EERA DeepWind'2014 – Session B2: Grid Connection

Ancillary Services Analysis of an Offshore Wind Farm Cluster – Technical Integration Steps of a Simulation Tool

M.Sc. Tobias Hennig, Fraunhofer IWES – Kassel, January, 20th 2012

Content

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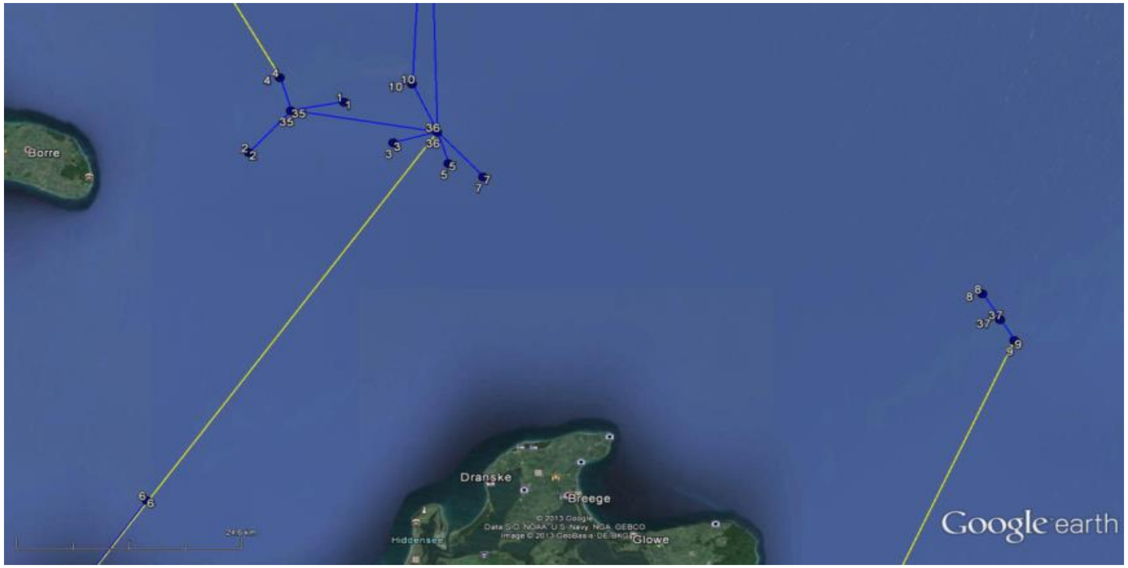
EERA-DTOC Project[1]

The **EERA (European Energy Research Alliance)** partners are pooling their resources in support of the Strategic Energy Technology plan (SET plan) of the European Commission. Some partners of the Joint Programme on Wind Energy have state-of-the-art software models in **single and multiple wake, energy yield** and **electrical models**. Then, the concept of the **EERA's Design Tool for Offshore Wind Farm Clusters (EERA-DTOC)** project is thus to **combine their expertise** in a common **integrated software tool** for the optimised design of offshore wind farms and wind farm clusters acting as wind power plants (WPP).

The project has defined the following Objectives:

- Integrate existing atmospheric and wake models from single wind farm to cluster scale
- Predict energy yield precisely through simulation
- Interconnection optimization for grid and offshore wind power plant system service
- Validation of the newly integrated existing models based on wind farm observations

Kriegers Flak Study Case[2][3]



- Layout done by optimization tool (Net-Op), data include
  - Conenction points
  - Cable length
  - Applied technology (AC/DC)
  - Transmission capacity

Wind Cluster Management System I

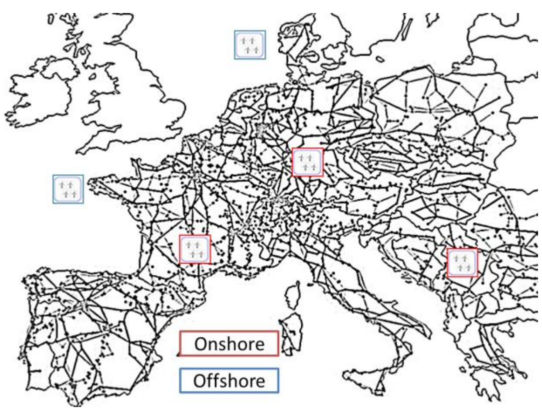
- geographically distributed wind farms aggregated to clusters
  - Differ in size depending on considered service
  - Span over one or more voltage levels
- Provide grid supporting functionality
- Coordinated manner
- Considering grid structure
- forecast data with different temporal resolutions
- Applications:
  - Field test in portugal
  - Park controller including forecast (alphaventus)
  - Coordinated reactive power supply including **short-term forecast** and transformer **tap-changer control** in **meshed distribution grids** with **multiple feeders**

