REVIEW MEETING
BRUSSEL, BELGIUM
20 and 21 MARCH 2017
Project Proposal Presentations

Project: PROMOTioN
Contract: 691714
Place: Brussels, 354 Av Van Volxemlaan, Wiels Contemporary Art Centre
Date: 20th of March 2017
Time: 13:00 – 17:00
Attendance: All proposal participants and PMG

13:00 Start

**Introduction**

(5 min) Welcome of the participants
Project Coordinator

(1 hour) Explanation of project scope & objectives
Explanation of WP8 situation
Explanation of liberated budget
Explanation of the selection procedure
Project Coordinator

**Presentations of proposals**

(2 hours) Presentations of proposals
- Basic idea
- Motivation
- Impact
- Deliverables
- Partners
- Budget
All proposal leaders

(20 min) Presentation of new partner
- SCibreak
Project Coordinator & Scibreak

(20 min) Summary of the proposals in project context
R&D Coordinator

**Conclusions**

(20 min) Discussion and review
Next steps & timeline
PO

17:00 Close
Periodic review meeting
Project: PROMOTioN
Contract: 691714
Place: Brussels, 354 Av Van Volxemlaan, Wiels Contemporary Art Centre
Date: 21st of March 2017
Time: 09:00 – 17:00
Attendance: All partners and PMG

Start
09:00 Reception and coffee

Introduction
09:30 Welcome of the participants
Welcome word of project officer

Review of the:
- Overall objectives of the project
- Role of each partner
- Update on project context

Technical review
Review of the work done to date with comparison to the original description of work, milestones and deliverables

09:50 - WP 1
TenneT

10:30 - WP 2
RWTH Aachen

11:00 - WP 3
DTU

11:30 - WP 4
KU Leuven

12:00 Lunch

13:00 - WP 5
DNV GL

13:30 - WP 6
University of Aberdeen

14:00 - WP 7
TenneT

14:30 - WP 8
Siemens

15:00 - WP 13
SOW

15:30 Summary of the main achievements to date and results
R&D Coordinator

15:45 Tea break
Management aspects
16:00 Management of the project: Project Coordinator
- Collaboration and interaction
- Administrative and financial aspects with comparison of financial resources versus original planning

Description of work review Implementation plan next period
16:20 Proposal for the next period: Project Coordinator
- Description of work for next period
- New proposals
- New partner

Conclusions
16:40 Discussion PO + reviewer
- Quality assessment
- Recommendations
- Reporting

17:00 Close
CONTENT

• Project overview
• WP8 situation
• New proposals
• New partner
• Summary
Project overview
Project overview

Project scope
Project overview

Project scope
Project overview

Project scope
Project objectives

- Identify **technical requirements** and investigate possible **topologies** for **meshed HVDC offshore grids**
- Develop **protection schemes** and **components** for HVDC grids
- Establish components’ **interoperability and initiate standardisation**
- **Demonstrate cost-effective** offshore HVDC equipment
- Develop recommendations for a coherent EU and national **regulatory framework** for HVDC offshore grids
- Develop **recommendations for financing mechanisms** for offshore grid infrastructure deployment
- Develop a **deployment plan** for HVDC grid implementation
- **Disseminate results** to relevant stakeholder communities
PROMOTioN - The Project

Project Structure

- Foundation
- Demonstration
- Exploitation

Time
PROMOTioN - The Project

Project Structure - Requirements

Requirements – WP1
PROMOTioN - The Project

Project Structure - Converters

- **Foundation**
  - Requirements – WP1

- **Demonstration**
  - Converters
    - WP2
    - WP3
    - WP8

- **Exploitation**

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PROMOTioN - The Project

Project Structure – Protection Systems

- Requirements – WP1
- Foundation
- Conversion
- Protection Systems
  - WP2
  - WP3
  - WP8
- Protection Systems
  - WP4
  - WP9
PROMOTioN - The Project

Project Structure – DC Circuit Breakers

- Requirements – WP1

Foundation
- Converters
  - WP2
  - WP3
  - WP8

Demonstration
- Protection Systems
  - WP4
  - WP9

Exploitation
- DC Circuit Breakers
  - WP5
  - WP6
  - WP10
PROMOTioN - The Project

Project Structure – Finance & Regulation

- **Foundation**
  - Requirements – WP1

- **Demonstration**
  - Converters – WP2, WP3, WP8
  - Protection Systems – WP4, WP9
  - DC Circuit Breakers – WP5, WP6, WP10

- **Exploitation**
  - Finance & Regulation – WP7
PROMOTioN - The Project

Project Structure – Standards & Deployment plan

Foundation
- Requirements – WP1

Demonstration
- Converters: WP2, WP3, WP8
- Protection Systems: WP4, WP9
- DC Circuit Breakers: WP5, WP6, WP10
- Finance & Regulation: WP7

Exploitation
- Standards and deployment plan – WP11 & WP12
PROMOTioN - The Project

Project Structure

WP 1 - Requirements for meshed offshore grids

WP 2 - Grid topology & converters
RWTH

WP 3 - WTG - Converter Interaction
DTU

WP 4 - DC grid protection systems development
KU Leuven

WP 5 - Test environment for HVDC circuit breakers
DNV GL

WP 6 - HVDC circuit breaker performance characterization
UniAbdn

WP 7 - Regulation and Financing
SOW

WP 8 - Wind farm demonstrator prototype
SIEMENS

WP 9 - Demonstration Protection system demonstration
SHE Trans

WP 10 - Circuit Breaker performance demonstration
DNV GL

WP 11 - Harmonisation towards standardization
DTU

WP 12 - Deployment plan for future European Offshore grid
TENNET

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Introduction

Role of partners
PROMOTioN - The Project

Project Structure

WP 1 - Requirements for meshed offshore grids

WP 2 - Grid topology & converters
- RWTH

WP 3 - WTG - Converter Interaction
- DTU

WP 4 - DC grid protection systems development
- KU Leuven

WP 5 - Test environment for HVDC circuit breakers
- DNV GL

WP 6 - HVDC circuit breaker performance characterization
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WP 7 - Regulation and Financing
- DNV GL

WP 8 - Wind farm demonstrator prototype
- SIEMENS

WP 9 - Demonstration Protection system demonstration
- SHE Trans

WP 10 - Circuit Breaker performance demonstration
- DNV GL

WP 11 - Harmonisation towards standardization
- DTU

WP 12 - Deployment plan for future European Offshore grid
- TENNET

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## Project overview

### WP8 scope change

<table>
<thead>
<tr>
<th>Date</th>
<th>Event and Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-2016</td>
<td>Demonstrator review deliverable requested in 1&lt;sup&gt;st&lt;/sup&gt; amendment</td>
</tr>
<tr>
<td>22-01-2016</td>
<td>Lab-scale demo introduced during 1&lt;sup&gt;st&lt;/sup&gt; meeting</td>
</tr>
<tr>
<td>19-04-2016</td>
<td>Need for thorough evaluation of demonstration options discussed during WP8 Kick-off</td>
</tr>
<tr>
<td>16-06-2016</td>
<td>Further justification for lab demo provided during Stockholm meeting</td>
</tr>
<tr>
<td></td>
<td>Several meetings between PC, Siemens and EC</td>
</tr>
<tr>
<td>01-12-2016</td>
<td>Consortium informed of Siemens NO GO decision in Berlin meeting. Prysmian scope to go ahead</td>
</tr>
<tr>
<td>26-01-2017</td>
<td>No DRU demo of any scale in PROMOTioN announced during Schiphol PMG meeting</td>
</tr>
</tbody>
</table>
Project overview

Liberated budget

- Prysmian scope will be reduced; no transport or installation
- Siemens WP8 budget returned: EUR 10,928,400,--
Project overview

Selection process new proposals

- 09-12-2016  Call for new proposals
- 23-01-2017  Deadline for proposals
- 26-01-2017  1st review in PMG
  - 1st selection
  - suggestions for improvement
- 16-02-2017  2nd review in PMG → selection criteria
  - 4 small proposals as amendment
  - 2 large proposals to be presented to EU as new WP
- 27-02-2017  2 large proposals sent to General Assembly
- 08-03-2017  General Assembly vote in favour of 2 large proposals
- 13-03-2017  Late contributions added to DC GIS & MMC test bench proposals
Cost Benefit Analysis for North Sea grid development

- Lead: TenneT
- Contact: Daimy Abdoelkariem
- Involved partners: Deutsche Wind Guard
- Budget: EUR 250,000,--
CONTENT

• Motivation & objective
• Relation to PROMOTioN’s objectives
• Expected impact

• Description of work/budget
Motivation

• The current scope of WP7 is to provide a framework for evaluating costs and benefits of European infrastructure investments
• Current ENTSO-E CBA methodology has room for improvement
• North Sea grid development highlights important principles (e.g. accounting for project interaction)

Objective

• Building on existing ENTSO-E methodology
• Drafting a CBA methodology, with a special focus on North Sea grid development
• To provide a common and uniform basis for the assessment of project with regard to their value for European society
### Relation to PROMOTioN’s objectives (WP12)

<table>
<thead>
<tr>
<th>Status of implementation</th>
<th>ENTSO-E 1.0 (approved by the EC in 2015)</th>
<th>ENTSO-E 2.0 (version for ACER opinion)</th>
<th>ENTSO-E Market design - balancing</th>
<th>Significantly more important in the offshore context?</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT(1) Project interaction must be taken into account in the project and baseline definition</td>
<td>One baseline (TOOT), arbitrary clustering rules</td>
<td>One baseline (TOOT), ambiguous update of the clustering rule</td>
<td>Harder applicable but dealt with.</td>
<td>Almost greenfield development</td>
</tr>
<tr>
<td>INPUT(2) Data consistency and quality should be ensured</td>
<td>TYNDP</td>
<td>TYNDP</td>
<td>TYNDP</td>
<td></td>
</tr>
<tr>
<td>INPUT(3) Costs should be reported in disaggregated form</td>
<td>Not clear</td>
<td>Not clear</td>
<td>Not clear</td>
<td>Immature technology</td>
</tr>
<tr>
<td>CALCULATION(4) CBA should concentrate on a reduced list of effects</td>
<td>Reduced list</td>
<td>Reduced list</td>
<td>Reduced list</td>
<td></td>
</tr>
<tr>
<td>CALCULATION(5) Distributional concerns should not be addressed in the calculation of net benefits</td>
<td>OK</td>
<td>OK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CALCULATION(6) The model used to monetise the production cost savings and gross consumer surplus needs to be explicitly stated</td>
<td>Explicit model available</td>
<td>Explicit model available</td>
<td>Explicit model available</td>
<td></td>
</tr>
<tr>
<td>CALCULATION(7) A common discount factor should be used for all projects</td>
<td>4% for all</td>
<td>4% for all</td>
<td>Uniform: aligned with TYNDP &amp; PCI</td>
<td></td>
</tr>
<tr>
<td>CALCULATION(8) A stochastic approach/scenario analysis should be used to address uncertainty</td>
<td>OK</td>
<td>The need is mentioned, but not specified how to apply the tools</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>OUTPUT(9) Benefits should be reported in disaggregated form</td>
<td>Not clear</td>
<td>Not clear</td>
<td>Regional and country effects should be reported</td>
<td>Various winners/losers</td>
</tr>
<tr>
<td>OUTPUT(10) Ranking should be based on monetisation</td>
<td>Multi-criteria analysis</td>
<td>Multi-criteria analysis, additional monetization of losses</td>
<td>Monetized ranking is suggested</td>
<td>Various significant externalities</td>
</tr>
</tbody>
</table>
Expected Impact

• Provide policy makers and system operators with insights to properly value the cost and benefits of European (offshore) investments

• Provide a more concrete basis for the framework for cross border cost allocation (CBCA)

Scope of work
work/ budget

• No expertise within the Consortium; subcontractor (tender)

• Detailed project plan with timeframe & milestones

• Report on CBA methodology Support stakeholder management/presentations ENTSO-E, ACER, EC

• Tender: EUR 250.000 (incl. travelling and other expenses)

• No additional partner MM
Hybrid HVDC Breaker – logistics and assembling

- Lead: ABB
- Contact: Jenny Josefsson
- Budget: 240 kEUR
CONTENT

• Basic idea
• Motivation
• Impact & Relevance
• Tasks & Deliverables
• Partners & Roles
• Budget
Basic Idea

• ABB will test the Hybrid HVDC Breaker at the laboratory of DNV GL.
• ABB was granted 638 kEUR fundings.
• This covers working time and travel for all WP:s.
• ABB is therefore applying for 240 kEUR funding for:
  • Logistics
  • Assembling and disassembling of HHB
  • Installation of HHB control system
Motivation
Motivation

- The HHB contains several components. For example the UFD will be supplied from CHABB.
- The extra fundings will allow for a flexibility of components to be sent to DNV GL.
- The extra fundings will also allow for support to DNV GL to install the control system in an efficient way.
- Without the extra funding ABB will be more limited in which components to send, for example only the main breaker or prototypes.
Impact & Relevance

• A limitation of HHB components to be tested will still show the functionality of an HVDC breaker and the test circuit. However, a complete breaker set-up will also show the interoperability between the components.

• Support of installing the control cubicle will shorten the installation time, and limit the interference with other DNV GL testing commitment.
Tasks & Deliverables

• Task 10.6: Testing of HVDC circuit breakers (M37-48)
• Task 10.7: Full demonstration of test circuits and test methods (M40-48).
Partners & Roles

• ABB, supplier of test object
## Budget

<table>
<thead>
<tr>
<th>Type of Expense</th>
<th>kEUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistics</td>
<td>10</td>
</tr>
<tr>
<td>Assembling and disassembling of HHB (factory and at DNV GL)</td>
<td>80</td>
</tr>
<tr>
<td>Installation of HHB control system</td>
<td>150</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>240</strong></td>
</tr>
</tbody>
</table>

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MMC test bench demonstrator

• Lead: RWTH Aachen
• Contact: Cora Petino
• Involved partners: DTU, DNV GL, KTH
• Budget: EUR 3.973.250,--
MMC Test Bench Proposal for PROMOTioN

Proposal for PROMOTioN
Proposal leader: IFHT, RWTH Aachen University
Motivation

Basic Idea

Impact and Relevance

Tasks and Deliverables

Partners and Roles

Budget
Enhancing PROMOTioN’s objectives (1/2)

Motivation

- Overall target in the PROMOTioN context
  - Improve **confidence** in technological and systemic solutions
  - Reduce investment risks by **de-risking** technological decisions
  - Contribute to the **near-future** deployment of meshed offshore HVDC grids

- PROMOTioN present status
  - Termination of full scale DRU demonstrator in WP8
  - Demonstration character of project is at risk

➤ **Building of a RTS supported MMC Test Bench**
  - Allows an **investigation of planed** project results based on a small scale demonstrator
  - Additional investigations on interaction of offshore DC grid with meshed AC system becomes interesting option **without additional costs**
  - Setup of fully operational MMC Test Bench system in 2017 possible
  - **Demonstration** of developed controls strategies, protection schemes and simulation models from entire PROMOTioN project context
Enhancing PROMOTioN’s objectives (2/2)

Specific Benefits

- Simulations as project core
  - Simulative investigation of general principles
  - Investigation of general system behavior
  - Development of basic (control) concepts

- RTS
  - Simulative investigation in real-time context
  - Time critical system responses taken into account
  - First testing of basic (control) concepts

- MMC-Test-Bench + RTS
  - Hardware representation of converter components (no simulation)
  - More exact system and component response
  - Fully realistic testing of control concepts

- Full Scale Demonstration System

Promotion

Work Packages

MMC Test Bench Proposal

Additional investigations

WP 8 Wind Farm Demonstrator

Additional investigations
Agenda
MMC Test Bench Proposal for PROMOTioN

Motivation

Basic Idea

Impact and Relevance

Tasks and Deliverables

Partners and Roles

Budget
Lab scale Modular Multi-Level Converter

Basic Idea

- 8 MMC units for laboratory investigations
  - Two configurations possible: 4T bipolar and 8T monopole
  - Hardware converter containing control unit, submodules, arm inductors, measurement and protection
  - Configurable submodules (half bridge / full bridge)

**Technical Data per MMC**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage (DC)</td>
<td>400 V</td>
</tr>
<tr>
<td>Rated current (DC)</td>
<td>15 A</td>
</tr>
<tr>
<td>Number of Levels</td>
<td>11</td>
</tr>
<tr>
<td>Output power</td>
<td>6 kW</td>
</tr>
</tbody>
</table>

- Implementation of control schemes
  - Free programmable station and submodule control
  - Software interface: MATLAB/Simulink
  - Analysis of different control concepts under **realistic** constraints possible
Integrating the DC into the AC grid

Basic Idea

- Modelling (of relevant parts) of the European transmission system with a real time simulator (RTS)

- **Coupling** of the MMC Test Bench and the AC grid simulation by power amplifiers
  - Real physical behavior of converters and control circuits interacts with the real time simulation
  - Investigate impact of offshore DC system on onshore AC grid scenarios
  - Analysis of interactions between AC and DC system
  - Investigation of resonance phenomena

➢ Overall solution includes
  1. Lab scale MMC Test Bench with transmission lines
  2. RTS simulator for European transmission system
  3. Power Amplifiers for coupling both components
Motivation

Basic Idea

Impact and Relevance

Tasks and Deliverables

Partners and Roles

Budget
Advantages and Flexibility

Impact and Relevance

- Small scale demonstrator compensates major investigations of full scale demonstrator

