all options score the same.

- Ideally **the same criteria** should be applicable across all relevant design parameters whether they are legal, economic, or financial.

- We want the **minimum number of criteria** consistent with the above.
Criteria used so far to draft the tasks reports

1. Economic benefits: The objective is to deliver solutions at least cost and maximum benefit for society.

2. Speed of implementation: How quickly can the MOG be built under the proposed regime? Both the time needed to design and legislate for the regulatory regime/s for each governance model and the consequent impact on the time needed for construction after the regime is in place.

3. Socio-political acceptance: Acceptance by policy-makers at national (countries around the North Sea) and EU-level (European or supranational institutions).

4. Provision of private capital: Facilitation of private capital provision to maximize the chances of raising 100 billion+ € to pay for the MOG
Final step: compile recommendations to provide a consistent regulatory and financial framework

What should these recommendations look like:

- We agreed to design a final deliverable without hard boundaries, but providing two-three scenarios, whenever possible ranking them in terms of likelihood of possible implementation.
- We must support the definition of options and criteria which account for the existence of solutions with no sharp edges for the regulatory and financing policies: the fast-changing scenario in Europe could determine sudden changes in the macro-economic scenario, crashing any hard-coded plan into pieces.
How to get there?

1. Reach a definitive conclusion about the business parameters to be tackled and how to cover them

- October 2018
- November 2018
- December 2018
- January 2019
- February 2019
- March 2019
- April 2019

Activity 1: Review
Deliverable Activity 1
Activity 2
Deliverable Activity 2
Activity 3
Deliverable Activity 3
Activity 4
Deliverable Activity 4
Activity 5
Deliverable Activity 5

- Selection of the elements
- Combination of the elements
- Elaborate a final set of proposals
- Drafting of deliverable 7.9

2. Work in the first part of this activity to assess options for all business parameters and scoring criteria

3. Evaluate the opportunity to extend the task until end of January so to have enough time to iterate the proposal for options and scoring criteria

4. Evaluate all possible inconsistencies and unrealistic combinations of combinations and prepare the scoring

5. Score the remaining scenarios and prepare the final summary for the drafting of the recommendations
Any Questions?
WP10

HVDC Circuit Breaker Demonstration

René Smeets / Nadew Belda
DNV GL  KEMA Laboratories
WP 10

• Demonstration of full-power testing of HV DC circuit breakers
• Started January 2018
• Deliverables under review (M36)
  D10.1: “Testing of prototypes of HVDC circuit-breakers”
  D10.2: “Evaluation of the interaction of CB sub-components with the circuit”
• Three demonstrators scheduled for 2019
Activities

• WP5: Full-power testing feasible for technologies of project partners
• Over-current protection and application of DC voltage stress requires real-time current monitoring with very fast switching technology (triggered spark gaps)
• Design of an experimental HVDC breaker (current injection type) to evaluate stresses
• Single, double and three-break vacuum gaps
• Design of instrumentation
VSC assisted technology

- Demonstration of single module testing of VSC assisted resonant breaker
- In cooperation with SciBreak
- Positive results, 10 kA, 40 kV TIV, 3 ms
Testing of experimental HVDC breaker
Evaluation of HVDC breaker stresses

- Mechanical interrupter, vacuum interrupter
  - High-frequency (> 5 MHz) performance measurements
- Surge arrester for energy absorption
  - Multi-channel, high-voltage isolated data acquisition system
  - Transient thermal, IR
  - Transient electrical
Interruption process

- injection start
- counter voltage
- re-ignition
- interruption
- restrike

Time [ms]
Voltage [kV] / Current [kA]
Identifying critical parameters and their relevance

Voltage [kV] / Current [kA]

Time [ms]

di/dt at CZ (A/us)

Ipk prior to CZ (kA)

re-ignition

interruption %

fail
interrupt
fail restrike
interrupt restrike
Thermal stresses

- Surge arrester is another critical component
- Current is shared between a number of columns
- Non-linear character of the ZnO needs careful design and application
- Current and temperature is monitored to evaluate stresses during full power testing
- Analysis in progress
Thermal stresses

- 8 channel measurements with an optical system
- To be used by WP6 to verify thermal model of the energy absorption
- Accumulation of stored energy at repeated operation
Current sharing

- 8 channel measurements with electrically isolated Rogowski coils
- To be used by WP6 to develop thermal model of the energy absorption
- Analysis is ongoing
- D10.3

Current (thermal load) not always shared equally
Dissemination

- 3rd paper under review IEEE TPD
- CIGRE Paris workshop HVDC breakers
- 8 presenters, 140 participants
- Follow-up CIGRE-IEC Japan
- WP 5, 10, 15 tutorials
- PhD thesis in preparation
Standardization

- Inventory on the need of standards made in IEC AHG 04, 60
- It summarizes Chinese National Standard NB/T 42107, 2017 on HVDC breakers
- Combines recommendation of CIGRE JWG A3/B4.34 with PROMOTioN experiences
  Definitions proposed
- Report submitted to IEC TC 17A, Nov. 2018
- IEC TC17A decides to establish 5 working groups on HVDC switchgear:
  - Switchgear (4), incl. circuit breakers
  - Switchgear assemblies (1)
- Reported to ctrl & prot workshop WP11 20181206
Demonstrators 2019

• Demonstration of testing in 2019:
  - multiple-unit breaker of active current injection type
  - multiple-unit breaker of VSC assisted resonant current type
  - full hybrid type of HVDC circuit breaker

• TRL level 7
Any Questions?
WP11 – Progress report to plenary meeting

06-12-2018, Poul Sørensen, Technical University of Denmark
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 harmonise the work between existing and future working groups.
• To ensure that different manufacturer concepts are considered.

Outputs are formulation and justification of:

• Functional specifications / requirements.
• Test and measurement procedures.
• Simulation models.
• Procedures for compliance validation.
WP11 Tasks

Original contract

- Task 11.1 Coordination and harmonisation across working groups (DTU).
- Task 11.2 Contributions to CENELEC TC8X WG06 on system aspects of HVDC grids (RWTH)
- Task 11.3 Contribution to relevant working groups in CIGRE (KUL).
- Task 11.4 Contribution to Standards for Wind Power Plants (DTU)
- Task 11.5 Recommendations to grid codes (FGH)
- Task 11.6 Recommendations for best-practices in compliance evaluation (FGH)

Amendment 7

- Task 11.1 Coordination of harmonisation activities and initiatives (DTU M25-54).
- Task 11.2 Contributions to harmonization of control and protection of HVDC systems (KUL M25-52).
- Task 11.3 Contribution to Standards for Wind Power Plants (DTU M25-51)
- Task 11.4 Recommendations to grid codes and compliance evaluation (FGH M31-51)
WP11 Deliverables

Original contract

- D11.1. Report with harmonised functional specifications of HVDC systems and connected WPPs (RWTH M46)
- D11.2. White paper on test procedures for WPPs connected to HVDC systems (DTU M36)
- D11.3. Report with justified recommendations to grid codes (FGH M42)
- D11.4. Report with recommendations to best practice for compliance evaluation (FGH M42)
- D11.5. Report with recommendations on harmonized requirements for tests and models of WPPs connected to HVDC systems (DTU M45)
- D11.6. White paper on harmonisation of models for WPPs connected to HVDC systems (DTU M46)

Amendment 7

- 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)
- D11.6 Report with summary of findings from PROMOTioN final harmonization workshop (DTU M54)
Links to other work packages

WP11

11.1 Coordination of harmonisation activities and initiatives

11.2 Contributions to harmonization of control and protection of HVDC systems

11.3 Contribution to Standards for Wind Power Plants

11.4 Recommendations to grid codes and compliance evaluation

WP 2, 4, 5, 6, 9, 10, 15, 16

WP 3, 16

WP 1-4
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
• Contributions to existing WGs
• New work proposals
• Deliverables
• Other

Final Workshop
• Disseminate PROMOTioN contributions
• Discuss future work
Harmonization catalogue

- Template
- Describe relevant harmonization activities
- Analyse potential for including PROMOTioN findings
- Recommend initiatives
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**
  - ENTSO-E HVDC
  - ENTSO-E Requirements for generators
  - ENTSO-E Demand connection Code
  - inter-TSO coordination in CNC implementation

IEA
CIGRE
IEEE
IEC
CENELEC
Grid codes

R&D&D
Best practice
Standard
Requirement
PROMOTioN WP11 workshops on harmonization towards standardization

• Workshops are organised with regards to
  • HVDC GIS (done 2018-09-20 – WP15)
  • Control and Protection of HVDC systems (2018-12-06)
  • HVDC connected wind power – IEC TC88 focus (2019-01-15)
  • Grid codes (2020-01?)
  • Final harmonisation workshop (2020-05?)

