EERA Design Tool for Offshore wind farm Cluster (DTOC)

Madsen, Peter Hauge; Hasager, Charlotte Bay

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EERA Design Tool for Offshore wind farm Cluster (DTOC)

PETER HAUGE MADSEN. Director
Charlotte Hasager. Senior scientist
DTU Wind Energy
Project partners

- DTU Wind Energy (former Risø)
- Fraunhofer IWES
- CENER
- ECN
- EWEA
- SINTEF
- ForWind
- CRES
- CIEMAT
- University of Porto
- University of Strathclyde
- Indiana University
- CLS
- Statkraft
- Iberdrola Renovables
- Statoil
- Overspeed
- BARD
- Hexicon
- Carbon Trust
- E.On
- RES
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- RES

“Design Tool for Offshore wind farm Clusters” is the first EERA project. EERA is based on national science activities.
**Background:** The EERA JP Wind Energy was officially launched at the SET-Plan conference in Madrid in June 2010. The strategy and main activities of the JP is described in the "Strategic Action Plan" (yearly updated).

The programme vision is:
- to provide strategic leadership for the scientific–technical medium to long term research
- to support the European Wind Initiative and the Technology Roadmap’s activities on wind energy, and on basis of this
- to initiate, coordinate and perform the necessary scientific research.

**Joint Programme and Sub-programmes**

**Wind Conditions.** Coordinated by Prof. Erik Lundtang Petersen, DTU Wind Energy (DK)

**Aerodynamics.** Coordinated by Dr. Peter Eecen, ECN (NL)

**Offshore Wind Energy.** Coordinated by Dr. John O. Tande, SINTEF (NO)

**Grid Integration.** Coordinated by Dr. Kurt Rohrig, FhG IWES (DE)

**Research Facilities.** Coordinated by Dr. Pablo Ayesa Pascual, CENER (ES)

**Structural design and materials.** Coordinated by Dr. Denja Lekou, CRES (GR)
Topic ENERGY.2011.2.3-2:  
Development of design tools for Offshore Wind farm clusters

Open in call: FP7-ENERGY-2011-1

Funding scheme: Collaborative project

- EERA DTOC is 3.5 years: January 2012 to June 2015
- Budget is 4 m€ hereof 2,9 m€ from EC
- Parallel project is ClusterDesign coordinated by 3E
• To contribute to the SET-Plan on the development of offshore wind power.

• To demonstrate the capability of designing virtual wind power plants composed of wind farms and wind farm clusters while minimizing the negative spatial interactions, improving the overall power quality output and providing confidence in energy yield predictions.
The objective of this topic is to develop new design tools to optimise the exploitation of individual wind farms as well as wind farm clusters, in view of transforming them into virtual power plants.

Such design tools should integrate:

• Spatial modelling: medium (within wind farms) to long distance (between wind farms) wake effects

• Interconnection optimisation: to satisfy grid connection requirements and provide power plant system service.

• Precise energy yield prediction: to ease investment decisions based on accurate simulations

The project should focus on offshore wind power systems and make optimal use of previously developed models.
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WP structure

Year 1
- WP1: Wake models
- WP2: Grid models
- WP3: Energy yield

Year 2
- WP4: Integrating software

Year 3
- WP5: Validation Demonstration

WP6: Dissemination
EERA DTOC concept

Meteorological data / Cluster layout / Turbine data

Grid data

Wake models

Grid models

Yield models

System services

Energy yield

Optimised Cluster Design
EERA DTOC main components

- Use and bring together existing models from the partners
- Develop open interfaces between them
- Implement a shell to integrate
- Fine-tune the wake models using dedicated measurements
- Validate final tool
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User Requirements
Design and model selection guided by end-users

Two main user groups were identified:
- Strategic planners
- Developers of offshore wind farms

Associated users could be:
- Consultants
- Research institutions
- Manufacturers
- System Operators
As a developer I can determine the wake effects of neighbouring wind farm clusters on a single wind farm.

As a developer I can determine the optimum spacing, position, turbine model and hub height of turbines within an offshore wind farm.

As a strategic planner I can determine the optimum strategic infrastructure to accommodate offshore wind farm clusters.

14 relevant user stories in total
As a developer I can determine the optimum spacing, position, turbine model and hub height of turbines within an offshore wind farm.

Software supports the comparison of many design scenarios.

Comparative reporting enables selection of optimised configurations.

