MID-TERM CONFERENCE PROMOTioN
AMSTERDAM, NETHERLANDS and
HALF YEARLY MEETING RIJKSUNIVERSITEIT
GRONINGEN (RUG), GRONINGEN,
NETHERLANDS

6 -8 JUNE 2018
PROMOTION MID-TERM CONFERENCE
6 JUNE 2018, AMSTERDAM, THE NETHERLANDS

1 OPENING
- Identification of the System Needs: the optimal grid
  Ben Voorhorst – TenneT, the Netherlands
- Vision for MOG and their benefit for Europe
  Jan Hermans – FPS Economy, Belgium
- Shaping a Meshed HVDC Offshore Grid for the Northern Sea
  Diederik Peereboom, T&D Europe

2 TOWARDS MOG
- Towards meshed off shore grids – Development of a roadmap
  Michiel de Schepper, TenneT, the Netherlands

3 REGULATORY – SESSION 1
- How to compare offshore grid solutions? A CBA methodology
  Wil van der Veen – DNV GL, the Netherlands
- How to develop an economic regulatory framework for MOG?
  Pradyamna Bhagwat – EUI-FSR, Belgium
- How to regulate a MOG? Legal regulatory challenges.
  Ceciel Nieuwenhout – RUG, the Netherlands
- Where does the money come from? Financing challenges for a MOG.
  Alexandra Armeni/Gerhard Gerdes – Deutsche WindGuard, Germany

4 REGULATORY – SESSION 2
- Potential flagship projects of the North Seas Energy Cooperation
  Sue Harrison, BEIS UK, United Kingdom
  Henriette Nesheim & Nicole Versijp, DG Energy, Belgium
- Regulatory challenges of a meshed offshore grid – NRA perspective
  Hannah Müller – Authority for Consumers & Markets, the Netherlands
- TYNDP and PROMOTioN – complementing or competing
  Antje Orths – Energinet/ENTSO-E, Denmark
5 TECHNICAL – SESSION 1
- WP2 – Grid Topology & Converters
  Chritina Brandle – RWTH Aachen University, Germany
- Characterisation of DC Circuit Breakers
  Dragan Jovcid, University of Aberdeen, United Kingdom
- DC grid protection
  Dirk van Hertem – KU Leuven, Belgium
- Overview of key technologies
  Cornelis Plet – DNV GL, the Netherlands
- Wind Turbine – Converter Interaction
  Ömer Göksu – DTU Wind Energy, Denmark

6 TECHNICAL – SESSION 2
- Best Paths & PROMOTioN – Utilizing project synergies
  Oliver Despouys – RTE, France
- HVDC Gas Insulated Switchgear Demonstration
  Paul Vinson – SuperGrid Institute, France
- HVDC Circuit Breaker Testing
  René Smeets, KEMA Laboratories DNV GL, the Netherlands
- Demonstration of Operation of DC Grid Protection
  Yash Audichya – SHE Transmission, United Kingdom
- MMC Test Bench Demonstrator
  Philipp Ruffing – RWTH Aachen, Germany
- VSC-based controller oscillations in Power system
  Ørsted, Denmark
- The need for demonstration
  Cornelis Plet – DNV GL, the Netherlands
Identification of the System Needs: the optimal grid
Vision for MOG and their benefit for Europe
Jan Hensmans, Belgium

- Double our capacity
- The reinforcement of the onshore network
- A new connection point
- The UK Benelux cluster of the North Seas
- ...
Towards meshed off shore grids – Development of a roadmap

6th June 2018, Amsterdam, Michiel de Schepper
Introduction

Intuitively a Meshed & Coordinated Offshore Grid will deliver measurable benefits to the Offshore (Wind) Supply sector.

Logical aggregation of design choices into concepts

Concept 1
Concept 2
Concept 3
Concept 4

Cost Benefit Analysis

Technical / Financial & Economic / Legal Feasibility

Recommendations
Deployment Plan
Stakeholder direction

Volume Scenarios
Topology
Market Requirements
Legal & Regulation
## What do we need to achieve?

<table>
<thead>
<tr>
<th>Premise</th>
<th>Meaning</th>
<th>Who</th>
</tr>
</thead>
<tbody>
<tr>
<td>A、Acceptance of a joint approach</td>
<td><em>Do we want to – are we interested and what do we expect/want it to do</em></td>
<td>EU / Member states</td>
</tr>
<tr>
<td>B、Is it technologically feasible</td>
<td><em>How can we do it (what &amp; when)</em></td>
<td>R&amp;D / market ready</td>
</tr>
<tr>
<td>C、Is it feasible; legal &amp; regulation</td>
<td><em>How to ensure that we are we allowed to do it</em></td>
<td>EU &amp; National law &amp; regulations</td>
</tr>
<tr>
<td>D、Is it economically feasible</td>
<td><em>Is it attractive to do it – are (social) benefits &gt; costs</em></td>
<td>EU / Member states</td>
</tr>
<tr>
<td>E、Is it organisationally feasible</td>
<td><em>How to organise, cooperation model</em></td>
<td>EU / Member states Operator / owner</td>
</tr>
<tr>
<td>F、Is it financially feasible</td>
<td><em>How to enable a bankable business case we make an investable case</em></td>
<td>Operator / owner Market / Equity funders</td>
</tr>
</tbody>
</table>
To Harvest the Benefits of a Meshed Offshore Grid (discussed this morning) there is a long road to take to get there...
National ecosystems focus: Build vs Coordinate

National ecosystems promote build of Offshore wind capacity, but coordination and forward thinking to facilitate a regionally optimal transmission solution are lacking.

• The situation today is largely uncoordinated internationally:
  • Different national regimes / starting points;
  • Different technical solutions;
  • Different National character / preferences.
• Currently the “easy” projects are being built, i.e. close to shore, existing technology.
• Timing /planned horizon (when can you influence future development [up to 10 years]).
• Distance to shore and density of infrastructure make a coordinated approach more logical.
• Benefit gained from combining the functions of interconnection and the evacuation of offshore wind energy
• Increased utilisation and cost optimisation of infrastructure
• Technology availability (new solutions HVDC meshing).
• Underlying Framework:
  • Legal
  • Regulatory → Business Model
  • Other
Elements of Analysis - Topology

Initial Analysis focuses on Topology – “Concepts”

International Distributed Hub Concept

Business as Usual

Centralised International Coordinated Hub Concept

National Distributed Hub Concept
### Technology forms a bottleneck, as required solutions not yet fully developed.

<table>
<thead>
<tr>
<th>Converter Technology</th>
<th>Interoperability</th>
<th>HVDC Cables</th>
<th>System control</th>
<th>Protection Philosophy</th>
<th>HVDC Circuit Breakers</th>
<th>HVDC GIS</th>
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</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
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</tbody>
</table>

12.2 will use Cost benefit techniques applied to concepts and volume scenarios to establish appropriate technical architecture for Scenario’s.
Elements of Analysis - Topology

Scenarios integrate expected timing, volume and location of OWF roll-out

Prognosis of OWF capacity
In Yellow additional capacity of Fixed in GW to install per 5 Years

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
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<tbody>
<tr>
<td>High</td>
<td>0.4</td>
<td>3</td>
<td>25.0</td>
<td>20.1</td>
<td>15.6</td>
<td>27.0</td>
<td>25.5</td>
<td>28.0</td>
<td>31.5</td>
</tr>
<tr>
<td>Central</td>
<td>0.4</td>
<td>3</td>
<td>25.0</td>
<td>9.6</td>
<td>12.0</td>
<td>15.3</td>
<td>19.6</td>
<td>20.0</td>
<td>24.5</td>
</tr>
<tr>
<td>Low</td>
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<td>3</td>
<td>25.0</td>
<td>2.8</td>
<td>7.4</td>
<td>8.1</td>
<td>9.4</td>
<td>11.2</td>
<td>12.6</td>
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<tr>
<td>Dogger Bank (energy Island)</td>
<td>High</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>12</td>
<td>25</td>
<td>30</td>
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<tr>
<td>Dogger Bank (energy Island)</td>
<td>Central</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>12</td>
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<tr>
<td>Dogger Bank (energy Island)</td>
<td>Low</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Market clearing does not drive an unique architecture for active elements in an offshore grid,

- Active power flows through each converter depend strongly on market clearing for each offshore wind generator
- For cross-border flows in line with the market clearing (e.g. in case several converters connect an offshore grid to a country)
- Voltages (in both the AC and the DC grid).
- Scheduling process is the link between the market system and the settings of the converters.

Several practical aspects will be considered, driving the analysis and the tech choices:

- Controlling power flows
- Optimizing the DC grid topology
- Consideration of AC and DC constraints
- Compensating imbalances
- Operational security of the grid
- Partial restoration of the grid after a fault

12.1 Opens the discussion of these issues
12.2 Considers appropriate technical solutions to satisfy the market constraints.
Elements of Analysis - Regulatory

**Regulatory framework & governance**

**Pre-Feasibility phase**
- Initial evaluation of where to site Capacity

**Feasibility**
- Preliminary evaluation of opportunities

**Concession Phase**
- Where to build? Rollout of assets?

**Build**
- Coordination of investments International & National Projects

**Operate**
- Market Regulation Security Ownership Other

**Transfer**
- Ownership of assets Liability

**De-commission**
- Clean-up of infrastructure

WP7.1 has analysed the current legal framework, WP7.6 makes global recommendations for each scenario. These are validated in WP12.2
Elements of Analysis – Economics & Finance

Economic feasibility and business model

CBA methodology is based on ENTSO-E technique and publically available literature. It will be applied in WP12.2 to make:
1. CBA of technical choices within each Concept
2. CBA of different Concept-Scenarios
3. Conclude on Economic feasibility of each Concept-scenario
Elements of Analysis - Finance

Financeability

Subsidies
- Support for national and International offshore projects
- Anticipatory investment (like Airbus, JSF or Boeing)
- Loan Structures

Private Strategic Investment / TSO
- Limits to investment capacity
- Ownership and management issues

Private Investment Banks and Funds
- Amount of required investment
- Timing
- Perceived risks
  - Stability of cash dividends
  - Priority
- Required return on investment
Elements of Analysis

National preferences

• Cultural inclination towards or away from central coordination / regulation?
  • UK (Anglo Saxon values, organic, financially efficient) vs Germany (Planned, central coordination, technically strong)

• Refer to precedents
  • Oil & gas infrastructure (pipeline, tunnel infrastructure)
  • Communication

• Can non-Northern Sea member states contribute to Norths Sea wind power development?
  • What if finance derived from non-Northern Sea member states?
  • Can such a country finance and build capacity in designated areas?
  • If yes, who gains the RES credits?
## Results

### What do we need to achieve...

A potential way to summarise results *may be*:

<table>
<thead>
<tr>
<th>Choice</th>
<th>Motivation</th>
<th>Options</th>
<th>Impact of each option</th>
<th>Recommended choice</th>
<th>Owner now</th>
<th>Ideal owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage levels</td>
<td>Assets with different voltage ratings cannot be connected together to form a grid. Due to the fact that high power HVDC-HVDC conversion is not yet developed</td>
<td>Cigre TB on recommended voltages</td>
<td>Amount of power Technical maturity Availability of manufacturers Cost ...</td>
<td>Some form of standardisation Future ...</td>
<td>In AC projects onshore, TSO determines voltage based on standardised voltage classes. In turn key HVDC projects often voltage level chosen by OEM to optimise link</td>
<td>IEC standards and TSOs</td>
</tr>
</tbody>
</table>
Results

Conclusions or summary

• Not one solution – many potential routes
  • Business as usual is real and today
  • May be expected to follow route of least resistance
• Make benefits of choices transparent

We can’t change the direction of the wind, but we can adjust the sails to always reach the destination.