• Each workshop will contain sessions on:
  • Overview of ongoing standardisation activities
  • Presentation of current status of standardisation in different working groups
  • Gathered knowledge in PROMOTioN
  • Discussion and potential alignment of the current standardisation work
  • Identification of future standardisation activities
Workshop on HVDC Control and Protection

Workshop on HVDC Control and Protection of HVDC systems
6 December 2018 in Brussels

• Premesis:
  • CENELEC office

• 17 participants

• Representatives from:
  • CENELEC
  • CIGRE
  • IEC
<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Responsible party</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:30 – 10:00</td>
<td>Welcome and Coffee</td>
<td>Geraint Chaffey, Christina Brantl</td>
</tr>
<tr>
<td>10:00 – 10:35</td>
<td>Introduction &amp; Presentation of PROMOTioN</td>
<td>Poul Sørensen, Christina Brantl, Dirk van Hertem</td>
</tr>
<tr>
<td>10:35 – 10:50</td>
<td>Overview of existing and ongoing standardisation work in the field of</td>
<td>Christina Brantl</td>
</tr>
<tr>
<td></td>
<td>HVDC control and protection</td>
<td></td>
</tr>
<tr>
<td>10:50 – 11:10</td>
<td>Coffee break</td>
<td></td>
</tr>
<tr>
<td>11:10 – 11:30</td>
<td>CENELEC work on HVDC control and protection</td>
<td>Marcus Zeller</td>
</tr>
<tr>
<td>11:30 – 11:50</td>
<td>CIGRÉ work on HVDC control and protection</td>
<td>Willem Leterme</td>
</tr>
<tr>
<td>11:50 – 12:10</td>
<td>Standardisation with regard to HVDC switchgear</td>
<td>René Smeets</td>
</tr>
<tr>
<td>12:10 – 12:30</td>
<td>Presentation of afternoon break-out sessions</td>
<td>Christina Brantl</td>
</tr>
<tr>
<td>12:30 – 13:30</td>
<td>Lunch break</td>
<td></td>
</tr>
</tbody>
</table>
Workshop on Control and Protection of HVDC systems
Afternoon breakout sessions – prepared discussion topics

Protection systems

• Design of protections system
• Performance evaluation of protections system
• Fault separation concepts
• Insulation coordination
• Communication protocols
• Communication interfaces
• Testing of protection devices

Control

• Integration of DRU
• DC FRT
• AC FRT
• Interoperability
• Control in large grid structures
• Harmonics / models
Workshop on HVDC connected wind power plants
15 January 2018 in Roskilde, Denmark

• Back to back with relevant WG meetings in IEC TC88 Wind Energy Generation Systems
  • WG21: Measurement and assessment of electrical characteristics
  • WG27: Electrical simulation models
• Migrate also invited

• Identified discussion topics:
  • Control
    • Grid forming
    • FRT (AC and DC)
    • Ancillary services
  • Harmonic
    • Test
    • Modelling
    • Validation
  • EMT
    • Modelling
    • Validation
APPENDIX

DISCLAIMER & PARTNERS

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The opinions in this presentation are those of the author and do not commit in any way the European Commission

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PARTNERS

APPENDIX

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Deployment Plan for an Offshore Grid
Plenary Session – Lyon

Brussels 26th November 2018
John Moore TenneT
Objectives of Work Package 12

To produce a Deployment Plan for European future offshore grid development

Technical

Governmental

Financial

Economic

Market

Legal & Regulatory

Stakeholder actions & guidance
**Project Planning**

- **New Deadlines (subject to Amendment 7)**

**Extended & Changes to Scope**

- New task T12.6 added in March 2018: “Overview economic evaluation of operational strategies” led by FGH. It will be rolled into D12.2
- Scope and description modified to match requirements of CBA November 2018
- Contents changes: D12.2 (include detail of CBA, include overview of Outputs other WPs) and D12.3 (Including stakeholder specific recommendations)

<table>
<thead>
<tr>
<th>Task</th>
<th>Old Due Date</th>
<th>New Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>D12.1v2</td>
<td>No official due date. Reviewed, will be finalised after bottlenecks in 12.2 solved</td>
<td></td>
</tr>
<tr>
<td>T/D12.2</td>
<td>36</td>
<td>38</td>
</tr>
<tr>
<td>T12.6</td>
<td>36</td>
<td>38</td>
</tr>
<tr>
<td>T/D12.3</td>
<td>36</td>
<td>38</td>
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</table>

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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.
The deliverables of WP12 will be structured as follows:

<table>
<thead>
<tr>
<th>D12.2 An Optimal Scenario for an Offshore Grid</th>
<th>D12.4 Deployment Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Scenarios</td>
<td>Recommendations per Stakeholder</td>
</tr>
<tr>
<td>Detailed description of concepts</td>
<td>Technical Trajectory</td>
</tr>
<tr>
<td>Grid topologies</td>
<td>Governmental</td>
</tr>
<tr>
<td>Cost Benefit Analysis</td>
<td>Finance</td>
</tr>
<tr>
<td>Social Benefits (ex-D12.6)</td>
<td>Economic</td>
</tr>
<tr>
<td>Markets Analysis</td>
<td>Legal &amp; Regulatory</td>
</tr>
<tr>
<td></td>
<td>Markets</td>
</tr>
<tr>
<td></td>
<td>Short Term Actions/Projects</td>
</tr>
<tr>
<td></td>
<td>Summary of Barriers</td>
</tr>
<tr>
<td></td>
<td>Summary of Outcomes Other work Packages</td>
</tr>
</tbody>
</table>

Other work Packages
Progress on D12.2 Optimal Scenario delayed due to difficulties with locating wind and building topologies

PROMOTiOn GA asked WP12 to evaluate different grid concepts to assess the relative costs & benefits of potential grid solutions
Wind problem solved with stricter adherence to TYNDP prognosis, which although is realistic may not maximise Benefit
Topology problem is more fundamental as this is related to the ability to build a large scale Meshed Offshore Grid
Business as Usual prognosis 2050 indicates the scale of our project
Consensus and Vision versus outcomes Work Packages

• The gap appears to be the difference between “a few simple projects” and a fully meshed grid. This seems inside PROMOTioN as well as in other programs.

• The challenge is to go from a few small initiatives today, compared to the 40-100 projects required to build a full 205GW grid.

PROMOTioN promises a fully meshed grid
WP12 is seeking guidance on the scale up of the grid – needed to be able to progress the topology and perform a CBA

- A bottleneck was identified during the Topology optimisation:
  - When ambition in terms of generation capacity was communicated back questions raised on the scope and complexity of the grid
  - WP2 and WP4 both concerned about higher complexity and indicated that the simulation and testing within these WPs was far less complex.
  - We understand that for WP4 a scale up if not straightforward, is possible to evaluate.
  - For WP2 and 5, the control aspects are far more complex and would require significant longer term research.

- We are working with WP2 and experts in other WPs to solve this, but it potentially has material impact on the PROMOTioN outcomes:
Large portions of WP12 are delayed until the topology is finalised.

• Goal needs to be **realistic**: we can expect that it could be built.

• If some weaknesses in the design, we realise that **not all of items are available** and on the market today. However the step to solve these are known and are anticipated to be solved during or soon after PROMOTioN.

• However, we need to make **assumptions** for the benefit of progress.

• We require approval by the Consortium of the issues described in order to progress.
  • Be aware of this when voting on Wednesday!
Short Term Projects Update – the Dirk Sneaky Proposal

• Evaluation of existing projects.
  • 5 projects from Roland Berger study – 3 include relevant HVDC components – if not complex
  • 2/5 relate to a single TenneT project. Today this is at critical phase of negotiations. We are unable today to discuss these 2 projects
  • 1/5 is Cobra cable that has already been laid.
    • Designed to include a branch to a wind park.
    • No suitable wind park planned and German government has serious problems if an OWF is subsidised and not connected directly to Germany.
    • Cable is now almost completed. Mixed meaning about the ease of pulling the cable to connect a wind farm.
  • 2 Projects identified in Sweden. May be possible modification to meshed HVDC. To be discussed.
  • TSO Consortium partners within WP12 asked to make an inventory of potential projects

• TenneT island concept will be open to using HVDC also
  • Longer term
  • Limited HVDC
  • But space and ambition to include some HVDC meshing.
Short term initiatives are being evaluated

Roland Berger Study – 5 projects 3 possible

Other Projects – Planned but not yet evaluated

Identify Short & Mid Term Projects

Evaluate Projects

- €AA
- Planning Goal modification/justification +€XX
- Additional benefits related to technical capabilities +€YY
- New additional Technology path specification -€BB
- Contingency for additional fault options -€CC
- Contingency for Catastrophic Fault -€DD
- Actions/contribution EC +€ZZ

Total Project Value +€A+X+Y+B+C+D+Z=NN

Project Solution

Recommend Support from Stakeholders to de-risk Projects

Brussels 26.11.2018
Short term projects issues arising to date:

1. Barriers to modification of projects are also related to non-financial factors which also need evaluation.
2. Confidential issues around multi-party projects, makes it difficult to break in.  
   - solution to create a “shadow” project analysis being investigated.  
   - Difficult to influence confidential negotiations and discussions.
3. Mind set as in previous slides: people not yet looking at the long term.
4. But, realisation that if we are to develop HVDC meshing, a first step is needed, and we cannot continue pushing this into the future.
Any questions?
WP13
Dissemination

Stiftung OFFSHORE-WINDENERGIE ● Andreas Wagner
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 #5 for Q4/2018, topics amongst others**
  - Successful Factory Acceptance Test MMC Test Bench (WP16)
  - Successful Completion of HVDC gas insulated switchgear (GIS) test prototype installation (WP15)
  - CBA Methodology (WP7)
  - Optimal scenarios for the future European offshore grid (WP12)
  - Two low-power demonstrator DC circuit breakers developed and tested at University of Aberdeen laboratory (WP6)
**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 between 2:51 min (September) and 1:48 min (November) on our website**
- **Visitors look at ~ 2 different pages per visit (average bounce rate ~ 50%)**
- **Highest “consumption” of pages per session in France, Germany, the UK & the Netherlands (between 4 and 2)**
- **Lowest in the US, Russia and Czech Republic**

**Visits**: Number of overall visits  
**Unique Visitors**: Distinct individuals  
**Page Impressions**: Number of different pages
Progress Task 13.4 - Development of a targeted mailing list

1,209 Stakeholders

- **European Bodies**: 288
- **Financing Bodies**: 24
- **Policy institutions**: 403
- **Academia & Consulting**: 147
- **Industry Stakeholders**: 245
- **Others**: 102

**Stakeholder Categories**

Lyon, 11.12.2018
Progress Task 13.6 - Production of public reports, papers/articles, presentations

Good news! We are right on track!