- **Additionally** an enhanced testing environment is created for
  - System related investigations (e.g. impact of control systems, resonance phenomena)
  - Detailed, real-life analysis of interactions between existing meshed AC grid and off-shore HVDC grid

- MMC Test Bench is available to all members of PROMOTioN consortium on long term

- **Flexibility** of investigations and hardware regarding
  - In grid topology
  - In converter topology
  - In control schemes (e.g. vendor specific)
  - Different fault scenarios applicable (AC faults and DC faults)
  - Different load flow scenarios
  - Different networks (strong / weak AC grids)
  - Different dynamic AC grid responses in real-time
Links to other WPs

Impact and Relevance

- Impact on other PROMOTioN work packages
  - **Demonstration** of interoperability, controllability for different converter configurations (WP2)
  - **Demonstration** of applicability of WT and WPP control (WP3)
  - **Demonstration** of interoperability of protection (WP4)
  - **Demonstration** of interoperability of lab scale MMC, AC grid and DRU (WP8)
  - **Improvement** of certainness for road mapping process and standardization efforts (WP12)

- Pushing the investigations across several PROMOTioN work packages towards demonstration / exploitation

- Promoting compatibility through testing

  ➢ Significant improvement of WP results possible
Differences to “Best Paths” Project
Impact and Relevance

- **MMC Test Bench** allows flexible investigation of converter control
- Extensive modelling of large AC grid and meshed DC grid possible
- Investigation of control induced resonance phenomena possible
- Approach close to real-world large scale HVAC and HVDC system

- “Best Paths” demonstrator includes single wind farm emulator
- Other Converters directly connected to AC grid
- DC grid is radial-only structure
- Focus of “Best Paths” is on converter operation and interoperability of converters

Source: Best Paths publication, WP2 deliverable 2.1
Agenda
MMC Test Bench Proposal for PROMOTioN

Motivation

Basic Idea

Impact and Relevance

Tasks and Deliverables

Partners and Roles

Budget
Gantt-Chart
Task and Deliverables

| Tasks / Month                                                                 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 |
|--------------------------------------------------------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| T 2.0.1 - Definition and specification of test cases for the new test bench   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| T 2.0.2 - Preparatory measures for the MMC test bench set up                 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| T 2.0.3 - MMC test bench lab setup                                           |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| T 2.0.4 - Commissioning and basic testing of the MMC test bench system       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| T 2.0.5 - Implementation of an analytical method for analysis of resonance phenomena |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| T 2.0.6 - Demonstration of defined test cases regarding interoperability and control schemes |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| T 2.0.7 - Analysis of the impact on requirements for meshed off-shore HVDC grids |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
Task description (1/2)

Task and Deliverables

- **Task 2.0.1 – Definition and specification of test cases for the new test bench**
  - Start: M16; End: M20; Participants: RWTH, DTU, DNV GL, KTH
  - Derive test cases from WP 2.2, as well as WP 3, WP 4 and WP 8
  - Definition of additional cases related to grid code development
  - Adaptation of scenarios from WP 2.3

- **Task 2.0.2 – Preparatory measures for the MMC test bench set up**
  - Start: M16; End: M24; Participants: RWTH, DTU, DNV GL, KTH
  - Preparatory measures for test bench setup, including adjustment of existing infrastructure and preexisting testing equipment
  - Preparation of developed control models from WP 2.2 for application in test bench

- **Task 2.0.3 – MMC test bench lab setup**
  - Start: M22; End: M24; Participants: RWTH, DNV GL, KTH
  - Assembly of components and basic training

- **Task 2.0.4 – Commissioning and basic testing of the MMC test bench system**
  - Start: M25; End: M26; Participants: RWTH, DNV GL, KTH
  - Conduction of basic tests on real-time components, mirroring the test bench hardware
  - After successful tests, conduction of first test in real test bench hardware
Task description (2/2)

Task and Deliverables

- Task 2.0.5 – Implementation of an analytical method for analysis of resonance phenomena
  - Start: M25; End: M33; Participants: RWTH, DTU, DNV GL, KTH
  - Implementation of an analytical method for resonance phenomena utilizing the test bench system
  - Proposition of a converter harmonic model for AC system stability evaluation

- Task 2.0.6 – Demonstration of defined test cases regarding interoperability, control schemes and protection
  - Start: M27; End: M39; Participants: RWTH, DTU, DNV GL, KTH
  - Conduction of test cases defined in Task 2.0.1
  - Investigation of developed methodology for resonance phenomena analysis
  - Controller replica from wind turbine vendors will be used in CHIL (controller hardware in the loop) verification
  - Investigation and demonstration of interoperability of control schemes and protection

- Task 2.0.7 – Analysis of the impact on requirements for meshed off-shore HVDC grids
  - Start: M34; End: M42; Participants: RWTH, DTU, DNV GL, KTH
  - Parallel evaluation of results from test cases
  - Based on results, recommendations, minimum requirements and general principles are developed for offshore HVDC grids
  - Transition of results into WP 12, extending the grid codes developed in WP 11
Deliverables and Milestone planning

Task and Deliverables

- **Deliverables**
  - **D2.0.1 – M21 (Public)**
    Overview of all defined test cases to be investigated on the test bench
  - **D2.0.2 – M24 (Confidential)**
    Detailed documentation of the lab set-up, technical specifications and configuration possibilities
  - **D2.0.3 – M36 (Public)**
    Overview of the conducted tests, the results and the associated analyses with respect to the research questions and analyses within WP 3
  - **D2.0.4 – M42 (Public)**
    Overview of the conducted tests, the results and the associated analyses with respect to requirements towards sustainable and interoperable meshed off-shore HVDC grids
  - **D2.0.5 – M33 (Public)**
    Documentation of the investigated/developed analytical methods for analysis of resonance phenomena

- **Milestones**
  - M2.0.1 – M21: All test cases defined
  - M2.0.2 – M24: Set-up completed
  - M2.0.3 – M27: First test successfully completed
  - M2.0.4 – M36: Test cases regarding WP3 successfully completed
  - M2.0.6 – M42: All test cases successfully completed
Agenda
MMC Test Bench Proposal for PROMOTioN

Motivation

Basic Idea

Impact and Relevance

Tasks and Deliverables

Partners and Roles

Budget
Project partners and roles

Partners and Roles

- **Sub-project carried out by:**
  - **IFHT, RWTH Aachen University**
    - Call for tenders and acquisition of MMC test bench
    - Creating first test models & Conduction of lab demonstration
    - Building and primarily testing of MMC test bench
    - Project coordination
  - **DNV GL**
    - Work on control replica and testing of wind turbine models
    - Development and validation of resonance phenomena models
  - **Technical University of Denmark**
    - Selection of test cases & Conduction of lab demonstration
    - Preparation of models for demonstration
  - **KTH Royal Institute of Technology in Stockholm***
    - Testing of protection system of WP4 on MMC test bench
    - Demonstration of interoperability of protection

*The contribution of KTH is an additional amendment to the initial proposal*
Motivation

Basic Idea

Impact and Relevance

Tasks and Deliverables

Partners and Roles

Budget
Budget and WP effort

Budget

- Budget calculation including possible traveling expenses to / from RWTH testing facilities

- Equipment expenses include
  - Hardware of MMC test bench, real time simulator, power amplifiers and DC line model (RWTH)
  - Upgrade of existing OPAL-RT system to support controller replicas of wind turbines (DNV GL)

- Other goods and services include
  - Professional training from MMC test bench manufacturer (all)
  - Extern service charges for minor room / building adjustments in test bench site (RWTH)

- Calculated WP effort for realization
  - RWTH Aachen: 30 PM
  - DTU: 24 PM
  - DNV GL: 12 PM
  - KTH: 24 PM*
  - Total: 90 PM

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**Total equipment costs** 2,560,000 €

*The contribution of KTH is an additional amendment to the initial proposal*
Summary

MMC Test Bench Proposal for PROMOTioN - WP2

- Core content of the proposal:
  - Installation of a lab scale MMC test bench
  - Interconnection of the test bench with RTS for large scale AC grid representation using power amplifiers

- Enhancing confidence in simulation results
  - Highly flexible demonstrator for different DC grid and converter configurations, control systems and strategies as well as AC grid models
  - Demonstration of applicability of developed controls and simulation models of PROMOTioN
  - Technical and economical de-risking for the deployment and continuous operation of meshed HVDC-systems
  - Improvement of certainness for road mapping process and standardization efforts

- Contributions to WP 2, 3*, 8 and 12 through lab demonstration and experience with real hardware

*The contribution of KTH is an additional amendment to the initial proposal
Thank you for your attention
DC GIS technology demonstrator

- Lead: ABB
- Contact: Jenny Josefsson
- Involved partners: DNV GL, TU Delft, SHE Transmission, TenneT
- Budget: EUR 4,420,955,
Basic Idea
CHAPTER 1 – Basic Idea

DC GIS Technology Demonstrator

- Develop a thorough understanding of technical and operational requirements of gas insulated DC systems in meshed offshore HVDC grids
- Develop and demonstrate monitoring and diagnostic methods
- Develop meaningful standardized test programs based on existing standardization work and increase technology readiness level (TRL) of DC GIS technology
- Demonstrating a full-scale prototype in an independent test lab
CHAPTER 1 – Basic Idea

DC GIS Technology Demonstrator - Idea

• Review of state-of-the-art of DC GIS technology and its state-of-development
• Determine operational stresses on DC GIS through simulation and FMEA
• Develop recommendations for specifying DC GIS installations
• Develop meaningful test program based on Cigré draft and with TSO approval
• Review, compare and develop monitoring techniques based on temperature, gas pressure, gas density and partial discharge measurements

• Review, compare and develop diagnostic methods based on evaluating monitoring outputs
• Analyze and evaluate the performance of a different type of insulating gas*
• Carry out long duration testing on real DC GIS system in high voltage laboratory
• Review and verify monitoring and diagnostic results

* The contribution of SGI is an amendment to the original proposal
Motivation
CHAPTER 2 – Motivation

Advantages of gas insulated systems

- A DC GIS installation can be built with a much higher degree of compactness and significantly lower sensitivity to ambient factors than with air-insulated switchgear (AIS).
- The most obvious cost-saving potential can be found on off-shore converter platforms where the required air-clearance for AIS leads to much larger and heavier off-shore structures.
- By using DC GIS, the volumetric space of the switchgear installation can be drastically reduced e.g. by 70%-90%.
The HVDC-GIS technology spans a number of switchgear components, e.g.:

- Bus-ducts and high voltage DC conductors
- Disconnect- and earthing switches
- Bushings and cable terminations
- Current- and voltage measurement sensors
- Surge arresters
## CHAPTER 2 – Motivation

### Application options

<table>
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<th>DC GIB</th>
<th>DC Hub</th>
<th>DC Hall</th>
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| Flexible “3D routing” and connections on platforms | Connections of several DC cables of OHL (MTDC)  
With or without DC circuit breaker | Compact converter station design |

![DC GIB Diagram](image1)

![DC Hub Diagram](image2)

![DC Hall Diagram](image3)
CHAPTER 2 – Motivation

AC - DC

\[ I = \frac{U}{R} + C \frac{d(U)}{dt} \]

Transition

\[ \tau = RC = \frac{\varepsilon_0 \varepsilon_r}{\sigma} \]

\[ t = 0 \quad ("AC") \quad t \to \infty \quad ("DC") \]

\[ \frac{U_1}{U_2} = \frac{C_2}{C_1} \quad \frac{U_1}{U_2} = \frac{R_1}{R_2} \]
CHAPTER 2 – Motivation

Dimensioning of a HVDC GIS

[Graph showing electric field distribution]

AC 30 kV

DC

E Field [1]

[Color scale indicating electric field strength]

© PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714.
CHAPTER 2 – Motivation

Physical effects in HVDC gas-solid insulation

The gas-solid interface is key
CHAPTER 2 – Motivation

History

- First research
- First 150 kV GIS
  - Gotland 2
- First 150 kV GIS
  - Gotland 3
- First long-term test
  - BPA (USA)-ABB
- First 150 kV GIS
  - Gotland 2
- First long-term test
  - (Japan)
- First 250 (500) kV GIS
  - KII – link (Japan)

- 1980
- 1983
- 1987
- 1995
- 2000
- 2020
CHAPTER 2 – Motivation

Questions

• Users intending to employ gas-insulated HVDC systems expect the same reliability and long-term performance.

• That leads to the question of the necessity of long-term tests on gas-insulated HVDC systems in general and to the formulation of relevant test procedures if applicable.
  • The most convincing pro-argument for such testing is the lack of experience with this new technology.
  • A long-term test under real service conditions can help to overcome this deficiency. This test should be carried out for collecting more experience with this kind of DC technology and should simulate the real conditions and practical load cycles.
  • Based on project results, a prototype installation test procedure shall be proposed which can prove the long-term capability of this type of new technology and could be used as input for future standardization.
  • In addition, the availability of proven diagnostic methods and monitoring tools are required in order to ensure a safe and reliable operation and maintenance operation of HVDC gas-insulated systems.
  • Moreover, and the use of alternative insulating gases for HVDC systems will be investigated*

* The contribution of SGI is an amendment to the original proposal
Impact and Relevance
CHAPTER 3 – Impact and Relevance

Impact 1/3

- By studying the operational and functional stresses on DC GIS in meshed HVDC offshore grids and providing recommendations for specifying DC GIS systems, the applicability of DC GIS in meshed offshore HVDC grids will be illustrated.

- Guarantee minimum acceptable quality levels at lowest cost by developing effective and well-balanced test program based on existing CIGRE and IEC initiatives. Contributing to interoperability by aiming for industry wide adoption of common test method.
CHAPTER 3 – Impact and Relevance

Impact 2/3

• By developing and demonstrating monitoring techniques and diagnostic methods, it will be shown that ageing and degradation mechanisms are well-understood

• and that the condition of DC GIS equipment can be continuously and effectively assessed and preventative action taken, reducing the risk of wide spread damage or outages in case of a defect or damage.

• The work package aims to unlock the cost reduction and reliability increasing potential of the next generation of compact DC GIS by demonstrating its technological maturity and reliability, bringing it a step closer to real-world adoption and reducing required platform footprint.
CHAPTER 3 – Impact and Relevance

Impact 3/3

- Ecological aspects
  - Less footprint (smaller platforms)
  - Much higher degree of compactness and significantly lower sensitivity to ambient factors than with air-insulated installations.
  - By using HVDC-GIS, the volumetric space of the switchgear installation itself can be drastically reduced e.g. by 70%-90% which may result in a size reduction of circa 10% of the total converter platform.

- The performance of an alternative gas to SF6 will be investigated to compare their behavior for different types of defects with SF6 and especially at an equivalent dielectric strength.*

* The contribution of SGI is an amendment to the original proposal
Tasks and Deliverables
CHAPTER 4 – Tasks and Deliverables

Task 1 - Scope

• **Defining specifications & long term testing requirements**
  • M18-M24
  • Leader: SHE Trans

• Participants
  • SHE Trans
  • ABB
  • TenneT
  • TU Delft
  • DNV GL
  • SGI*

* The contribution of SGI is an amendment to the original proposal
CHAPTER 4 – Tasks and Deliverables

Task 1 - Details

- Review of DC GIS technology state-of-the-art.
- Analysis of function of DC GIS components in a MTDC network to determine number of operations, and stresses during normal operation and during emergency operation such as faults by modelling the DC GIS system.
- The specific stresses on the various key-components will be identified.
- The analysis will be supported by a review of the environmental impact of the intended offshore application, possible DC substation layouts and operational strategies.
- The identified operational requirements and stresses are translated to test requirements, procedures, methods and test circuits.
CHAPTER 4 – Tasks and Deliverables

Task 2 - Scope

• **Develop monitoring and diagnostic method and applicability of SF6 alternatives**
• M18-M48
• Leader: TU Delft

• Participants
  • TU Delft
  • ABB
  • DNV GL
  • SHE Trans
  • SGI*

* The contribution of SGI is an amendment to the original proposal
CHAPTER 4 – Tasks and Deliverables

Task 2 – Details Monitoring and Diagnostics

• Monitoring of critical components
  • Temperature monitoring (to enable dynamic loading, load management)

• Monitoring of insulating parameters
  • Partial discharges (gas/solid insulation degradation)
  • Gas pressure (leakages and partial pressures)
  • Gas quality (gas insulation degradation)

• Diagnostics of components
  • Interpretation of results
  • Localization of faulty component
  • Comparison with laboratory tests
  • Risk assessment
  • Maintenance decision

Increase technology readiness level (TRL) of DC GIS technology from 6 to 8
CHAPTER 4 – Tasks and Deliverables

Task 2 – Details Monitoring and Diagnostics

- Design sensors and acquisition systems
- Monitor
- Analyse
- Interpret
- Act

- Less hardware requirements
- Affordable system
- Select valid data
- Diagnosis criteria
- Standardization
- Prevent failures and outages
- Schedule maintenance
- Improve reliability
- Improve performance

- Innovative algorithms for data processing by TU DELFT

- Compare with lab results
- Evaluate risks

- Prove technology readiness
CHAPTER 4 – Tasks and Deliverables

Task 2 – Details Monitoring and Diagnostics

Characterization of partial discharges on full scale DC GIS with alternative gas* and comparison with SF6