Jimmy Dean
T7.6: How to compare offshore grid solutions? A CBA methodology

Wim van der Veen (DNV GL), PROMOTioN mid-term conference
T7.6: How to compare offshore grid solutions? A CBA methodology

Wim van der Veen (DNV GL), PROMOTioN mid-term conference
Content Slide

• CBA methodology for offshore grids
• Challenges in comparing offshore grid solutions
• KPIs
• Conclusions
• To develop a CBA methodology able to identify the “best” offshore grid design
• Compare different project alternatives (offshore grid topologies)
PROMOTioN – CBA methodology for offshore grids

Scope
PROMOTiON – CBA methodology for offshore grids

Dimensions

- Scope
- Scenarios
- KPI assessment
- Project alternatives
- Tools
- KPI definition
- Assess -ment framework
PROMOTioN – CBA methodology for offshore grids

Pragmatic versus ideal methodology
- for each dimension -

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Activity</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope</td>
<td>CBA</td>
<td><strong>Value to society</strong>&lt;br/value to each&lt;br&gt;(surrounding / North Sea) state&lt;br/values to society &amp;&lt;br&gt;(surrounding/North Sea) state&lt;br/values to all stakeholders</td>
</tr>
<tr>
<td></td>
<td>Non-monetised CBA</td>
<td>Augmented CBA (hybrid)&lt;br/Financial CBA (full monetisation)</td>
</tr>
<tr>
<td>Purpose of project</td>
<td>Offshore grid for evacuation of wind&lt;br/ &amp; market integration</td>
<td>Offshore &amp; onshore grid for evacuation of wind&lt;br/ &amp; market integration</td>
</tr>
</tbody>
</table>
Content Slide

• CBA methodology for offshore grids
• Challenges in comparing offshore grid solutions
• KPIs
• Conclusions
PROMOTioN – Challenges

Scenarios

• How to evaluate project alternatives?

Onshore scenarios

Offshore scenarios

Technologies

Market design

Grid development

Source: ETO, DNV GL

Source: DNV GL

Source: TenneT

Source: Platts
PROMOTioN – Challenges

Scenarios

• Guidelines on scope of scenarios to avoid bias
• Onshore and offshore scenarios
• Ideal vs practical
• PINT vs TOOT
• Reference for project assessment
  o Null-alternative = base-case = BAU
PROMOTioN – Challenges

Assessment framework

- Project comparison
- Limits on full monetisation of KPIs
- Objective KPIs and weights
- Ideal vs practical

Degree of quantification and monetisation
CBA methodology might differ depending on concept
• Purpose of the project
• Sectors/technologies where project alternatives can draw from
• Ideal versus practical
PROMOTioN – Challenges

Project alternatives - boundaries

- How to deal with the onshore grid?
- Connection points
- Ideal vs practical

Degree of complexity
Content Slide

• CBA methodology for offshore grids
• Challenges in comparing offshore grid solutions
• KPIs
• Conclusions
• ENTSO-E Guideline V2.0
• Relevance for offshore grid
• Degree of quantification/monetisation
For each KPI:

• Definition

• Relevance for the CBA for offshore grids

• How to calculate the KPI?
  • Ideal vs practical execution

• What is the interaction with other KPIs?
  • Double counting
Content Slide

• CBA methodology for offshore grids
• Challenges in comparing offshore grid solutions
• KPIs
• Conclusions
Challenges in comparing offshore grid solutions

- Complexity in CBA dimensions
- Single project vs system
- Financial vs societal CBA
- Ideal vs practical methodology
- CBA approach may differ between evaluated project alternatives
How to develop an economic regulatory framework for MOG?

Mid-Term Conference
Pradyumna Bhagwat, EUI-FSR, Amsterdam, June 6, 2018
PRESENTATION STRUCTURE

• MOG Planning

• MOG Investment
PLANNING
Cost benefit analysis for offshore electricity grid infrastructure

Recommendation I
- Dealing with interactions between (offshore) PCIs

Recommendation II
- Gain trust and public acceptance

Recommendation III
- Reduce the politics in valuation of (offshore) PCIs

For more details & download: http://hdl.handle.net/1814/48524
ECONOMIC FRAMEWORK FOR OFFSHORE GRID - PLANNING

COORDINATING ONSHORE-OFFSHORE GRID PLANNING

LOCATIONAL REQUIREMENTS FOR RES SUPPORT

<table>
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<th>Germany</th>
<th>Denmark</th>
<th>UK</th>
<th>Sweden</th>
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<tr>
<td>Zoned</td>
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<td>Single-site</td>
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ONSHORE GRID ACCESS RESPONSIBILITY

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<th>Sweden</th>
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</table>

GRID CONNECTION COSTS

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<th>UK</th>
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<td>Super shallow</td>
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<td></td>
</tr>
<tr>
<td>Deep</td>
<td></td>
<td></td>
<td></td>
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</tbody>
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For more details & download: [http://hdl.handle.net/1814/47406](http://hdl.handle.net/1814/47406)
Understanding Public Perception

Understanding Public Participation

For more details & download: http://hdl.handle.net/1814/47406

For more details & download: http://hdl.handle.net/1814/54884
INVESTMENTS

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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.
ECONOMIC FRAMEWORK FOR OFFSHORE GRID - INVESTMENT

COOPERATION MECHANISMS FOR RENEWABLE SUPPORT

Directive 2009/28/EC

Statistical Transfers Joint Projects Joint Support Schemes

Proposed renewables directive (recast)
Article 5
Opening of support schemes for renewable electricity

Joint Support Scheme

Joint PV Auctions

For more details & download: http://hdl.handle.net/1814/47406

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Dedicated Incentives

For more details & download: http://hdl.handle.net/1814/51324

Conclusions

1. Incentives may not be sufficient for investment in a meshed solution

2. Default regulatory frameworks have not moved towards the investment zone

3. The use of dedicated incentives has increased as a way of fostering strategic investments

4. Dedicated incentives can be a solution to ensure sufficient incentives for development of meshed offshore grids

Results of this study will be published in the final report
ECONOMIC FRAMEWORK FOR OFFSHORE GRID PLANNING

Transmission Tariff Design

For more details & download: http://hdl.handle.net/1814/47406

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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.
Key insights

• In the MOG context, binding contracts would be extremely relevant to ensure avoiding stranded investments and ‘bridges to nowhere’.

• A common CBCA for a group of projects within the MOG could be a key enabler for their development (e.g. considering complementarity of projects).

• In multi-country projects such as the MOG, the significance threshold may become a barrier in allocating costs and reaching a complete CBCA.

Results of this study will be published in the final report
CONTRIBUTING ORGANISATIONS FOR INTERMEDIATE REPORT

KU LEUVEN

Tennet

European University Institute

CARBON TRUST
Thank You!
Pradyumna Bhagwat
Email: pradyumna.bhagwat@eui.eu
LinkedIn: www.linkedin.com/in/pcbhatwag
Twitter: @PCBhagwat
APPENDIX

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MAIL info@promotion-offshore.net WEB www.promotion-offshore.net

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PROJECT COORDINATOR
DNV GL, Kema Nederland BV
Utrechtseweg 310, 6812 AR Arnhem, The Netherlands
Tel +31 26 3 56 9111
Web www.dnvgl.com/energy

CONTACT
Pradyumna Bhagwat
European University Institute – Florence School of Regulation
Pradyumna.bhagwat@eui.eu

PARTNERS
How to regulate a MOG?
Legal regulatory challenges

Amsterdam, 6-6-2018, Ceciel Nieuwenhout, WP7.1
OUTLINE

• Introduction
• Overview of results 2016-2018
• Future outlook: Research aims 2018-2019
• Focus on current research: Asset Classification
• Conclusion
• Q&A
INTRODUCTION
Legal and Regulatory Challenges: Where to Start?

Overview Results 2016-2018

The first year was used to investigate the status quo and current legal challenges.

Stakeholder interaction: check whether findings D7.1 match practice.

Topic of today’s presentation

Overview of status quo & challenges
- International Law
- EU Law

Which legal instrument fits which problem?
Approach at international/EU/national level or a combination?
Legal and Regulatory Challenges: Where to go next?

Future outlook: Research aims 2018-2019

- How to regulate support schemes in an offshore grid?
- How to streamline license and permit granting processes for cross-border infrastructure?
- Input for WP12 + public report + stakeholder interaction

Support Schemes

Offshore Grid Operation

Licenses and Permits

Decommissioning

Final Report

Which legal action is needed for smooth offshore grid operation?

What to do at the end of the lifetime of offshore wind farms connected to an offshore grid?
• Hub-to-hub
• Offshore wind farms are connected to an existing interconnector (Tee-in)
• The entire asset (windfarm connection and interconnection) is constructed more or less at the same time
• A meshed offshore grid with grid extensions from time to time

Currently:
- how an asset is connected determines regulatory status!
- Legislation does not do justice to specifics of hybrid/meshed grids: access/dispatch
- Wish to keep current regulatory system in place for existing infrastructure = more legal certainty
• Retain current laws > Kriegers Flak
• Classification as “upstream” > gas pipeline system on the North Sea
• New Definition?

• Cross-border between two or more states
• Offshore (geographically located in the seabed, except where the cable ‘lands’ in the onshore grid)
• Starting from onshore connection point (i.e. HVDC converter station or AC transformer station), to be specified in lower legislation such as Network Codes
• With the purpose of connecting offshore renewable electricity generators to the onshore transmission network/s and of hosting cross-border electricity flows
‘cross-border offshore electricity grid’

=  

‘transmission assets that connect offshore generation from renewable energy sources to onshore connection points in two or more national electricity systems.’
‘Cross-border offshore electricity grid’

= 

‘transmission assets that connect offshore generation from renewable energy sources to onshore connection points in two or more national electricity systems.’
CHAPTER 1 – SAMPLE TITLE FOR THIS CHAPTER

CONSEQUENCES

Financial Regulation:
For the ‘cross-border offshore electricity grid’, income should be based on regulated income rather than on congestion revenue.

Access & Dispatch:
No more priority access&dispatch, instead focus on development of good market principles.
CONCLUSION + Q&A
APPENDIX

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PROJECT COORDINATOR
DNV GL Netherlands B.V.
Utrechtseweg 310, 6812 AR Arnhem, The Netherlands
Tel +31 26 3 56 9111
Web www.dnvgl.com/energy

CONTACT
C.T. Nieuwenhout
Groningen Centre for Energy Law
c.t.nieuwenhout@rug.nl
+31 50 3635688

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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.
Where does the money come from?
Financing challenges for a MOG

Mid-term conference, Amsterdam, 06-06-2018
Alexandra Armeni, Gerhard Gerdes, Deutsche WindGuard
• Financing challenges
• Possible investment models for a MOG in the North Sea
• Conclusion
Financing challenges
CHAPTER 1 – Financing challenges

Financing challenges & private investors’ concerns

• Huge investment volume
  – EUR 100 billion by 2030 for offshore grid in the North Sea (ENTSO-E, 2014)

• Public & private capital is needed.