Conference Papers
- Published: 28
- Submitted/In Review: 26
- Gap/Surplus: +4

Journal articles
- Published: 8
- Submitted/In Review: 13
- Gap/Surplus: -4

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Lyon, 11.12.2018
Progress Task 13.7. – Stakeholder Interaction

Upcoming Events [I]

ACDC 2019 - The 15th IET international conference on AC and DC Power Transmission (papers submitted by e.g. WP2 & WP4)
5 – 7 February 2019 in Coventry, UK

NorthSEE & Baltic LINes MSP Conference (PROMOTioN WP7 contribution)
13 - 14 February in Hamburg, Germany

The Baltic InteGrid: Roadmap for a meshed offshore grid in the Baltic Sea region (PROMOTioN presentation by Cornelis Plet)
26 - 27 February 2019 in Berlin, Germany

Joint MIGRATE and PROMOTioN Workshop → Details next slide
28 February 2019 in Berlin, Germany
Joint MIGRATE & PROMOTioN Event [I]

„PROMOTioN & MIGRATE –

Technical challenges and recommendations for the future European power grid“

Background and schedule

• Mariana asked for a closer collaboration between MIGRATE and PROMOTioN
• Workshop on highlighting the technical complementarity of the two projects
• 13 December 2018: Save The Date
• 17 January 2019: Official Invitation
• 28 February 2019: Workshop in Berlin, Germany
• Expected number of participants lies between 50 and 100
**Joint MIGRATE & PROMOTioN Event [II]**

PROMOTioN contributions on:
- **the changes in system inertia (WP 2 & 4)**
  What impact does changing inertia have on offshore HVDC power system?
- **the control and operation of no or low inertia grids (WP 3)**
  Offshore windfarm voltage control & black start capability
- **power quality questions (WP 16)**
  Modelling and validation of inverter harmonics
- **regulation & grid codes (WP 2 & 11)**
  Recommendations for offshore HVDC grid inverter interfaces

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**Schedule:**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:30 – 10:00</td>
<td>Walk In &amp; Registration</td>
</tr>
<tr>
<td>10:00 – 10:30</td>
<td>Future of power systems</td>
</tr>
<tr>
<td></td>
<td>• Overview MIGRATE (15 min)</td>
</tr>
<tr>
<td></td>
<td>• Overview PROMOTioN (15 min)</td>
</tr>
<tr>
<td>10:30 – 11:45</td>
<td>Change in system inertia</td>
</tr>
<tr>
<td></td>
<td>• Introduction &amp; Expectations of the audience (10 min)</td>
</tr>
<tr>
<td></td>
<td>• MIGRATE: How does inertia change and what is impact on existing power system (20 min)</td>
</tr>
<tr>
<td></td>
<td>• PROMOTioN WP 2 &amp; 4: What impact does changing inertia have on offshore HVDC power system (20 min)</td>
</tr>
<tr>
<td></td>
<td>• Wrap Up &amp; Discussion</td>
</tr>
<tr>
<td>11:45 – 12:00</td>
<td>Coffee Break</td>
</tr>
<tr>
<td>12:00 – 13:15</td>
<td>Control and operation of no or low inertia grids</td>
</tr>
<tr>
<td></td>
<td>• Introduction &amp; Expectations of the audience (10 min)</td>
</tr>
<tr>
<td></td>
<td>• MIGRATE: WP 3: Offshore windfarm voltage control &amp; black start capability (20 min)</td>
</tr>
<tr>
<td></td>
<td>• MIGRATE: Operating a system with 100% power electronics (20 min)</td>
</tr>
<tr>
<td></td>
<td>• Wrap Up &amp; Discussion</td>
</tr>
<tr>
<td>13:15 – 14:00</td>
<td>Lunch Break</td>
</tr>
<tr>
<td>14:00 – 15:15</td>
<td>Power Quality</td>
</tr>
<tr>
<td></td>
<td>• Introduction &amp; Expectations of the audience (10 min)</td>
</tr>
<tr>
<td></td>
<td>• MIGRATE: WP 16: Modelling and validation of inverter harmonics (20 min)</td>
</tr>
<tr>
<td></td>
<td>• MIGRATE: Impact of harmonics on future converter dominated power system (20 min)</td>
</tr>
<tr>
<td></td>
<td>• Wrap Up &amp; Discussion</td>
</tr>
<tr>
<td>15:15 – 16:30</td>
<td>Coffee Break</td>
</tr>
<tr>
<td>15:30 – 16:45</td>
<td>Regulation &amp; grid codes</td>
</tr>
<tr>
<td></td>
<td>• Introduction &amp; Expectations of the audience (10 min)</td>
</tr>
<tr>
<td></td>
<td>• MIGRATE: Impact of the project results and recommendations for the future power system (20 min)</td>
</tr>
<tr>
<td></td>
<td>• PROMOTioN WP 2 &amp; 11: recommendations for offshore HVDC grid inverter interfaces (20 min)</td>
</tr>
<tr>
<td></td>
<td>• Wrap Up &amp; Discussion</td>
</tr>
<tr>
<td>16:45 – 17:00</td>
<td>Closing Remarks</td>
</tr>
<tr>
<td>17:00</td>
<td>End of Event</td>
</tr>
</tbody>
</table>
Progress Task 13.7. – Stakeholder Interaction

Upcoming Events [II]

WindEurope Conference & Exhibition 2019
2 - 4 April 2019 in Bilbao, Spain

CIRED 2019 (papers submitted by PROMOTioN partners)
3 - 6 June 2019 in Madrid, Spain

CIGRÉ International Symposium (papers submitted by e.g. WP2, WP3, WP4, WP6)
04 - 07 June 2019 in Aalborg, Denmark

EU Sustainable Energy Week → Details next slide
17 – 21 June 2019 in Brussels, Belgium
PROMOTioN will apply to host a policy conference session during the EUSEW 2019

Application deadline: **28 January 2019**

General Structure

- Session will take place between 18 - 20 June 2019
- 90 minutes per session

Suggested topics for the conference:

- “The next step towards meshed offshore grids – recommendations how to regulate and finance the future European power grid” (WP7)
- “Deployment plan for a European meshed offshore grid – A roadmap until 2050” (WP12)

SOW will prepare the application in close cooperation with DNV GL and the relevant partners.
Further upcoming events (yet unclear PROMOTiON contribution)

• Hamburg Offshore Wind Conference (organised by EEHH & DNV GL)
  2./3. April 2019 in Hamburg, Germany

• Support Group 2 Meeting
• 3rd North Seas Energy Forum
• Roland Berger Presentation of results from cluster study

• IEEE PES Powertech 2019, Milano, Italy
  23rd – 27th June 2019

• ENTSO-E conference (Q3 2019)
Global Wind Summit 2018 – Review of PROMOTioN activities

- PROMOTioN booth
- Press background talks
- DTU presentation on “black start capabilities”
- Workshop on WP7 content with 40 participants
Progress Task 13.7.2 - Reference Group meetings

- The ‘Reference Group’ (RG) consists of around 50 stakeholders from different branches
- Chatham house rule applies to the meetings → confidentiality agreement
- Objective: feedback on preliminary project findings
- Last facilitation: 6 December 2017, Brussels
- Future planning:
  - RG ‘Technical’ → suggested date: 27 February 2019
  - RG ‘Regulatory’ → suggested date: alongside NSEF in Q1 2019
Progress Task 13.8 – External Communication activities

- Includes press and media work (e.g. press briefings, social media)
- Press briefings & background talks (e.g. during Global Wind Summit 2018)
- Communication of news-items on Twitter channel (152 Followers) & LinkedIn
- High visibility on social media if “tweeted correctly”:
  - Own content is key!

→ Recommendations for making the most out of social media on the next slides
Examples of social media activity
How can we use Twitter/LinkedIn to our mutual advantage

**Twitter**
In order to function properly, project partners (companies) should

- **Forward contacts of Social-Media representatives** of your company to SOW
- **Follow the PROMOTioN Twitter Channel**
  Retweet & Like the Tweets by PROMOTioN (“on demand” – no constant effort needed!)