Partial discharges monitoring of DC GIS with internal defects
Long term tests

Data available for innovative data processing system

Monitoring system

Application in case of defects

Prove technology readiness

* The contribution of SGI is an amendment to the original proposal
CHAPTER 4 – Tasks and Deliverables

Task 3 - Scope

- **Long term testing of the DC GIS equipment**
- M24-M48
- Leader: DNV GL

- Participants
  - DNV GL
  - ABB
  - TU Delft
CHAPTER 4 – Tasks and Deliverables

Task 3 - DNV GL – KEMA Laboratories

AC GIS testing in KEMA laboratory

- Transfer of online monitoring from research environment to test-laboratory practice
- DC GIS dielectric tests not yet demonstrated in an independent test laboratory
- Experience with testing AC GIS and DC cable system at 320 kV
- Experience with HVAC cable systems long term tests (PQ: prequalification)
CHAPTER 4 – Tasks and Deliverables

Task 3 - KEMA HV laboratories test facility

DC cable system type test and AC cable system PQ test in KEMA laboratory
CHAPTER 4 – Tasks and Deliverables

Task 3 – Option for test set-up
### Task 3 – Proposal Ratings

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</table>
CHAPTER 4 – Tasks and Deliverables

Task 3 - Long term testing of the DC GIS prototypes by DNV GL

• Tests to be done in a dedicated DC testing laboratory
• Includes simulating of thermal stress due to daily DC load cycles as in service
• Monitoring of thermal and electrical stresses to be controlled by an automated system
• Controlling and analysing gas density and pressure to ensure a safe operation

• Remote monitoring test set-up during a long term cycle testing
• After 1 year or 1.5 year long term testing, superimposed switching impulse voltage tests to demonstrate the integrity of the DC GIS equipment as installed
• Full scope measured and recorded data to be evaluated long term effects for a DC GIS system
CHAPTER 4 – Tasks and Deliverables

Task 4 - Scope

• **Initiation of standardization activities for HVDC GIS design, testing and application**
  
• M43-M48

• Leader: ABB

• Participants
  
• ABB
• TU Delft
• SHE Trans
• DNV GL
• SGI*

* The contribution of SGI is an amendment to the original proposal
CHAPTER 4 – Tasks and Deliverables

Task 4 - Details

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

• Results of testrequirement studies, based on task 1 and verified in task 3 will be documented in a brochure to be delivered to CIGRE and/or IEC as input for future standards.
CHAPTER 4 – Tasks and Deliverables

Deliverables

- 2017: Document on test requirements, procedures and methods
- 2018: Report on DC GIS diagnostic and monitoring tools and methods
- 2019: Report on characteristics of PD Alternative gas: comparison with SF6 GIS*
- 2020: Anonymized test reports on tests carried out
- 2021: Report of diagnostic analysis and condition assessment
- Simulation models of DC GIS systems
- Report on long term monitoring of DC GIS with defects
- White- and position papers on pre-standardization of DC GIS testing

* The contribution of SGI is an amendment to the original proposal
CHAPTER 4 – Tasks and Deliverables

Milestones

Recommendations for specifying DC GIS defined
Milestone 1

Test requirements, procedure and method identified and agreed
Milestone 2

Monitoring and diagnostic analysis plan described and agreed
Milestone 3

Provided DC GIS systems are tested according to the test program
Milestone 4

2018

2018

2018

2020
Partners and Roles
CHAPTER 5 – Partners and Roles

Partners

• SHE Trans
  • Lead task 1
  • Participant task 2, 4

• DNV GL
  • Lead task 3
  • Participant task 1, 2, 4

• ABB
  • Lead WP, task 4
  • Participant task 1, 2, 3

• TU Delft
  • Lead task 2
  • Participant task 1, 3, 4

• TenneT
  • Participant task 1, 4

• SGI*
  • Participant task 1, 2, 4

* The contribution of SGI is an amendment to the original proposal
Budget
## Budget without SGI

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<td><strong>980 693 €</strong></td>
<td><strong>3 583 456 €</strong></td>
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Summary

The aim of this work package is to

- Define recommendations for specifying DC GIS systems based on technical and operational requirements
- Define long term testing requirements based on the experiences of the manufacturer, utilities, academia and independent testing labs to ensure that the DC GIS equipment is tested for real operation conditions
- Develop understanding of partial discharge behavior of different types of defects in different types of insulating gases*
- Develop monitoring and diagnostic methods to ensure a safe operation, to enable condition assessments, and develop criteria for acceptance
- Carry out long term testing of the DC GIS equipment and the monitoring equipment to prove the concept and increase the Technology Readiness Level (TRL) from 6 to 8 for DC GIS equipment
- Use long-term testing, monitoring, and diagnosis to verify and improve models and develop understanding of degradation mechanisms and failure modes

* The contribution of SGI is an amendment to the original proposal
Extension of original proposal

Contribution of SGI to original proposal

• TU Delft will develop a monitoring system for DC GIS. However, TU Delft lacks the facilities for handling of alternative gases and therefore will only study defects in SF6.

• SGI will complement TU Delft’s work by:
  • Characterising defects in DC GIS with SF6 alternative gas
  • Verifying the defect models through long term testing in DC GIS test pole using alternative gas
  • Verifying the diagnostic and monitoring system developed by TU Delft on gases other than SF6

• Analysis of alternative gases has strong support of TSOs
### CHAPTER 6 – Budget

#### Budget without SGI

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SGI participation results in increase of EUR 837 499 of required budget
New partner

SCibreak

• 03-2016 Coordinator contacted by SCibreak
• 08-06-2016 DC circuit breaker manufacturers consulted
• 15-06-2016 Introduction during Stockholm meeting
• 01-12-2016 Approval in PMG
• 10-01-2017 Official notification sent to General Assembly
• 24-01-2017 General Assembly vote in favour of accession
• 07-02-2017 Consortium Agreement signed
• 20-03-2017 Presentation to EC
What SCiBreak does

✓ SCiBreak AB is a small Swedish company founded in 2014 by former and current KTH staff

✓ The intention is to commercialize new ideas concerning the design of fast breakers for interrupting DC (or AC) current

✓ Our concept is suitable for the requirements encountered in HVDC grids i.e. having an interrupting time less than 5 ms

✓ SCiBreak thus develops and verifies technology for fast electric breakers
Key persons


**Staffan Norrga**, born 1968, MSc 1993, PhD 2005: Worked at ABB/Adtranz 1994-2011 in various capacities related to power electronics. Associate professor at KTH from 2011. Inventor or co-inventor of 12 granted patents and 13 patents pending, and has authored or co-authored more than 65 scientific papers.

**Tomas Modéer** was born in Stockholm, Sweden, in 1979. He received the MSc and PhD degrees KTH Royal Institute of Technology in 2004 and 2015 respectively. Worked at Optistring Technologies 2011-2015 managing the technology development.
Our links and collaborations

- We have a background in the power electronics group at KTH and some of us have been employed by ABB in the past (more than five years ago)

- No formal links to manufacturers, like ABB, Siemens or Mitsubishi

- We are supported by Innoenergy (an incubator-like entity which is part of the EIT)

- SCiBreak collaborates with SvK and KU Leuven in a development project HIBREAK which runs 2017-2018

- The company is owned by the founders and Innoenergy has an option for buying 10% of the shares
Key idea in our breaker concept

✓ proposed (and existing) concepts for DC breakers use a combination of mechanical switches and semiconductors

✓ however, the use of semiconductors in proposed DC breakers is inefficient, typically it only performs one switching in each breaking operation

✓ power electronics easily can operate at high frequency (10 kHz) and can perform many interventions while its mechanical counterpart separates the mechanical contacts

✓ we replace one switching at high voltage (requiring many series-connected semiconductors) by several consecutive switchings at lower voltage, reducing the amount of semiconductors by almost one order of magnitude, thereby improving the utilization of the provided devices
Excitation of current pulse

many devices switch simultaneously to achieve a large voltage step producing a desired current pulse

few devices consecutively switch a fraction of the high voltage to achieve the same current pulse
Basic principle for SCiBreak’s circuit-breaker

- strong artificial negative resistance can be created by power electronic means using feedback control.

Capacitor precharged to high voltage is discharged through the interrupter. Capacitor voltage evolves by resonance using low-voltage source.
Experimental work

- power electronic converter

control card using FPGA control

- vacuum breaker rated 24 kV, 630 A
- conventional mechanical actuator 1.1-1.7 m/s
max experimental results (Dec. 2016):

5 kA peak @ 10 kV peak
How will SCiBreak contribute to PROMOTioN?

SciBreak’s participation directly addresses the core objectives 1 through 3 of the project:

Core objective 1.
“To establish interoperability between different technologies and concepts by providing specific technical and operational requirements, behaviour patterns and standardization methods for different technologies”

SCiBreak’s contribution to fulfillment
SCiBreak intends to take part in the work towards standardization in the field of HVDC breakers, together with the other partners. By introducing its breaker technology to the project it will add a furhter perspective to this work. SCiBreak will also provide simulation models of its breaker, at different levels of abstraction, to the project.
How will SCiBreak contribute to PROMOTioN?

SciBreak’s participation directly addresses the core objectives 1 through 3 of the project:

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

SCiBreak’s contribution to fulfillment
SCiBreak is developing an HVDC breaker making use of advanced converter technology with increased utilization of the provided semiconductors, cutting the needed number of semiconductors by almost one order of magnitude, thereby reducing cost. The concept is suitable for HVDC grids and combines excellent performance with low cost.

By not having any links to the existing manufacturers in the industry SCiBreak will also be committed to interoperability among equipment for HVDC grids.
How will SCiBreak contribute to PROMOTioN?

SciBreak’s participation directly addresses the core objectives 1 through 3 of the project:

Core objective 3.
"To demonstrate different cost-effective key technologies for meshed HVDC offshore grids and to increase their technology readiness level by investigating and overcoming early adopter issues and pitfalls”

SCiBreak’s contribution to fulfillment
SCiBreak will provide a breaker module for testing and demonstration at DNV GL’S facilities.
### SCiBreak's budget for PROMOTioN activities

<table>
<thead>
<tr>
<th>WP</th>
<th>No of PM</th>
<th>Our activities</th>
<th>Pers. cost</th>
<th>Travel cost</th>
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</thead>
<tbody>
<tr>
<td>WP 5</td>
<td>2</td>
<td>Modelling of DCCBs – Attend meetings, PSCAD modelling of DCCB, review deliverable</td>
<td>10 k€ +indir</td>
<td>1 k€ +indir</td>
</tr>
<tr>
<td>WP 6</td>
<td>3</td>
<td>Modelling of DCCBs – Attend meetings, PSCAD modelling of DCCB, review deliverable</td>
<td>15 k€ +indir</td>
<td>1,5 k€ +indir</td>
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<tr>
<td>WP 9</td>
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<td>Support for RTDS modelling of meshed HVDC networks</td>
<td>10 k€ +indir</td>
<td>1 k€ +indir</td>
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<tr>
<td>WP 10</td>
<td>12</td>
<td>Setup and testing of HVDC breaker module, evaluation of results, create input to modelling in WP6. Contribute to standardization.</td>
<td>60 k€ +indir</td>
<td>6,5 k€ +indir</td>
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<td>Total</td>
<td>19</td>
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<td>Total + 25%</td>
<td></td>
<td></td>
<td>131,25 k€</td>
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Summary of proposals
# Summary of proposals

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<thead>
<tr>
<th>Identify technical requirements and investigate possible topologies for meshed HVDC offshore grids</th>
<th>DC GIS technology demonstrator</th>
<th>MMC Test bench</th>
<th>Extension of WP13</th>
<th>DC Circuit breaker</th>
<th>Analysis method</th>
<th>Cost Benefit</th>
<th>Budget for new partner</th>
<th>Cost Benefit</th>
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<tr>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Develop protection schemes and components for HVDC grids</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>Establish components’ interoperability and initiate standardisation</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstrate cost-effective offshore HVDC equipment</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Develop recommendations for a coherent EU and national regulatory framework for HVDC offshore grids</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>Develop recommendations for financing mechanisms for offshore grid infrastructure deployment</td>
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<td>X</td>
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<tr>
<td>Develop a deployment plan for HVDC grid implementation</td>
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<td></td>
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<tr>
<td>Disseminate results to relevant stakeholder communities</td>
<td>X</td>
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</table>
PROMOTioN - The Project

Project Structure

WP15
DC GIS demonstrator
ABB

MMC test bench

Budget for SCibreak
Cost benefit analysis method
Extension of WP13
DC circuit breaker logistics
## Summary of proposals

<table>
<thead>
<tr>
<th>Proposal</th>
<th>Person-months</th>
<th>Total estimated eligible costs</th>
<th>Max EU contribution</th>
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<td>DC GIS demonstrator</td>
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<td>€ 4 420 955.86</td>
<td>€ 3 287 794.10</td>
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<td>MMC test bench</td>
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<td>€ 3 973 250.00</td>
<td>€ 2 850 875.00</td>
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<td>Extension of WP13</td>
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<td>€ 486 161.25</td>
<td>€ 425 191.50</td>
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<td>DC circuit breaker logistics</td>
<td>0</td>
<td>€ 300 000.00</td>
<td>€ 210 000.00</td>
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<tr>
<td>Cost Benefit Analysis Method</td>
<td>0</td>
<td>€ 250 000.00</td>
<td>€ 175 000.00</td>
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<tr>
<td>Budget for new partner</td>
<td>19</td>
<td>€ 131 250.00</td>
<td>€ 91 875.00</td>
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<td><strong>All proposals</strong></td>
<td><strong>341.7</strong></td>
<td><strong>€ 9 561 617.11</strong></td>
<td><strong>€ 7 040 735.60</strong></td>
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</tbody>
</table>
• Background
• Proposal Wrap-Up
• Introduction for the discussion
Background
Background

• PROMOTioN has several demonstration aspects across different work package
  • Circuit breaker (WP 5 & 6)
  • Wind farm demonstrator/ diode rectifier unit (WP 8)
  • Protection systems (WP 9)

• WP8 Demonstrator arrived at a “No Go” decision mid to late last year
  • Unfortunate BUT foreseen in the proposal
  • Can the resources be steered towards other activities which also foster a swift diffusion of meshed HVDC offshore grids into practical application by tackling existing barriers?
Background

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Proposal Wrap-up
Proposal generation process

• Process to find alternative opportunities started end of December last year (2016)
  • 3 Months to design, coordinate, write and revise the proposals
  • Budget range several million euros

• Well fleshed out, high quality proposals
  • Well adjusted to the call/ project objectives
  • Well incorporated into the existing project
  • Well aligned to the needs of industrial stakeholders

• Achievement within itself
Proposal Wrap-up

Two categories of improvement

• Smaller, focussed adaptations and extensions
  • Increase the effectiveness of PROMOTioN as it is
  • Improve upon existing project branches
  • „Quality of life“ improvements

• Major extensions
  • Expand upon PROMOTioN’s core ideas
  • Add new aspects to the project in line with its key objectives
  • “MMC Test Bench” & “DC GIS Technology Demonstrator”
Proposal Wrap-up

Major extensions

• Significant new impulses for the project on different technical levels and numerous individual benefits

• Strong connection to the overall project and call objectives

• Closely aligned to the existing ideas and concepts as well as the project structure in place
  • MMC test bench: WP 2, 3, 4, 8 and 12
  • DC GIS demonstrator: WP 5, 6 and 12
Proposal Wrap-up

Major extensions - Summary of core benefits

• DC GIS demonstrator
  • Practical demonstration of GIS equipment in the context of HVDC grids
  • Make it ready for deployment developing associated standards
  • Provide confidence regarding technological questions

• MMC Test Bench
  • Creating a demonstrator for HVDC grid behaviour
  • Creating a suitable “tool” for operational analysis and de-risking of operational/ structural decisions of future grids
Introduction for the discussion
Expected Impact

**PROMOTioN Project**

- Accelerating the deployment of meshed HVDC off-shore grids, with particular emphasis on Northern Seas partner countries, before 2020.

- Ensuring that the technology will be ready for deployment in other regions in Europe for all transnational corridors defined in the trans-European energy infrastructure regulation, or be compatible (plug-and-play) with other upcoming technologies (e.g. ocean energy, solar energy, geothermal energy, etc. as soon as these technologies are ready for similar capacities).

- Ensuring plug-and-play compatibility of all relevant equipment of the key suppliers.

- Preparing for corresponding priority infrastructure projects identified under the trans-European energy infrastructure regulation.

- Facilitating the efficient connection of off-shore wind resources to on-shore loads and with other available generation resources for balancing, covering the main Northern Seas partner countries.
Expected Impact

PROMOTioN Project

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• Facilitating the **efficient connection of off-shore wind resources to on-shore loads** and with other available generation resources for balancing, covering the main Northern Seas partner countries.
Meshed HVDC offshore grids (technological focus)

Practical concerns and barriers

• Preparation
  • What meshed HVDC offshore grid layouts should be targeted?
  • What are viable technological options?
  • How can meshed HVDC grids be suitably connected to the existing grid?

• Implementation
  • Can systems be actually build today?
  • What are civil engineering pitfalls building these systems?

• Operation
  • How can these systems be safely and efficiently operated and maintained?
  • How are grids impacted by new/ changing assets?
  • How are grids impacted by new/ changing topologies?
Meshed HVDC offshore grids (technological focus)

What is gained by the new proposals – MMC

• Preparation
  • What meshed HVDC offshore grid layouts should be targeted?
  • What are viable technological options?
  • How can meshed HVDC grids be suitably connected to the existing grid?