Wind Cluster Management System II

Pan-European Synchronous Area

1. Provision of Frequency Support:
   - Primary Reserve

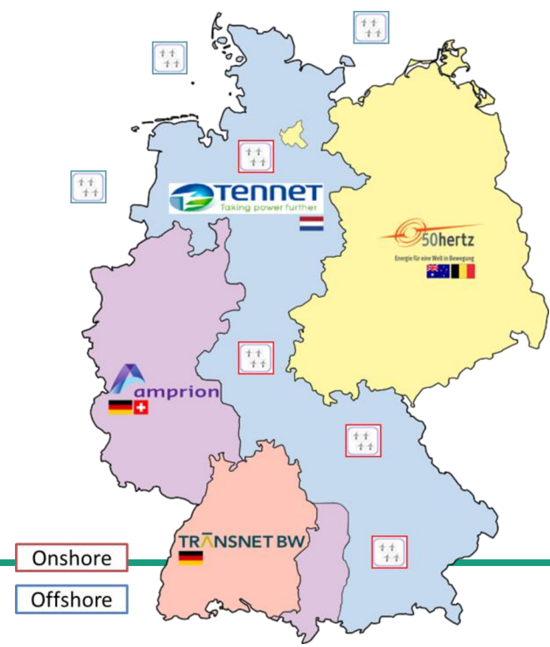
2. Congestion mgmt



Control Area

1. Provision of Frequency Support:
   - Secondary Reserve

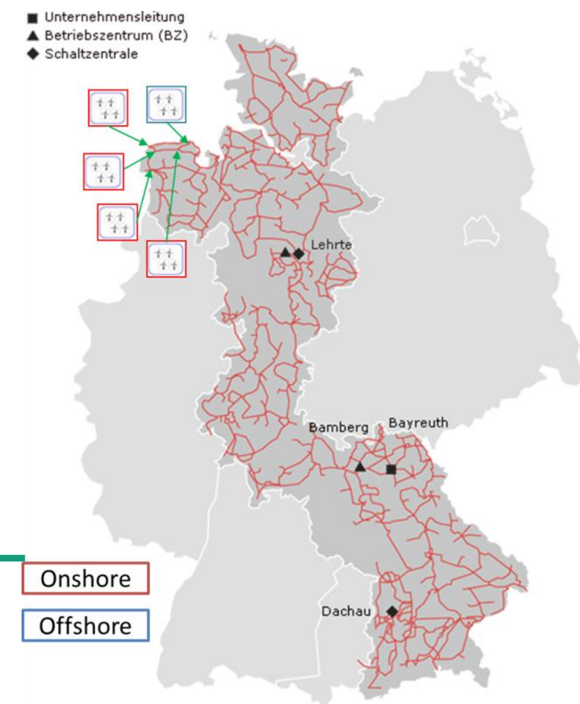
2. Congestion mgmt



Local/ Regional Area

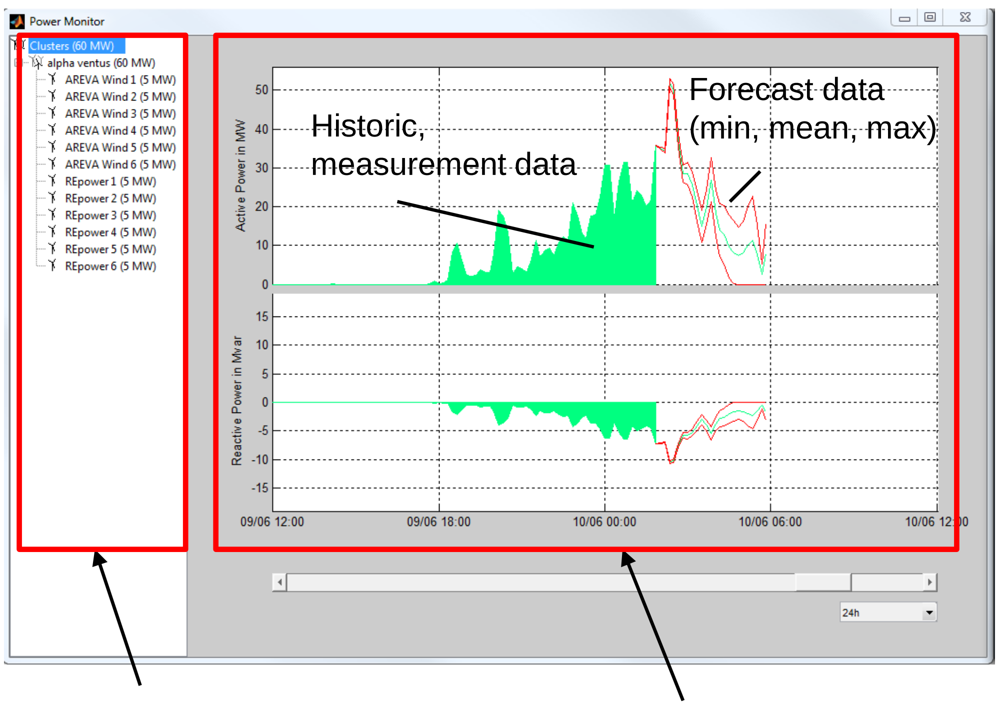
1. Provision of Voltage Support:
   - Voltage control
   - Reactive power