**LinkedIn Group**

- Same principle as Twitter, however, range depends on individual size of networks
- **Nevertheless:** [Join the LinkedIn project group](#) and forward the news on your profile

**Twitter Advantage and Example**

- Project News following K.I.S.S.-principle (events, demonstration etc.)
- One tweet by PROMOTioN reaches 152 followers – but: if retweeted by the WP leads affiliation only, we can reach more than **113,000 followers**
Any Questions?
WP15
HVDC Gas Insulated Systems Demonstrator

ABB ● Uwe Riechert
Half-yearly meeting Lyon, Monday, 10th December
Task Structure

WP15 – HVDC GIS technology demonstrator

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

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

Task 15.2: TU Delft
Develop monitoring and diagnostic method and applicability of SF$_6$ alternatives

Task 15.4: ABB
Initiation of standardization activities for HVDC GIS design, testing and application

WP1

WP4

WP11
**Milestones & Deliverables**

- **Aberdeen Meeting**
- **Valencia Meeting**
- **Groningen Meeting**

**Task 15.1**
- D15.1 Document on recommendations for specifying DC GIS systems

**Task 15.2**
- D15.2 Document on test requirements, procedures and methods

**MS68**
- Recommendations for specifying DC GIS defined

**MS69**
- Test requirements, procedure and method identified and agreed

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Task Structure

WP15 – HVDC GIS technology demonstrator

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\textsubscript{6} alternatives

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

Task 15.4: ABB
Initiation of standardization activities for HVDC GIS design, testing and application
### Achievements: specifications

- HVDC GIS prototype installation test values

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Voltage (U_n)</td>
<td>±320 kV</td>
</tr>
<tr>
<td>Rated dc operation voltage (U_r)</td>
<td>±350 kV</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage (U_p)</td>
<td>±1050 kV</td>
</tr>
<tr>
<td>Switching impulse withstand voltage (U_s)</td>
<td>±950 kV</td>
</tr>
<tr>
<td>Rated normal current (I_r)</td>
<td>4000A</td>
</tr>
<tr>
<td>Short-time withstand current, 1 second (I_{sc})</td>
<td>50kA</td>
</tr>
<tr>
<td>Superimposed lightning impulse withstand voltage</td>
<td>±1050 kV</td>
</tr>
<tr>
<td>Lightning impulse voltage DC voltage</td>
<td>350 kV</td>
</tr>
<tr>
<td>Superimposed switching impulse withstand voltage</td>
<td>±950 kV</td>
</tr>
<tr>
<td>Switching impulse voltage DC voltage</td>
<td>350 kV</td>
</tr>
</tbody>
</table>
Task Structure

WP15 – HVDC GIS technology demonstrator

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 SF₆ alternatives

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

Task 15.4: ABB
Initiation of standardization activities for HVDC GIS design, testing and application
Main Achievements

1- Detection of PD currents in the GIS compartments – HFCT

The approach has proven feasibility in Laboratory experiments.

Advantages
- Simplicity
- Lower hardware specs
- Higher spatial sensitivity
- Estimation of PD parameters plausible

Disadvantages
- Noise and disturbance
- Demand modifications to be implemented in spacers of new design
- Demand extra post-processing

HFCT is installed at one bolt of the GIS compartments, not in the ground path as conventionally has been used.
PROMOTioN – Task 15.2. To develop monitoring and diagnostic methods for HVDC GIS equipment.

Main Achievements

1- Detection of PD currents in the GIS compartments - Magnetic antenna

The proof of concept of a pick up coil installed in the opening of the compartments showed to be feasible for PD detection

Advantages

- Use already existing openings so its implementation if feasible
- lower hardware specs
- Higher spatial sensitivity

Disadvantages

- Absolute sensitivity needs to be improve
- Only meant for PD detection, quantification of PD parameters is not possible.
PROMOTioN – Task 15.2. To develop monitoring and diagnostic methods for HVDC GIS equipment.

Working Plan – Follow-up

<table>
<thead>
<tr>
<th>WP 15. HVDC GIS Technology Demonstrator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task 15.1</strong></td>
</tr>
<tr>
<td><strong>Task 15.2</strong></td>
</tr>
<tr>
<td><strong>TU Delft</strong></td>
</tr>
<tr>
<td><strong>month</strong></td>
</tr>
</tbody>
</table>

- Experimentation with DC voltage
- Validation of the HFCT system on ABB HVDC GIS (long term testing)
- Research on algorithms for PD parameter estimation for monitoring and diagnostics
- Post processing techniques for disturbances and noise cancelation
- Research on automatic clustering techniques
PROMOTiON WP15.2

Subtask WP15.2.4

• Short term PD behavior for SF6 and SF6 alternative gases with defects
  • Two kinds of defect: protrusion on HV busbar and metallic particle on spacer surface
  • 4 measuring systems are used: conventional method, UHF method, light emission and High Frequency Current Transformer (HCFT) – in collaboration with TU Delft

### Investigated gases for SGI Task

<table>
<thead>
<tr>
<th>Gas</th>
<th>Pressure (bar abs)</th>
<th>Equivalent pressure to SF6 (bar abs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF6</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Air Plus</td>
<td>0.5</td>
<td>7</td>
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<td></td>
<td>0.5</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>10.5</td>
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<tr>
<td>FN-CO₂ mixture</td>
<td>0.32</td>
<td>7.68</td>
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<tr>
<td></td>
<td>0.65</td>
<td>5.85</td>
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</table>

### Defect Gas Experiment Data

<table>
<thead>
<tr>
<th>Defect</th>
<th>Gas</th>
<th>Experiment</th>
<th>Data analysis</th>
<th>Deliverable D15.7</th>
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</thead>
<tbody>
<tr>
<td>Protrusion</td>
<td>All gases</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Metallic particle on spacer surface</td>
<td>Config. 1 – all gases</td>
<td>✓</td>
<td>✓</td>
<td></td>
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<tr>
<td></td>
<td>Config. 2: AirPlus</td>
<td>✓</td>
<td>✓</td>
<td></td>
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<tr>
<td></td>
<td>Config. 2: FN-CO₂ mixture</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Config. 2: SF6</td>
<td>✓</td>
<td>✓</td>
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</table>
Subtask 15.2.5

- Long term PD behavior for SF6 and SF6 alternative gases with defects
  - Two kind of defect: protrusion on HV busbar and metallic particle on spacer surface
  - Different measuring systems
  - Different gases

![Test circuit diagram]

<table>
<thead>
<tr>
<th>Task</th>
<th>Progress</th>
<th>Expected date</th>
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<tbody>
<tr>
<td>Test circuit design and development</td>
<td>✔️</td>
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<tr>
<td>Test circuit supply</td>
<td>🚨</td>
<td>2019 March</td>
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<tr>
<td>Assembling</td>
<td>🚨</td>
<td>2019 April</td>
</tr>
<tr>
<td>Validation tests</td>
<td>🚨</td>
<td>2019 May</td>
</tr>
<tr>
<td>Beginning of test</td>
<td>🚨</td>
<td>2019 June</td>
</tr>
</tbody>
</table>
WP15 – HVDC GIS technology demonstrator

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

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Long term testing of the DC GIS equipment

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Initiation of standardization activities for HVDC GIS design, testing and application

WP1
WP4

WP11
Achievements: assembly
### Achievements: prototype installation test

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Nominal DC voltage $U_n$</strong></td>
<td>± 320</td>
<td>$kV_{dc}$</td>
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<tr>
<td><strong>Rated DC voltage $U_r$</strong></td>
<td>± 350</td>
<td>$kV_{dc}$</td>
</tr>
<tr>
<td><strong>Rated superimposed LI withstand voltage $U_P / U_r$</strong></td>
<td>± 1050</td>
<td>$kV_{dc}$</td>
</tr>
<tr>
<td></td>
<td>± 350</td>
<td>$kV_{dc}$</td>
</tr>
<tr>
<td><strong>Lightning impulse voltage</strong></td>
<td>DC voltage</td>
<td></td>
</tr>
<tr>
<td><strong>Rated superimposed SI withstand voltage $U_S / U_r$</strong></td>
<td>± 950</td>
<td>$kV_{dc}$</td>
</tr>
<tr>
<td></td>
<td>± 350</td>
<td>$kV_{dc}$</td>
</tr>
<tr>
<td><strong>Switching impulse voltage</strong></td>
<td>DC voltage</td>
<td></td>
</tr>
<tr>
<td><strong>Rated DC withstand voltage to earth $U_w$</strong></td>
<td>± 610</td>
<td>$kV_{dc}$</td>
</tr>
</tbody>
</table>

- **HV Connection DC Bushing**
- **Extension option**
- **AC Heating Current**
  3 conventional CTs

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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.
Achievements: test program

- HVDC GIS prototype installation test procedure

<table>
<thead>
<tr>
<th>Pre-Tests</th>
<th>BLOCK 1</th>
<th>BLOCK 6</th>
<th>BLOCK 7</th>
<th>add. Tests</th>
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</thead>
<tbody>
<tr>
<td>60 days DC (+ or -) HL or ZL SIM LI/SI 10 C/O</td>
<td>2</td>
<td>60 days DC (+ or -) HL or ZL SIM LI/SI 10 C/O</td>
<td>30 days LC (+ and -) SIM LI/SI</td>
<td></td>
</tr>
<tr>
<td>10 C/O</td>
<td>4</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Nov. 2018 - Dec. 2019

- 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 $U_{ac}$

Monitoring:
- Gas density
- PD: UHF/Optical/HFCT
- Arc Detection
- Enclosure Temperature
## Achievements: status