• Cannot be covered only by debt side
  – TSO balance sheet constraints

• Significant equity is needed but
  – state-owned TSOs face government’s budget constraints
  – legal restrictions on access to private equity

• Private investors’ concerns:
  – TSO-monopoly
  – TSO legal ownership restrictions
  – regulatory clarity/retroactive actions/regulatory consistency
  – complexity due to different national regulatory frameworks
  – lack of central pan-European grid planning and structure

• If interest rates increase:
  – greater competition with alternative investments in the market
  – danger of limited financing potential for the sector
Important: North Sea MOG vs coupling of grid areas

• The North Sea MOG is an integrated grid, not a coupling of national TSO grids
Possible investment models for a MOG in the North Sea
CHAPTER 2 – Possible investment models for a MOG in the North Sea

Model 1: North Sea Grid (NSG) TSO

NSG planner
Dedicated working group of national TSOs & national authorities

NSG regulator
- NRAs
- Set grid tariffs for North Sea region

NSG TSO
- National TSOs
- National TSOs & private investors

NSG TSO
- Obtain permits
- Investment
- Construction & technical design
- Operation & maintenance
CHAPTER 2 – Possible investment models for a MOG in the North Sea

Model 1: North Sea Grid (NSG) TSO – Evaluation

• One entity responsible for construction and operation of the MOG
  – less interfaces
  – less effort for operational grid co-ordination
  – achieve faster a common approach to the development of a MOG

• If NSG TSO is an enterprise with a reasonable RoE and allows private shareholders
  – attractive to private investors
  – facilitate equity provision

• Challenges:
  – TSO legal ownership restrictions
  – Exclusion of the current TSOs’ role
  – Great effort for development of a uniform legal and regulatory framework and tariff structure

• Set up a NSG regulator responsible for setting a grid tariff system for the MOG
CHAPTER 2 – Possible investment models for a MOG in the North Sea

Model 2: National TSOs

- NSG planner & co-ordinator
  - NSG ISO (separate body)

- NSG regulator
  - NRAs
  - Set grid tariffs for North Sea region

National TSOs
- Existing role of national TSOs & OFTOs
CHAPTER 2 – Possible investment models for a MOG in the North Sea

Definition: NSG ISO (Independent System Operator)

• It is an integrated grid, not a coupling of national TSO grids
• Set up a NSG ISO: national TSOs and/or national authorities
• NSG ISO responsible for:
  – Grid planning
  – Operational co-ordination
  – Efficient management of the entire MOG
  – Technical requirements & specifications
CHAPTER 2 – Possible investment models for a MOG in the North Sea

Model 2: National TSOs - Evaluation

- Existing regulatory basis and structures already in place

- Challenges:
  - Private equity provision constraints
  - Additional regulations for cross-border connections of OWFs
  - Great effort for co-ordination and convergence of different regulations

- Set up a NSG ISO to ensure efficient management and development of the MOG
- NSG ISO complementary to national TSOs
- Set up a NSG regulator responsible for:
  - setting up a common grid tariff system
  - common business plans
  - streamlined cross-border investments
  - clearer revenue streams
  - eliminate investor risks
CHAPTER 2 – Possible investment models for a MOG in the North Sea

Model 3: 3rd party investor

- Private or public investors
- National or international
- Public-private consortia

NSG planner & coordinator
NSG ISO (separate body)

NSG regulator
- NRAs
- Set grid tariffs for North Sea region
- Manage tenders

3rd party investor

SPV (Concessionaire)

Obtain permits
Investment
Construction & technical design
Operation & Maintenance of the offshore asset (CATO)
CHAPTER 2 – Possible investment models for a MOG in the North Sea

Model 3: 3rd party investor-International experience

• International experience in tendering of transmission assets of Brazil, Peru and UK

• Brasil: 1999-2017 → ~90000 km transmission lines → 24% cost savings

• Peru: 100% of the high voltage transmission system is in private hands

• UK: introduction of competition in onshore transmission grid → CATO (Competitively Appointed Transmission Owners)

• Key learnings:
  • A stable, long-term legal & regulatory framework
  • Multiple transmission owners co-exist without compromising the efficiency & security of the system
  • Significant cost savings
  • Increase efficiency
Model 3: 3rd party investor - Evaluation

- Private equity provision is facilitated through tenders.
- Higher competition for construction and technical design of offshore assets:
  - capital costs savings
  - create cost benchmarks
  - increase innovation
- At the same time more transmission assets can be built

Challenges:
- Legal restrictions in some countries on implementation of the 3rd party model
- Exclusion of the current TSOs’ role
- Higher effort for communication and co-ordination with several entities

Set up a NSG ISO for:
- grid planning
- system needs
- stronger operational co-ordination of the MOG

Set up a NSG regulator for:
- common grid tariff system
- manage tenders

Set up a NSG ISO for:
- grid planning
- system needs
- stronger operational co-ordination of the MOG

Set up a NSG regulator for:
- common grid tariff system
- manage tenders
CHAPTER 2 – Possible investment models for a MOG in the North Sea

Model 4: Combined model

- NSG planner & co-ordinator
- NSG ISO (separate body)
- NSG regulator
  - NRAs
  - Set grid tariffs for North Sea region
  - Manage tenders

National TSOs/OFTOs (existing structures) & for strategic offshore transmission assets tenders to 3rd parties

SPV (Concessionaire)

- Obtain permits
- Investment
- Construction & technical design
- Maintenance of the offshore asset
- Operation of the asset only under CATO model
Model 4: Combined model - Evaluation

- Private equity provision is facilitated.
- Introduction of competition for construction & technical design
- Capital cost savings
- Create cost benchmarks
- Increase innovation

Challenges:
- Legal constraints for application of 3rd party investor model
- Higher effort for communication and co-ordination with several entities

Set up a NSG ISO:
- operational co-ordination
- efficient management and development of the MOG

Set up a NSG regulator:
- common grid tariff system
- manage tenders
Potential flagship projects of the North Seas Energy Cooperation

Sue Harrison, BEIS UK
Henriette Nesheim & Nicole Versijp, DG Energy
Midterm conference: "PROMOTIoN Shaping a meshed HVDC offshore grid for the Northern Seas"
NORTH SEAS OFFSHORE WIND IS PIVOTAL TO REALIZE A 100% DECARBONIZATION OF THE ELECTRICITY SUPPLY
Offshore wind contribution to RES targets: cooperation, cost reduction and MSP optimisation required

2030 & 2050 RES targets of EU

- 2030: Cut GHG emissions by 40% (compared to 1990) and increase RES share in energy mix to 27%
- 2050: Cut GHG emissions by 80-95% (compared to 1990)

Significant contribution by offshore wind

- North Sea, Baltic Sea and EU Atlantic Ocean potential of 64-86 GW installed by 2030 (WindEurope)
- North Sea potential up to 250 GW by 2050 (WEC)

Challenges for expansion of offshore wind

- Cross-stakeholder cooperation on regional level
- Reduction of offshore grid development cost
- Optimisation of maritime spatial planning (MSP)
Based on developed knowledge, North Seas Energy Cooperation took a practical approach

**NSCOGI: From 2009 until 2016**

- Theoretical approach: design a regulatory, legal and market framework to incentivise projects
- No concrete projects:
  - Too early, high cost of offshore wind generation
  - Insufficient interest from business community
  - BUT developed comprehensive theoretical framework

**NSEC: From 2016 until today**

- New context: significant cost reductions in offshore wind and political commitment for 2030-50
- Agreed (cluster) approach:
  - Bottom-up identification of potential flagship projects
  - Extensive stakeholder interaction and support for early movers
  - Learning by doing - step-by-step development of framework
  - Share knowledge and best practices
In a study, potential flagship project starting points identified in 4 clusters across North Seas.

**Phase 1:** Identification
- Project Irish Sea

**Phase 2:** Evaluation

**Phase 3:** Action Plans
- North Sea Wind Power Hub
- COBRA Cable
- DE OWF connected to NL
- CGS DE OWF – NL OWF
- NeuConnect
- CGS IJmuiden Ver – Norfolk
- IJmuiden Ver OWF to UK
- UK OWF connected to BE

**Phase 4:** Lessons learned

Source: 4COffshore

1) Location / routing indicative
Phase 2: Evaluation

- High-level evaluation of potential flagship projects regarding commercial and societal benefits; assessment of barriers to project implementation
- Development of cluster-specific Action Plans to overcome identified barriers and facilitate implementation
- Collection and dissemination of lessons learned and best practices
- Flagship projects are considered potential building blocks of future grid – modular development: no-regret projects and built-in optionality

Phase 4: Lessons learned

Long-term (regionally) optimised grid (possibly including storage / power to X) addressed by PROMOTioN
Six hybrid project concepts: building blocks for optimised grid development

A "Combined grid solution"

B "Modular grid"

C "Interconnector tie-in"

D "Offshore hub"

E "Neighbour lease"

F "Cross-border OWF"

- Offshore wind farm
- Converter station
- EEZ border
- Offshore cable
The future offshore grid?
Thank you for your attention!
Do you have any questions?
Regulatory challenges of a meshed offshore grid - NRA perspective -

Hannah Müller
Presentation

I. Short introduction

II. Regulation of the offshore TSO

III. Challenges for regulation

IV. Outlook
Background

• Works at the Directorate Energy of the Dutch regulatory authority: Authority for Consumers & Markets (ACM)
  - regulation of TenneT as onshore and offshore TSO
  - integration of the European energy markets

• PhD research at the University of Groningen
  - Thesis: Developing a legal framework for a transnational offshore grid in the North Sea
Offshore grids in the Netherlands

1) First round
   • two OWFs: one in territorial sea, one in EEZ
   • OWFs were responsible for cable to shore

2) Second round
   • in 2009, 12 permits were granted
   • only 3 OWFs received subsidy and were built
   • OWFs were responsible for cable to shore

3) Third round
   • new legal regime in 2015/2016
   • government allocates offshore wind energy areas
   • the offshore wind areas are tendered
   • TenneT TSO responsible for connecting OWFs
Overview offshore wind in the NL: next step?

Source: 4coffshore.com
Presentation

I. Short introduction

II. Regulation of the offshore TSO

III. Challenges for regulation

IV. Outlook
Regulation of TenneT as offshore TSO I

• Certification and designation of TenneT TSO B.V. in 2016

• Investments in Dutch offshore grid:
  - Ministry issues an ‘offshore wind scenario’, which lays down how and when to connect OWFs
  - TenneT works this out in an investment plan
  - ACM assesses the motivation and reasoning
  - when the investment plan is finalized, the investments are considered necessary

• As TSO, the income of TenneT for these investments is regulated
Regulation of TenneT as offshore TSO II

The income regulation
- income is set in advance
- incentives to be efficient
- ex post: project specific efficiency assessment
- ex post: benchmark

TenneT incentivised to make efficient investments

Currently, the income is financed via a subsidy.
Presentation

I. Short introduction

II. Regulation of the offshore TSO

III. Challenges for regulation

IV. Outlook
View of the NRA

- The regulation has a rather national focus and is already complex
- Ensure efficient investment and adequate tariffs

Transnational offshore grid?
- how to ensure efficient choices to keep costs low?
- how to allocate costs and benefits?
- who would be responsible?
- how to finance?
- if TSO would be responsible:
  - incentives
  - clarity needed about responsibility TSO
  - no rules for oversizing
  - interconnector vs. offshore grid
  - allocation of capacity
Unclear regulatory situation
Presentation

I. Short introduction

II. Regulation of the offshore TSO

III. Challenges for regulation

IV. Outlook
Conclusion

• The current legal and regulatory framework is focused on national grids
  In consequence, regulation is rather national

• If there is the political will, this could be changed

• Important for the NRA
  - choose the most efficient approach
  - ensure that the market has sufficient role
  - make a robust regional CBCA
  - ensure balance between financial incentives for TSOs and sufficient certainty
Thank you for your attention!

Questions?
TYNDP and PROMOTioN – complementing or competing?