2. Congestion mgmt



Wind Cluster Management System III

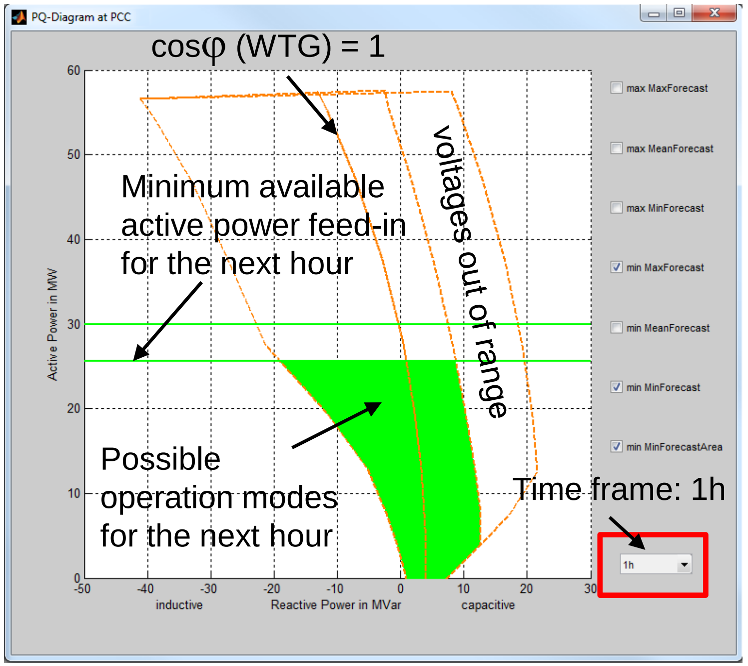
Power Monitor



Get information of a single turbine or the whole cluster

Active and reactive power data (gross values – without grid losses)

PQ-Curve at UW Hagermarsch



Active and reactive power data relating PCC node (net values – including grid losses)