<table>
<thead>
<tr>
<th>Step</th>
<th>Test</th>
<th>Conditions</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Thermal cycle pre-test</td>
<td>Heating up to steady state with $I_{eqac}$ or $I_l$</td>
<td>LC / HL</td>
</tr>
<tr>
<td>2</td>
<td>AC PD measurement</td>
<td>Pre-stress at $U_{acpre}$;</td>
<td>ZL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PD measurement at $U_{acpd}$.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>DC PD measurement</td>
<td>Pre-stress at $\pm U_{dcpre}$;</td>
<td>ZL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PD measurement with $\pm U_{dcpd}$.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Lightning impulse test</td>
<td>LI voltage $U_{TP}$</td>
<td>ZL</td>
</tr>
<tr>
<td>5</td>
<td>Switching impulse test</td>
<td>SI voltage $U_{TS}$</td>
<td>ZL</td>
</tr>
<tr>
<td>6</td>
<td>Superimposed LI test</td>
<td>Positive and negative rated DC voltage $U_l$ and $U_{TP}$</td>
<td>ZL</td>
</tr>
<tr>
<td>7</td>
<td>Superimposed SI test</td>
<td>Positive and negative rated DC voltage $U_l$ and $U_{TS}$</td>
<td>ZL</td>
</tr>
<tr>
<td>8</td>
<td>Polarity reversal test</td>
<td>Polarity reversal $\pm U_T$</td>
<td>ZL / HL</td>
</tr>
</tbody>
</table>

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Task Structure

**WP15 – HVDC GIS technology demonstrator**

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

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  Long term testing of the DC GIS equipment

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---

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Interactions With Other Work Packages (WP11)

- Workshop: HVDC GIS WP 15 HVDC GIS prototype installation test
  - 26 participants
  - Presentations of WP 15 tasks
  - Information from other manufacturer
  - Visit of prototype installation
  - Discussion with Cigré and IEC
Planning

WP 15 – HVDC GIS Technology Demonstrator

1. Defining specifications and test requirements

2. Develop monitoring and diagnostic method and applicability of SF6 alternatives

3. Long term testing of the DC GIS equipment

4. Extension

- Defining specifications and test requirements
  - 1
  - 2
  - 68
  - 69

- Develop monitoring and diagnostic method and applicability of SF6 alternatives
  - 3
  - 70
  - 71

- Long term testing of the DC GIS equipment
  - 4

- Extension
  - 5
  - 71

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Any Questions?
WP16

MMC Test Bench Demonstrator

Plenary Session 10.12.2018
Philipp Ruffing – RWTH Aachen
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714.
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

Objectives:
➢ Demonstration of applicability of developed controls and simulation models of PROMOTioN
➢ Technical de-risking for the deployment and continuous operation of meshed HVDC systems
➢ Improvement of certainty for road mapping process and standardization efforts
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714.

Task Structure of WP16

- **T16.1** Definition and specification of test cases for the new test bench
- **T16.2** Preparatory measures for the MMC test bench set up
- **T16.3** MMC test bench lab setup and commissioning
- **T16.4** Basic testing of the MMC test bench system
- **T16.5** Implementation of an analytical method for analysis of harmonic resonance phenomena
- **T16.6** Demonstration of defined test cases regarding interoperability, control schemes and protection
- **T16.7** Analysis of the impact on requirements for meshed off-shore HVDC grids

WP2, 3, 4

WP11, 12
Progress

Milestones & Deliverables

<table>
<thead>
<tr>
<th>MS / D</th>
<th>Due</th>
<th>Topic</th>
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</thead>
<tbody>
<tr>
<td>D16.1</td>
<td>28 (Apr 18)</td>
<td>Test case overview</td>
</tr>
<tr>
<td>MS73</td>
<td>28 (Apr 18)</td>
<td>All test cases defined (alignment with WP2 and consortium)</td>
</tr>
<tr>
<td>D16.2</td>
<td>32 (Aug 18)</td>
<td>Lab documentation</td>
</tr>
<tr>
<td>D16.5</td>
<td>38 (Feb 19)</td>
<td>Analytical approach of converter impedance modelling</td>
</tr>
<tr>
<td>MS74</td>
<td>32 → 38 (Feb 19)</td>
<td>Set up completed</td>
</tr>
<tr>
<td>MS75</td>
<td>35 → 39 (Mar 19)</td>
<td>First tests completed</td>
</tr>
<tr>
<td>D16.7</td>
<td>38 (Feb 19)</td>
<td>Update D16.2 (new)</td>
</tr>
<tr>
<td>D16.3</td>
<td>47 (Nov 19)</td>
<td>Test case analysis for WP3</td>
</tr>
<tr>
<td>D16.6</td>
<td>52 (Apr 20)</td>
<td>Test case analysis: WT Control + Protection HIL</td>
</tr>
<tr>
<td>D16.4</td>
<td>53 (Mai 20)</td>
<td>Test case analysis WP3</td>
</tr>
</tbody>
</table>

Jan 2018 - Aachen Kickoff WP16
Apr 2018 - WebCo: Presentation of Testcases to Consortium
Jun 2018 - Groningen
Jul 2018 - Arnhem T16.5 Progress Meeting
Oct 2018 - Montreal FAT MMC Test Bench
Nov 2018 - Valencia T16.5 Progress Meeting
Dec 2018 - Lyon
Feb 2018 - Aachen Commissioning MMC Test Bench
Jan 2019
Mar 2019
May 2018
Jul 2018
Sep 2018
Nov 2019
Changes in Amendment no. 7
Deliverable 16.1
Definition and Specification of Test Cases

**MTDC Test Bench - PHiL**
- Demonstration of the controllability and interoperability offshore MTDC networks
  - Grid & converter configurations
  - Interaction MTDC network and OWP
  - MTDC and OWP fault handling
  - AC grid support with meshed offshore grids

**Diode Rectifier Unit - CHiL**
- Demonstration of the operation of DRU-enabled wind turbine control systems
  - in multi-terminal HVDC systems
  - with actual wind turbine controls
  - with commercial protection hardware
  - black and brown start operation for wind farms in islanded control

**Harmonic Resonance Studies**
- Development and validation of impedance models of wind turbine and HVDC converters
- Analysis of harmonic stability and potential interactions of active components and the AC grid

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Deliverable 16.2
Lab Documentation of the MMC Test Bench

Detailed description of MMC Test Bench:
• Converters, transmission line, transformers, ...
• Real-Time Simulators
• Power Amplifiers
• Laboratory Facilities

➢ Update after commissioning of the MMC Test Bench lab

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal DC Voltage</td>
<td>400 V</td>
</tr>
<tr>
<td>Nominal DC Current</td>
<td>15 A</td>
</tr>
<tr>
<td>Nominal Output Power</td>
<td>6 kW</td>
</tr>
<tr>
<td>Nominal AC Voltage per phase</td>
<td>400/208 V (3ph-LL)</td>
</tr>
<tr>
<td>Nominal AC RMS current</td>
<td>16.7 A</td>
</tr>
<tr>
<td>MOSFET Switching Frequency</td>
<td>0-10 kHz</td>
</tr>
<tr>
<td>Number of Cells (Submodules)</td>
<td>10</td>
</tr>
<tr>
<td>Nominal Cell Voltage</td>
<td>40 V</td>
</tr>
<tr>
<td>Cell Capacitor</td>
<td>4.92 mF</td>
</tr>
<tr>
<td>Arm inductor</td>
<td>2.5 mH</td>
</tr>
</tbody>
</table>
MTDC Test Bench - PHiL

Achievements:
- Specification (D16.2) and acquisition of the MMC test bench system (Manufacturer: OPAL-RT)
- Control model development
- Testing on “Digital Twin” of the laboratory MMCs
- Successful Factory Acceptance Test in Montreal

Stepping Stones:
- Delay in acquisition/delivery of the MMC Test Bench system → December 2018

Next Steps
- System setup in Jan19 & commissioning (beginning of Feb19) → MS79
- Comparison between simulation and PHIL (Mar19)
- Execution of the defined test cases (starting in Apr19)
Diode Rectifier Unit - CHiL

Achievements:
• Implementation of DRU models and wind turbine controls from WP3 on real-time simulators (RTS)
• Development of an interface for the integration of external control and protection hardware to RTS
  ➢ CHIL Protection Real-Time demonstrator prototype completed

Stepping Stones:
• Delay in acquisition/delivery of commercial relays P543 MiCOM: 5433CR1BM0H98M (Schneider)

Next Steps
• CHIL Protection Real-Time demonstrator prototype completion MS79 (M46 – Oct19)
Harmonic Resonance Studies

Achievements:
• Specification and acquisition of the wind turbine converter controller replica and 1 MW physical converter
• Commissioning of WT PHIL test system

Stepping Stones:
• Logistics of 1 MW physical Inverter
• Measurement methodology for input admittance and validation method

Next Steps
• CHIL input admittance measurement and validation methodology development
  ➢ D16.5: Implementation of an Analytical Method for Analysis of Harmonic Resonance Phenomena (M38)
• Commissioning of 1 MW Inverter

Flexible Power Grid Lab @ DNV GL

Harmonic injection 200 kW - PA
Real Wind Turbine Converter (T4)
DUT (1 MW)