Antje Orths
Energinet
ano@energinet.dk
They are complementing each other!
Thank you for your attention!
Different purpose:

- **TYNDP**: regularly informing EU about impact of different future scenarios on infrastructure. Identifying needs; assessing projects against scenarios.
- **2012** – serving NSCOGI with offshore grid study:
  - case by case // modular development // all technologies (AC, DC), various designs (radial – hubs – hybrid - meshed)
- **PROMOTioN** – research. Diving into the "meshed" part, investigating many details and designs, including demonstrations. Broad spectrum of issues (technology – regulatory issues).
Identification of the System Needs (IoSN) - Process

The general process of the TYNDP

Scenario building process

Identification of System Needs in 2040

CBA

All reference scenarios used for all analysis performed

New capacity increases would be necessary by 2040.

To evaluate the impact of planned network reinforcements
Identification of the System Needs - Scenarios

Scenario used in TYNDP process

Key factors:
- Transport
- Heating
- Power
- Renewable Gases

Main update respect the TYNDP 2016

Cooperation with ENTSOG
Publication of Clean Energy Package

1 Scenario
2 Scenarios (coal vs gas merit order switch)
3 Scenarios
3 Scenarios
Identification of the System Needs - Scenarios

2040 scenarios - Key Indicators

Key indicators

- **Transport**
  - Electric and hybrid vehicles: High growth
  - Gas vehicles: High growth

- **Heating**
  - Electric heat pump: High growth
  - Hybrid heat pump: High growth

- **Power**
  - Storage: Moderate growth
  - Wind: High growth
  - Solar: High growth

- **Renewable Gases**
  - Power-to-gas: High growth
  - Bio-methane: High growth
Identification of the System Needs - Scenarios

2040 scenarios - Electricity

Installed Capacity

Energy Mix

PV and Wind drive RES development

Generation Mix shifts towards low Carbon sources

from: IoSN Report – Consultation Version, Jan 20
Identification of the System Needs - Scenarios

2040 scenarios - Electricity: Energy Mix

Scenarios create contrasted Country level results

RES share:
2030: 50-58%
2040: 62-77%

from: Scenario Report for Consultation, Oct 201
Identification of the System Needs - Methodology

Main steps of the approach

Market studies
- Identification of potential needs based on marginal costs diff. and the cost of capacity incr.
- Check of economic efficiency

Network studies
- Identification of cross border and internal bottlenecks
- Update of costs of capacity increase

Regional expert check
- Integration of renewable generation
- Reduction of risk of SoS issue
- Check of interconnection targets

Main update respects the TYNDP 2016
Better balance between overall EU view and RG's specificity

Additional capacity increases not necessarily result in new projects in TYNDP 2018
Many investments needed..

Challenged AC borders

Internal reinforcement needs

Standard costs per 1 GW

RGNS RegIP – details online: http://tyndp.entsoe.eu/
Global Emissions Trading Scheme
Large scale development of renewable resources. Low Carbon technologies
High economic growth & Energy Efficiency
Electric and gas vehicles displace oil in the private transport sector
Gas helps the decarbonisation of the shipping and heavy goods transport sectors
Power-to-gas commercially available. Bio-methane
Electric and hybrid heat pump technology help to decarbonise heating

'Prosumer' lead climate action, helped by strong EU Policies and an efficient ETS.
Storage drives climate action
Decentralised growth of RES
High economic growth
Smart cities enabled with electricity storage and demand response
Decarbonisation of transport driven by electric vehicles
Hybrid heat pumps offer consumer choice and flexibility

National focus on climate change, driven by ETS and national subsidies
Steady growth of renewable resources
Moderate economic growth
Gas sees significant growth in the shipping and transport sectors
Electrification of heating and transport sees stable development
Strong development in Bio-methane but none in Power-to-gas
Heat pump technology most common in new buildings
The cost of no action....

3 to 14 €/MWh reduction in marginal costs (prices)

.. and 40 to 60 Mton reduction in CO2

Benefits...

...referring to IoSN 2040 capacities

compared to the 2020 grid
Summer Package - Focus on 2030 time horizon

Long term needs (2040)

Medio term targets and boundaries (2030)

Project assessment (2030 & 2025)

Benefits

- B1 Socio-economic welfare
- RES fuel savings
- Emissions cost savings

Costs

- C1. CAPEX
- C2. OPEX

Residual impacts

- S1. Environmental
- S2. Social
- S3. Other

Project assessment

- System adequacy
- System security

Increases of capacities from 2030 to 2040 Summary
ENTSO-E’s 2016 view on the 2030 offshore grid infrastructure

General findings
• Modular, step-wise development of the Northern Seas grid infrastructure is ongoing and re-evaluated every 2 years
• Cooperation among countries and among stakeholders is key.

Key Facts and Figures
- 25 individual projects develop into a global scheme
- Infrastructure costs of 12 - 25 bn €
- Socio-economic benefits of 2 - 3 bn € / yr
- Additional RES integrated of 15-32 TWh/ yr
- CO2 reduction of +10 200 ... -19 500 kt/ yr

See the whole story here:
http://tyndp.entsoe.eu/insight-reports/north-seas/
## Northern Seas Offshore Grid Infrastructure - 2018

**TYNDP18 edition**

### On- and Offshore wind development (TYNDP16 vs TYNDP18)

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<th>TYNDP16</th>
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### Assessment Results for NS-OGI

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<td><strong>CO2 [kT/y]</strong></td>
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<td><strong>RES [GWh/y]</strong></td>
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20 projects developing into the global scheme.
## North Sea Wind Power Hub

**TYNDP18 edition**

### On- and Offshore wind development (TYNDP16 vs TYNDP18)

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### Assessment Results for NSWPH

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<td>Costs</td>
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Welcome the ENTSO-E summer package 😊

Thank you!
WP2 – Grid Topology & Converters

Intermediate Conference Amsterdam
Christina Brantl – RWTH Aachen University

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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.
CONTENT

- Objectives of WP2
- Topologies
- Converters
- Overview Studies & Results
Overview

Objectives of WP 2

Trade-off analysis of different topologies

Interconnection of VSC and DRC systems

Control concepts to ensure interoperability

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

**Evolution of HVDC topologies in Europe**

**Type of topology:**

**Existing**
- LCC-Links
- VSC-Links for
  - Grid reinforcement
  - OWF connection
  - Interconnectors

**Planned**
- Radial VSC Multi-terminal systems
- Meshed VSC Multi-terminal systems
- DC Overlay grid

**Schematic representation:** VSC based HVDC systems
Topologies

Challenges due to topology development

Normal Operation & System Design
- DC voltage level
- DC configuration
- Operational strategy
- Interoperability

Role of Offshore Wind Farms
- New requirements?
- Use of control capabilities for AC and DC FRT

DC side faults and contingencies
- Reliability and availability criteria
- Impact of faults and fault clearing strategies

AC system dynamics
- Provision of ancillary services
- AC FRT of the overall system
- Respect the different frequency reserves

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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.
Converters
Converters

Converter types & models

State of the art MMC-systems
- Half-bridge based
- Symmetric monopolar configuration

Planned systems
- Full-bridge based
- Bipolar configuration

Under development
- Diode rectifier based HVDC systems
- Combinations of the given systems
Converter controls

EMT models based on Cigré
- Adaptation for different configurations, topologies and models

Enhancement of controls
- Studies on combined wind farms and DC grid models
- Grid forming and grid following controls for wind farms
- Frequency support strategies

DRU controls
- From energization to fault operation
- Combination in different grid layouts
- Technical interoperability of different converter types and controls
Studies & Results
Studies & Results

Overview Studies

Normal Operation & System Design

- Optimal power flow with different objectives
- Operational strategies
- Interoperability of DRUs

Role of Offshore Wind Farms

- Requirements on OWFs for various fault clearing strategies
- Use of control capabilities for AC and DC FRT

DC side faults and contingencies

- Impact of faults and fault clearing strategies on the overall systems and its components

AC system dynamics

- Frequency support
- AC FRT of the overall system
- Impact of DC faults and their clearance on the AC power flow
Studies & Results

Exemplary achievements and conclusions

- Extended converter PSCAD models have been integrated into the Cigré working group B4-69
- Operation of DRUs in different grid layouts is possible
  - From steady-state to fault operation
  - Parallel operation of grid forming and grid following wind farms
- Test of different frequency support strategies in a variation of test scenarios successful
- Different DC fault clearing strategies in the DC grid lead to different requirements for the wind farm controls
Thank you for your attention!
Characterisation of DC Circuit Breakers

June 2018
Dragan Jovcic, University of Aberdeen

PROgress on Meshed HVDC Offshore Transmission Networks
CONTENT

• Motivation for DC CB characterisation,
• Overview of WP6 (DC CB characterisation),
• Common test system and model verification plan,
• Hybrid DC CB characterisation,
• Mechanical DC CB characterisation,
• VARC DC CB characterisation,
• Hardware DC CB demonstration,
1) Motivation for Characterisation of DC CBs

- DC CBs are new components, not used in power systems previously,
- DC CB technology is much different, and more complex compared with AC CBs,
- There are multiple substantially different DC CB technologies,
- DC CB models are required for DC Grid system studies (protection, power flow, stability, ...),
- It is essential to study component failure modes to understand impact on DC grids,
- Low-power prototypes enable flexibility in hardware-based studies,
- Roadmap for technology development is important for dc grid planners,
- Common platform and verification program for DC CB models,
### 2) Characterisation of DC CBs, WP overview

<table>
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<th>Lead</th>
<th>Partners</th>
<th>Timeframe</th>
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<td>Develop system-level model for hybrid DC CB</td>
<td>UAbdn</td>
<td>ABB, SGI, DNV-GL</td>
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<td>Develop system-level model for mechanical DC CB</td>
<td>DELFT</td>
<td>MEU, DNV-GL</td>
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<td>6.3</td>
<td>Develop component-level and real-time model for hybrid DC CB</td>
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<td>Develop kW-size hardware prototypes for hybrid and mechanical DC CBs</td>
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<td>Demonstrate DC CB failure modes on kw-size hardware prototypes</td>
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<td>Analyse hybrid DC CB integration into EHV DC grid</td>
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<td>Develop roadmap for VARC DC CB scaling to EHV DC voltage</td>
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<td>Develop standard DC CB verification plan and RTDS models</td>
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</tbody>
</table>
3) Common test system and model verification plan

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

2. Verification of IGBT-based Hybrid DC CB model,

3. Verification of Thyristor-based Hybrid DC CB model,

4. Verification of Mechanical DC CB model,

5. Verification of VSC assisted (VARC) mechanical DC CB model,

6. RTDS (Real Time digital Simulation) modelling and verification of IGBT based hybrid DC CB,

7. RTDS modelling and verification of mechanical DC CB,
3) Common test system and model verification plan

General DC CB model verification plan,

1. Test circuit
   a. Agreed with all participants,
   b. Realistic 320kV case with DC cable,
   c. Representing difficult case,

2. Model testing with external trip signal
   a. Opening on rated interrupting current,
   b. Opening on low load current (0.01kA-0.2kA),
   c. Closing on load current,
   d. Repeated open-close (Reclosing in fault)
   e. Reverse current direction (all the above),

3. Model testing with no external trip signal (self protection)
   a. Low impedance fault,
   b. High-impedance fault,

4. Model testing with different parameters
   a. Different Ldc,
   b. Different cable parameters,

Figure 1. Test circuit for DC CB model verification.

Figure 2. Open-close sequence for DC CB model verification.
4) Hybrid DC CB characterisation

Hybrid DC CB model:

1. 320kV, 16kA test system,

2. Detailed model:
   a. Load Commutation switch,
   b. Ultrafast disconnector,
   c. Main valve,
   d. Energy absorber,

3. DC CB Controller
   a. Opening sequence,
   b. Closing sequence,
   c. Self protection,

Figure 3. Hybrid DC CB.