• Implementation
  • Can systems be actually build today?
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  • How can these systems be safely and efficiently operated and maintained?
  • How are grids impacted by new/ changing assets?
  • How are grids impacted by new/ changing topologies?
Meshed HVDC offshore grids (technological focus)

What is gained by the new proposals – GIS

• Preparation
  • What meshed HVDC offshore grid layouts should be targeted?
  • What are viable technological options?
  • How can meshed HVDC grids be suitably connected to the existing grid?

• Implementation
  • Can systems be actually build today?
  • What are civil engineering pitfalls building these systems?

• Operation
  • How can these systems be safely and efficiently operated and maintained?
  • How are grids impacted by new/ changing assets?
  • How are grids impacted by new/ changing topologies?
Summary

• Different parts of the suggested amendment
  • Smaller adaptations provide significant benefits to existing lines of work
  • Major extension expand the project to address additional aspects

• Major extensions promise substantial additional value in the context of PROMOTioN and the underlying call
  • Additional demonstration of relevant technological options/solutions
  • Tools for the secure operation and development of future grids
  • Tools for de-risking technological choices

• Strongly interlinked with the exiting tasks, expanding within the project’s scope
• The proposed additions are ambitious, but realistic
• Significant steps to make meshed HVDC a viable infrastructure decision
Thank you for your attention
Discussion & Questions
Thank you
Periodic review meeting

21st of March 2017 / Brussels
CONTENT

• Introduction
• Technical review
• Management aspects
• Next period
• Conclusions
Introduction

Objectives

• Identify **technical requirements** and investigate possible **topologies** for **meshed HVDC offshore grids**

• Develop **protection schemes** and **components** for **HVDC grids**

• Establish components’ **interoperability and initiate standardisation**

• **Demonstrate cost-effective** offshore HVDC equipment

• Develop recommendations for a coherent EU and national **regulatory framework** for **HVDC offshore grids**

• Develop **recommendations for financing mechanisms** for offshore grid infrastructure deployment

• Develop a **deployment plan** for **HVDC grid implementation**
Offshore wind developments
WP13 – Policy and Market Development Context
Offshore Wind in 2016

• Policy Context
• Market Development in Europe
• Outlook 2017 and beyond
WP13 – Policy Context and Market

June 2016  MoU signed for North Seas Energy Cooperation, accompanied by wind industry’s cost reduction statements

NL tender results for Borselle 1+2, → 72,7 €/MWh

July 2016  New German RE Act passed – fundamental shift from FIT to auction regime

Sep. 2016  DK Nearshore tender results → 60,8 €/MWh

Nov. 2016  DK Kriegers Flak tender result → 49,9 €/MWh

NL Borssele 3+4 tender result → 54,5 €/MWh

EU Clean Energy Package proposals
WP13 – Offshore Wind Market Development 2010-16
CONSTRUCTION SUMMARY 2016

Compared against 2015

1,558 MW Installed capacity -48%
338 Grid-connected turbines -55%
361 Turbines erected -12%
568 Foundations installed +41%

Source: WindEurope
WP13 – Offshore Wind Technology Development 1991-2016

The average turbine connected to the grid in 2016 was **4.8 MW**. Turbines in 2016 are **15% larger** than in 2015.

Source: WindEurope
WP13 – Market Outlook
WP13 – Outlook 2017 and beyond

2017 TENDER SCHEDULE for Offshore Wind Farms

• UK: Next CfD round - Bids open 3 April 2017

• NL: Zuid-Holland I +II, Bid open 2017 for 700MW

• FR: Third tender at Dunkirk, Selection process in progress

• DE: Transitional tenders
  • 1st tender April 2017 (1.55GW)
  • 2nd tender April 2018 (1.55GW)

• UK: Additional two CfD rounds before 2020
HVDC developments
WP1 – DC Developments

- DC concepts TenneT
- DC within synchronous areas
- Developments in China
Introduction

Project context – DC concepts TenneT

• Long term vision: North Sea Wind Power Hub, cooperation TenneT and Energinet.dk, discussion with other potential partners ongoing

• Near term development IJmuiden Ver: all options being considered (up to 6 GW)
  • AC with compensation
  • DC radial
  • DC radial with island
  • DC with windconnector
  • DC with combinations of AC or DC connections offshore

• Interconnectors and windconnection competing for same onshore grid capacity

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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.
Introduction

Project context – DC in synchronous areas

- Connecting load centers to centralized renewable energy production (offshore wind)
- New concepts for operation become available, how to integrate into existing operational and market designs
  - Possibly operation at 100% capacity, where in the AC grid N-1 is standard
  - Reactive power compensation
  - Redirection of flows
Introduction

Project context – DC in China

- Zhoushan 5 terminal project commissioned in 2016 with Circuit Breaker (200kV, 400/300/100/100/100 MW)
- Zhangbei first application of meshed HVDC, 500kV overhead lines, half-bridge VSC converters
- Back to back combinations of LCC and VSC
- ‘Intercontinental’ scale (10.000MW, 800kV)
Work Package 1
Requirements for meshed offshore grids
CONTENT

• WP1 objectives & relevance
• Technical review
• Management aspects
• Next period
Work Package 1
Technical Review – WP1

WP1 – Introduction

Niek de Groot

- Economic Adviser DC Interconnectors at TenneT TSO
- PROMOTioN Project WP1 Workpackage lead
- Systems Engineering, Policy Analysis & Management, TU Delft

Email: Niek.de.Groot@TenneT.eu
WP1 – Requirements for Meshed Offshore Grids

WP 1 – Requirements for meshed offshore grids

WP 2  Grid Topology & Converters  RWTH
WP 3  WTG – Converter Interaction  DTU
WP 4  DC Grid protection system development  KU Leuven
WP 5  Test environment for HVDC circuit breakers  DNV GL
WP 6  HVDC CB performance characterisation  UniAbdn
WP 7  Regulation and Financing  TenneT
WP 8  Wind farm demonstrator  Siemens
WP 9  Demonstration of DC grid protection  SHE Transmission
WP 10 Circuit Breaker performance demonstration  DNV GL
WP 11 Harmonization towards standardisation  DTU
WP 12 Deployment plan for future European offshore grid development  TenneT
WP 13 Dissemination  SOW
WP 14 Project Management  DNV GL
Technical Review – WP1

WP1 – Requirements for Meshed Offshore Grids

• To define reference scenarios and fundamental topologies from a holistic point of view
• To compile and analyze studies and available and emerging technologies for offshore grids
• To assess and evaluate the operational, financial, technical, regulatory, planning, reliability and availability aspects of offshore connections and grids
• To identify under which circumstances a certain fundamental topology is likely to be implemented
• To validate that the requirements that are defined in the beginning of the project, are still valid when the first conclusions are drawn from work done in the project

Create a foundation for the rest of the project; facilitate early interaction between the different workpackages; steer and guide activities towards usable results
### WP1 – Task description

<table>
<thead>
<tr>
<th>Task 1.1</th>
<th>Requirements, Reference scenarios and Fundamental topologies</th>
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<tbody>
<tr>
<td>Task 1.2</td>
<td>Collect knowledge from literature</td>
</tr>
<tr>
<td>Task 1.3</td>
<td>Collect knowledge from projects</td>
</tr>
<tr>
<td>Task 1.4</td>
<td>Design Initial roadmap</td>
</tr>
<tr>
<td>Task 1.5</td>
<td>Review requirements Task 1.</td>
</tr>
</tbody>
</table>
WP1 – Planned partner participation
Technical Review – WP1

WP – Partner participation – Planned vs Actual
WP1 – Personal experience

- Pleasantly surprised by the contributions of many of the PROMOTioN project partners
- Great learning experience for young people in the project, great way of sharing experience for more senior people

Positives
- Wealth of experience and knowledge available within the project consortium
- Wide range of expertise allowing for a holistic approach and end-result
- Strong mix of do-ers, thinkers and experienced reviewers

Challenges
- The scope of the project makes it a challenge to get all the different expertise on the same page
- Sometimes a challenge to reach out to and get input from the many partners in a predefined timeline. Important inputs often arrive late in the production of a deliverable
- Coordination and organization is labour intensive and takes dedication
Technical Review – WP1

Meetings

3 physical meetings D1.1

General PROMOTioN project meetings

6 physical meetings D1.5
D1.6 kick-off

D1.3 Stakeholder workshops

In addition to numerous Telco’s, bilateral meetings, calls etc.

M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12

Amsterdam
Brussels
Madrid
Stockholm
Edinborough
Amsterdam
Hamburg
Brussels
Amsterdam
Copenhagen
Arnhem
Copenhagen
Arnhem
Berlin

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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.
### WP1 – Requirements for meshed offshore grids

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<th>#</th>
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<th>2017</th>
<th>2018</th>
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<td>1.1</td>
<td>Define requirements, reference scenarios and fundamental topologies</td>
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<td>1.2</td>
<td>Studies, available and emerging technologies for offshore grids</td>
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<td>Assessment and inputs from existing offshore connections and grids</td>
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<td>Initial roadmap for the evacuation of offshore renewable generation</td>
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<tr>
<td>1.5</td>
<td>Re-evaluate requirements based on work of other packages</td>
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</table>

= Deliverable
• Definition of requirements
• First deliverable of the PROMOTioN project after only 3 months
• Large amount of partners involved
• First defining what requirements are
• Then development of qualitative set of requirements through iterative process
Technical Review – WP1

Task 1.1 Deliverable 1.1

Tasklead: TenneT TSO

Objective: Definition of requirements

- Introduction of possible topologies
- Definition of System Requirements
  - Transmission and capacity requirements
  - Interoperability
  - Reliability
  - Stability and Controllability
- Introduction of interfaces and interface requirements
- Quantified in D1.5
Task 1.2 Deliverable 1.3

Tasklead: Tractebel

Objective: Report with a synthesis of the available studies on offshore meshed HVDC grids and related barriers/gaps at the inception of the project

• Tasklead Tractebel delivered an excellent review of available studies with the following chapters:
  • System planning and grid topologies
  • Converters
  • Protection systems
  • Circuit Breakers
  • Finance and Regulation

• The document serves as a very good overview for specialists that want to broaden their view and people new to the subject
1. It is unlikely that the final solution consists of a single large interconnected offshore grid: roadmaps usually come up with several offshore grids not connected together by DC branches.

2. Complex offshore topologies (i.e. radial multi-terminal and meshed grids) appear to be cost-efficient only for scenarios considering both a high offshore wind generating capacity and numerous offshore hubs to collect this energy (geographical spreading).

3. The economical advantage of complex offshore topologies such as radial multi-terminal and meshed grids can only be demonstrated when the overall grid structure is optimized.

4. Adding HVDC components will lead to interactions, especially in weak offshore AC grids. Introduction of DRU will lead to new phenomena of which the impact is still unknown.

5. There is no consensus on the best protection system mechanism for MOG, and no basic protection system mechanism fulfills all the requirements for the operation of a MOG. A key barrier is the lack of detailed data on the behavior of DC Circuit Breakers.

6. There appears to be no consensus on the way to alleviate regulatory and financial barriers. Several reports propose different and sometimes conflicting recommendations.
Task 1.3 Deliverable 1.2

Tasklead: Iberdrola

Objective 1: Report document results of the questionnaire on best practices

Objective 2: Stakeholder workshops to enrich the information

• Questionnaire developed in dual format (word and online)
• Two workshops organized, one in Edinborough and one in Hamburg
Task 1.3 Deliverable 1.2
Tasklead: Iberdrola

- A broad range and large quantity of stakeholders was targeted with the questionnaire
- Challenge to get good response to questionnaire even after many mails and mentions in presentations
- The responses we received were generally of good quality and led to interesting insights

- The workshops focused on the UK/Nordics in Glasgow, and continental Europe in Hamburg.
- Both workshops had a good attendance and interesting speakers
Objective: Report with reference scenario and related offshore meshed HVDC grid topology

• Making available and selecting existing scenario’s
  • TYNDP
  • E-Highways

• HVDC grid topology;
  • Fundamental topologies already introduced in D1.5 (‘building blocks’ for a Meshed Offshore Grid)
  • Benchmark topologies were developed by WP2 & 4 in alignment with WP1, ensuring the use of consistent test networks
  • ‘Reference Networks’ in development in D1.6 and WP12
Technical Review – WP1

Task 1.1 Deliverable 1.5

Tasklead: TenneT TSO

Objective: Quantified set of requirements
• Strong interaction with technical WPs
Task 1.1 Deliverable 1.5 approach

2x3 Expert meetings with a scope of chapters out of Deliverable 1.1:
- **Chapter 4**: Onshore AC – DC grid
- **Chapter 5/6**: Meshed Offshore Grid – Offshore Windfarm
- **Chapter 7**: DC grid protection / operation

- Strong interaction with WP 2, 3 and 4.
- Ensuring consistency in assumptions between different studies

Leading to a set of quantified requirements to be reviewed and updated in Task 1.5, D1.7
Technical Review – WP1

Dissemination

• Deliverables
  • Published on website
  • Disseminated via other media by WP13

• Contribution to Reference Group meetings

• Contributions to WP13 efforts (media interviews, promo video’s etc.)

• Stakeholder workshops Task 1.3
  - Glasgow
  - Hamburg
Next period

1.4 Initial roadmap for the evacuation of offshore renewable generation
• Simulation of roadmap development
• Reporting and development of reference networks
• Development of visualization tool by Phase to Phase

1.5 Re-evaluate requirements based on work of other packages
• Task starting after the summer of 2017

Draft output Phase to Phase visualisation
Draft output Tractebel simulation draft roadmap development
Work Package 2
Grid Topology and Converters
CONTENT

• Introduction to WP2
• Report on Task 2.1
• Status presentation Task 2.2
• Overview dissemination and timeline
Introduction – WP 2
Objectives WP 2

- To compare and perform a trade-off analysis of different topologies
- To develop control and operational concepts for different configurations to ensure interoperability
- To study and demonstrate the interconnection of VSC and DRC HVDC systems in realistic scenarios
- To define recommendations on onshore and offshore power systems for existing grid codes
Technical Review – WP2

Timeline

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

✓ D 2.1: Grid topology and model specification

2.2 Adaption of simulation models for the meshed HVDC offshore topologies

→ D 2.2: Scenario and test case specification

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

→ D 2.3: Simulation results and benchmark

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

→ D 2.4: Requirements for grid code extension
Overview of Research Questions Addressed

- Meshed offshore grid
  - Onshore AC
- Meshed offshore grid
  - Operation
- Meshed offshore grid
  - Offshore generation

Steady State Operation

Normal Set point Changes

Fault Or Outtakes
Technical Review – WP2

Involved Partners

- Work Package Leader:
- Participants:

SIEMENS  ABB  GE  Prysmian

Technical University of Denmark
University of Strathclyde
Glasgow
Universitat Politècnica
de València

FGH

DNV·GL  TRACTEBEL Engineering  GDF SUEZ  IBERDROLA
Technical Review – WP2

Beneficiaries contribution and integration

PROMOTioN – WP 2

- Meshed offshore grid
  - Onshore AC
- Meshed offshore grid
  - Operation
- Meshed offshore grid
  - Offshore generation

**Steady State Operation**
- Applicability of limits from HVDC grid code for point-to-point connections on meshed grids

**Normal Set point Changes**
- Allowable and necessary ramp rates
- Power oscillation damping

**Fault Or Outtakes**
- AC and DC FRT
- Power flow loss over time
- Frequency support
- Protection Coordination
- Synthetic inertia

**Grid design & planning**
- Capacity and redundancy
- Operation

**Characteristics offshore grid**
- Allowable frequencies

**Suitable MTDC Grid controller**
- MTDC/Droop Control
- Recovery after fault

**Response times of WPP**
- From order to shut down
- Possible ramp rates

**System FRT**
- Synthetic inertia
- Protection coordination

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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. 14.04.2020 49
Integration in the overall project scope

WP 1
Requirements for meshed offshore grids

Converter model specification
MS 17

WP 3
Wind Turbine converter interactions

WP 2
Grid Topology and converters

WP 4
DC Grid protection system development

WP 12
Deployment plan for future European offshore grid development

Requirement specifications
MS 5, MS 8

Model parameter coordination
MS 6

Protection approaches
MS 9

WPP model
MS 7

Requirements for meshed offshore grids

WP 1

Technical Review – WP2

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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.
Report on Task 2.1: Definition of model and control parameters for offshore topologies
1. Analysis of existing and planned systems
   • Input from WP 1 (D1.3)
   • Ten Year Network Development Plan (TYNDP)
   • Cigré compendium of all HVDC projects

2. Deduction of topology and component specifications
   • Comparison of different topologies
   • Representation of different technologies

3. Definition of model and control structure
   • Based on Cigré definitions
   • Different simulation time frames and scopes
   • Modelling expertise of beneficiaries
Task 2.1 – Definition of flexible network topology

Aims
• Represent realistic scenarios
• Allow flexibility for different research aims

Considerations
• Current and future technological limits
• Geographical characteristics of the North Sea region

Technical options
• Meshing on the DC side
• Meshing on the AC side
• Different synchronous zones
Task 2.1 – Specifications of key component parameters

- All offshore components and onshore representations included
- Hardware specification according to existing and planned projects, e.g. German windfarms interconnected by HVDC
- Input from vendors on converter technology and cable specifications
Task 2.1 – Model specifications for key components