Score for comparison: Levelised Cost of Energy
Optimisation Process

1. Generate Design Options
   - Scenario 1
   - Scenario 2
   - Scenario 3
   - Scenario 4
   - Scenario 5
   - Scenario 6
   - Scenario 7

2. Evaluate Design Options
   - Wake Model
   - Electrical Model
   - Energy model

3. Compare Design Options

4. Iterate steps 1 to 3

Score: Levelized cost of energy

What decision parameter can we use to compare design options?
EERA DTOC vision

• A robust, efficient, easy to use and flexible tool created to facilitate the optimised design of individual and clusters of offshore wind farms.

• A keystone of this optimisation is the precise prediction of the future long term wind farm energy yield and its associated uncertainty.
Introduction

The “big wake” picture

Cluster scale wake model

Wind farm scale wake model

Upstream WF

Target WF

Wake info

Coupling

Wind

http://www.renewbl.com

http://www.offshore-power.net

AEP
Wind farm scale wake models

- DWM
- WASP/NO J
- RANS
- CRES flowNS
- Ainslie
- FarmFlow
- FUGA
- GCL
- NOJ

- Engineering
- Simplified CFD
- Full CFD
Benchmarking purpose

Selecting the most appropriate models for the different usage scenarios of the design tool.
Horns Rev 1 benchmark (DONG energy & Vattenfall)
Lillgrund benchmark (Vattenfall)

Example:
Power deficit along one row

Horns Rev, wdir = 270 ± 15°, spacing = 7D, ws = 8 ± 0.5 m/s

![Graph showing power deficit vs. spacing for different models](image-url)
Gross energy: FINO-1 test case (BMU)

- Wind speed and direction data (10 minutes)
  From 13/01/2005 to 30/06/2012 (total of 7.5 years data)
  (Generic power curve (1.225 kg/m³))
Gross energy – output parameter checks

- Mean wind speed (before filtering)
- Mean wind speed (after filtering)
- Long term mean wind speed, free decision
- Vertical extrapolation between 100m and 120m
- Gross energy P50
- Gross energy P90
Gross energy P90

Gross Energy P90. Mean value +/- 8.5%
O&M losses

- Offshore Wind Farm
  - Inputs
    - Turbine layout and turbine model
    - Site wave climate
    - Location of O&M base (from 10 to 150 km)
  - O&M strategy
  - SWARM software

### Wave Climate Scenario

<table>
<thead>
<tr>
<th>Wave Climate Scenario</th>
<th>Description</th>
<th>Mean Wind Speed at 100m [m/s]</th>
<th>% of Time Above Hs Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.5 meters</td>
</tr>
<tr>
<td>1</td>
<td>Benign Climate</td>
<td>9.0</td>
<td>16.5%</td>
</tr>
<tr>
<td>2</td>
<td>Moderate Climate</td>
<td>9.4</td>
<td>21.0%</td>
</tr>
<tr>
<td>3</td>
<td>Severe Climate</td>
<td>9.5</td>
<td>28.3%</td>
</tr>
</tbody>
</table>

### Number of Workboats and Helicopters

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Number of Workboats</th>
<th>Number of Helicopters</th>
<th>Wave Hs Limit for Boats [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>0</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Aims of grid layout optimization

- Design tool and procedure assisting the optimization of the electrical design;
- Clustering;
- Grid code compliance;
- Power plant ancillary services;
- Evaluate impact of the variability and the predictability.
Methodology

1. Determine the models chain, interactions, I/O;
2. Establish the data flow/ data gaps according to the user cases;
3. Procedure to fill overcome gaps was investigated:
   1. Automatic electrical data generation
   2. User intervention providing accurate data.
   3. Implementation of a new module
4. Dry runs (based on scenarios)
5. Assessment/ convenience evaluation
Kriegers Flak case study

<table>
<thead>
<tr>
<th>#</th>
<th>Country</th>
<th>Wind farm</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DK</td>
<td>Kriegers Flak A K2</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>DK</td>
<td>Kriegers Flak A K3</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>DK</td>
<td>Kriegers Flak A K4</td>
<td>200</td>
</tr>
<tr>
<td>4</td>
<td>DK</td>
<td>Kriegers Flak B K1</td>
<td>200</td>
</tr>
<tr>
<td>5</td>
<td>DE</td>
<td>EnBW Baltic 2</td>
<td>288</td>
</tr>
<tr>
<td>6</td>
<td>DE</td>
<td>EnBW Baltic 1</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>DE</td>
<td>Baltic Power</td>
<td>500</td>
</tr>
<tr>
<td>8</td>
<td>DE</td>
<td>Wikinger</td>
<td>400</td>
</tr>
<tr>
<td>9</td>
<td>DE</td>
<td>Arkona Becken Südost</td>
<td>480</td>
</tr>
<tr>
<td>10</td>
<td>SE</td>
<td>Kriegers Flak</td>
<td>640</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Branch type</th>
<th>max distance</th>
<th>max power</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>65 km</td>
<td>700 MW</td>
</tr>
<tr>
<td>DC-direct</td>
<td></td>
<td>1000 MW</td>
</tr>
<tr>
<td>DC-mesh</td>
<td></td>
<td>1000 MW</td>
</tr>
<tr>
<td>converter</td>
<td></td>
<td>1000 MW</td>
</tr>
</tbody>
</table>
Kriegers Flak case study results
Expected achievements