Figure 4. Hybrid DC CB operating under self-protection.
4) Hybrid DC CB characterisation

Fault current limiting:

1. Enables control of fault current for a limited time period,
2. Can be used for connecting circuits (starting resistors),

Figure 5. Fault current limiting with hybrid DC CB.
5) Mechanical DC CB characterisation

Mechanical DC CB model

1. Main interrupter,
2. Resonant circuit,
3. Closing switch,
4. Residual breaker,
5. Energy absorber,

Figure 6. Mechanical DC CB.

Figure 7. Mechanical DC CB for multiple open-close.
5) VARC DC CB characterisation

VARC DC CB (from Scibreak) model
1. Main interrupter,
2. Resonant circuit,
3. VSC converter,
4. Energy absorber,
5. Residual breaker,

Figure 8. VARC DC CB.

Figure 9. VARC DC CB opening on rated fault current.
6) Hardware DC CB demonstration

Purpose of hardware DC CB demonstration
1. Demonstrate hardware DC CB on reasonable power levels,
2. Same (as close as possible) topology as high-power DC CBs
3. Provide flexibility for testing:
   1. failure modes,
   2. new topologies,
   3. new controls,

Hardware includes:
1. Test circuit 900V, 500A,
2. Hybrid DC CB 900V, 500A, 1kJ,
3. Mechanical DC CB 900V, 500A, 2kJ,

Figure 10. Testing DC CB test circuit.

Figure 11. DC CB test circuit and hybrid DC CB.
Hybrid DC CB demonstration:
1. Ultrafast disconnector, 2ms, 3mm (9kV).
2. 900V, 500A, 2ms, 1kJ.
3. Fault current limiting.

Figure 12. Hardware hybrid DC CB interrupting 500A

Figure 13. Ultrafast disconnector with magnetic braking.
6) Hardware DC CB demonstration

New control method is studied: (Voltage control of ultrafast disconnector)
1. Enables faster operation of hybrid DC CB,
2. Peak current is lower,
3. Energy dissipation is lower,
4. Demonstrated on model and on hardware,

Figure 14. Voltage and current with UFD voltage control.  
Figure 15. Energy with UFD voltage control.
6) Hardware DC CB demonstration

Mechanical DC CB:
1. 3 x 900V vacuum interrupters,
2. LC resonant circuit,
3. Energy absorber,
4. Opening time is 5ms,

Figure 16. Hardware mechanical DC CB.

Figure 17. Opening on 500A with mechanical DCCB.
Conclusions

1. DC CB Models completed,
   a. Hybrid DC CB,
   b. Mechanical DC,
   c. Thyristor-based hybrid DC CB,
   d. VARC DC CB,
2. RTDS models completed,
3. Hardware demonstrators completed,
   a. Hybrid DC CB,
   b. Mechanical DC CB,
4. On going work on new DC CB topology and control,
5. On going work on new DC CB failure mode analysis,
6. Forthcoming work:
   a. Roadmap development for all 3 topologies,
   b. Failure mode study,
DC grid protection
Promotion WP4 outcomes

Dirk Van Hertem, KU Leuven, Belgium
Promotion midterm conference Amsterdam, June 2018
Contents

• Why DC grid protection research
• Protection: fault detection & clearing → protection strategy
• Towards risk based development of DC protection systems
• Early results
• The IED
Fault currents within a DC grid

Example pole-to-pole fault

- Fault current:
  - No zero crossings
  - High rate-of-rise
  - High steady state value
  - Sensitive (expensive) converters
Different technologies exist to interrupt a DC fault current

- **Converter AC breakers**
  - As used in existing projects
  - Slow (40-60 ms opening time)
  - Not selective

- **Fault-current blocking converters**
  - Higher losses compared to half-bridge
  - Fast (responsive within a few ms)
  - Not selective

- **DC circuit breakers**
  - Operating time of 2-10 ms
  - Trade-off in losses vs speed
  - Allows selective fault clearing
The use of different technologies leads to various fault clearing strategies

- **Selective:** using DC breakers in every line
- **Partially selective:** split DC grid in sub-grids
- **Open Grid:** alternative breaker sequence
- **Non-selective:** shut down the whole DC grid
Small – Medium – Large (impact)

• **“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 the same impact as 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.
Protection matrix approach determines converter response for each type of fault (based on CENELEC TC8X WG6)

<table>
<thead>
<tr>
<th>Fault separation concepts</th>
<th>Typical separation times</th>
<th>Behaviour of the DC grid System or parts thereof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continued operation</td>
<td>&lt; few ms</td>
<td>Only the protection zone having the fault gets discharged, power flow in the other protection zones is maintained, probably with some adjustments to accommodate for the new grid topology without the faulty part.</td>
</tr>
<tr>
<td>Temporary stop</td>
<td>&lt; 200 ms</td>
<td>The power flow in the entire DC grid System or a zone thereof is temporarily affected. The affected converters or DC circuit breakers control the fault current to zero or break it. After separating the faulty part of the protection zone, the remaining DC grid System is recharged and power flow recovers.</td>
</tr>
<tr>
<td>Permanent stop</td>
<td>&gt; 200 ms</td>
<td>The regarding protection zone will shut down. It can be restarted manually or automatically.</td>
</tr>
</tbody>
</table>
Relevant fault causes $\rightarrow$ consequences and probability $\rightarrow$ risk

(source: RTE memento on electrical system security now on-line).
Detailed analysis on different parameters to characterize fault clearing strategies

Key components

Technical layout

Primary fault clearing sequence

Backup fault clearing sequence

Protection matrix
Example protection matrix for partially selective strategy

Faults which the protection system is expected to protect against

Other faults
### D4.2: broad comparison of fault clearing strategies for DC grids

<table>
<thead>
<tr>
<th>STRATEGY ABBR.</th>
<th>PHILOSOPHY</th>
<th>MAIN COST DRIVER</th>
<th>FEASIBILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 FS DCCB</td>
<td>Fully Selective</td>
<td>DCCB</td>
<td>✓</td>
</tr>
<tr>
<td>Option 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 FS DCCB</td>
<td>Fully Selective</td>
<td>DCCB and Converters</td>
<td>✓</td>
</tr>
<tr>
<td>Option 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 FS DCCB</td>
<td>Fully Selective</td>
<td>DCCB</td>
<td>✓</td>
</tr>
<tr>
<td>Option 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 FS SFCL</td>
<td>Fully Selective</td>
<td>SFCL</td>
<td>✓</td>
</tr>
<tr>
<td>5 NS ACCB</td>
<td>Non-Selective</td>
<td>/</td>
<td>✓</td>
</tr>
<tr>
<td>6 NS FB</td>
<td>Non-Selective</td>
<td>FB</td>
<td>✓</td>
</tr>
<tr>
<td>7 NS DCCB</td>
<td>Non-Selective</td>
<td>DCCB</td>
<td>✓</td>
</tr>
<tr>
<td>8 NS SFCL</td>
<td>Non-Selective</td>
<td>SFCL</td>
<td>✓</td>
</tr>
<tr>
<td>10 Open Grid</td>
<td>Non-Selective</td>
<td>DCCB</td>
<td>✓</td>
</tr>
<tr>
<td>11 ParS PS</td>
<td>Partially Selective</td>
<td>DCCB/DCD C</td>
<td>✓</td>
</tr>
<tr>
<td>12 ParS TS</td>
<td>Partially Selective</td>
<td>DCDC/DCB B/FB</td>
<td>✓</td>
</tr>
</tbody>
</table>
Next tasks: comparing costs and benefits of strategies

- Different strategies will lead to different possible end states
- Towards CBA
- Risk = probability × impact
- Example: benefit of DC busbar breaker (including backup)
HVDC IED developed and tested

• Zedboard
  • Sufficient computing power to have several algorithms in parallel
  • Multiple I/O capabilities

• Device has been developed

• Configurable

• Central or decentral configuration

• Communication protocol
  • Ethercad or HSR

• Developing tests:
  • Using similar types of tests as for AC relays
  • Fault detection
  • Selectivity
  • Noise sensitivity
  • …

• Promotion KTH IED

• Mitsubishi IED
Conclusions

• DC grids require protection
  • Different philosophies using different technologies
• Risk-based evaluation as in AC systems necessary
• Continuation has the focus on:
  • Towards industrialized solutions
    • Interoperability
    • Failure modes
    • Performance evaluation
  • Continuing developing IED and adding new algorithms
  • Developing tests
  • Cost benefit analysis (deviations due to protection equipment)
Overview of key technologies

06-06-2018, Amsterdam, Cornelis Plet
Ingredients for a meshed offshore HVDC grid

- Topology
  - Adequacy and security
- Converters
  - AC grid compliant
  - Interoperable
- Grid & wind farm control
  - Ancillary services
    - Black start capability
  - Grid restoration
  - Interoperable hierarchies
- Protection system
  - Fault detection technology
  - Fault clearing strategy
- Nodes
  - HVDC GIS
  - HVDC circuit breakers
**PROMOTioN Mid-term conference** Technical break-out session 1

**PROMOTioN research on meshed HVDC grid**

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<th>Converter &amp; Grid Control</th>
<th>Wind Farm Control</th>
<th>Protection System</th>
<th>HVDC Circuit Breakers</th>
<th>HVDC GIS</th>
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<td>WP4 WP5</td>
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<td>WP6</td>
<td>WP15</td>
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<td>WP12</td>
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<td>WP12</td>
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<tr>
<td>Standardisation</td>
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</tbody>
</table>

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

DISCLAIMER & PARTNERS

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MAIL info@promotion-offshore.net WEB www.promotion-offshore.net

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

PROJECT COORDINATOR
DNV GL Netherlands B.V.
Utrechtseweg 310, 6812 AR Arnhem, The Netherlands
Tel +31 26 3 56 9111
Web www.dnvgl.com/energy

CONTACT

PARTNERS

03.05.16 4
Wind Turbine – Converter Interaction

PROMOTioN WP3

Ömer Göksu, DTU Wind Energy

06 June 2018, PROMOTioN Mid-Term Conference, Amsterdam
• Diode Rectifier as offshore HVDC
• Grid Forming Wind Turbines
• Offshore AC Grid Start-up
• Black Start by Offshore Wind Turbines
• Recommendations for Standards
Wind Turbine – Converter Interaction

Diode Rectifier Units as offshore HVDC

current VSC solution

new DRU solution

Key features of the Modular Diode Rectifier Unit:
- Encapsulated, rugged equipment
- Bio-degradable and flame retardant insulation
- Simple and robust power electronics
- Small platform with easy transport and installation
- High reliability, minimal maintenance
- No offshore DC converter as single point of failure
- Flexible offshore installation options due to modular rectifier concept

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Wind Turbine – Converter Interaction

Grid Forming Wind Turbines

Grid forming wind turbines control
- dq current control based
- voltage/angle control based
- GPS synchronization based
- master/slave based
Wind Turbine – Converter Interaction

Offshore AC Grid Start-up Options

Umbilical AC Cable

Nearby VSC-HVDC (or AC)

Local Energy Storage (e.g. battery, diesel)

Black-startable wind turbines
Wind Turbine – Converter Interaction

**Black Start by Offshore Wind Turbines**

**Objective:**
To avoid issues of non-operating wind turbines;
- Moisture
- Icing
- Vibrations
- Deformation

**Objective:**
To energize WPP and substations’ auxiliary w/o any external supply

**Objective:**
To provide black start for the onshore power system

### Step 1
**Self-start of Wind Turbine**
- Wind turbines will start w/o grid voltage
- Wind turbines will supply themselves using wind (houseload operation)

### Step 2
**Self-Energization of Wind Power Plant**
- WPP will energize up to the onshore PoC

### Step 3
**Contribution to Grid Restoration**
- WPP will operate similar to the conventional black start units
Wind Turbine – Converter Interaction

Recommendations for Standards
PROMOTioN WP3: Wind Turbine – Converter Interaction

- Functional requirements to DRU connected WPPs
- General control algorithms for DRU connected WPPs
  - Fundamental operation
  - Fault response
  - Ancillary services
- Compliance test procedures for DRU and VSC connected WPPs
  - Compliance test requirements for single offshore wind turbines
  - Compliance test requirements at offshore WPP level
  - Validation procedure for simulation models
- Recommendations to adapt and extend existing grid codes
  - Paradigm shift from grid following wind turbines to grid forming wind turbines
The opinions in this presentation are those of the author and do not commit in any way the European Commission.