Consideration of

- Different simulation scopes
- Variety of simulation tools
Status presentation task 2.2
Technical Review – WP2

Task 2.2 – Adaption of simulation models

Detailed Model set-up in PSCAD
- Based on Cigré working group B4.69
- Adaption to parameter settings from D2.1
- Implementation of network structure

RMS model set-up in various tools
- Based on parameters and control structure of EMT model
- Level of detail according to research scope

Quasi-stationary model set-up in Integral
- Based on data from TYNDP
Task 2.2 – Model validation on test cases

Definition of test cases
- Consideration of future investigations
- For steady-state, set point changes and fault situations

Validation of models
- Comparison to vendors’ models
- Vendors’ experience
- Feedback from other WPs
Overview dissemination and timeline
Ongoing:
Interaction with Cigré modelling group on HVDC converters B 4.71, sharing experience in modelling HVDC systems for future system studies

Planned:
Deliverable 2.4: Define recommendations for minimum requirements on onshore and meshed offshore DC power systems in order to adapt and extent existing grid codes
• More holistic approach on HVDC systems
• Consider AC and DC system as one to investigate influence on each other
• Reducing overdimensioning of equipment
On going- preparations for task 2.3:
• Detailed specification of research questions
• Set-up of simulation plan
• Close collaboration with task lead
Technical Review – WP2

Summary WP 2

✓ Specification of models and topologies completed

✓ Adaption of simulation models for planned simulative investigations

✓ On-going validation of simulation models

✓ Identification of open questions to be addressed within the field of WP 2

✓ Preparations for task 2.3 for a quick start of simulative investigations
Thank you for your attention
Work Package 3
Wind Turbine – Converters Interaction
WP3 Partners
WP3 Core Objectives

To develop reliable and cost-effective technology for new type of offshore converter for wind power integration

To establish interoperability between different technologies and concepts by providing specific technical and operational requirements, behaviour patterns and standardization methods for different technologies
WP3 Objectives

1. define functional **requirements** to OWFs, focusing on DR-HVDC case
2. develop general **control** algorithms for OWFs, focusing on DR-HVDC case
3. define and apply **compliance** evaluation procedures for OWFs by simulations

verify **interoperability** of the WT and OWF controls by simulations

generate **grid code recommendations** for DR-HVDC connection of OWFs
WP3 Plan

**Technical Review – WP3**

**WP3 Plan**

- **March '16** – **T3.1**
  - Functional requirements to WPPs

- **September '16** – **T3.2**
  - General control algorithms

- **December '16** – **D3.1**, **MS16**, **MS17**
  - T3.1

- **September '17** – **T3.3**
  - Compliance evaluation procedure

- **December '17** – **D3.2**, **MS18**
  - T3.2

- **March '18** – **D3.3, D3.4, D3.5**, **MS19**
  - **T3.3**

- **December '17** – **D3.6**, **MS18**
  - **D3.2**

- **June '19** – **D3.7, D3.8, MS20**
  - Compliance evaluations based on detailed numerical simulations
Technical Review – WP3

WP3 Meetings

kick off WP3
start T3.1

DR-HVDC seminar
by Siemens & UPV

start T3.2

D3.1 submission

M1 M2 M3 M4 M5 M6 M7 M8 M9 M10 M11 M12

Roskilde, 24 attendees
Telecon, 21 att.
Telecon, 8 att.
Stockholm, 26 att.
Telecon, 13 att.
Telecon, 21 att.
Telecon, 18 att.
Glasgow, 14+5 att.
Berlin, 18 att.
OPERATIONAL REQUIREMENTS
- Operational States
- Start-up
- Voltage Ranges
- Frequency Ranges
- Rate of Change of Frequency Ranges
- Active Power Control
- Islanded Operation
- Harmonics
- Interoperability

SYSTEM STABILITY REQUIREMENTS
- Offshore frequency control/support
- Offshore voltage/reactive power control
- Offshore AC symmetrical/asymmetrical fault
  - Fault Ride-Through
  - Fault Current Injection
  - Post-Fault Recovery
- Onshore AC fault
  - Detection
  - Active Power Limitation
  - Active Power Recovery
- DC fault
  - Permanent DC Fault
  - Securely Cleared DC Fault
- Onshore frequency support/control
  - Fast Frequency Support
  - Synthetic Inertia
- Power Oscillation Damping to onshore AC grid

[ENTSO-E RfG and HVDC network codes and national grid codes have been utilized too]
Technical Review – WP3

D3.1 Detailed functional requirements to OWFs

D1.1 & D2.1 → case studies for DRU-HVDC connection → Task 3.2 Control Specs.

e.g. interoperability (with blackbox models)
D3.1 Detailed functional requirements to OWFs

D3.1 → Task 3.2 Control Specifications → Modeling and Simulation Results

- e.g. offshore fault-ride-through
- e.g. frequency support to onshore grid

![Graph showing voltage time characteristics](image)

\[ \Delta P \text{ [pu]} \]

\[ \Delta P = K_f \times (\Delta f - \Delta f_{nom}) \text{ [Hz]} \]

- \( K_f < 0.1 \) and \( K_f < -0.1 \)
- \( K_f < 0.1 \) and \( K_f < -0.1 \)

for example \( \Delta f_{nom} = 0.1 \text{pu} \) when \( \Delta f = 1 \text{Hz} (f=49 \text{Hz}) \)
Technical Review – WP3

D3.1 Detailed functional requirements to OWFs

D3.1 → OWF Modeling for HVDC connection(s) → T3.2 Detailed Modeling

genetic OWF layout

VSC-connected OWF model (to WP2)
Technical Review – WP3

T3.2 General control algorithms for OWFs

with focus on DRU-HVDC connection

[D3.2] Base line scenario with three DRU platforms

[D3.2] Energization procedure

+ 7 levels of aggregation

P.S.: Deliverable 3.2 is currently being submitted
WP3 Dissemination

Wind Integration Workshop, 15-17 November 2016
- Connection of OWPPs to HVDC Networks Using VSCs and Diode Rectifiers: an Overview
- Modelling of the Diode-Rectifier Based HVDC Transmission Solution for Large Offshore Wind Power Plants Grid Access
- Simultaneous Connection of Type-3 and Type-4 Offshore Wind Farms to HVDC Diode Rectifier Units

Offshore Wind Energy Conference, 6-8 June 2017
- Generic Electrical Models for HVDC-connected Offshore Wind Power Plants

Powertech, 18-22 June 2017
- Asymmetrical Fault Analysis at the Offshore Network of HVDC connected Wind Power Plants
Technical Review – WP3

WP3 Next Period (M13-M24)

T3.2 General control algorithms [M09-M24]
   D3.2 (being submitted)
   Specifications of the control strategies and the simulations test cases

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

T3.3 Compliance evaluation procedure [M21-M27]
   (kick off September 2017)

T3.4 Compliance evaluations based on detailed numerical simulations [M24-M42]
   (kick off December 2017)
Work Package 4
DC Grid protection system development
Objectives

This WP aims to develop multivendor DC grid protection system. The goal is:

▶ to develop a set of functional requirements for various DC grids: from small scale to large overlay grids and for a variety of system configurations and converter topologies
▶ to analyse a wide range of DC grid protection philosophies on a common set of metrics
▶ to identify the best performing methods for the systems under study
▶ to develop detailed protection methodologies for the selected methods
▶ to develop configurable multi-purpose HVDC protection IEDs to enable testing of the methodologies
▶ to investigate the key influencing parameters of protection systems on the cost-benefit evaluation
## WP4 worktable

<table>
<thead>
<tr>
<th>Task</th>
<th>LEAD</th>
<th>Description</th>
<th>Start</th>
<th>End</th>
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<tr>
<td>WP4</td>
<td>KUL</td>
<td>DC Grid protection system development</td>
<td>3</td>
<td>42</td>
</tr>
<tr>
<td>4.1</td>
<td>Statoil</td>
<td>Investigation and evaluation of fault detection and selectivity methods, towards functional requirements</td>
<td>3</td>
<td>12</td>
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<td>4.2</td>
<td>KUL</td>
<td>Screening analysis of various protection methods for different topologies</td>
<td>8</td>
<td>20</td>
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<tr>
<td>4.3</td>
<td>KUL</td>
<td>In depth study of selected protection methods towards practical implementation</td>
<td>18</td>
<td>42</td>
</tr>
<tr>
<td>4.4</td>
<td>KTH</td>
<td>Development of configurable HVDC protection IEDs for multi-purpose and multi-vendor grid protection 0)</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>4.5</td>
<td>SGI</td>
<td>Preparation of cost/benefit analysis of studied protection solutions</td>
<td>3</td>
<td>42</td>
</tr>
</tbody>
</table>

- Large WP: 362 PM (in 2016 75.6 PM used)
- 18 partners
- Set up a core group to streamline efforts (bi-weekly meetings/telco)
Basic flows within Promotion related to WP4

4.1 Functional requirements + tests (Statoil)

4.2 Benchmarking algorithms (KUL)

4.3 Industrializing protection methods (KUL)

4.4 IED Development (KTH)

4.5 Cost benefit analysis protection (SGI)

9 Validation in RTDS (SSE)

10 Roadmap for HVDC Grids (TenneT)
Basic flows within Promotion related to WP4

4.1 Functional requirements + tests (Statoil)

4.2 Benchmarking algorithms (KUL)

4.3 Industrializing protection methods (KUL)

4.4 IED Development (KTH)

4.5 Cost benefit analysis protection (SGI)

9 Validation in RTDS (SSE)

12 Roadmap for HVDC Grids (TenneT)
Deliverables

- D4.1: Definition of representative test cases for DC grid protection and functional requirements for DC grid protection methodologies (M12)
- D4.2: Report on the broad comparison of protection philosophies for the identified grid topologies (M18)
- D4.3: Report on performance, interoperability and failure modes of selected protection methods (M36)
- D4.4: Preparation of protection methodologies for testing in the MTTE environment (M30)
- D4.5: Requirements for DC switchgear [joint deliverable with WP5] (M42)
- D4.6: Functional HVDC protection IED including documentation (M36)
- D4.7: Preparation of cost-benefit analysis from a protection point of view (M42)
Goal of D4.1

- Definition of representative test cases for DC grid protection and functional requirements for DC grid protection methodologies (M12)

- Objectives:
  - agree on how to design a protection system for DC systems, based on functional requirements
  - understand and agree about the interactions in AC/DC grids for protection purposes
  - understand and agree on the main parameters which need to be analysed
  - define benchmark networks and test cases to be able to create consistent benchmarks
  - agree on a common vocabulary
  - Very hard task (many opinions/stakeholders)
Delivery of D4.1

Iterative process to collect data from our partners on functional requirements

- Questionnaire sent out in April
- 10-12 responses received
- Internal discussions over the summer
- First proposal after the summer (London meeting)
- WP4 partner comments on functional requirements (October 1)
- 1st Expert meeting DC grid protection (WP1+WP4) October 4
- Aggregating inputs and sending them out in new version to all partners together with WP1
- Telephone conference to discuss feedback on the inputs (November 1)
- 2nd Expert meeting DC grid protection (WP1+WP4) November 15
- (3rd call for feedback, together with WP1, November 22)
- Near consolidated version 30/11
- Delivery to reviewers early January, submission to EU end of January
Results from D4.1

- Maximum loss of infeed is dependent on time
- Time intervals: few ms, hundred of ms, permanent
- Aligned with continuous operation, temporary stop or permanent stop during protection
Results from 4.1 (II)

- Voltage specifications (at DC side) are necessary
- Specifications depend on a wide number of parameters
- Definition of continuous operation, temporary stop and permanent stop at DC side

(source: Cigré B4-56)
Results from D4.1 (III)

- Zone 1: out of norm
  - Highly unlikely
  - No particular protection design to address them

- Zone 2: unacceptable consequences
  - High impact, high probability
  - Reduce probability or impact (e.g., by adapting system design or protections)

- Zone 3: unacceptable risk
  - Medium impact, med-high probability
  - Adapting protections needed

- Zone 4: acceptable risk
  - Low impact, med-high probability
  - No actions necessary
Small, medium, large systems

“Small impact” grid: the loss of the whole HVDC grid will only have limited impact on the AC grids, seen as small voltage and frequency variations which are quickly restored. Loss of the system has an impact comparable to an “N-1” event.

“Medium impact” grid: the loss of the whole HVDC grid will cause significant voltage, rotor angle and frequency transients seen on the AC grid; AC grids are able to recover from the contingency, without black-out, but possible load shedding in part of the system.

“Large impact” grid: The DC grid forms the backbone of the transmission system and loss of this system likely leads to a blackout.
WP4.2: Screening analysis for various protection methods for different topologies

- Step 1: a literature study of fault identification methodologies and protection philosophies
- Step 2: qualitative assessment of fault clearing strategies. Linking protection with specific systems (protection matrix concept)
- Step 3: quantitative (high level) assessment of fault clearing strategies
- Develop a benchmarking tool/approach for different protection methods
- Comparative study and analysis of different approaches, with different breaker technologies using protection matrices
- Robustness of schemes
- Backup approach
- Effect of inductors, OHL/Cable, grounding, . . . Cost elements? ⇒ nr breakers needed, max operating speed allowed, . . . (input from WP4.5)
- Started September 2016, Deliverable 4.2 by M18
- Task Leader: Willem Leterme (KU Leuven)
WP4.3: in-depth study of selected protection methods

- Start July 2017
- Select top ranked candidates
  - Do study towards practical implementation
- Including measurements, communication, noise management, . . .
- Multi-vendor application of protection methods
- Restoration after faults
- Standardization of operating ranges (with WP 6)
- Validate functional requirements
- “EMT” based studies
- Task Leader: KU Leuven
WP4.4: development of configurable HVDC protection IED for multi-purpose and multi-vendor DC grid protection

- Start October 2017
- Develop programmable IEDs which allow all protection methods of 4.3 to be implemented
- FPGA based solution
- Make sure it has a degree of “userfriendliness”.
- To be used in the RTDS of WP9
- Task Leader: Staffan Norrga (KTH)
WP4.5: Preparation of cost-benefit analysis for studied protection methods

- Provide initial indicators to evaluation done in 4.2
- Preparation towards delivery to WP12
- Initial indicators: nr of breakers, EENS, system losses? Volume of breakers offshore,...
- Goal: CBA of protection methods
- Tool developed by SGI, focusing on the reliability/protection aspects of HVDC grid protection strategies
- Methodology is described in an internal report
- In order to have realistic results, realistic data is necessary
- Cost data is very tricky to obtain
- Task Leader: Serge Poullain (SGI)
Promotion: WP4 report – EU Review Meeting 1

Dissimination

- Functional requirements were presented to outside stakeholders
  - Reference group meeting in Hamburg
  - Invited presentation at HVDC2016 conference in Shanghai
- General approval of the idea and concepts
  - Written feedback received from two partners
- Two contributions at IET ACDC 2017 (based on work in year 1)
WP4: summary

- Kickoff meeting March 9, 2016, further meetings in July, September, November
- Tasks 4.1, 4.2 and 4.5 started
- Task 4.1: Finalized
  - Functional description of protection systems
  - Defining test systems
  - D4.1: delivered M13
- Task 4.2: Started
  - Benchmarking different options for protection
  - Which are the fault clearing strategies (literature review completed and assessment approach determined)
  - How to benchmark?
- Task 4.5: Started
  - Cost-benefit analysis of the protection aspect
  - Description of approach available
  - Providing input to task 4.2
  - Cost data!
Questions?

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APPENDIX

DISCLAIMER & PARTNERS

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Vestas Offshore Wind AS, Energinet.dk, Scottish Hydro
Electric Transmission plc
Work Package 5
Test Environment for HVDC Circuit Breakers
CONTENT

• Introduction
• Objective of WP5
• Works completed in 2016
• Works in progress
WP5 – Test environment for HVDC circuit breakers

Testing of HVDC CB

- System behaviour during fault
- Different Technologies of HVDC CBs
- Interaction of HVDC CBs with System
- Test-Circuits and Test Methods

Test Requirement Definition
WP5 – Test environment for HVDC circuit breakers

**Objectives:**

- Identify **worst fault situations** in meshed HVDC grids
- Produce dynamic, **black-box models** of HVDC circuit breakers of various technologies
- Embed these models in a benchmark system to quantify the **electrical stresses** (current, voltage, energy) to which HVDC circuit breakers are subjected during a fault.

- Develop **test requirements and test procedures** for HVDC circuit breakers
- Investigate and compare different HVDC CBs test-circuits and methods
- Realize **high-power test-circuits** including the necessary equipment (components) specifically needed for HVDC testing.
## WP5 – Test environment for HVDC circuit breakers

### Tasks and Deliverables

<table>
<thead>
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<th>#</th>
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<th>2018</th>
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<td>5.2</td>
<td>HVDC circuit breaker modelling and analysis</td>
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<td>Fault stress analysis</td>
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<td>Test requirement specification</td>
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<td>5.5</td>
<td>Definition of test procedures</td>
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<td>5.6</td>
<td>Characterization of candidate test-circuits</td>
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<tr>
<td>5.7</td>
<td>Realization of test environment</td>
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</tbody>
</table>

= Deliverable
Task 5.1 - HVDC Network Fault Analysis

- **HVDC Network Study grid**
  - Five terminal HVDC grid with bipolar converter configuration
  - ±320 kV, half bridge MMC converter topology
  - Only cable interconnection is considered
  - A pole-to-ground fault is investigated

- To identify worst case situations of faults from grid simulations
Technical Review – WP5

Task 5.1 - HVDC Network Fault Analysis

- Studied the impacts of various system and fault conditions
  - Grid topology
  - Fault location
  - DC current limiting reactor
  - AC network strength
  - Converter blocking
The first few milliseconds dominated by sub-module capacitor discharge ($t_2$-$t_3$)

At $t_3$ converter blocks.