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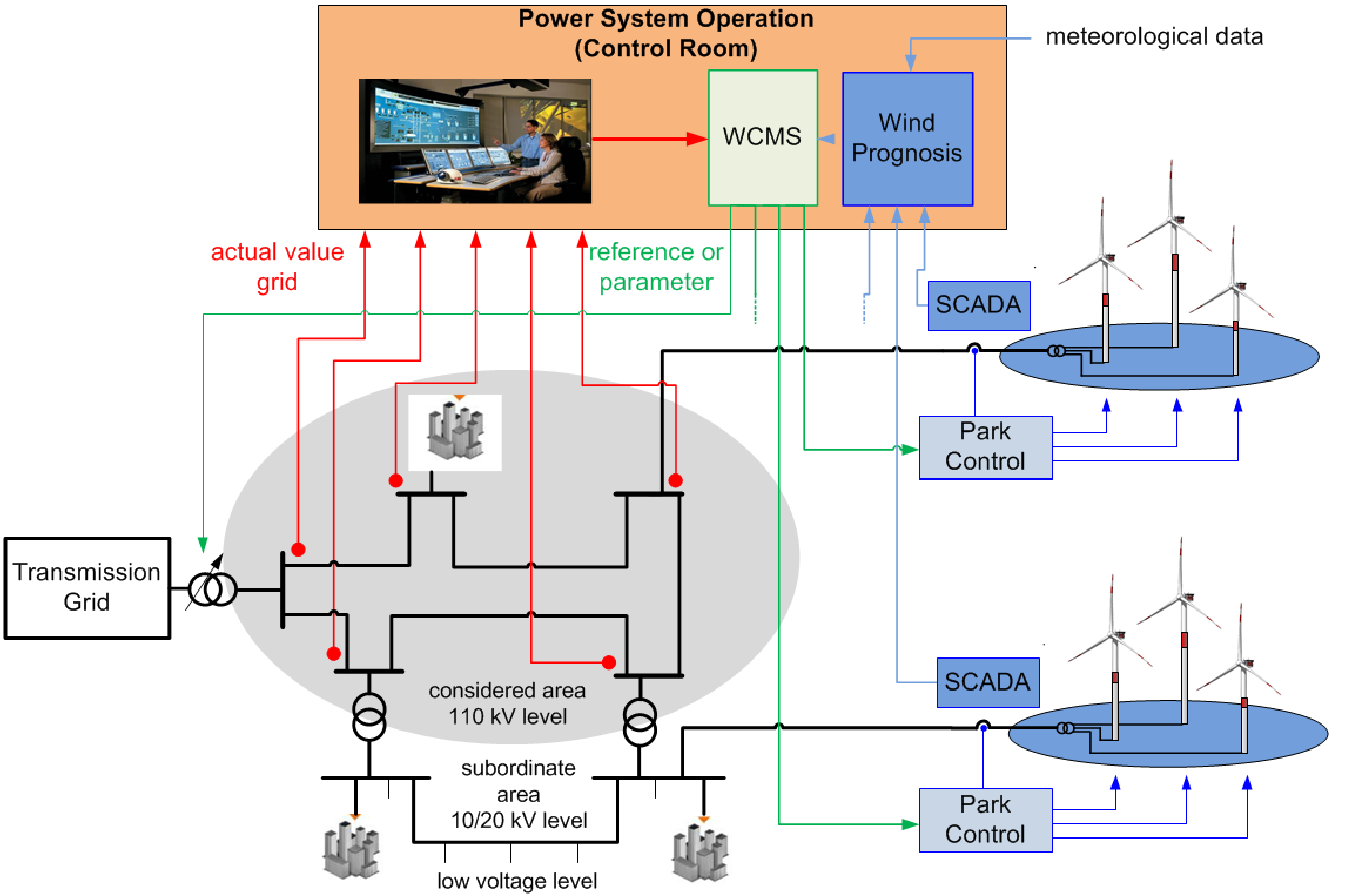
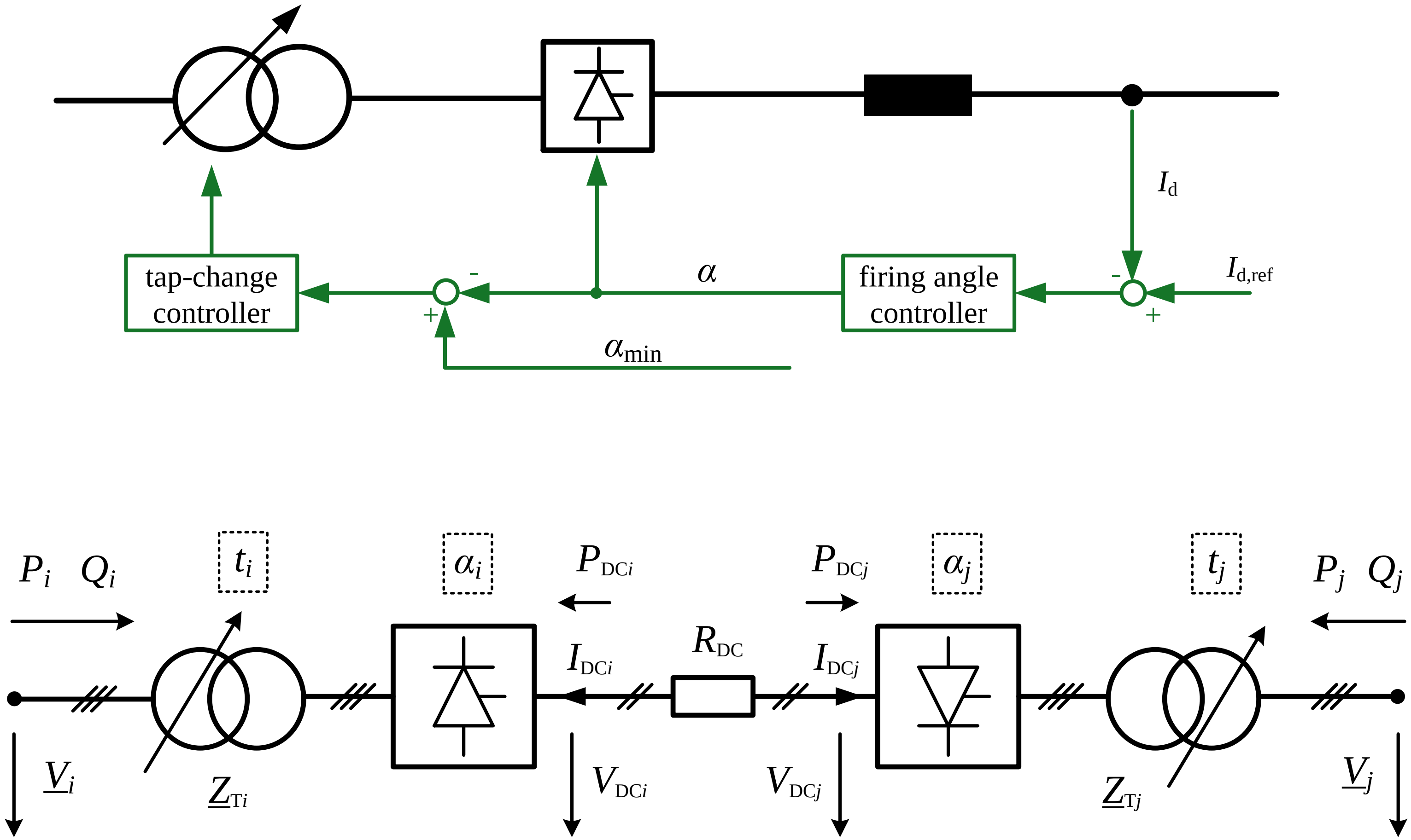
Wind Cluster Management System IV