PARTNERS

Best Paths & PROMOTioN – Utilizing project synergies

6th June, 2018, PROMOTioN Mid Term Conference, Amsterdam
CONTENT

• Overview of the Best Paths project
• Topics of common interest in Best Paths and PROMOTioN
• Synergies between the two projects?
Overview of the Best Paths project
CHAPTER 1 – Overview of the Best Paths project

Best Paths EU R&D project

• BEyond State-of-the-art Technologies for re-Powering AC corridors and multi-Terminal HVDC Systems

• October 2014 – September 2018 (4 years)
• Total budget: 62.8M €
• EC contribution: 35.5M €
• 5 Large-scale demonstrations
• Replication and upscalability project
• Coordinated by Red Eléctrica de España (REE)
CHAPTER 1 – Overview of the Best Paths project

Best Paths Demos

1. HVDC in offshore wind farms and offshore interconnections
2. HVDC-VSC multivendor interoperability
3. Upgrading multiterminal HVDC links
4. Innovative repowering of AC corridors
5. DC Superconducting cable
Topics of common interest in Best Paths and PROMOTioN
CHAPTER 2 – Topics of common interest in Best Paths and PROMOTioN

Offshore wind and DCG mockup (BP DEMO 1)

• Development of a DC facility to simulate offshore MTDC DC grids and their interaction with wind generators

• 4-terminal DC grid with MMC prototypes and a Real Time Digital Simulator system to emulate the AC grid

• To investigate the electrical interactions between HVDC link converters and wind turbine converters in offshore wind farms.

• To de-risk the multivendor and multiterminal schemes in terms of resonances, power flow and control
CHAPTER 2 – Topics of common interest in Best Paths and PROMOTioN

Interoperability in multi-vendor VSC systems (BP DEMO 2)

• Assessment of interoperability (IOP) performed on a wide variety of situations and conditions
• Maximize IOP for multivendor HVDC systems based on recent VSC converters from world-leading vendors
• Recommendations for standardization bodies and stakeholders for future DCG
• EMT / Real-Time simulation
• 15% IOP issues detected
• Methodology to fix IOP issues
• Interactions between Hybrid HVDC Breakers and converters
Synergies between the two projects?
CHAPTER 3 – Synergies between the two projects?

Synergies between the two projects?

• Scope of work
  • Bilateral workshop between Best Paths and PROMOTioN (April 12th, 2018)
  • No overlap between both projects!

• Communication
  • Dissemination activities (bi-directional)

• Complementarity
  • E.g. interoperability: protection-wise vs. converter-wise (or mixed protection-converter)
CHAPTER 3 – Synergies between the two projects?

Synergies between the two projects?

• Continuity
  • From Best Paths to PROMOTioN
  • Yet, some restrictions on deliverables regarding confidentiality
  • But also some valuable outputs from Best Paths made available
    • MATLAB ‘Open Access’ Toolbox: http://www.bestpaths-project.eu/

• Hybrid DCCB model available in Hypersim

• A matter of people! (partners involved in both projects)
HVDC Gas Insulated Switchgear Demonstration - WP 15

Paul VINSON – SuperGrid Institute, AMSTERDAM, June 6th 2018
• Context & Motivations
• Workpackage detail
• Specifications
• GIS demonstrator
• Partial discharge under DC
• Initiation of standardization
Offshore HVDC Grid control and protection require new switchgears and components providing:

- Compactness
- Adequacy to “new” DC stresses
- High reliability level

Gas Insulated Switchgear technology (GIS) offer advantages like:

- Reduced footprint and weight (70%-90% volumetric reduction of the switchyard compared to AIS)
- Insensitiveness to pollution and climatic conditions
- High reliability (no ageing under neutral gaseous atmosphere)

GIS technology needs to be investigated and proved mature to facilitate the development of HVDC Offshore grids

WP15 – HVDC GIS technology demonstrator

Task 15.1
Defining specifications and long term testing requirements

Task 15.2
Monitoring and diagnostic methods
Applicability to SF6 alternatives

Task 15.3
Long term testing of the DC GIS equipment

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

WP1
WP4
WP11
HVDC GIS DEMONSTRATION

Specifications and test procedures

System specifications and test requirements of the HVDC GIS demonstrator rely on HVAC GIS experience, HVDC cable’s test requirements and on recent works:

- Offshore DC HUB studies (SSE)
- Dielectric Testing of gas-insulated HVDC Systems CIGRE D1/B3.57 (under Progress)
- Start of IEC AHG37
- Test methods PROMOTioN
- Pre Standardization PROMOTioN

Recommendations for specifying DC GIS systems

PROMOTioN

Specifications

Test Procedures
Extensive test program at DNV GL KEMA laboratories will demonstrate the capability of the GIS to fulfil the service life requirements.

**HVDC GIS DEMONSTRATION**

**Performance demonstration of a HVDC GIS system**

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep. and Oct. 2018</td>
<td>Commissioning</td>
</tr>
<tr>
<td>Nov. 2018 to Nov. 2019</td>
<td>Long term</td>
</tr>
<tr>
<td>After Nov. 2019</td>
<td>Additional</td>
</tr>
</tbody>
</table>

**Demonstrator**

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Tests</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal calibration, Corona current testing, PD, LI, SI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-term test cycles</td>
<td>± 1.0 ... 1.2</td>
<td>pu</td>
</tr>
<tr>
<td>HL (AC equivalent)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated superimposed LI / SI</td>
<td>± 0.8</td>
<td>pu</td>
</tr>
<tr>
<td>Long-term test cycles with DC</td>
<td>± 1.0 ... 1.2</td>
<td>pu</td>
</tr>
<tr>
<td>ZL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated superimposed LI / SI withstand V</td>
<td>± 0.8</td>
<td>pu</td>
</tr>
<tr>
<td>Final verification tests &amp; additional tests</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

XXX : High Load ZL: Zero Load

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CHAPTER 1 – HVDC GIS DEMONSTRATION

Partial discharge monitoring: measuring techniques

- Condition monitoring of GIS is greatly appreciated by system’s operators for AC but is not mature for DC yet:
  - From measurement techniques perspectives
  - From defect patterns and recognition algorithms perspectives

- Investigations are launched to investigate classical and a new techniques:
  - Conventional method
  - UHF
  - Light emission
  - High Frequency Current transformer (HFCT)

Outcomes of the work tend to prove that condition monitoring is also available for DC and will support the acceptance of the technology introduction.
CHAPTER 1 – HVDC GIS DEMONSTRATION

Partial discharge monitoring: database & SF6 alternatives

Substitutes to SF6 gas are emerging and products are commercially available for AC

Different gas mixtures

FN-CO2 / AirPlus / SF6

Different defects and test conditions

Observed with the 4 measuring techniques

Background knowledge on PD recognition strategies for DC GIS

2018: Tests realization, data collection, pattern recognition and main conclusions

2019: Long term test to study the evolution of calibrated defect in DC GIS and the reliability of the measuring techniques
CHAPTER 1 – HVDC GIS DEMONSTRATION

Initiation of standardization activities

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

ABB – Task Coordination

Subtask A – ABB:
- Integration/addition of DC specific standardization into existing AC GIS standardization
- Parallel DC GIS standardization activities

Subtask B – SHE: DC specific ratings

Subtask C – TU Delft / SuperGrid Institute: PD in DC, differences between SF6 and alternative gases

Subtask D – DNV GL: DC specific testing

Workshop with IEC (AHG37) & CIGRE (D1/B3.57)

Compilation of results into deliverable D15.6

An important step forward towards technology maturity evidence and acceptance
HVDC CIRCUIT BREAKER TESTING

Midterm Conference, June 6, Amsterdam
René Smeets, KEMA Laboratories DNV GL
WPs 5/10: Testing of HVDC CBs

• Define test requirements from system transient studies
• Analyse, compare and design test-circuits
• Validate suitable test-circuits in high-power laboratory
• Define and quantify actual stresses on breaker sub-components, analyse failure modes
• Provide input data for models of HVDC circuit breakers
• Demonstrate testing HVDC circuit breakers of various technology
• Multi-module testing of HVDC CBs
• Initiate standardization
Interruption strategy

AC interruption:
Capture the swinging mass in its outer position (current zero)
Zero kinetic energy – Max potential energy

DC interruption:
Oppose the motion of a linearly moving mass (counter voltage)

15 kA in 100 km line = 11 MJ = 30 ton train at 100 km/h
Testing DC with AC?

16.7 Hz

Test Circuits for HVDC Circuit Breakers,
N. A. Belda and R. P. P. Smeets,

Analysis of Faults in Multi-Terminal HVDC Grid for Definition of Test Requirements of HVDC Circuit Breakers,
N.A. Belda, C.A. Plet, R.P.P. Smeets
IEEE Trans. on Pow. Del., Vol. 33, no.1, 2018

Full-Power Testing of HVDC Circuit-Breakers with AC Short-Circuit Generators Operated at Low Power Frequency
N.A. Belda, C.A. Plet, R.P.P. Smeets
IEEE Trans. on Pow. Del. (in review)
Active Current Injection prototype breaker testing

- 16 kA fault current, 125 kV pk TIV
- Up to 4 MJ energy
- 16.7 Hz test-circuit

[Graphs showing current and voltage measurements]
Next: subcomponent stresses - failure mode analysis

DC steady state

- high di/dt fault current
- local current zero
- energy absorption
- counter voltage
- interruption
- DC withstand

fault current
local current zero
energy absorption
interrupted current
prospective current
TIV
DC withstand
APPENDIX

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MAIL info@promotion-offshore.net WEB www.promotion-offshore.net

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PROJECT COORDINATOR
DNV GL Netherlands B.V.
Utrechtseweg 310, 6812 AR Arnhem, The Netherlands
Tel +31 26 3 56 9111
Web www.dnvgl.com/energy

CONTACT
rene.smeets@dnvgl.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. 03.05.16
PROMOTION – WP9

Demonstration of operation of DC Grid Protection
Work Package 9 - Demonstration

- Requirements
  - Foundation
  - Demonstration
  - Exploitation
- Converters
- Protection Systems
- HVDC Switchyards
- Finance & Regulation
- Standards and deployment plan
RTDS Test Set-up

RTDS Simulator is interfaced to the IEDs via GTIO Cards. RTDS Test Set-up

Test circuit modelled in RSCAD

LAN connection

Workstation PCs

Hardwired low voltage connection

IEDs
Sample Test Circuit 1
Sample Test Circuit 2

Graphical representation of the test circuit modelled in RSCAD.
WP9 – Task 9.1

Task 9.1: (M30 – M36)
Integration of Protection Relays and DC CB models from WP4

Subtasks:
9.1.1 - IEDs from WP4 – Task 4.4 – (M22 – M40)
9.1.2 - DCCB models in RTDS from WP6 – Task6.3
WP9 – Task 9.2 and Task 9.3

Task 9.2: (M30 – M36)
Develop DC Grid benchmark model in RTDS.
Subtasks:
9.2.1 – RTDS models for DC Grid and AC network.
9.2.2 – Fault case list.