The DC voltage drops following converter blocking

From $t_4$ onwards AC infeed through diode rectifier

DC current limiting reactors are used to limit the magnitude of fault current to circuit breakers interruption capability

- D5.1 Report describing the fault analysis (M09)
HVDC CB Models

Task 5.2 – Dynamic, blackbox models HVDC circuit breakers

Active current injection HVDC CB
Task 5.2 – Dynamic, blackbox models HVDC circuit breakers

Hybrid HVDC CB Type I

Hybrid HVDC CB Type II

D5.2 PSCAD Software models for the electrical behavior of the HVDC CB (M09)
Technical Review – WP5

Task 5.3 - Fault stress analysis

• Current interruption by various technologies of HVDC CBs have been studied
• The main transient stresses on HVDC CB are identified
• Breaker operation
• Maximum current interruption capability
• Energy absorption capability

D5.3 Report on fault stress analysis for the various technologies - (M11)
Task 5.6 - Characterization of candidate test-circuits
Technical Review – WP5

Contributions

• Work package lead
  • Project management
  • Modelling & simulations
  • Reporting D5.1, D5.2 & D5.3

• Contributing partner
  • Modelling & simulations
  • Reporting D5.1 & D5.3

• Reviewing partner
  • Reviewing partner

• Reviewing partner

• Reviewing partner

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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.
Meetings

- 22 February
  - DNV GL visit to ABB
  - 17th March, Arnhem

- 23 June
  - DNV GL visit to MELCO
  - 15th June, Stockholm

- 8th September
  - 8th September, London

- 29th November
  - 29th November, Berlin
Dissemination


Technical Review – WP5

Works in progress

• 5.4 Test requirement specification
  • 5.4.1 Define different types of test
  • 5.4.2 Determine test requirements
• 5.5 Definition of test procedures
  • 5.5.1 Determine sequence, type, duty and frequency of tests
  • 5.5.2 Determine pass/fail criteria
  • 5.5.3 Determine measurements to be made
• 5.6 Characterization of candidate test-circuits
  • 5.6.1 Identification of candidate test circuits
  • 5.6.2 Comparison of candidate test circuits
  • 5.6.3 Qualification of candidate test circuit
Technical Review – WP5

Works in progress

- 5.7 Realization of test environment
- 5.7.1 Design and realisation of test circuit
- 5.7.2 Preliminary experiments
- 5.7.3 Commissioning of test circuit
Thank you for your attention!

Questions?
Work Package 6
HVDC circuit breaker performance characterization
WP6 – HVDC Circuit Breaker Characterisation

Objectives:

• To develop and verify system-level offline model for hybrid and mechanical DC CB,

• To develop and verify detailed component level model for hybrid and mechanical DC CB,

• To develop and verify kW-size hardware prototypes for hybrid and mechanical DC CBs,

• To demonstrate DC CB failure modes on kw-size hardware prototypes,

• To develop roadmap for hybrid DC CB scaling to EHV DC voltage,

• To develop roadmap for mechanical DC CB scaling to EHV DC voltage.
## WP6 – HVDC Circuit Breaker Characterisation

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Lead</th>
<th>partners</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>
</tr>
<tr>
<td>6.2 Develop system-level model for mechanical DC CB</td>
<td>DELFT</td>
<td>MEU, DNV-GL</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>
</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>
</tr>
<tr>
<td>6.5 Develop kW-size hardware prototypes for hybrid and mechanical DC CBs</td>
<td>UAbdn</td>
<td>ABB, DELFT, DNV-GL</td>
</tr>
<tr>
<td>6.6 Demonstrate DC CB failure modes on kw-size hardware prototypes</td>
<td>UAbdn</td>
<td>DELFT</td>
</tr>
<tr>
<td>6.7 Develop roadmap for hybrid DC CB scaling to EHV DC voltage</td>
<td>UAbdn</td>
<td>ABB, DELFT</td>
</tr>
<tr>
<td>6.8 Develop roadmap for mechanical DC CB scaling to EHV DC voltage</td>
<td>DELFT</td>
<td>MEU</td>
</tr>
</tbody>
</table>
WP6 Deliverables

- D6.1: Offline models for hybrid DC CBs (UniAbdn, M11) *Delivered December 2016*
- D6.2: Offline models for mechanical DC CBs (TU Delft, M11) *Delivered December 2016*
- D6.3: Detailed component-level model for hybrid DCCBs (UniAbdn, M24)
- D6.4: Detailed component-level model for mechanical DCCBs (TU Delft, M24)
- D6.5: Hardware prototypes of DC CBs (200V, 400A) at Uni. laboratory (UniAbdn, M30)
- D6.6: Demonstration and report on DC CB failure modes study (UniAbdn, M42)
- D6.7: Techno-economic roadmap for hybrid DC CB scaling to EHV DC voltage (UniAbdn, M42)
- D6.8: Techno-economic roadmap for mechanical DC CB scaling to EHV voltage (TU Delft, M42)
WP6 – HVDC Circuit Breaker Characterisation

Meetings:

- Arnhem Netherlands, January 2016. 9 participants in person and 3 over phone.
- Aberdeen, UK, June 2016. 15 Participants.
- Teleconference, November 2016. 8 Participants.
- Berlin, Germany, November 2016. 17 Participants.
- DELFT, Netherlands, February 2017. 15 participants.

Deliverables completed:

- D6.1 Develop system-level model for hybrid DC CB
- D6.2 Develop system-level model for mechanical DC CB

Technical papers:

1. D Jovicic and M.H. Hedayati “DC Chopper based test circuit for high voltage DC circuit breakers” IET ACDC Power transmission, Manchester, February 2017,
WP6 – HVDC Circuit Breaker Characterisation

Contributions:

- DNV GL: 53.6%
- ABB: 8.4%
- SGI: 27.1%
- MEU: 4.5%
- UniAbdn: 6.0%
- TU Delft: 0.3%

Figure 1. Actual partner contributions in WP6 for 2016
Task 6.1 Modelling of Hybrid DC CB

Modelling IGBT Hybrid DC CB:
- Load Branch (Load switch and Ultrafast disconnector),
- Breaker Branch (Commutation switch),
- Energy Absorption Branch (Surge arresters),
- Residual current breaker,
- Series inductor,

Figure 2. Structure of IGBT based hybrid DCCB
Task 6.1 Modelling of Hybrid DC CB

Modelling IGBT Hybrid DC CB:

Figure 3. IGBT based Hybrid DC CB Simulation results for reclosing in fault
Technical Review – WP6

Task 6.1 Modelling of Hybrid DC CB

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

![Figure 4. Structure of Thyristor based Hybrid DC CB](image)
Task 6.1 Modelling of Hybrid DC CB

Modelling thyristor hybrid DC CB:

Figure 5. Thyristor based Hybrid DC CB Simulation results for opening
Task 6.2 Modelling of Mechanical DC CB

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

Figure 6. Structure of mechanical DCCB with active resonance.
Task 6.2 Modelling of Mechanical DC CB

Modelling mechanical DC CB

Figure 7. Simulation comparison of model 1 and model 2 for mechanical DC CB.
Task 6.5 Develop kw-size hardware prototypes for hybrid and mechanical DC CB

Ultrafast disconnector for hybrid DC CB

Figure 8. Ultrafast disconnector for hybrid DC CB.
Task 6.5 Develop kw-size hardware prototypes for hybrid and mechanical DC CB

Ultrafast disconnector for hybrid DC CB

Figure 8. Experimental tests for ultrafast disconnector.
Task 6.5 Develop kw-size hardware prototypes for hybrid and mechanical DC CB

Test circuit for DC CBs
• Provides 500A peak DC Current, 900V DC voltage, and 2500J,
• Testing load conditions and fault conditions,
• DSP controlled, fast DC voltage control,
• Supports testing fast repeated operations,

Figure 10. Experimental test circuit for DC CB.
Task 6.5 Develop kw-size hardware prototypes for hybrid and mechanical DC CB

Test circuit for DC CBs

Figure 11. Layout of experimental test circuit for DC CB.
WP6 – HVDC Circuit Breaker Characterisation

Future work:

- Task 6.3 Develop component-level and real-time model for hybrid DC CB
- Task 6.4 Develop component-level and real-time model for mechanical DC CB
- Task 6.5 Develop kW-size hardware prototypes for hybrid and mechanical DC CBs
- Inclusion of Scibreak
- Possible Task 6.9. Develop DC CB self-protection, repeated operation and general testing
- Next meeting: Aberdeen 31st May 2017.
Work Package 7
Regulation and Financing
Objective:

- To develop the appropriate European regulatory target framework – in legal, economic & financial properties – for the development of integrated offshore electricity transmission infrastructures with aim:

- to foster efficient investments by creating a level playing field;
- to coordinate the offshore grid development and the connection of wind farms; and
- to ensure its financeability or bankability
WP7 Setup

Building blocks

Offshore grid planning
- Spatial planning
- Jurisdictional constraints
- Joint planning instruments

Offshore grid investment/construction
- Licensing regimes
- Connection responsibility
- Support schemes

Offshore grid operation
- Access rules
- Balancing responsibility
- Grid code compliance

REGULATION

Legal framework
- CBA Method
- Offshore-onshore coordination
- Participation of grid users
- Spatial planning
- Jurisdictional constraints
- Joint planning instruments

Economic framework
- (Joint) support scheme
- Revenue models/tariff design
- Investment and efficiency incentives
- CBCA methods

FINANCING

Financial framework
- Analysis existing financing structures
- Ownership & governance
- Investor participation and funding mechanisms
- Analysis risk perception capital providers (ROIC)
- Connection/access charging
- Rules on ancillary services
- Capacity allocation

Balance responsibility

Large interdependencies between topics

Overlap investment phases
<table>
<thead>
<tr>
<th>#</th>
<th>Task</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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<tbody>
<tr>
<td>7.1</td>
<td>Legal framework</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.2</td>
<td>Economic framework</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.3</td>
<td>Financial framework</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.4</td>
<td>Stakeholder management/reporting</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>7.5</td>
<td>Policy recommendations EU target framework</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- ✔️ = deliverable
- ≠ = aftercare & assistance WP12
Technical Review – WP7

Task 7.1 – Legal framework

• Analysis offshore competences

• Analysis EU competences and Relevant legislation applicable to a North Sea grid

• Analysis country specific framework and barriers
**Task 7.2 – Economic framework**

**Case studies**

### CBA Principles

<table>
<thead>
<tr>
<th>Status of implementation</th>
<th>ENTSO-E 1.0</th>
<th>ENTSO-E 2.0</th>
<th>Significantly more important in the offshore context?</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT(1) Project interaction must be taken into account in the project and baseline definition</td>
<td>One baseline (TOOT), Arbitrary clustering rules</td>
<td>One baseline (TOOT), ambiguous update of the clustering rule</td>
<td>Harder applicable but dealt with.</td>
</tr>
<tr>
<td>INPUT(2) Data consistency and quality should be ensured</td>
<td>TYNDP</td>
<td>TYNDP</td>
<td>TYNDP</td>
</tr>
<tr>
<td>INPUT(3) Costs should be reported in disaggregated form</td>
<td>Not clear</td>
<td>Not clear</td>
<td>Not clear</td>
</tr>
<tr>
<td>CALCULATION(4) CBA should concentrate on a reduced list of effects</td>
<td>Reduced list</td>
<td>Reduced list</td>
<td>Reduced list</td>
</tr>
<tr>
<td>CALCULATION(5) Distributional concerns should not be addressed in the calculation of net benefits</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>CALCULATION(6) The model used to monetize the production cost savings, and gross consumer surplus needs to be explicitly stated</td>
<td>Explicit model available</td>
<td>Explicit model available</td>
<td>Explicit model available</td>
</tr>
<tr>
<td>CALCULATION(7) A common discount factor should be used for all projects</td>
<td>4 % for all</td>
<td>4 % for all</td>
<td>Uniform: aligned with TYNDP &amp; PCI</td>
</tr>
<tr>
<td>CALCULATION(8) A stochastic approach/scenario analysis should be used to address uncertainty</td>
<td>OK</td>
<td>The need is mentioned, but not specified how to apply the tools</td>
<td>OK</td>
</tr>
<tr>
<td>OUTPUT(9) Benefits should be reported in disaggregated form</td>
<td>Not clear</td>
<td>Not clear</td>
<td>Regional and country effects should be reported</td>
</tr>
<tr>
<td>OUTPUT(10) Ranking should be based on monetization</td>
<td>Multi-criteria analysis</td>
<td>Multi-criteria analysis, additional monetization of losses</td>
<td>Monetized ranking is suggested</td>
</tr>
</tbody>
</table>

### Table 1: CBA Methodology

<table>
<thead>
<tr>
<th>Phase</th>
<th>EWIC (IRL-UK)</th>
<th>COBracable (NL-OK)</th>
<th>ISLES (SCO-IRL- N-IRL)</th>
<th>Concern in the ENTSO-E 1.0 and 2.0 methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU funding</td>
<td>Commissioned in September 2012</td>
<td>Final investment decision taken, expected to be in operation by 2019</td>
<td>On the 2013 and 2015 PCI list. EirGrid funding received/allocated for studies and construction (86.5 m€)</td>
<td>In the study phase</td>
</tr>
<tr>
<td>INPUT(1) Project interaction must be taken into account in the project and baseline definition</td>
<td>TOOT approach is applied, and change in congestion rent of other interconnectors is calculated</td>
<td>P1O PCI projects is taken into account. The interaction between ISLES clusters is assessed separately</td>
<td>Critical</td>
<td></td>
</tr>
<tr>
<td>INPUT(2) Data consistency and quality should be ensured</td>
<td>Ok</td>
<td>Ok</td>
<td>No TYNDP by local data is utilized although from respected sources.</td>
<td></td>
</tr>
<tr>
<td>INPUT(3) Costs should be reported in disaggregated form</td>
<td>Ok</td>
<td>Ok</td>
<td>Ok for the 2015 analysis. However, not the ENTSO-E CBA 1.0 list is applied.</td>
<td></td>
</tr>
<tr>
<td>CALCULATION(4) CBA should concentrate on a reduced list of effects</td>
<td>Ok</td>
<td>Ok</td>
<td>Ok</td>
<td></td>
</tr>
<tr>
<td>CALCULATION(5) Distributional concerns should not be addressed in the calculation of net benefits</td>
<td>Ok</td>
<td>Ok</td>
<td>Ok</td>
<td></td>
</tr>
<tr>
<td>CALCULATION(6) The model used to monetize the production cost savings, and gross consumer surplus needs to be explicitly stated</td>
<td>Explicitly stated but not detailed market and network model used</td>
<td>Ok, explicitly stated and detailed market and network model are used (details are not public)</td>
<td>Ok, explicitly stated and detailed market and network model are used</td>
<td></td>
</tr>
<tr>
<td>CALCULATION(7) A common discount factor should be used for all projects</td>
<td>Ok, there was no common discount factor determined thus the allowed WACC of E1.0 was used</td>
<td>Ok, 2 scenarios are applied plus sensitivity analysis by varying total cost and discount factor</td>
<td>A very low discount factor is applied in the 2012 analysis (2%) and no value is provided in the 2015 analysis</td>
<td></td>
</tr>
<tr>
<td>CALCULATION(8) A stochastic approach/scenario analysis should be used to address uncertainty</td>
<td>Uncertainty is disregarded, no scenario or sensitivity analysis applied</td>
<td>Ok, scenario and sensitivity analysis are applied, although not using the TYNDP scenarios.</td>
<td>Scenario and sensitivity analysis are applied, although not using the TYNDP scenarios.</td>
<td></td>
</tr>
<tr>
<td>OUTPUT(9) Benefits should be reported in disaggregated form</td>
<td>Only the benefits for Ireland are considered</td>
<td>Ok, benefits are reported disaggregated</td>
<td>Ok, benefits are reported disaggregated</td>
<td></td>
</tr>
<tr>
<td>OUTPUT(10) Ranking should be based on monetization</td>
<td>Ok, full monetization is applied</td>
<td>Partial monetization is applied, but a final NPV value of the project is unfunded. Additional indicators in non-monetary metrics are mentioned more for informational purposes</td>
<td>Both qualitative and qualitative cost and benefit indicators are reported. No full monetization is conducted.</td>
<td></td>
</tr>
</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.

03.05.16 120
Task 7.2 – Economic framework

**Coordination onshore-offshore grid planning**

The exact position of each regulatory regime is illustrative.