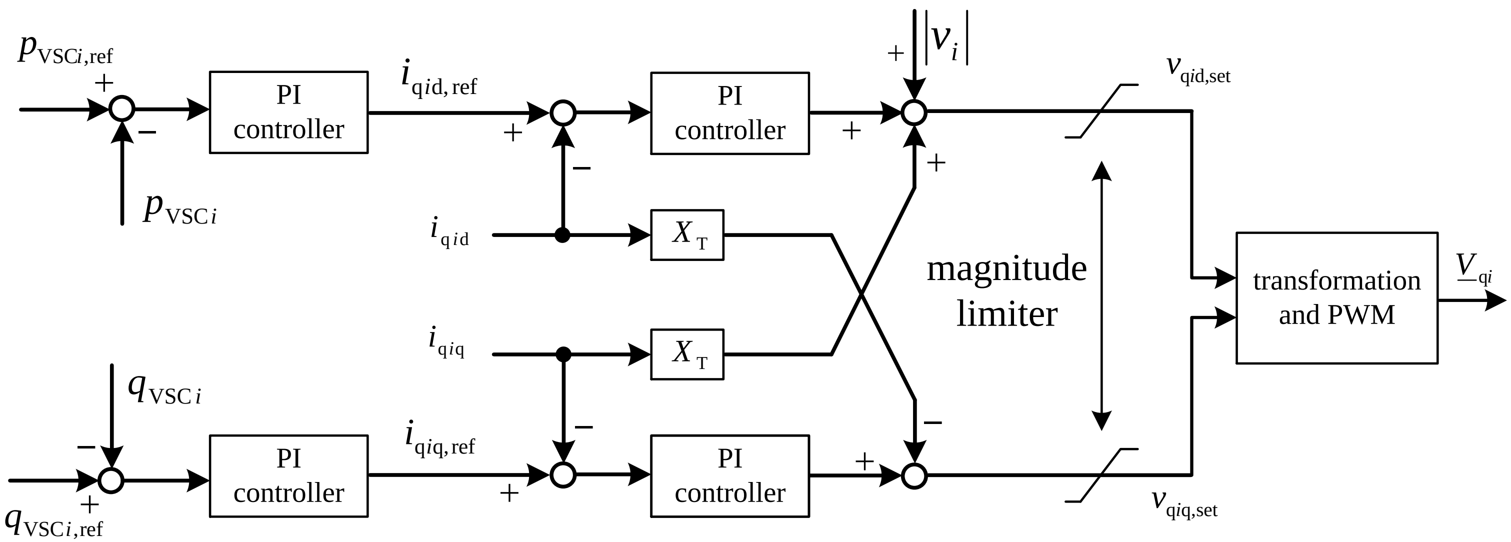
HVDC Technology Integration

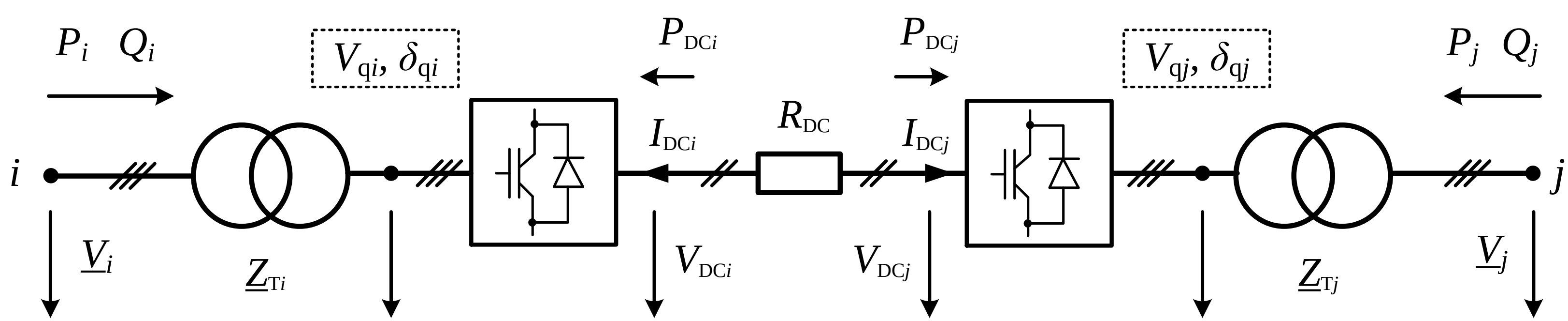
- major impact is evoked by representing and respecting HVDC technology during the calculation process
- VSC-HVDC systems are the preferred technology for offshore grids
  - Voltage control
  - Islanding operation
- CSC-HVDC systems manageable if the grid is strong enough
  - e.g. meshed connection to onshore nodes
- Critical size in terms of power → switching losses VSC still higher than CSC
- Both technologies considered and implemented

CSC-HVDC Load Flow Model[4]



VSC-HVDC Load Flow Model[4]





Modified Newton-Raphson Load Flow Algorithm I [4]

$$\begin{pmatrix} \Delta\vec{V}_{\mathrm{AC}} \\ \Delta\vec{\delta}_{\mathrm{AC}} \end{pmatrix} = \mathbf{J}_{\mathrm{AC}} \cdot \begin{pmatrix} -\Delta\vec{P}_{\mathrm{AC}} \\ -\Delta\vec{Q}_{\mathrm{AC}} \end{pmatrix}$$

$$\begin{pmatrix} \Delta\vec{V}_{\mathrm{AC}} \\ \Delta\vec{\delta}_{\mathrm{AC}} \\ \Delta\vec{V}_{\mathrm{q}} \\ \Delta\vec{\delta}_{\mathrm{q}} \end{pmatrix} = \begin{bmatrix} \mathbf{J}_{\mathrm{AC}} + \mathbf{J}_{\mathrm{UL}} & \mathbf{J}_{\mathrm{UR}} \\ \mathbf{J}_{\mathrm{LL}} & \mathbf{J}_{\mathrm{LR}} \end{bmatrix}^{-1} \cdot \begin{pmatrix} -\Delta\vec{P}_{\mathrm{AC}} \\ -\Delta\vec{Q}_{\mathrm{AC}} \\ -\Delta\vec{f}_{\mathrm{VSC}} \end{pmatrix}$$