Task 9.3: (M30 – M36)
Develop DC Grid protection testing procedures and guidelines.
Subtasks:
9.3.1 – DC Protection testing procedures and protocols.
9.3.2 – DC Protection testing guidelines for meshed DC Grids and standardisation requirements.
WP9 – Task 9.4 and Task 9.5

Task 9.4: (M36 – M42)
Demonstration of DC Grid protection using Hardware-in-loop testing.

Subtasks:
9.4.1 – Already tested protection algorithms included in IEDs.
Demonstration (M42).

Task 9.5: (M42 – M46)
Demonstration of protection interoperability.

Subtasks:
9.5.1 – Multiple protection relays and DCCB models (mechanical DCCB, hybrid DC CB).
Demonstration (M42).
WP9 – Task 9.6

Task 9.6: (M42 – M46)

Demonstrate primary and back-up protection and system level consequences of protection failure.

Subtasks:

9.6.1 – List of worst-case protection failure modes.

9.6.2 – System level consequences of protection failure.

Demonstration (M42).

Work Package 9 Task Effort Distribution

- 9.1 Integration of IED and DCCB
- 9.2 Develop DC Grid Benchmark models
- 9.3 Develop DC Grid Testing Procedures
- 9.4 Demonstrate DC Grid protection
- 9.5 Demonstrate protection interoperability
- 9.6 Demonstrate back-up protection
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WP16 – MMC Test Bench Demonstrator

PROMOTioN Intermediate Conference 06.06.2018
Philipp Ruffing – RWTH Aachen
Motivation:

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

Objectives:

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

Work Package 16: Investigation regarding the operation and control of meshed HVDC system

- Power Hardware in the Loop (PHiL)
- Control Hardware in the Loop (CHiL)
- Real-Time Simulation (RTS)
WP16 - MMC Test Bench Demonstrator

Overview and Objectives of WP16

MTDC Test Bench - PHiL

Diode Rectifier Unit - CHiL

Harmonic Resonance Studies

Analysis of the controllability of meshed DC offshore networks

Increase the confidence in controllability of DRU connected wind farms

Analysis of harmonic stability problems related to resonance phenomena
WP16 - MMC Test Bench Demonstrator

MTDC Test Bench - PHiL

State of knowledge:
Limited experience regarding the
- operation of MTDC systems
- interactions between MTDC systems, large AC systems and wind power plants

Objectives:
Investigation of the
- controllability and interoperability
- fault handling in meshed offshore grids
- AC grid support with meshed offshore grids

Expected outcome:
- Increase the confidence in the feasibility of MTDC operation
- Increase TRL of controls for MTDC systems

DC Hardware Testbench:
- 4 MMC converter stations
- DC voltage: \( V_{dc} = 400 \text{ V} \)
- Power: \( S_{MMC} = 6 \text{ kW} \)
- Number of Levels per Arm: \( n_{SM} = 10 \)
- Monopolar and bipolar configuration

Real-Time Simulation:
- AC Network up to 3000 nodes
- Coupling via high bandwidth power amplifiers
- Detailed AC grid models
- Detailed wind farm models
State of knowledge:

✓ Islanded control concepts for DRU connected offshore wind farms

• Focus on aggregated or partially aggregated wind farm representation

• No experience between the interaction of protection relays and DRU connected WFs

Expected outcome:

• Increase in confidence regarding the control of DRU connected wind farms

• Development of black and brown start operation for wind farms in islanded control

Objectives:

Demonstration of the operation of DRU-enabled wind turbine control systems

• in multi-terminal HVDC systems

• with actual wind turbine controls

• with commercial protection hardware
WP16 - MMC Test Bench Demonstrator

Harmonic Resonance Studies

State of knowledge:
• Increasing penetration of active components in transmission systems
• Harmonic oscillation between offshore wind turbine and HVDC converters

Objectives:
• Development of frequency dependent impedance models of wind turbines and HVDC converters
• Extraction of the frequency behaviour of a (real) wind turbine converter and of the MMC from the HVDC test bench
• Analysis of harmonic stability and potential interactions of active components and the AC grid

Expected outcome:
• Validated impedance models of wind turbine and HVDC converters
• Better understanding of harmonic stability, especially in offshore grids

Flexible Power Grid Laboratory (@ DNV GL)

Disturbance 200 kW - PA
Real Wind Turbine Converter (T4)
AC Grid Emulator
DC Grid Emulator
WP16 - MMC Test Bench Demonstrator

THANK YOU FOR YOUR ATTENTION

Partners of WP16:
APPENDIX

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PROJECT COORDINATOR
DNV GL Netherlands B.V.
Utrechtseweg 310, 6812 AR Arnhem, The Netherlands
Tel +31 26 3 56 9111
Web www.dnvgl.com/energy

CONTACT
Philipp Ruffing
WP16 Leader
ruffing@ifht.rwth-aachen.de

PARTNERS
VSC-based controller oscillations in power system

6th June, 2018, PROMOTioN Mid Term Conference, Amsterdam
CONTENT

• Background
• Grid-connected converter controller oscillations
• Input admittance measurements and validation
• Work Package 16
Background
CHAPTER 1 – Background

Steady state harmonics in power converters

- Test report according to IEC 61400-21-1 provides results potentially affected by background harmonics in the grid.

- In some cases the IEC test report is used directly for harmonic studies, i.e. ideal harmonic current source.

- IEC TR 61400-21-3 was proposed to give more understanding about harmonic behavior and extend the modelling approach.

CHAPTER 1 – Background

Small signal instability in power converters

- Subsynchronous oscillation
- Supersynchronous oscillation
- Non-characteristic harmonics
- Setpoint dependent

Grid-connected converter controller oscillations
CHAPTER 2 – VSC-based controller oscillations

Norton/Thevinen equivalent
CHAPTER 2 – VSC-based controller oscillations

Input admittance derivation - STATCOM

- Sub-synchronous oscillation
- Super-synchronous oscillation
- Harmonic oscillation
- Side-band oscillation

\[ f_1 = 50 \text{ Hz} \]
\[ f_s = \text{switching frequency} \]

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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.
CHAPTER 2 – VSC-based controller oscillations

Input admittance analytical derivation

\[
\begin{bmatrix}
\Delta I_d \\
\Delta I_q 
\end{bmatrix}
= \begin{bmatrix}
\frac{Y_{tcl+dq}(s-j\omega_1) - Y_{tcl-dq}(s-j\omega_1)}{Y_{tcl-dq}^*(s-j\omega_1)} \\
\frac{Y_{tcl-dq}^*(s-j\omega_1) - Y_{tcl+dq}^*(s-j\omega_1)}{Y_{tcl-dq}(s-j\omega_1)} 
\end{bmatrix}
\begin{bmatrix}
\Delta E_d \\
\Delta E_q 
\end{bmatrix}
\]

\[
\begin{bmatrix}
\frac{Y_{tcl+dq}(s)}{Y_{tcl-dq}(s-j\omega_1)} \\
\frac{Y_{tcl-dq}^*(s-j\omega_1)}{Y_{tcl+dq}(s-j\omega_1)} 
\end{bmatrix}
\]

\[
\begin{bmatrix}
\Delta I_d \\
\Delta I_q 
\end{bmatrix}
= \begin{bmatrix}
\left\{1 + G_{tol,dq}^m(s)\right\}^{-1} G_{tol,dq}^m(s) Y_{pll}^m \\
\left\{1 + G_{tol,dq}^m(s)\right\}^{-1} Y_{o,dq}^m(s) 
\end{bmatrix}
\begin{bmatrix}
\Delta E_d \\
\Delta E_q 
\end{bmatrix}
\]

\[
\begin{bmatrix}
\Delta I_d \\
\Delta I_q 
\end{bmatrix}
= \begin{bmatrix}
\left\{1 + G_{tol,dq}^m(s)\right\}^{-1} G_{tol,dq}^m(s) Y_{PLL}^m - Y_{tlo,dq}^m \\
Y_{tcl,dq}^m 
\end{bmatrix}
\begin{bmatrix}
\Delta E_d \\
\Delta E_q 
\end{bmatrix}
\]
Input admittance measurement and validation
CHAPTER 3 – Input admittance measurement and validation

kW level input admittance measurement

Measurement setup – 10 kW

Source: courtesy of Tampere University of Technology, Finland.
CHAPTER 3 – Input admittance measurement and validation

Converter input admittance measurements

Testing Setup Complexity

TRL 4/5

Source: AAU Harmony

TRL 7/8

MW

kW

System Uncertainty

high
CHAPTER 3 – Input admittance measurement and validation

MW level input admittance measurement

1.32 MVA
0~1500 Volts

0.2 MVA
(bandwidth 5 kHz)

1 MVA
(bandwidth 1.2 kHz)
WP 16 Planning
Chapter 4 – WP 16 Planning

WP 16 Planning

Task 16.5 Start

- **2018.07**
  - Task 16.5 - Input admittance derivation – theoretical work completion

- **2018.12**

- **2019.07**
  - Task 16.5 - Input admittance measurement and validation work completion

- **2019.12**
  - Task 16.6 – offshore wind farm case study work completion

- **2020**
Chapter 4 – WP 16 Planning

Industrial relevance

WorkPackge 16 – First 1 MW Level Converter Harmonic Model Validation

IEC TR 61400-21-3
“Wind turbine harmonic model and its application”

IEC SC8A
“Grid Integration of Renewable Energy Generation”

CIGRE JWG C4/B4.38
“Power Network Harmonics Calculation”

CIGRE JWG C4/B4.38
“Multi-frequency stability of converter-based modern power systems”
The need for demonstration

6th of June 2018 – Amsterdam – Cornelis Plet
PROMOTioN Mid-term conference Technical break-out session 2

From idea to product
**Technology Readiness Levels**

<table>
<thead>
<tr>
<th>Level</th>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Idea</td>
<td>Unproven concept, no testing has been performed</td>
</tr>
<tr>
<td>1</td>
<td>Basic research</td>
<td>Principles postulated and observed but no experimental proof available</td>
</tr>
<tr>
<td>2</td>
<td>Technology formulation</td>
<td>Concept and application have been formulated</td>
</tr>
<tr>
<td>3</td>
<td>Applied research</td>
<td>First laboratory tests completed; proof of concept</td>
</tr>
<tr>
<td>4</td>
<td>Small scale prototype</td>
<td>Built in laboratory environment</td>
</tr>
<tr>
<td>5</td>
<td>Large scale prototype</td>
<td>Tested in intended environment</td>
</tr>
<tr>
<td>6</td>
<td>Prototype system</td>
<td>Tested in intended environment close to expected performance</td>
</tr>
<tr>
<td>7</td>
<td>Demonstration system</td>
<td>Operating in operational environment at pre-commercial scale</td>
</tr>
<tr>
<td>8</td>
<td>First of a kind commercial system</td>
<td>Manufacturing issues solved</td>
</tr>
<tr>
<td>9</td>
<td>Full commercial application</td>
<td>Technology available for consumers</td>
</tr>
</tbody>
</table>
### TRL of meshed HVDC grid technologies

<table>
<thead>
<tr>
<th>Converter Technology</th>
<th>Interoperability</th>
<th>HVDC Cables</th>
<th>System control</th>
<th>Protection Philosophy</th>
<th>HVDC Circuit Breakers</th>
<th>HVDC GIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
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<tr>
<td>Medium</td>
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<tr>
<td>High</td>
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</tbody>
</table>

**TRL Levels:**
- **Low**
- **Medium**
- **High**

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Demonstration considerations

• Technical maturity also relates to:
  • General acceptance and understanding of technology and its application
  • Availability of agreed testing methods and procedures
  • Availability of monitoring and condition assessment tools

• Technology
  • Component or System
  • Functionality (software)
  • Scope of test object

• Performance
  • What to test?
  • How to test?
  • What are realistic stresses?
  • What are acceptable pass criteria?