Flexible Power Grid Lab @ DNV GL

Harmonic injection 200 kW - PA
Real Wind Turbine Converter (T4)
DUT (1 MW)
Wind Turbine PHIL Test System

Achievements:
- Commissioning of WT PHIL test system
- Accurate FPGA sampling compensation enabled for the PWM input.
- Back-to-Back wind turbine model is built in matlab/simulink

Converter Currents:

FPGA compensation for PWM input

CPU only
## Amendment no.7
### Impact on WP16

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**WP16**
- **T16.1**: Definition and specification of test cases
- **T16.2**: Preparatory measures for the MMC test bench set up
- **T16.3**: Implementation of an analytical method for analysis of harmonic resonance phenomena
- **T16.4**: Demonstration of defined test cases regarding interoperability, control schemes and protection
- **T16.5**: Analysis of the impact on requirements for meshed off-shore HVDC grids

**Task/ Month**
- **D16.1**: Preparations for Dissemination (CIGRE)
- **D16.2**: MMC test bench lab setup & Commissioning
- **D16.3**: Basic testing of the MMC test bench system
- **D16.4**: Test case analysis
- **D16.5**: Test case analysis
- **D16.6**: WT Control + Protection HIL

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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.
Any Questions?
APPENDIX

DISCLAIMER & PARTNERS

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The opinions in this presentation are those of the author and do not commit in any way the European Commission

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PARTNERS
WP 12 GA Vote Slides
Alignment on the CBA
Agenda

Introduction
Voting block 1: (Tim: Vote 5, 6 & 7)
Voting block 2: (Yongtao: Vote 1)
Lunch
Voting block 3: (Olivier: Vote 2, 3 & 4)
Updates Topologies & Security (Olivier & Dirk)
Introduction on GA votes
John (TenneT)
What does Choice mean?

Why a voting session:

1. Within PROMOTioN WP12 is intended to build consensus. A lot of positive work is done outside these meetings, but we wish to include the whole GA

2. The Concepts we are developing represent “realistic options” to ILLUSTRATE potential outcomes:
   1. Reality will almost certainly be different
   2. We cannot calculate out all potential solutions.

3. The voting process is not strictly necessary, and we can in most cases live with a “Yes” or a “No”.
   1. However a “No” requires an alternative realistic solution, provided by the person or organisation objecting to the sum.
   2. This may also lead to timing delays as WP12 works through the new assumptions.
Important points

1. The formulation of the Grant Agreements indicates a flow of Conclusions and Recommendations to WP12

2. We realise that this is unreasonable and have been working on a dialogue

3. WP12 was also late in signalling to other WPs the scale of the Grid to be proposed.

4. Good cooperation received from other WPs, and inputs and assumptions for modelling are based on these.
What does choice mean?

1. In an illustration, different choices could have been made, both in Topology and in Technical choice.

2. Our assumptions represent:
   1. ambition: e.g. in the choice of a Voltage and in the scope of the topology and
   2. reserve, e.g. in the grid constraints, which while constantly under review, are difficult to change.

3. If there is time, some sensitivities checking different options may be done, if we have straight outcomes and extra time
Consequences of non-agreement

1. In the CBA we do have to make assumptions to get to real topologies. These illustrate Concepts/Scenarios.

2. Without agreement on basic assumptions, D12.2 and D12.3 cannot continue and PROMOTioN will be delayed

3. We will include the options and arguments leading to the decision in the analysis, but cannot calculate each potential technical solution.
   1. We need to limit what we take into account
   2. We need to tighten the Deployment plan scope
Process of voting

1. The vote is introduced

2. Argumentation for the votes are given
   1. Questions can be asked during the presentation
   2. Please save comments/opinions till after

3. The vote is brought up on the screen

4. The floor is opened for discussion
   1. We have to stick to schedule otherwise we will not finish

5. At a set time (indicated by DNV GL): Voting will happen
Voting block 1: (Vote: 5, 6, 7)

Tim Kroezen (TenneT)
The use of Diode Rectifier Units is not taken into account quantitatively in the CBA, but its use could be described as future option.

November 28, 2018
The use of Diode Rectifier Units is not taken into account quantitatively in the CBA

• DRUs can
  • Work in combination with offshore wind (PROMOTioN WP3 has done work on the AC side)
  • Offer a savings potential for radial grids (due to reduced size/weight)

• Deployment plan to be built on “generic” converters. Simple calculations on potential savings for DRUs can be made.
  • E.g. for radial grid → calculate costs saved if platforms are smaller (where information is available)

• So far, there are no conclusions on whether meshing works for DRUs. Thus, it cannot be taken into account for the CBA.
Vote 5: The use of Diode Rectifier Units is not taken into account quantitatively in the CBA, but its use could be described as future option.

November 28, 2018
DC/DC converters remain out of the technical scope of PROMOTioN (1). A financial margin is applied to account for potentially required investments.

November 28, 2018
DC/DC converters remain out of the technical scope of PROMOTioN (1). However, due to the possible need for advanced power flow control, an additional financial margin is applied to account for potentially required investments.

• Within PROMOTioN no detailed research has been carried out on DC/DC converter requirements. As DC/DC converters were taken out of scope in WP 1.

• However, given the complexity of the proposed topologies, DC/DC converters may be required.

• Therefore, PROMOTioN will perform the CBA without taking DC/DC converters into account, but will account for an additional financial investment requirement.
Can we control power flow in complex structures?

We do not know, and we do not have the time to research it within PROMOTioN (1).
Vote 6: DC/DC converters remain out of the technical scope of PROMOTioN (1). However, due to the possible need for advanced power flow control, an additional financial margin is applied to account for potentially required investments.

November 28, 2018
HVDC MOGs will consist of true bipole connections (within PROMOTioN). For Radial connections monopoles are allowed.

November 28, 2018
HVDC MOGs will consist of true bipole connections (within PROMOTioN)

- We do not anticipate that the combination of monopoles and bipoles is realistic.

- For radial connections: monopoles are allowed

- For meshed grid structures true bipole connections are required for protection & control in more complex grid structures.

- Maximum capacity used per pole will comply with current maximum allowed loss of infeed for the respective area; an increase of this maximum is not anticipated.
Vote 7: HVDC MOGs will consist of true bipole connections (within PROMOTioN). For radial connection monopoles are allowed.

November 28, 2018
Voting block 2: (Vote 1)
Yongtao Yang (DNV GL Norway)
The GA accepts the current cost document for use in the CBA

- Document to be circulated separately
- Presentation and Discussion took place in Brussels
- Is additional discussion required – please inform Cees/John

Vote 1
Voting block 3: (Vote 2, 3 & 4)
Olivier Antoine (Tractebel)
The GA accepts the 525kV as the overall used voltage for the CBA Vote 2

November 27, 2018
CONTENT

⇒ General considerations
⇒ Proposition
General considerations
### General considerations

**Cigré TB684 - Recommended voltages for HVDC grids**

<table>
<thead>
<tr>
<th>Recommended DC voltage</th>
<th>Power range GW</th>
<th>Overhead</th>
<th>Available cable voltages *</th>
<th>AC voltage (ph–ph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 100, 150, 200 kV</td>
<td>Application specific</td>
<td></td>
<td>EXTR 320 kV</td>
<td>MI 245 kV</td>
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<tr>
<td>± 250 kV</td>
<td>&lt; 0.5</td>
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<td></td>
<td>362 kV</td>
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<tr>
<td>± 320 kV</td>
<td>(0.5) – 1.0</td>
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<td>525 kV</td>
<td>362 kV &amp; 420 kV</td>
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<td>± 400 kV</td>
<td>(1.0) – 1.5</td>
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<td></td>
<td>550 kV</td>
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<td>± 500 kV</td>
<td>(1.5) – 3.0</td>
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<tr>
<td>± 600 kV</td>
<td>(3.0) – 4.0</td>
<td>No inherent limit</td>
<td>Tested 600 kV</td>
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<td>± 800 kV</td>
<td>(4.0) – 8.0</td>
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<tr>
<td>± 1100 kV</td>
<td>&lt; 12</td>
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* Corresponding DC voltages as of end 2018

**Question:** will the MOG use 320kV, 525kV or higher voltage levels?
General considerations

Recent projects

- **NordLink**
  - 1.4 GW
  - 623 km
  - ±525 kV

- **NEMO Link**
  - 1.0 GW
  - 140 km
  - ±400 kV

- **IFA2**
  - 1.0 GW
  - 204 km
  - ±320 kV

- **ElecLink**
  - 1.0 GW
  - 69 km
  - ±320 kV

- **ElecLink**
  - 1.0 GW
  - 69 km
  - ±320 kV

- **North Sea Link**
  - 1.4 GW
  - 730 km
  - ±515 kV

- **ALEGrO**
  - 1.0 GW
  - 90 km
  - ±320 kV

For 1 GW, the voltage level is limited to 320-400 kV, but 525 kV is used already for 1.4 GW.
General considerations

High scenario (~200GW in 2050)

North Seas
= North Sea
+ Skagerrak
+ Kattegat
+ Irish Sea
+ Channel

A meshed grid is not going to connect the North Sea to the Channel and to the Irish Sea...