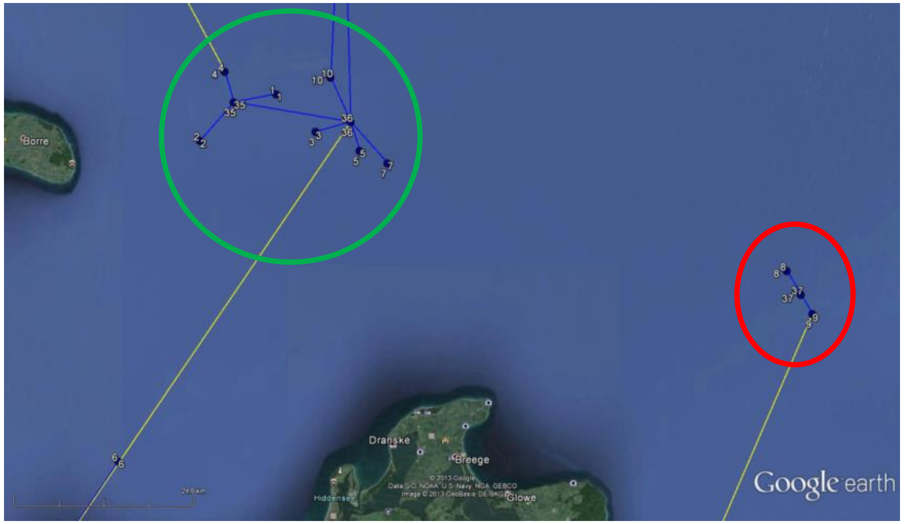
Modified Newton-Raphson Load Flow Algorithm II [4]

	Converter at node i
Active power	Master (set-point compliance) $\Delta f_{\text{VSC1}} = P_{\text{VSC}i,\text{iter}} - P_{\text{VSC}i,\text{ref}}$
Reactive Power	Specified reactive power provision $\Delta f_{\text{VSC3}} = Q_{\text{VSC}i,\text{iter}} - Q_{\text{VSC}i,\text{ref}}$
$\mathbf{J}_{\text{UL}}$	$\partial P_{\text{VSC}i}/\partial V_i, \partial P_{\text{VSC}i}/\partial \delta_i, \partial Q_{\text{VSC}i}/\partial V_i, \partial Q_{\text{VSC}i}/\partial \delta_i$
$\mathbf{J}_{\text{UR}}$	$\partial P_{\text{VSC}i}/\partial V_{\text{q}i}, \partial P_{\text{VSC}i}/\partial \delta_{\text{q}i}, \partial Q_{\text{VSC}i}/\partial V_{\text{q}i}, \partial Q_{\text{VSC}i}/\partial \delta_{\text{q}i}$
$\mathbf{J}_{\text{LL}}$	$\partial \Delta f_{\text{VSC1}}/\partial V_i, \partial \Delta f_{\text{VSC1}}/\partial \delta_i, \partial \Delta f_{\text{VSC3}}/\partial V_i, \partial \Delta f_{\text{VSC3}}/\partial \delta_i$
$\mathbf{J}_{\text{LR}}$	$\partial \Delta f_{\text{VSC1}}/\partial V_{\text{q}i}, \partial \Delta f_{\text{VSC1}}/\partial \delta_{\text{q}i}, \partial \Delta f_{\text{VSC3}}/\partial V_{\text{q}i}, \partial \Delta f_{\text{VSC3}}/\partial \delta_{\text{q}i}$

Modified Newton-Raphson Load Flow Algorithm III [4]

Converter at node j
Slave (balancing mode) $\Delta f_{\mathrm{VSC2}} = P_{\mathrm{VSC}i,\mathrm{iter}} + P_{\mathrm{VSC}j,\mathrm{iter}} - R_{\mathrm{DC}} I_{\mathrm{DC}}^2$
Voltage control $\Delta f_{\mathrm{VSC4}} = V_{j,\mathrm{iter}} - V_{j,\mathrm{ref}}$
$\partial P_{\mathrm{VSC}j} / \partial V_j, \partial P_{\mathrm{VSC}j} / \partial \delta_j, \partial Q_{\mathrm{VSC}j} / \partial V_j, \partial Q_{\mathrm{VSC}j} / \partial \delta_j$
$\partial P_{\mathrm{VSC}j} / \partial V_{qj}, \partial P_{\mathrm{VSC}j} / \partial \delta_{qj}, \partial Q_{\mathrm{VSC}j} / \partial V_{qj}, \partial Q_{\mathrm{VSC}j} / \partial \delta_{qj}$
$\partial \Delta f_{\mathrm{VSC2}} / \partial V_i, \partial \Delta f_{\mathrm{VSC2}} / \partial \delta_i, \partial \Delta f_{\mathrm{VSC2}} / \partial V_j, \partial \Delta f_{\mathrm{VSC2}} / \partial \delta_j, \partial \Delta f_{\mathrm{VSC4}} / \partial V_j$
$\partial \Delta f_{\mathrm{VSC2}} / \partial V_{qi}, \partial \Delta f_{\mathrm{VSC2}} / \partial \delta_{qi}, \partial \Delta f_{\mathrm{VSC2}} / \partial V_{qj}, \partial \Delta f_{\mathrm{VSC2}} / \partial \delta_{qj}, \partial \Delta f_{\mathrm{VSC4}} / \partial V_{qj}$