• Environment
  • What is environment? Laboratory vs intended vs commercial
  • How to deal with limitations?
    • Physical limits on voltage, current, energy, frequency
    • Computational limits
### Demonstration of MOG technologies

<table>
<thead>
<tr>
<th>Time</th>
<th>Session Description</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:10-14:20</td>
<td>HVDC circuit breaker testing</td>
<td>Rene Smeets, DNV GL</td>
</tr>
<tr>
<td>14:20-14:30</td>
<td>HVDC protection system demonstration</td>
<td>Yash Audichya, SSE</td>
</tr>
<tr>
<td>14:30-14:40</td>
<td>HVDC system control demonstration</td>
<td>Philipp Ruffing, RWTH Aachen</td>
</tr>
<tr>
<td>14:40-14:50</td>
<td>Offshore wind turbine controller demonstration</td>
<td>Lukasz Kocewiak, Ørsted</td>
</tr>
<tr>
<td>14:50-15:00</td>
<td>HVDC gas insulated switchgear demonstration</td>
<td>Paul Vinson, Supergrid Institute</td>
</tr>
<tr>
<td>15:00-15:10</td>
<td>Best Paths &amp; PROMOTioN – Utilizing project synergies</td>
<td>Olivier Despouys, RTE</td>
</tr>
<tr>
<td>15:10-15:30</td>
<td>Panel discussion</td>
<td>Guest moderator: Steven de Clerck, ELIA</td>
</tr>
</tbody>
</table>
APPENDIX

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PROJECT COORDINATOR
DNV GL Netherlands B.V.
Utrechtseweg 310, 6812 AR Arnhem, The Netherlands
Tel +31 26 3 56 9111
Web www.dnvgl.com/energy

CONTACT

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Groningen meeting - Schedule and Venues

This document aims to provide information on the programme and the venues of the Groningen meeting on 7-8 June. The meetings will take place in different university buildings in the city centre, all located within 200m away from each other in the Broerstraat and the Oude Kijk in ‘t Jatstraat. The dinner location is outside the city center. Please find the address and travel options below.

<table>
<thead>
<tr>
<th>Thursday 7 June</th>
<th>Activity</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:45-09:00</td>
<td>Registration + coffee</td>
<td>Bruinszaal</td>
</tr>
<tr>
<td>09:00-12:30</td>
<td>Meetings WP2, WP3, WP4, WP6, WP7, WP12, WP15</td>
<td>See below</td>
</tr>
<tr>
<td>10:30-11:00</td>
<td>Coffee break</td>
<td>Bruinszaal</td>
</tr>
<tr>
<td>12:30-13:30</td>
<td>Lunch</td>
<td>Bruinszaal</td>
</tr>
<tr>
<td>13:30-17:00</td>
<td>Meetings WP7, WP9, WP10, WP11, WP16</td>
<td>See below</td>
</tr>
<tr>
<td>15:00-15:30</td>
<td>Tea break</td>
<td>Bruinszaal</td>
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<tr>
<td>18:30-19:00</td>
<td>Drinks at dinner venue</td>
<td>De Buitensociëteit</td>
</tr>
<tr>
<td>19:00-...</td>
<td>Dinner</td>
<td>De Buitensociëteit</td>
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<table>
<thead>
<tr>
<th>Friday 8 June</th>
<th>Activity</th>
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<td>08:45-09:00</td>
<td>Registration + coffee</td>
<td>Bruinszaal</td>
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<tr>
<td>09:00-12:00</td>
<td>General Assembly</td>
<td>A900</td>
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<tr>
<td>10:30-11:00</td>
<td>Coffee break</td>
<td>Bruinszaal</td>
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<table>
<thead>
<tr>
<th>WP schedule</th>
<th>Time:</th>
<th>Building:</th>
<th>Room:</th>
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</thead>
<tbody>
<tr>
<td>WP2</td>
<td>09:00-12:30</td>
<td>Harmony Building</td>
<td>Exposition Room</td>
</tr>
<tr>
<td>WP3</td>
<td>09:00-12:30</td>
<td>Harmony Building</td>
<td>13110120</td>
</tr>
<tr>
<td>WP4</td>
<td>09:00-12:30</td>
<td>University Library</td>
<td>Jantine Tammeszaal</td>
</tr>
<tr>
<td>WP6</td>
<td>09:00-12:30</td>
<td>University Library</td>
<td>Bladergroenzaal II</td>
</tr>
<tr>
<td>WP7</td>
<td>11:00-12:30; 13:30-17:00</td>
<td>Harmony Building</td>
<td>R3</td>
</tr>
<tr>
<td>WP9</td>
<td>13:30-17:00</td>
<td>University Library</td>
<td>Jantine Tammeszaal</td>
</tr>
<tr>
<td>WP10</td>
<td>13:30-17:00</td>
<td>University Library</td>
<td>Bladergroenzaal II</td>
</tr>
<tr>
<td>WP11</td>
<td>13:30-17:00</td>
<td>University Library</td>
<td>Bladergroenzaal I</td>
</tr>
<tr>
<td>WP12</td>
<td>09:00-12:30</td>
<td>University Library</td>
<td>Bladergroenzaal I</td>
</tr>
<tr>
<td>WP15</td>
<td>09:00-12:30</td>
<td>Harmony Building</td>
<td>R2</td>
</tr>
<tr>
<td>WP16</td>
<td>13:30-17:00</td>
<td>Harmony Building</td>
<td>Exposition Room</td>
</tr>
</tbody>
</table>
MINUTES OF MEETING

GENERAL ASSEMBLY

Groningen - Friday, 8th of June, 2018 – 09:00 – 12:00

Present: see attendance register

Agenda: Welcome
General updates and issues
Reporting
D14.4 Exploitation plan
Dissemination activities update
WP12 Progress update

Minutes:

GENERAL UPDATES AND ISSUES (CORNELIS PLET – DNV GL)

The next half yearly meeting will be held in week 50 from the 10th to the 12th of December 2018. The location will be decided. Possible options are Denmark (Kopenhagen, DTU, Energinet, Orsted, MVOW), France (Lyon, SGI & RTE) or Italy (Florence, FSR & Prysmian).

The meetings will not start before noon on Monday.

Wei Hei (Equinor): If an extension to the project is required, the request for this should be started soon.

Cornelis Plet (DNV GL): An extension will be requested to enable WP15 and WP16 to realistically meet their goals, the process will be started in Q3 2018.

Paul Raats (DNV GL): The extended testing suggested by ABB could be another legitimate reason for extension.

Stig Sorensen (Energinet): Is it possible to set up a joint workshop with ENTSO-E to feedback preliminary project results and findings to ENTSO-E partners?

Cornelis Plet (DNV GL): Yes, let’s arrange bilaterally.
REPORTING (MARGA VAN DEELEN – DNV GL)

Ramon Blasco-Gimenez (UPV) asks if reporting can be sent before August.

Marga van Deelen (DNV GL): reporting can be handed in all of July.

Alan Croes (TenneT) asks if the excel sheet with financial reporting has to be sent.

Marga van Deelen (DNV GL): This is not compulsory as the reporting can be extracted from ECAS. However, the spreadsheet can be helpful in order to prepare all the numbers which need to be entered in ECAS.

Michiel de Schepper (TenneT) asks what is the difference between ‘researchers’ and ‘other personnel’.

Cornelis Plet (DNV GL): anyone who writes hours on PROMOTioN and is not support stuff, and the personnel that works for PROMOTioN but is part of support staff.

Alan Croes (TenneT) asks if indicated excess budget will be taken away.

Cornelis Plet (DNV GL): assessed budget not being used per partner is only an indication for PMG. If PMG would like to use ‘left overs’, coordinator will come back to individual beneficiary to discuss and agree on eventual budget transfer.

D14.4 EXPLOITATION PLAN (PAUL RAATS – DNV GL)

Alan Croes (TenneT): is the improvement of internal company processes (using the built up knowledge) also an exploitable result? A: simple definition of Exploitation of Results is anything that brings value coming from the project effort.

Andreas Wagner (SOW): are you sure a change of grid code is a policy change? A: thinks so yes. Changes of standards, grid codes, laws relate to change in policy.

Dragan Jovcic (University of Aberdeen): you are mainly collecting the exploitation plans. Can we expect some help? A: be encouraged to think beyond the daily usual activity. How can I make money? When? What do I need etc…

Lorenzo Zeni (Ørsted): can we expect to review the report? A: yes, current M30 report is first version. We can iterate from there and also for instance organize a workshop on this after summer.

Serge: what is the timeline? A: M30 - help of consultant already active.

DISSEMINATION ACTIVITIES UPDATE (ANDREAS WAGNER – SOW)

Dragan Jovcic (University of Aberdeen): The presented numbers of submitted conference and journal papers do not seem realistic. There should be more. A: these numbers represent the current status known to SOW. Please report any new papers to SOW according to publication procedure.

Andreas Wagner (SOW) stresses that any event with external participation should be mentioned to SOW.
WP12 PROGRESS UPDATE (MICHEIL DE SCHEPPER – TENNET & PIERRE HENNEAUX – TRACTEBEL)

Cornelis Plet (DNV GL): how will you arrange / register agreement on basic and underlying assumptions?

Andreas Wagner (SOW): Request for agreement should be made very specific

Ramon Blasco-Gimenez (UPV): are you adding dc-dc converter degree of freedom into picture? A: not clear yet, could be considered, but TRL and cost not clear, this is part also of control questions which should be answered by technical WPs once topologies have been derived

Sebastian Menze (SOW): What is your expectation when all partners need to agree on assumptions?

Karim Karoui (Tractebel): this is a formal milestone [red: MS54 in Month 34: Agreement among the consortium partners on a scenario of the deployment plan]

Ralf Puffer (RWTH Aachen): the timeline of getting agreement and process should be made very clear and communicated properly

Karim Karoui (Tractebel): it is fundamental that we agree that no concept is missing from the presented four. Goal is to have credible CBA, needs list of equipment, this will be obtained from WPs after topologies have been generated, then costs added

Pierre Henneaux (Tractebel): consortium partners also have duty to be proactive about providing opinion on communicated WP12 work

Ralf Puffer (RWTH Aachen): a dedicated task has been set up to reach out and get input and agreement

Michiel de Schepper (TenneT): next week the first draft of D12.1 v2 will be made available, as work package leader Michiel also has the duty to make consortium aware of any expectations, so Pierre can focus on doing the work

Niklas Svensson (SvK): have you identified any barriers or showstoppers to the realisation of a DC grid, like lack of benefits? One could be time it takes to test the installations.

Michiel de Schepper (TenneT): not yet, but this should be part of the deployment plan

Karim Karoui (Tractebel): showstoppers are either technical, economic and/or regulatory

Alan Croes (TenneT): legal should main barrier, regulatory falls under it cq is part of it

Ceciel van Nieuwenhout (RUG): yes they are different but both frameworks are in law, constraints are the time it takes to change law

Wei He (Equinor): asked about offshore loads at beginning of project, is valuable to be included in scope. Offshore load can reach GW scale, can have big impact. Wei He will write note about vision of presence of offshore loads

Pierre Henneaux (Tractebel): capacity of loads should also be accompanied with location, otherwise cannot be used.

Alan Croes (TenneT): is the load really going to substantially change any decisions regarding transmission grid development? Probably not. Do we see financability as showstopper?
John Moore (TenneT): yes, this is discussed, it is included in economic framework

Paul Raats (DNV GL): Can we get agreement on whether the four concepts are complete in this meeting?

Cornelis Plet (DNV GL): need to make sure everyone understands the point of the concepts

Alan Croes (TenneT): needs to follow process of decision making and announced ahead of time