Most of the off-shore wind farms will be installed in the North Sea
Proposition
Proposition

Use of two voltage levels

North Sea: 525 kV
- High amounts of offshore wind energy to evacuate
- Maximum loss of power infeed higher than 1400MW
- Maximum length ~300km

Irish Sea + Channel: 320 kV
- A few GWs spread
- Maximum loss of power infeed limited to 700MW

Impact:
- Simplifying assumption
- Encourage meshing in the development of topologies
- Provide adequate topologies for a CBA analysis

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>Rating of the pair (MW)</th>
</tr>
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<tbody>
<tr>
<td>±320</td>
<td>700</td>
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<tr>
<td></td>
<td>900</td>
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<tr>
<td></td>
<td>1200</td>
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<tr>
<td>±525</td>
<td>1000</td>
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<td>1400</td>
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<td></td>
<td>1600</td>
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</table>
The GA accepts 320kV as voltage level used in the Channel and Irish sea, and 525kV as the voltage used in the North Sea for the CBA?

⇒ Yes
⇒ No
⇒ Abstention
Vote 2: The GA accepts the 525kV as the overall used voltage for the CBA. (And 325kV for low English channel / iris sea)
The GA accepts the current maximum infeed losses as security limitation  Vote 3

November 27, 2018
What are planning criteria?

¶ In a nutshell: reliability (adequacy & security) requirements
  ¶ The power system must be able to accommodate power flows and endure contingencies while staying within acceptable working conditions

¶ Transmission planning criteria typically cover
  ¶ The system states and the contingencies (including faults) to study
  ¶ The acceptable system operating limits in normal operation (pre-contingency) and post-contingency states
  ¶ The acceptable response of the system to outages and to fault disturbances
General ideas

We do **not** want a hard N-1 constraint on offshore grids such that the offshore grid has to withstand the loss of any single element without offshore wind curtailment.

However, as the offshore grid is part of the European power system, we want some form of N-1 security:

- A single contingency in the offshore grid should not lead to major disturbances in the onshore grid.
  - E.g. it should not lead to load shedding.
- The impact on the onshore grid should be limited to the maximum loss of power infeed.
Planning criteria used in the development of the topologies

Planning criteria under normal operating conditions

- Deterministic operating conditions: grid is sized to evacuate all the installed off-shore wind
- No curtailment allowed when all equipment are available (i.e. DC lines within their thermal and voltage limits)

Planning criteria post-contingency:

- Stability of the DC-grid must be maintained
  - No uncontrolled cascading outage is allowed (but the disconnection of an offshore wind farm radially connected, or an action of an automatic Remedial Action Scheme is allowed)
  - Electrical variables (e.g. power flows, voltages) must be within emergency operating limits just after the contingency, once the automatic voltage droops of converter controller have stabilized the system, and they should go back to normal (continuous) operating limits after system adjustments.
- Stability of the AC-grid must be maintained
  - No changes to the existing planning criteria
- No load shedding is allowed
- It is proposed to consider as single contingency the loss of a converter, the loss of a cable with or without a fault and the loss of an overhead line (OHL) with or without a fault
Proposition
In practice

- Cables and converters are sized to evacuate all the wind power production in all operating conditions when all equipment are in service.
- The DC-grid is designed to limit the permanent loss of power infeed into a specific synchronous area below the currently used reference incident
  - Continental Europe: 3 GW
  - Nordic: 1.35 GW
  - GB: 1.85 GW
  - Ireland: 0.5 GW
The GA accepts the current maximum infeed losses as N-1 security criterion

- Yes
- No (proposition of another criterion?)
- Abstention

Vote 3
Vote 3: The GA accepts the current maximum infeed losses as security limitation

Continental Europe: 3 GW
Nordic: 1.35 GW
GB: 1.85 GW
Ireland: 0.5 GW

November 27, 2018
The GA accepts the Load & Onshore generation profiles from TYNDP as input for the CBA with extrapolation to 2050.

November 28, 2018
Scenarios of the TYNDP2018 as a basis

- Already designed with assessment of transmission assets in mind
- Familiar to many stakeholders and the EC
Load-generation scenarios

Matching PROMOTioN with 2030/2040 ENTSO-E scenarios

- DG scenario is about distributed solutions and therefore sees higher solar deployment.
- It is also of interest to maintain one scenario with a high ratio of solar to wind generation.
- GCA has highest overall RES penetration (by 2040), so it makes sense to combine this with the High offshore.
- ST has a lower RES penetration than GCA, so it makes sense to combine it with the Central offshore.
Adjustments are necessary

- Not exactly the same offshore wind capacity in the North Seas!

Proposition: adjust the on-shore RES (wind, PV) in the ENTSO-E scenarios in the least intrusive manner by trying to respect the following principles:

- Total dispatchable RES production (onshore + offshore + solar PV) remains constant
- Ratio Solar PV to onshore wind remains constant
- Distribution of technologies between countries remains constant
Load-generation scenarios

Adjustments

-Reworked Sustainable Transition (ST)
-Amount of non-dispatchable RES remains limited after adjustment
-The adjustment is closely in line with the initial ENTSO-E scenario
Load-generation scenarios

**Adjustments**

- Reworked Distributed Generation (DG)
  - Solar PV remains the strongest in terms of capacity
  - Offshore wind is adjusted downwards. This is compensated by an increase in onshore wind and solar PV
Reworked Global Climate Action ([(ST-)GCA])

- Higher amount of non-dispatchable RES is kept compared to other scenarios.
- The increase in offshore wind generation is compensated by a decrease in onshore wind and PV
Load-generation scenarios

Extrapolation to 2050

Main assumptions
- Demand: Continue with weighted average growth rate of 2035-2040 (all the countries grow in parallel)
- RES: Continue growth rate; maintain tech proportions; ensure 2050 targets are met
- System load factor: Continue growth rate of 2020-2040
- Fuel prices: Hold flat at 2040 value
Load-generation scenarios

Extrapolation to 2050

Example: energy and peak load projections GCA
Load-generation scenarios

Extrapolation to 2050

Example: energy and peak load projections GCA
Load-generation scenarios

Extrapolation to 2050

Example: energy and peak load projections GCA

![Graphs showing energy and peak load projections for Denmark, Ireland, and Luxemburg from 2020 to 2050. The graphs depict the trend of TWh and GW over the years.]
Load-generation scenarios

Extrapolation to 2050

Example: RES capacity GCA
Vote 4: The GA accepts the Load & Onshore generation profiles from TYNDP as input for the CBA with extrapolation to 2050

November 28, 2018
Updates on Topologies & Security
Olivier Antoine (Tractebel)
Dirk van Hertem (KU Leuven)
Topology Update

➔ Olivier & Pierre to deliver at meeting
Protection Systems Update

Dirk to deliver at meeting
NOTES: GENERAL ASSEMBLY

Aachen meeting chosen dates are 11, 12 and 13 June 2019
First day should be WP meetings
Second day plenary session and visit to RWTH Aachen labs
Third day General Assembly followed by PMG

GA does not object to the DRAFT Grant Agreement being sent to Mariana for preparation

29 partners present, quorum reached and votes valid

Poul: The wording should be changed from ‘…but its use could be described…’ to ‘….but its use will be described…’ even though agrees that technology is not yet mature enough and not enough is known yet, but this should be taken into account

Karim: DRU is cost saving option. If cost without it is OK, DRU will make it better assuming that it does not increase elsewhere. How do we assure ourselves that no other unknown large costs may appear during development of the technology?

Ramon: does not agree with statement that no conclusions are available that meshing with DRU works. Early work shows that it is controllable, but requires further study.

Tim: WP12 happy to include qualitative discussion on benefits and challenges of using DRU in topologies but not as a quantitative factor in the development of a topology, because not enough is known yet.

John: the use of DRU might balance the topology development towards radial if it does not work well with meshed

Dirk: All votes are associated with disclaimers to guide the vote. The disclaimers need to be complete and correct, and ideally should be included and elaborated in a document

Yash: We should make sure that treatment of DRU in CBA should be aligned with earlier choices in the project

Dragan: DRU can be made to work in any case with DC/DC converter, there is no technical barrier. But why include a technology which Siemens offers who pulled out of the project

Poul: We should be very clear on the potential of DRU in reducing the costs to society, supported by sound analysis

Karim: Coordinator should make sure omitting DRU is not in breach of contract (GA).

Poul: The minimum is that even though we do not take the DRU into account in the CBA, there should be a thorough explanation of the potential of including DRU in a public deliverable

John: a retrospective indication of savings could be given in all potential sites where a DRU could have been used, but not clear where technical application is

Ramon/Dragan: No technical hurdles, either with DC/DC converter or through advanced control strategies. A potential way to get out is to include a thorough technical analysis of the topologies and the applicability and potential benefit of applying the DRU
Dirk: it is clear that technologies in 2050 cannot be predicted. But a small test case could be included which illustrates the benefits on a high level. Maybe CBA should be made less technology sensitive on for example generic converter

Andreas: further to Poul’s comment, it should read ‘….but its use will be qualitatively described...’

Paul Neilson: There should be at least a high-level description of the aggregated impact that the availability of the technology could have

Cees: change it to ...its use and potential impact...