Control Mode Selection

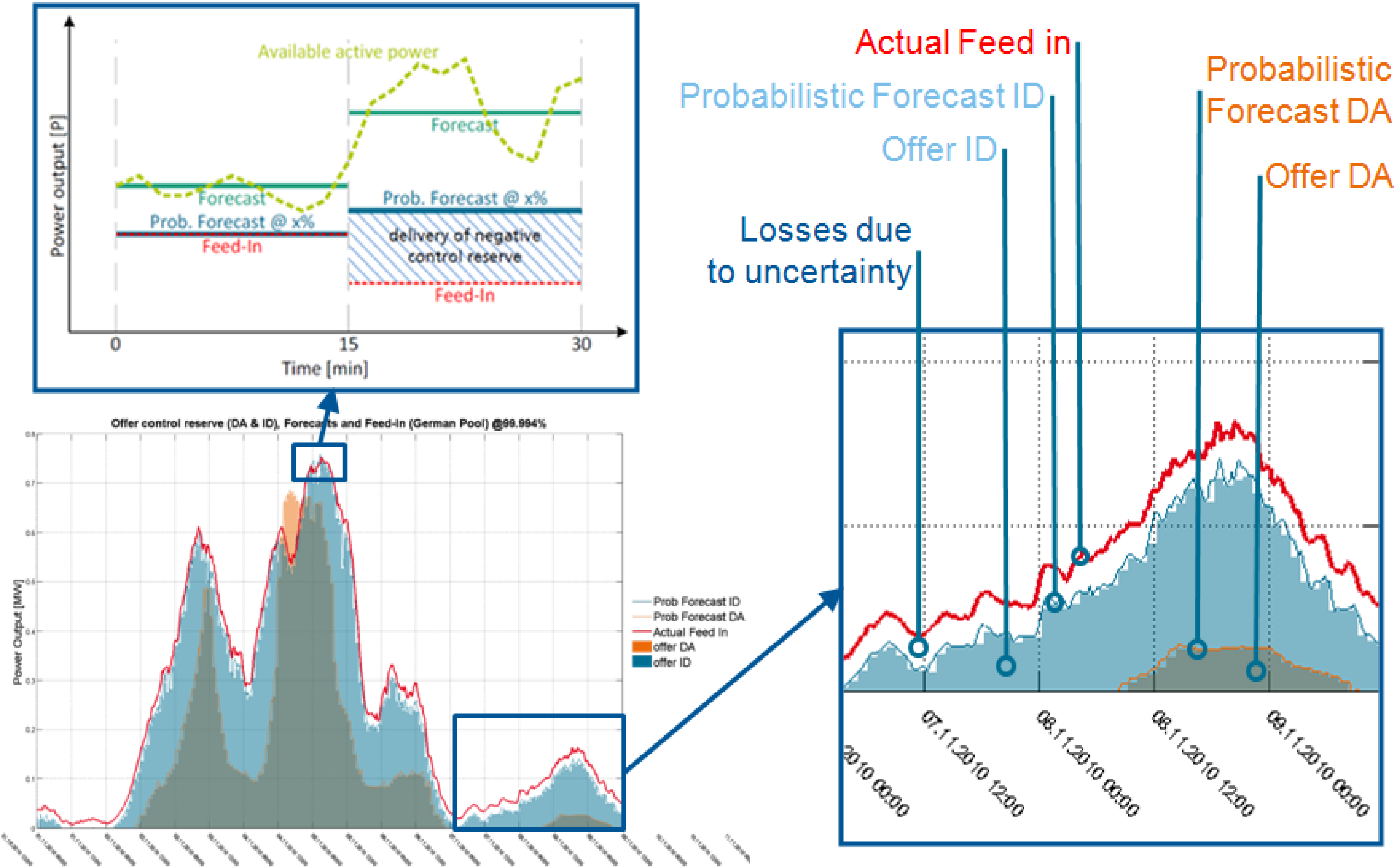


- Scanning for swing bus (slacks) in synchronous areas
- Slack Mode Operation of HVDC
- Set-point allocation due to demand or reserve restrictions
- **Offshore grid operational control needs to be coordinated with ancillary service provision**