![Diagram]

**Locational siting RES support**

<table>
<thead>
<tr>
<th>Valid for 2017</th>
<th>Germany</th>
<th>Denmark</th>
<th>UK</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-door</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Zoned</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-site</td>
<td>x</td>
<td>x</td>
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</tbody>
</table>

**Onshore access responsibility**

<table>
<thead>
<tr>
<th>Valid for 2017</th>
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<th>Denmark</th>
<th>UK</th>
<th>Sweden</th>
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<tr>
<td>TSO</td>
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<td>x</td>
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<td>Developer</td>
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<tr>
<td>Third Party</td>
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**Grid connection cost**

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<th>UK</th>
<th>Sweden</th>
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</thead>
<tbody>
<tr>
<td>Super shallow</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shallow</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Deep</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>
### Task 7.3 – Financial framework

**Regulation has a profound impact on financeability**

- Overview historical development ownership & governance
- Analysis existing regulatory models and financing structures
  - onshore grid investments
  - offshore grid investments
  - interconnectors

<table>
<thead>
<tr>
<th>No.</th>
<th>Key elements</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Regulatory authority</td>
</tr>
<tr>
<td>2</td>
<td>Regulatory period</td>
</tr>
<tr>
<td>3</td>
<td>Revenue cap mechanism</td>
</tr>
<tr>
<td>4</td>
<td>Allowed revenue: method</td>
</tr>
<tr>
<td>5</td>
<td>Allowed revenue: value</td>
</tr>
<tr>
<td>6</td>
<td>Allowed return on equity: method</td>
</tr>
<tr>
<td>7</td>
<td>Allowed return on equity: value</td>
</tr>
<tr>
<td>8</td>
<td>Risk-free rate</td>
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<tr>
<td>9</td>
<td>Market risk premium</td>
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<td>10</td>
<td>( \beta_{\text{equity}} )</td>
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<td>11</td>
<td>Gearing</td>
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<td>12</td>
<td>Cost of debt: method</td>
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<tr>
<td>13</td>
<td>Cost of debt: value</td>
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<td>14</td>
<td>Depreciation</td>
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<td>15</td>
<td>Costs deducted</td>
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<tr>
<td>16</td>
<td>Efficiency incentives/benchmarking methods</td>
</tr>
<tr>
<td>17</td>
<td>Innovation</td>
</tr>
<tr>
<td>18</td>
<td>Revenue adjustments</td>
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<tr>
<td>19</td>
<td>Ownership</td>
</tr>
<tr>
<td>20</td>
<td>Size of investments</td>
</tr>
<tr>
<td>21</td>
<td>Credit rating of TSOs</td>
</tr>
</tbody>
</table>
Technical Review – WP7

Next period

Legal framework
- proposal of solutions to legal barriers / policy choices
- analysis new forms of governance (institutional roles)
- developing the legal form of the legal framework (EU law, Treaty, or combination)
- case study/pilot projects application

Economic framework
- support schemes
- investment incentives
- cross border cost allocation
- revenue models/tariff design
- governance models regarding ownership, construction and operation
- rules on capacity allocation (interconnection vs generation capacity)
- rules on ancillary services

Financial framework
- financing instruments
- investor participation
- risk analysis for offshore grid planning, construction and operation

Policy recommendations on EU target framework
Meetings and stakeholder workshops

- 17th March, Arnhem
- 15th June, Stockholm
- 11th April, Arnhem
- 27th October, Varel
- 29th November, Berlin
- 29th June, Brussel
- 29th September, Hamburg
Technical Review – WP7

Contributions

- DNVGL: 40%
- KU Leuven: 11%
- Eirgrid: 14%
- DWG: 9%
- TenneT: 5%
- SOW: 3%
- Carbon Trust: 2%
- EUI: 1%
- Iberdrola: 1%
- T&D: 1%
- RUG: 1%

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714.
Work Package 8
Wind Farm Demonstrator Design
Technical Review – WP8

WP8 – Windfarm Demonstrator Prototype

Initiate and develop technical solution for a Windfarm Demonstrator Prototype plant at an existing onshore windfarm

- if possible realize and built the plant at site.
- first step: preparing a technical design, applying for necessary consents
- develop a detailed cost breakdown
- Investigation of different realization options will be investigated and evaluated based on a cost/benefit analysis.

A GO/NO GO decision milestone (MS36) is set after twelve months:

- different technical options will be compared and decided if and how the demonstrator prototype plant will be realized.
- This will depend on the elaborated technical solutions and the trade-off between demonstrator prototype cost and benefit.
- The GO/NO GO decision will be made by each WP8 participant for its own scope.

Targets:

- Investigate and compare different technical options on how the prototype can be realized
- Develop a design with dependable cost estimates
- To decide on GO/NO GO for the realization of the plant and if applicable
- To manufacture, assemble and test all equipment including advanced hybrid submarine cable prototype
- To energize and demonstrate functionality through tests especially proper turbine – rectifier interaction
### WP8 – Windfarm Demonstrator Prototype

<table>
<thead>
<tr>
<th>#</th>
<th>Task</th>
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<th>2017</th>
<th>2018</th>
<th>2019</th>
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<tr>
<td>8.1</td>
<td>Work package management</td>
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<tr>
<td>8.2</td>
<td>Work package scoping</td>
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</tr>
<tr>
<td>8.3</td>
<td>System Simulations and Design</td>
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<tr>
<td>8.4</td>
<td>Cable design and testing</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>8.5</td>
<td>Manufacturing and Installation of cable and cable accessories</td>
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<tr>
<td>8.6</td>
<td>DRU Manufacturing and Testing</td>
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<tr>
<td>8.7</td>
<td>Other Equipment Manufacturing and Testing</td>
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<tr>
<td>8.8</td>
<td>Civil Works</td>
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<td></td>
</tr>
<tr>
<td>8.9</td>
<td>Installation and Assembly</td>
<td></td>
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<tr>
<td>8.10</td>
<td>Commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.11</td>
<td>Plant operation and Test period</td>
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<td></td>
</tr>
</tbody>
</table>

**MS 36 – NO GO Decision**

- ▶ Deliverable
- ▼ Milestone
Technical Review – WP8

Task 8.2 – Work package scoping

Investigation on three different options for diode rectifier demonstration

- Klim demonstrator (originally proposed)
- Control concept demonstrator
- Oesterild demonstrator

Major goal: cost optimized de-risking of DRU technology

Results documented in

- D8.1 – Project time schedule
- D8.2 – Basic design report
- D8.3 – Plant layout and major equipment specification
- D8.10 – Demonstrator Prototype: Analysis and comparisons of different technical solutions for realization
- Justification for change of scope to European Commission
All components of an SGA DRU windfarm (DRU, HVDC Plus, WTG, cable, transformer) are separately type tested and qualified. The challenges for the successful operation of an SGA DRU wind farm are given by the interaction of all components.
Risk picture of technology

• Simulation Tool Validity

• Operation
  • Energization
  • Normal operation
  • Stability in operational modes

• Faults
  • AC fault onshore/offshore
  • DC fault, intersystem AC/DC

Risk Impact Analysis

• Delay
• Loss of production
• Needed investments
• Occurrence
  • Probability
  • Dependency on stage of commissioning

(Results confidential within Siemens)
**Task 8.2 – Work package scoping**

**Klim – Demonstrator**

- 20 MW nom. power of VSC
- 11 turbines (3.2 MW each)
- One DRU operating at max. 10 p.c. of nom. power
- One string

Klim would

- mainly address the demonstration of handling equipment and sufficient project management.
- also show that the concept in principle is working

but it is highly questionable if the results are transferable in a real offshore wind farm.
• Nominal Power 250kW operational range
• Low voltage level (nom. 400V AC; ±400V DC)
• Frequency nom. 50 Hz
• 48 back to back rectifier, PN = 5kW
• 3 x 12 pulse DRU
• Full bridge MMC
• DC voltage WTG: 640V
• AC voltage der WTG (sec): 400V
• AC voltage Offshore: 400V
• AC voltage DRU-Transformer (sec): 105V
• DC voltage cable: 800V (2 x 400V, symmetrical grounding)

Scaling of impedances

\[ Z_{Lab} = Z_{OWP} \cdot \lambda, \text{ with } \lambda = \left( \frac{U_{Lab}}{U_{OWP}} \right)^2 \cdot \frac{P_{OWP}}{P_{Lab}} \]

**To achieve correct dynamic behavior of converters:**
Scaling according to the using the correcting variable reserve as well as the time constants due to the fact that these values have a high influence on the dynamic behaviour of the system.
## Technical Review – WP8

### Task 8.2 – Work package scoping

<table>
<thead>
<tr>
<th></th>
<th>Simulation</th>
<th>Klim Demonstrator (I)</th>
<th>High power Lab Demonstrator (II)</th>
<th>Control Concept Demonstrator (III)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Behavior of 100+ WTG converters on a very weak AC grid</strong></td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>Possible to the extend of the quality of the simulation models</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Partially possible with 50 WTGs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partial verification of WTG model possible</td>
<td>Partial verification of WTG model possible</td>
<td>Partial verification of WTG model possible</td>
</tr>
<tr>
<td><strong>Operating a large cable grid on a weak umbilical cable</strong></td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>Possible to the extend of the quality of the simulation models</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Partially possible to the extend of the quality of the cable models</td>
</tr>
<tr>
<td><strong>Defined load situations</strong></td>
<td>+</td>
<td>−</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Full load range and critical situations possible</td>
<td>Depending on wind, load situation during test period is unpredictable</td>
<td>Full load range and critical situations possible</td>
<td>Full load range and critical situations possible</td>
</tr>
<tr>
<td><strong>WTG harmonic injection</strong></td>
<td>+</td>
<td>/</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Freely adjustable</td>
<td>Partially possible, load situation during test period is unpredictable</td>
<td>Freely adjustable</td>
<td>Freely adjustable</td>
</tr>
<tr>
<td><strong>Verification of converter control / Operation MMC-DRU</strong></td>
<td>+</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>Possible to the extend of the quality of the simulation models</td>
<td>Partially possible, depending on the extend of the MMC setup</td>
<td>Partially possible, depending on the extend of the MMC setup</td>
<td>Partially possible, depending on the extend of the MMC setup</td>
</tr>
<tr>
<td><strong>Risk/Costs</strong></td>
<td>+ +</td>
<td>− −</td>
<td>+ +</td>
<td>+ +</td>
</tr>
</tbody>
</table>

© PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714.
Dynamic voltage distribution of the series connected DRUs

Due to the series connection of the DRUs, in cases of changing the DC link voltage, different cable length of the DC cable lead to asymmetrical voltage drops, which has to be considered in the systems design.

In cases of faults, in the series connection (DC to ground) the dynamic behavior has such high transients that the isolations of cables may collapse.

Resonances related to active tower damping (ATD) and drive train damping DTD

The PP are equipped with control strategies to damp the drive system (DTD) active as well as the tower itself (ATD). The typical eigen frequencies are around 2 Hz (DTD) and 0.2 Hz (ATD).

The activation of these features may lead to power oscillations in the system, even in cases where the system is in islanded operation. Every WPP stores energy in the mechanic system and may become a low frequency source to start resonances with in the electrical system.

Resonances in high frequency ranges due to converter interaction

Unintended interactions between converters in frequency range of IGBT switching signals
The basic aspects to investigate are

- interactions of several WTG within one string
- interactions of strings connected in parallel
- supply of OWP via a long AC cable with aux. power
- interaction of OWP with uncontrolled DRU
- interaction OWP with DRU and DRU-filter
- interaction of 3 DRU on different locations via ringbus cable
- connection of DRU via a long DC cable

The control concept demonstrator is not intended

- To investigate/demonstrate interface protocols, (ISO/OSI Model)
- To test real world devices like C&P equipment,
- To investigate HVDC onshore operation
- For verification of the later on real word system behaviour (by definition impossible)
PRYSMIAN GROUP CONTRIBUTION – WP8

TRADITIONAL vs. INNOVATIVE options

Two HVDC bundled cables + One HVAC threecore cable

✓ HVDC cable technology
✓ HVAC cable technology
X Three cables
X Two installation processes
X Two routes

One Hybrid three-core cable

✓ One cable
✓ One installation process
✓ One route
✓ HVDC cores technology
✓ HVAC cores technology
PRYSMIAN GROUP CONTRIBUTION – WP8

Task 8.4 Cable design and testing

“The work package covers all design, build and operation tasks for testing a real size cable loop that could be used in the future with diode rectifier converter technology. It shall proof the functionality and feasibility of the new cable concept”

- Electrical analysis based on the IEC standards and proprietary computation programs.
- Thermal analysis based on the IEC standards and Proprietary computation programs.
- Construction details and bill of material definition.
- Selection of manufacturing plants to be involved on prototype construction.
- Mechanical analysis of cable behaviour.
- Definition of tests procedure.
Technical Review – WP8

Contributions

- Work package lead
  - Scoping phase
  - Modelling & simulations
  - Reporting D8.1, D8.2, D8.3 & D8.10

- Hybrid cable development

- Reviewing partner

- Reviewing partner

Σ 29,5 MM
Technical Review – WP8

Meetings

Risk Workshops (I, II), Hamburg
Kick off, Erlangen

Control concept Demo Workshop Hamburg

Meeting with EU representatives regarding Demonstrator

M1  M2  M3  M4  M5  M6  M7  M8  M9  M10  M11  M12

17th March, Arnhem
15th June, Stockholm
8th September, London
29th November, Berlin
Technical Review – WP5

Dissemination

No disseminations
After Siemens’ NO GO Decision:

• Update of the scope of work/objectives of WP8.
• (WP8 consists only of PRYSMIAN work.)

Remaining tasks:
Task 8.4 Cable design and testing (M06-M20)
Task 8.5 Manufacturing and Installation of cable and cable accessories (M12-M28)

Deliverables:
D8.7 Cable design and modelling parameters Report (M20)
D8.8 Feasibility Report on prototype cable (M24)
Dissemination
### Overview Status Deliverables WP13

<table>
<thead>
<tr>
<th>Deliverable Number</th>
<th>Deliverable Title</th>
<th>Submitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.1</td>
<td>Development of Project Identity</td>
<td>Jun. 16</td>
</tr>
<tr>
<td>13.2</td>
<td>Newsletter – bi-annual</td>
<td>Jun. 16</td>
</tr>
<tr>
<td>13.3</td>
<td>Establishment of internal/external Project information system</td>
<td>Jul. 16</td>
</tr>
<tr>
<td>13.4</td>
<td>Mailing list - regularly updated</td>
<td>Jun. 16</td>
</tr>
<tr>
<td>13.5</td>
<td>Executive summary of project interim report</td>
<td>Mar. 17</td>
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<td>13.6</td>
<td>Publications (x number of papers, articles, reports, conf. presentations …)</td>
<td>Dec. 16</td>
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<tr>
<td>13.7</td>
<td>Stakeholder interaction</td>
<td>Nov. 16</td>
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<tr>
<td>13.8</td>
<td>External Communication via marketing material and media work</td>
<td>Jul. 16</td>
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## Overview Status Milestones WP13

<table>
<thead>
<tr>
<th>Milestone Number</th>
<th>Milestone Title</th>
<th>Due Date</th>
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<tr>
<td>MS59</td>
<td>Beta version of website is launched</td>
<td>May 2016</td>
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<tr>
<td>MS60</td>
<td>Website launched</td>
<td>Jul. 2016</td>
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<tr>
<td>MS 61</td>
<td>First convention of Reference Group</td>
<td>Sep. 2016</td>
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<tr>
<td>MS62</td>
<td>Intermediate Conference</td>
<td>Jun. 2018</td>
</tr>
<tr>
<td>MS63</td>
<td>Final Conference</td>
<td>Dec. 2019</td>
</tr>
</tbody>
</table>
Corporate design

Task 13.1 - Development of project identity

• Deliverable 13.1 - submitted June 2016

• Corporate design:
  • Logo
  • Templates
  • Website
  • Fonts

• Templates:
  • Letters
  • Reports
  • Press releases
  • Invitation
  • PowerPoint
Task 13.2
Development and production of a newsletter

**Deliverable 13.2 - submitted June 2016**

- Published bi-annually
- 264 subscribers

**Structure:**
- Editorial
- Policy News
- PROMOTioN
- Upcoming events

**Newsletter #1 – Content (30th June 2016)**

- Intro -> DNV GL (Paul Raats)
- Editorial ( “About PROMOTioN”)
- Introduction WP 1
- Introduction WP 7
- Report/Summary Deliverable 1.1
- Announcement Kick-off stakeholder workshop (WP7)
- North Sea Political Declaration of 6 June
- Upcoming events
Editorial: Paul Raats (DNV GL)

POLICY:
• EU Winter Package
• New electricity interconnection targets expert group
• Ground-breaking ceremony NordLink HVDC power grid interconnection
• Fichtner study (Germany): Acceleration and cost reduction potentials for Offshore HVDC Grids (June 2016)

PROMOTioN:
• Review of Stakeholder Interaction 2016
• Deliverable 1.3: Synthesis of available studies on offshore meshed HVDC grids
• Deliverable 5.1: HVDC Network Fault Analysis
• Deliverables 6.1 and 6.2: System-level models for three DC circuit breakers

UPCOMING EVENTS
Online activities

Task 13.3
Content management for website and intranet

- Deliverable 13.3 Project information system - launched July 2016
- Internal area for stakeholder interaction e.g. Reference Group

- [www.promotion-offshore.net](http://www.promotion-offshore.net)
Mailing list

Task 13.4
Development of a targeted mailing list

• Deliverable 13.4 - submitted June 2016

• For stakeholder interaction
• More than 1000 recipients
• Regularly updated
• Input from project partners

STAKEHOLDER CATEGORIES

1. European bodies
2. Policy institutions
3. Industry Stakeholders
4. Financing bodies
5. Academia & Consulting
6. Others
Dissemination