Alexander: this is a good description in its current form

Dirk: We can let vote go through, but disclaimers should be detailed in document

Final vote text is: The use of diode rectifier units is not taken into account for the full system CBA, but its use and potential impact will be described as future options

Dragan gives in promptu ‘crash-course’ on DC/DC converters

Karim: Why do we need DC/DC converters in green-field network development in which bottlenecks can be avoided? What is the vote about, is it about completely leaving the option of DC/DC converters out?

Dragan, because different voltage levels or technologies will be used by different users which will need to be interfaced

Dragan: dual active bridge will cost about two VSC converters of same voltage and current rating. Second presented option will cost about 1,3 times as much.

Yongtao: we need to think of strategic placement, they will not need to be used everywhere

Philipp: for a power flow converter a substantially reduced cost could be realized when using series MV converters

Dragan: TRL is still very low so it is not considered in CIGRE WG

Dirk: Other options to prevent flow problems exist such as dispatch or extra cables, but it can be solved with complete power flow studies but this is out of scope for PROMOTioN. But a fixed extra margin is too simplistic. In any case, the DC/DC converter can only improve on the case without

Tim: the cost is associated with the burden of power flow control, not a DC/DC converter specifically. It leaves the technological implementation out,

Wei: Very difficult to say yes or no,

Cees: abstain is option

VOTE text changed to: DC/DC converters remain out of the technical scope of PROMOTioN. The use of power flow controlling options will be described qualitatively.

Cees: did all technical WPs indicate that bipole is required?

Dragan: some demo work is done on monopole systems. This requires additional description, justification and clarification. The systems can be connected using DC/DC converter anyway.
Dirk/Dragan: sufficient knowledge is generated in PROMOTioN to demonstrate technology readiness of bipole technology

Dirk: future solution is probably mixed, advantages and disadvantages to both, bipole might be 20% more expensive than monopole, but it should be fine to say for PROMOTioN to simply use bipole for the analysis

Dragan: if choice is made, it should be same for all concepts for matters of comparison

Bruno: main determinant of choice is the system behaviour during faults and voltage vs current stresses. Bipole is reasonable for large systems as it avoids overvoltages during faults

Lorenzo: Is 525 kV bipole technology in the short term? And does true bipole mean three cables (i.e. metallic return)?

Tim: This is looking into the future where it is reasonable to assume their availability and volume still to be acceptably low, and Yes

Andreas, A timeline on production capacity and TRL should be included in deployment plan to address supply chain limitations qualitatively

Staffan: does it mean that extension of asymmetrical monopoles to bipole is considered?

Tim: no, we plan blocks of several bipoles at each time period

Olivier: It must be clear that when considering 525 kV bipoles there could be restrictions on the development of the DC grid per synchronous area due to maximum loss of infeed

Tim: this is clear, it is also the case for 320 kV systems for Ireland. It is also the reason that higher voltages such as 640 kV and 800 kV are not considered

Dirk: Why do we need to pick converter configuration? Can we not simply stick to power corridors?

Tim: no we need the level of detail for costing purposes. The choice of voltage level and configuration is illustrative and to provide a basis for calculation, it is not considered to be a prescriptive conclusion

Dirk: How will you model the difference between monopoles and bipoles?

Tim: Cost and redundancy.

Philipp: Will metallic return be the same as HV poles or a cheaper one?

Tim: it will be a cheaper separate cable

Final vote text: WP12 assumes the use of bipoles with metallic returns for its calculations of MOGs. For point-to-point connection monopoles are allowed.
Manufacturers voluntarily leave the room and abstain from vote: Staffan (SCiBreak), Uwe (ABB), Alexander (Siemens), Dimitris (Prysmian), Ito (Mitsubishi)

Christina: Is this a public document?
YY: Not yet, this is ongoing work, but it is supposed to be a public document

Lorenzo: There are large uncertainties (such as 525 kV platform cost). How will you handle that in WP12? Like a sensitivity analysis?
YY: Perhaps adjust for water depth and location

Lorenzo: Is the 30% margin stated in the cost to be added to the stated uncertainty?
YY: yes

Dirk, will the report be public, or open for feedback, or closed within consortium?
YY: until OEMs agree, it will not be published. It is not a formal document so there is no dissemination level.

Dirk: it might be good to try and publish it as it may help discussions in general. We should be as open as possible and keep the possibility open to accept corrections or more information
Andreas: this will also be very useful in the stakeholder communication

Karim: the numbers must be generated in accordance to the EU law and then they could be published
Paul: in addition there is also a commercial interest from the included OEMs which may be protected

Dragan: it is not clear how a 525 kV pole leads to 1,4 GW loss of infeed. Have you considered common mode faults?
Romaine: The choice of voltage level is related to the geographically specific loss of infeed, this is different in UK, Scand, Mainland EU, and Ireland, hence different voltages being proposed

Paul Neilson: Is the Channel meant to be the English Channel

Final vote text: The GA accepts the 525 kV as the overall used voltage for the CBA (and 320 kV for the English channel/Irish sea)

Dirk: the chosen approach is reasonable to get started
Ramon: is this based on a grid that is sized to be able to export all wind power generation so that no curtailment takes place?
Romain: Yes, although curtailment could be applied during emergency operation

Yash: Output from WP1 is that n-1 criteria should be applied offshore. This should be checked for consistency

John: No, but it was discussed that offshore grid should not violate n-1 criteria onshore

Yash: needs more clarification. Onshore n-1 means no shedding of load, only in case of n-2 this is allowed.

Romain: different definitions of n-1 are used. In promotion it means no shed of load in case of loss of one grid component (could be cable, or converter (pole), etc.)

Andreas: We should be aware that values of max loss of infeed could change in future

John, very difficult to change, envisaged to stay constant for the next 20 years

Henrik, these values have been determined by considering the level of risk behind it which could be considered

Karim: the idea is to be conservative but have a choice that can be calculated with

Dirk: the values are very likely to change due to dropping system inertia and commercial pressure, it is not clear how these will change, but simply a boundary condition for the calculations

Paul Neilson: The adopted security criterion does not consider redundancy

Romain: that si correct, but it might and it will impact the sizing of the cables and substation

Final vote text: The GA accepts the current maximum loss of power infeed following a contingency on the DC grid as security criterion

Poul: are the scenarios capacity or energy?

Romaine: it is in terms of production

Dirk: 50GW adjustments to scenarios are not small changes, they can have significant impact

Prad: Does it mean that the adjustment of the scenarios leads to a change of technologies within the scenarios and have you considered if this has an impact on other aspects of the scenarios? E.g. 50 GW extra offshore wind instead of 50GW onshore solar can have profound impact on onshore grid development

Dirk: also geographical spreading of scenario changes across Europe should be considered. Using ENTSO-E scenarios is safe, but changing them means opening up debate about the parameters

Prad: assumption that fuel prices do not change is too strong

Andreas: should follow trend

Karim: we take TYNDP scenarios onshore and do not change it
Bruno: why did we make adjustments?

Poul: alternative is to use entso-e data, but this is not very optimistic for offshore wind

Lorenzo: We need to increase the values in the project to meet the high scenario target

John: low and medium scenarios align with TYNDP, only the high scenario exceeds it

Romaine: to conclude, no problem to use the TYNDP, but the way the scenarios are adjusted must be better explained.

Dirk: is it acceptable to follow TYNDP for the low and medium scenarios, and only adapt the high one?

Andreas: GA can agree on acceptance of TYNDP laod and gen profiles as basis for CBA up to 2040, but how extrapolation is done up to 2050 must be better explained

Romaine: the vote will be held as is, but with a detailed disclaimer

### Results voting

<table>
<thead>
<tr>
<th>No</th>
<th>The GA accepts:</th>
<th>Yes</th>
<th>No</th>
<th>Abs</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>the current cost document for use in the CBA</td>
<td>23</td>
<td>0</td>
<td>7</td>
<td>accepted</td>
</tr>
<tr>
<td>2</td>
<td>the 525 kV as the overall used voltage for the CBA (and 320 kV for the English channel/Irish sea)</td>
<td>26</td>
<td>1</td>
<td>3</td>
<td>accepted</td>
</tr>
<tr>
<td>3</td>
<td>the current maximum loss of power infeed following a contingency on the DC grid as security criterion</td>
<td>27</td>
<td>0</td>
<td>3</td>
<td>accepted</td>
</tr>
<tr>
<td>4</td>
<td>the Load &amp; Onshore generation profiles from TYNDP as input for Cost Benefit Analysis (CBA) with extrapolation to 2050</td>
<td>28</td>
<td>0</td>
<td>2</td>
<td>accepted</td>
</tr>
<tr>
<td>5</td>
<td>the use of diode rectifier units is not taken into account for the full system CBA, but its use and potential impact will be described as future options</td>
<td>25</td>
<td>1</td>
<td>4</td>
<td>accepted</td>
</tr>
<tr>
<td>6</td>
<td>That the DC/DC converters remain out of the technical scope of PROMOTIoN. The use of power flow controlling options will be described qualitatively</td>
<td>26</td>
<td>1</td>
<td>3</td>
<td>accepted</td>
</tr>
<tr>
<td>7</td>
<td>That WP12 assumes the use of bipoles with metallic returns for its calculations of MOGs. For point-to-point connection monopoles are allowed.</td>
<td>25</td>
<td>1</td>
<td>4</td>
<td>accepted</td>
</tr>
</tbody>
</table>

1) 2 abstained, 5 manufacturers did not vote