Ancillary Services Analysis I

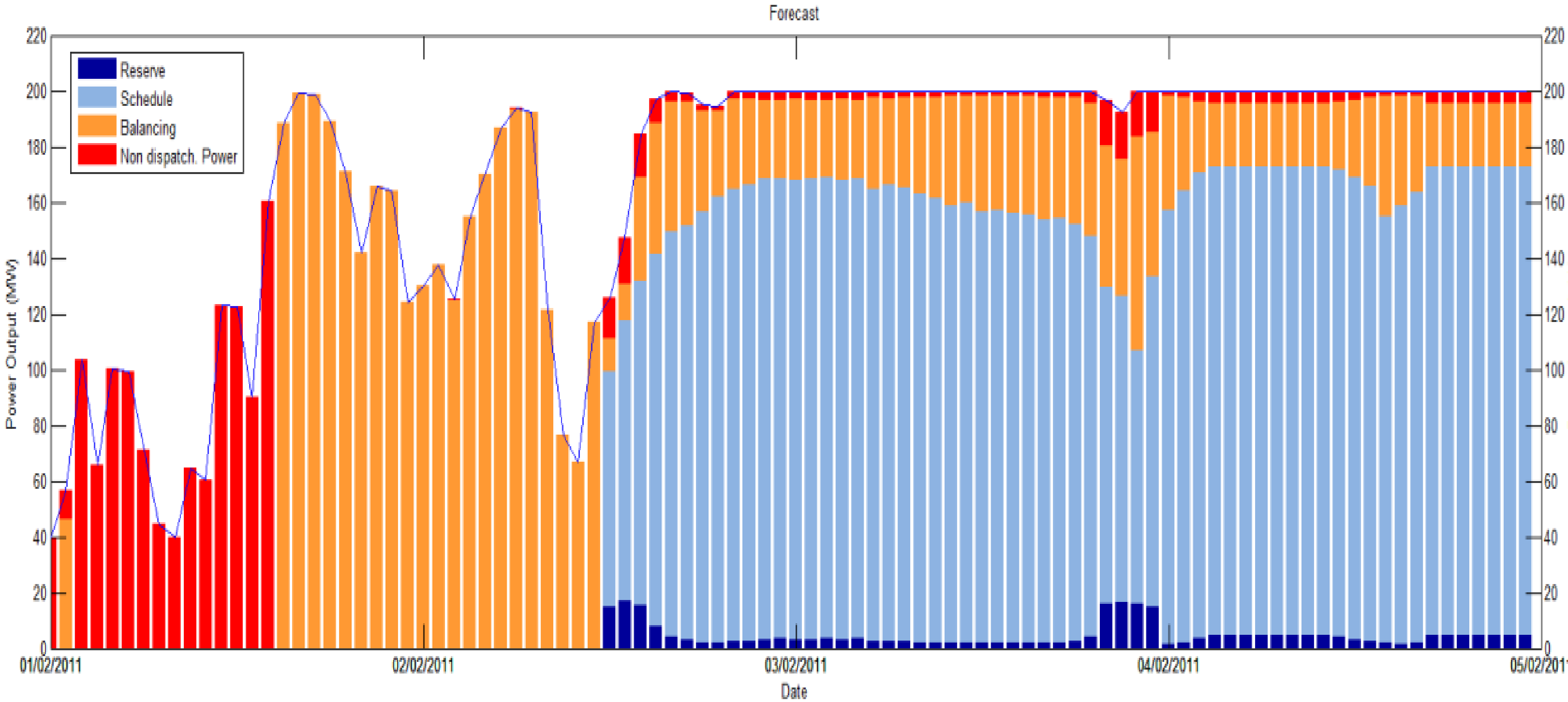
Category	Service	Description
Frequency Support	Reserve	Frequency Restoration Reserve (Secondary Reserve)
		Replacement Reserve (Minute Reserve)
	Balancing Power	Balancing power supply
Voltage Support	Reactive power contribution to onshore nodes	Reactive power provision of the cluster (if connected with AC) or by HVDC links to onshore nodes
System Management	Congestion Management	Maximum load flow into the grid due to congestions on land

Ancillary Services Analysis II [5][6]



Source: Malte Jansen – Fraunhofer IWES

Reserve and Balancing Power Provision



- Dark blue: day ahead forecast, probability 99.5 %, → possible reserve
- Light blue: day ahead forecast, probability 90 %, → schedule
- Orange: 1h forecast, probability 99.5 %, → balancing power (intraday)
- Red: non-dispatchable power → losses due to forecast uncertainties, security requirements

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Remarks and Outlook

- Results provided are technical solutions
- No procurement or market rules considered
- Coupling with market rules need to be investigated (see next slide)
- Optimization of voltage selection/ transformer placement, reflect cost in:
  - Necessary transformers
  - Insulation material of cables
  - Need for platform space due to insulation distances
- Modular expansion stages → optimization on time perspective
  - Evolving technologies (DC breakers, new converter…)
  - Market releases
- Reliability analysis and design of AC/DC systems

Virtual Power Plant (VPP) vs. Wind Farm Cluster (WFC)

VPP

Markets
- Bidding
- Cross market optimization

"Copper Plate"

WFC

Grids
- Voltage Support
- Congestion Mgmt

"Grids"

Common functionalities
- "Smoothing effect" advantage
- Portfolio optimization
- Frequency Support
  (Primary, Secondary and Tertiary Reserve)

References and Acknowledgement

[1] www.eera-dtoc.com

[2] Svendson, H. G. Planning Tool for Clustering and Optimised Grid Connection of Offshore Wind Farms, presented at EERA DeepWind'2013, Trondheim, 2013.

[3] Svendson, H. G. "Report on tools and results from a case study (D2.3)", EERA-DTOC Project Deliverable D2.3. February 2013.

[4] Panosyan, A. Modeling of Advanced Power Transmission System Controllers, PhD thesis Leibniz University Hannover, 2010.

[5] Jansen, M.; Speckmann, M.; et al. Impact of Control reserve Provision of Wind Farms on Regulating Power Costs and Balancing Energy Prices. EWEA Event 2012. Copenhagen, 2012.

[6] Jansen, M.; Speckmann, M. Wind turbine participation on Control Reserve Markets. EWEA Conference 2013. Vienna: EWEA, 2013.

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