**Task 13.6**
Production of public reports, papers/articles, presentations

- **Deliverable 13.6**
  - submitted December 2016
- 13 presentations in 2016
- 3 conference papers in 2016

- **Total amount of 25 journal articles and 50 conference papers is pursued**
  (acc. to GA Annex 1B Communications Activities)
<table>
<thead>
<tr>
<th>No.</th>
<th>Date</th>
<th>Event</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11 May 2016</td>
<td><strong>WindEurope Working Group: Offshore Wind</strong></td>
<td>Andreas Wagner - SOW</td>
</tr>
<tr>
<td>2</td>
<td>24 May 2016</td>
<td><strong>Belgian Electrical Engineers Society</strong></td>
<td>Karim KAROUI - Tractebel</td>
</tr>
<tr>
<td>4</td>
<td>28 Jun. 2016</td>
<td><em>Internal meeting with partners in Carbon Trust’s</em> Offshore Wind Accelerator (OWA) programme</td>
<td>Carbon Trust</td>
</tr>
<tr>
<td>5</td>
<td>14-16 Sep. 2016</td>
<td><strong>6th HVDC Doctoral Colloquium, Porto,</strong></td>
<td>Oscar Saborio-Romano, DTU</td>
</tr>
<tr>
<td>6</td>
<td>16 Sep. 2016</td>
<td><strong>RTDS European User Conference, Glasgou, UK</strong></td>
<td>SHE Trans</td>
</tr>
<tr>
<td>7</td>
<td>29 Sep. 2016</td>
<td><strong>WindEnergy Hamburg</strong></td>
<td>Cornelis Pleet - DNV GL</td>
</tr>
<tr>
<td>10</td>
<td>15-17 Nov. 2016</td>
<td><strong>Conference Baltic InteGrid project: Offshore Wind in the Baltic Sea:</strong></td>
<td>Oscar Saborío-Romano, Ali Bidadfar, Ömer Göksu, Müfit Altin, Nicolaos A. Cutululis, Poul E. Sørensen Department of Wind Energy Technical University of Denmark</td>
</tr>
<tr>
<td>11</td>
<td>25 Nov. 2016</td>
<td><strong>Conference Baltic InteGrid project: Offshore Wind in the Baltic Sea:</strong></td>
<td>Slavomir Seman, Ngoc Tuan Trinh, Rainer Zurowski, Sarina Kreplin; Energy Management Division SIEMENS AG</td>
</tr>
<tr>
<td>12</td>
<td>25 Nov. 2016</td>
<td><strong>Conference Baltic InteGrid project: Offshore Wind in the Baltic Sea:</strong></td>
<td>Ceciel Nieuwenhout (Groningen Centre of Energy Law)</td>
</tr>
</tbody>
</table>
Dissemination

Task 13.7
Interaction with stakeholders and other initiatives

- **Deliverable 13.7 - submitted November 2016**

- Task 13.7.1: Industry Reference Group and Advisory Board (M09-48)
- Task 13.7.2: Regional/External Events (M06-48)
- Task 13.7.3: Intermediate and Final Conference (M30, M48)
Stakeholder Interaction

13.7.1 Reference Group Meeting

29 September 2016 **Kick-off meeting**

Reference Group in Hamburg alongside WindEnergy Exhibition & conference

- participants: 20
- to provide additional feedback and input from outside the project consortium

**WindEnergy Hamburg**

The global on & offshore expo

27 – 30 September 2016

windenergyhamburg.com

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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.
Stakeholder Interaction

Kick-off Stakeholder workshop (WP7), 29 June 2016, Brussels (participants: 60)

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00-10:30</td>
<td>Registration and Coffee</td>
</tr>
</tbody>
</table>
| 10:30-10:45 | Opening and Welcome – PROMOTioN – Meshed Offshore HVDC Grids as a Pathway to a Sustainable European Electricity System  
               Paul Raats – DNV GL                                                  |
| 10:45-11:00 | Offshore-Windenergy – Present status and prospects                      
               TBD – WindEurope                                                    |
| 11:00-11:30 | The Vision of meshed HVDC Offshore Grids – What it means for Europe    
               Marie Donnelly – European Commission                               |
| 11:30-12:00 | Regulatory and Financial Aspects of meshed HVDC Offshore Grids          
               Alan Croes – TenneT                                                 |
| 12:00-13:15 | Panel and Stakeholder Discussion: Energy Policy Aspects of meshed HVDC Offshore Grids  
               Claude Turmes – EUNORMES President, MEP                           
               Jan Hensmanns – NSCOGI                                             
               Jean-Baptiste Paquet – ENTSO-E                                    
               Lineke van Ouden – The presidency of the Council of the EU (requested) 
               Moderation: Andreas Wagner – Stiftung OFFSHORE-Windenergie         |
| 13:15-14:30 | Joint Lunch                                                             |
| 14:30-16:00 | Panel and Stakeholder Discussion: Suitable Technologies for meshed HVDC Offshore Grids  
               Jenny Jøsifsson – ABB                                               
               Dr. Frank Schettler – Siemens                                      
               Samir Oukaili – Mitsubishi Electric Europe                         
               Alessandro Conte – Prysmian                                       
               TBD – GE Grid Solutions                                            
               Moderation: Dr. Gregor Nikolic – RWTH Aachen                      |
| 16:00-16:30 | Final statements and Wrap-Up                                            
               Paul Raats – DNV GL                                                |
| 16:30       | End of the Workshop                                                    |
Dissemination

Task 13.8

External communication via marketing material and media work

**Deliverable 13.8 - submitted July 2016**

**Marketing materials**

- Roll up banners
- Leaflets
- Business cards
- Standard project presentation (PPT)
**Press Releases**

- **14 March 2016**: PROMOTioN - New EU project to boost the development of meshed HVDC offshore grids in Europe
  - Announcement of the start of the PROMOTioN project, including official statements by the European Commission, Project Coordinator as well as valuable information on the content of the project.

- **23 June 2016**: EU project PROMOTioN launches new website
  - Announcement of official launch of the website of the PROMOTioN project, as well as newsletter and first stakeholder event on 29 June in Brussels
  - sent to around 1.500 media contacts
  - 27 media reports
Media activities – Task 13.8

Press Coverage

EU Examining Benefits of Meshed Offshore Grid

A 4-year project investigating the benefits of a meshed offshore transmission grid has been launched recently under the EU’s Horizon 2020 Research Program, and is currently the biggest energy project within the program.

A meshed offshore grid connecting offshore wind farms to land could provide significant financial, technical and environmental benefits to the European electricity market, DNV GL said.

The goal of the PROgress on Meshed HVDC Offshore Transmission Networks (PROMOTioN) project is to develop and demonstrate three key technologies:

1. Monitoring and control systems to assess the grid’s stability.
2. An innovative power-electronic converter that will link wind farms to the grid.
3. Protection systems and fault clearing procedures.

EU to weigh benefits of 'meshed' offshore grid in North Sea

The EU has launched a four-year project to boost the development of meshed HVDC offshore grids.

16/03/2016 Recharge

EU project to boost meshed HVDC offshore grids

Horizon 2020 | A meshed offshore transmission grid connecting offshore wind farms to land could provide significant financial, technical and environmental benefits to the European electricity market. Launched earlier this year, the project PROgress on Meshed HVDC to ensure a future-proof grid that is affordable, reliable and sustainable. By bringing in our 90 years of expertise in power systems, renewable technologies and experience in leading many joint industry projects, I am confident (the

02/05/2016 Ship & Offshore
Press Briefing

- Targeted at German trade press
- Explain the project more detailed at an informal setting
- Media: BizzEnergy, Energie und Management, Zeitschrift für Energiewirtschaft, Energate
- Project participants: DNV GL (C. Plet); TenneT (N. de Groot; D. Abdoelkariem); RWTH (S. Winter); SOW (S. Boie; A. Wagner)
- Highlighted project objectives and benefits, presented first deliverables and described the political context of the project
- Press Coverage: 2 articles
  - 2nd December 2016 Energie und Management
  - January 2017 Magazin für Energiewirtschaft
Testimonial video clips

Task 13.8
External communication activities

Testimonials - Video Clips

• Project partners highlight relevant aspects/aims of PROMOTioN

• Clips with Jenny Josefsson (ABB), Cornelis Plet (DNV GL), Niek de Groot (TenneT), Ceciel Nieuwenhout (RUG), Alexander Broy (Siemens), Andreas Wagner (SOW)

• 6 video clips, each roughly 1 minute

• Embedded on project website and YouTube channel

  • https://www.promotion-offshore.net/insight/detail/promotion-testimonials/
  • https://www.youtube.com/channel/UCnJOa4oeTyRIuI60Ufecpmw

• Support from subcontractor Edelmann.ergo
Project Management
Management Aspects

Project coordination

• Management Procedures & Actions
  • Collaboration & Interaction
  • Contract Management
  • Quality Control
  • Reporting
  • Liaison

• Financial Aspects
Management Aspects

Management procedures and methods

• Project plans for WPs: WBS, planning, budget allocation
• ProjectPlace: Online project collaboration tool
• Weekly project coordination meetings
• Monthly PMG telcons & physical meetings
• 6 monthly project conferences
  • Day 1 – WP meetings
  • Day 2 – WP reporting to consortium
  • Day 3 – General Assembly and PMG
• Liaising with EU and interested parties: BRIDGE, China State Grid, Hyosung, SCibreak
• 1 amendment carried out & 1 prepared
• Proposal selection process initiated after WP8 ‘NO GO’
Management Aspects

Project conferences and PMG meetings

21-22 January 2016
Kick-off
Arnhem, Netherlands

14-16 June 2016
6 Month meeting
Stockholm, Sweden

1-2 December 2016
12 Month meeting
Berlin, Germany

M1
19th February, telcon

M2
15th April, telcon

M3
19th May, telcon

M4
16th June, Stockholm

M5
13th July, Leuven

M6
16th August, telcon

M7
29th September, Hamburg

M8

M9

M10

M11

M12

2nd December, Berlin
Management Aspects

Quality control

• Publication review procedure - SOW
  • Inform Project Coordinator & WP13
  • PMG approval
  • Fast & normal procedures
  • Procedure for press release

• Deliverable review procedure – R&D Coordinator
  • Two reviewers from PMG
  • Two review rounds
    • 8 weeks prior - Structure and basic idea
    • 3 weeks prior - Content and quality
  • Review sheet
Management Aspects

Project internal reporting

• Per partner
  • Technical reporting
    • Work performed during the period
    • Explanatory note on major cost items
    • Explanation of the impact of major deviations from the budget
  • Financial reporting (excel)
    • Man-hours per person and costs
    • Travel cost linked to Meetings or other purposes
    • Equipment costs
    • Cost of other goods and services
    • Subcontracting cost
  • Each half year
  • If applicable combined with Periodic report to EU
    • First half year – 88% received, missing info partly accepted as participation in first half year was limited
    • Second half year / periodic report – 100% received
Management Aspects

Project internal reporting

• Per Work package by WP leader
  • PowerPoint presentation
    • Objectives (per quarter)
    • Progress
    • Deviations
    • Bottlenecks and remedy
  • Quarterly and presented and discussed in PMG
  • If combined with Periodic report to EU, a more detailed description in Word

• We started with a quarterly reporting in Word, but that didn’t work. PowerPoint is a good solution as it also discussed right away in the PMG.
## Management Aspects

### Planning

#### Period 1

<table>
<thead>
<tr>
<th>WP</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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Management Aspects

Financial Aspects

Person-months
- Used: 17%
- Remaining: 83%

Total costs
- Used: 9%
- Remaining: 91%
Management Aspects

Person-months budget – WP level

[Bar chart showing person-months budget for each WP level, with WP8 having the highest used and remaining values.]

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Management Aspects

Person-months % completion – WP level
Management Aspects

Work package participation – Partner level

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Management Aspects

Person-months budget – partner level

- DNV GL
- ABB
- KU Leuven
- KTH
- EIRGRID
- SGi
- DWG
- MEU
- Svk
- ALSTOM
- UniAbdn
- RTE
- TU Delft
- STATOIL
- TENNET
- SOW
- Siemens
- DTU
- RWTH Aachen
- UPV
- FGH
- DONG ENERGY
- CARBON TRUST
- TRACTEBEL
- EUI
- IBERDROLA
- T&D EUROPE
- USTRAT
- ADWEN
- PRYSMIAN
- RUG
- MVOW
- Eneginet
- SHE Trans

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Management Aspects

Person-months budget – Partner level
Next Period
### Management Aspects

#### Next period

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Management Aspects

Next Period

• Project conference in Aberdeen: 31st May – 2nd June
• Second stakeholder & reference group meetings
• Two amendments
  • New partner
  • New proposals
• End of work packages
  • work package 1 – Requirements for meshed offshore grids
  • work package 5 – Test environment for HVDC circuit breakers
• Start of demonstrators
  • Work package 9 – Demonstration of DC grid protection
  • Work package 10 – Circuit breaker performance demonstration
• Start of harmonisation & standardisation
• Start of deployment plan
## Summary of proposals

| Identify **technical requirements** and investigate possible topologies for meshed HVDC offshore grids | X | X |
| Develop **protection schemes** and **components** for HVDC grids | (X) | X | X |
| Establish components’ **interoperability and initiate standardisation** | X | X | X |
| **Demonstrate cost-effective** offshore HVDC equipment | X | X | X |
| Develop recommendations for a coherent EU and national **regulatory framework** for HVDC offshore grids | | | X |
| Develop **recommendations for financing mechanisms** for offshore grid infrastructure deployment | | | X |
| Develop a **deployment plan** for HVDC grid implementation | X | X | X | X | X |
| **Disseminate results** to relevant stakeholder communities | X | X |
Summary
Main achievements so far –

1st Year Wrap-Up

21th of March 2017 / Brussels
• Introduction
• Laying foundations
• Deliverables & quality management
• Project management
• Impact
Main achievements

Introduction

• PROMOTioN started 01. January 2016
• Running for about a year
• Ambitious work program, biggest H2020 energy project so far
• General challenges
  • Number of diverse topics
  • Number of deliverables
  • Number of partners
  • Structural changes
Main achievements

Introduction

• PROMOTioN started 01.January 2016

• Running for about a year

A smooth sea never made good sailors…

• Number of deliverables
• Number of partners
• Structural changes
Laying foundations

Starting up PROMOTioN

• Common challenges at the start of big projects
  • Communication needs to be organized and take up speed
  • Same description of work, different perspectives on its meaning
  • Open questions from the proposal stage
  • Need to further define various interfaces between work packages/different project branches
  • ...

• PROMOTioN is no exception to the rule
Laying foundations

• Organizational achievements
  • Management & communication structures set up
  • Same description of work, same understanding
  • Swift start of “actual work”

• First key project results
  • Setting up scenario frameworks and defining requirements (e.g. WP 1)
  • Unifying perspectives, methodologies and tools (e.g. WP 2)
  • Foundations for demonstration activities (e.g. WP 6)
  • … (and many more)

• Building the road for future activities, deliverables and the deployment plan
Deliverables & quality management

Overview

• Number of deliverables in PROMOTioN: 101

• Number of deliverables due to this date: 27 (> 2/ month)

• Majority of deliverables were delivered in time

• Exceptions

  • General staffing issues
  • Sum of minor subtask delays
  • “Rather a few weeks late, than having open endings/ being unclear”
Deliverables & quality management

Quality assurance (1)

• Deliverable quality assurance process set up
  • Internal reviews for all deliverables
  • Two reviewers from the PMG per deliverable
  • Ensures critical “external” feedback

• “We had meetings and meetings and meetings…”
  • Extensive coordination between partners
  • Many direct exchanges facilitating in depth discussions
  • Getting to know each other always makes coordination easier
Deliverables & quality management

Quality assurance (2)

• Making knowledge available where it is needed
  • Flexible handling of participation across WP
  • Good cooperation between work packages
  • Good cooperation across different work packages

• Build in quality assurance - predefined review loop
  • Requirements defined early in the project
  • Possibly: changing external framework, new internal insights
  • Re-evaluation of requirements in work package 1 mid project
Project Management

Addressing challenges

• WP 8 “No Go” decision
  • Significant implications for project structure and associated topics
  • Need to manage the “No Go process”
    → Robust project management structures

• Setting up a new proposal process
  • 3 months time
  • Several million euros “budget”
    → Effective project management structures

• Making adjustments where needed
  • Focussing on results pushing the TRL of relevant concepts and technologies
  • Revision of procedures and structures
    → Flexible project management structures
Impact

External exchanges and acknowledgements

• Reminder: We just finished year one!

• Good start of the stakeholder interaction
  • Participation at PROMOTioN events
  • Solid interest of press (although directed towards final results)
  • Very positive feedback from external organizations
  • First publications on their way

• International attention
  • Lots of feedback from European stakeholders
  • Interest of international stakeholders to exchange with PROMOTioN
Impact

Summary

• Foundations for the upcoming phases of the project are set

• Maintaining a strong focus on questions of high practical significance and pushing TRL of meshed HVDC offshore solutions

• Management structures working

• Successful start of project activities
• Foundations for the upcoming core phase of the project set

• Maintaining a strong focus on questions of high practical significance and pushing TRL of meshed HVDC offshore solutions

• Management structures working

• Successful start of project activities

…” but the project has proven to be able to stay on course despite rough waters
Thank you for your attention
Thank you