• Checking planned grid:
  – Fulfillment of full load flows $\rightarrow$ calculate component utilization factors.
  – Fulfillment of certain average load flows situations.
  – Checking congestions and voltages.
  – Control power:
    • Power reserve
    • Balancing power
  – Voltage control
  – Enabling market/ transport
Model workflow energy yield (WP3)

Filtering → Vertical extrapolation → Long Term

On site mast data (raw) → Clean data → HH Data

Long term ref. masts → Virtual data

LT Wind Data → Gross Energy → Layout Opt

Power curve → Lay out → Specifications

Net energy → Uncertainty

% losses

WP1, WP2

Uncertainty

Net AEP P50/P90

User input? Real data or virtual data?

General Tables

Wave conditions

Distance to O&M base

Availability

% losses

Net Energy

Cost

Specifications

Parameters

WP1

WP2
Model workflow wake (WP1)

- Reanalysis Inputs
  - Dynamical Mesoscale flow model
    - Time Series Database
      - Hybrid Mesoscale wake model
        - CorWind inputs
  - Mesoscale wake deficits
    - Statistical-Dynamical
      - Mesoscale wake model
        - Wind farms Layout
          - Wind farms Power Curve
            - Microscale wake model
              - Lib, Tab, NetCDF
                - Wind farm Power production
                  - AEP calculator
                    - Wind farm AEP
Model workflow “Electrical” (WP2)

- Cost Model
  - DTOC Cost Model, etc

- Grid Optimization
  - System Services (WCMS)

- Offshore Optimization
  - (NET-OP, …)

- Inter-array
  - (eeFarm II, …)

- Wake Effects
  - (out of scope)

- Synth. TS
  - (CorWind, meas., etc)

- NWP Forecast
  - (GFS, WRF, etc)

- Predictability
  - (Fh Model)

- Grid Optimization (Layout)

- Forecasts & Predictability
Total tool overview – very complex!
Open interfaces

- The sub-models are protected by IPR...
- ...but the interfaces in the model chain are going to be open

- File formats for data exchange are based on existing industry standard formats, e.g. the WAsP types based on XML and ESRI shape file standard
DTOC software development timeline

- **2012**
  - existing models

- **2013**
  - dry runs
  - proof of concept

- **2014**
  - design
  - prototype
  - DTOC V0.5
  - DTOC V1.0

- **End user requirements**
- **Pre-design**
- **Design**
- **Test reports**
Validation and demonstration
Rødsand 2 data (E.On)

10 minute statistical data from meteorological mast and Rødsand 2 turbines
(No data from neighbouring Nysted farm)
SAR satellite images (CLS, DTU)

- Belwind phase I
- Thomton phase II
- Thomton phase I & III

Wake length
Wake limit

Mooring area for ships

Clear evidence of wake
No evidence of wake
Lidar measurements (ForWind & Fraunhofer IWES)

- Long range wind scanner measurements from fixed positions
- Ship based LIDAR measurements
- EERA DTOC partners requested
- Alpha Ventus SCADA data
Industry partners are very important!

Iberdrola, Statoil, Carbon Trust, Hexicon, Statkraft, E.On, RES
Purpose of the scenarios

- The tool should fulfill the previously defined user requirements:
  - The tool should be useful, easy to use, complete and robust
- Functionality of all modules in EERA DTOC should be proven → All parts of the tool should be activated during the scenarios
- Inventory of user experiences:
  - How steep is the learning curve?
  - Which tutorials should be added?
- The results should LOOK realistic from an expert point of view
What is EERA-DTOC?

EERA-DTOC stands for the European Energy Research Alliance - Design Tool for Offshore Wind Farm Cluster. The project is funded by the EU – Seventh Framework Programme – and runs from January 2012 to June 2015. It is coordinated by the Technical University of Denmark - DTU Wind Energy. The concept of the EERA-DTOC project is to combine this expertise in a common integrated software tool for the optimized design of offshore wind farms and wind farm clusters acting as wind power plants.

Deliverables

- 7th Framework
Thank you very much for your attention
Support by

EERA DTOC project
FP7-ENERGY-2011-1/ n°282797