EERA-DTOC: How aerodynamic and electrical aspects come together in wind farm design

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• **EERA-DTOC: Introduction**

• EERA-DTOC: Scenarios to be calculated

• EERA-DTOC: Results from a preliminary scenario calculated with ECN’s tools FarmFlow and EEFARM
EERA-DTOC

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Start 1 January 2012, runs for 3.5 years, total funding is ~4 M€, EU share is 2.9 M€.

Product 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.
EERA-DTOC main idea

- 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 and demonstrate the final tool through likely scenarios
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Scenarios

- Demonstration of **INTEGRATED** design tool to verify user requirements
- Measurement data are scarce and synchronous measurement data for wind farm clusters are fully missing
  - Tools will be demonstrated on basis of likely scenarios.
- Industry is heavily involved in the definition of scenarios
Scenarios:

1. **Base and near future scenario**
   - *Base scenario*: Single 500 MW wind farm with 6 MW turbines,
   - *Near future scenario*:
     - Carried out in steps
       1. Single 1GW wind farm with 10 MW turbines
       2. Adding other wind farms \(\rightarrow\) cluster

2. **Far future** scenario:
   - Offshore wind farm clusters including innovations, e.g. floating turbines

Scenario 1\(\rightarrow\)2 reflects:
- A shift towards the future.
- Increasing complexity of the modeling problem
- A shift in target group:
  - Developers (base scenario)
  - Developers and strategic planners (far future scenario)
Present study focusses on near future scenario

- Single 1000 MW wind farm (other wind farms will be added at later stage to form a cluster)
- 100*10 MW turbines
  - Innwind.EU 10 MW reference turbine
- 20 parallel grid lines (66 kV) connecting 5 turbines to a central sub station
- North Sea wind climate
- Distance to shore: ~125 km
- Water depth: ~40 m
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Eventually the scenarios will be calculated with the final EERA-DTOC tool.

‘Preliminary’ scenario calculated with a combination of ECN’s aerodynamic (FarmFlow) and electrical tool (EEFARM):

- Demonstrates value of INTEGRATED electrical-aerodynamic tool
- Near future scenario, starting with 10D distance between the turbines (low aerodynamic losses versus high electrical losses and high costs for electrical infrastructure)

- Decrease distance
  - Higher aerodynamic losses can be balanced versus lower electrical losses and lower costs for electrical infrastructure
What is FARMFLOW?

- Calculates:
  - Losses and added turbulence due to wakes
  - Annual energy production (AEP)
- The model is based on UPMWAKE \(^1\)/WAKEFARM
  - Modified by ECN since 1993
  - Extensively validated with results from ECN’s research farms and measurements from EU projects (e.g. ENDOW, Upwind, EERA-DTOC)

\(^1\) Crespo et al. 1988
FARMFLOW: Theory and the Model description

- Solves the Parabolized Navier-Stokes equation
- Turbines modelled as actuator disc, prescribed by $C_{Dax}$
- Wake modelled with a k-ε turbulence model
• Parabolisation: Fast, but how to solve the near wake where axial pressure gradients are significant?

• Solution:
  – Prescribe axial pressure gradients from free vortex wake method!
    • Fast database approach
    • Wake interaction fully modeled including the effect of a non-zero pressure gradient and retaining the (fast) parabolisation

• Adjusted k-ε turbulence model parameters in near wake to account for actuator disc assumption, based on:
  – Measurements from ECN’s research farms and Horns Rev farm
  – Detailed wake measurements in TUDelft wind tunnel underway *)

*) Lorenzo Lignaroli, TUDelft, personal communication
What is EEFARM?

- Program to study and optimise the electrical performance of wind farms.
- Program is used to determine the:
  - Energy production,
  - Electrical losses,
  - Component failure losses
  - Price of the produced electric power
EeFarm-II linked to FarmFlow!

Aerodynamic power:
\[ P_{WT1} \ldots P_{WTN} = f(V_w, V_{dir}) \]

Investments
- \( P_{loss} \)
- \( P_{fail} \) per component

Levelized Production Costs
Reminder: Lay-out of 1GW farm

- 100 INNWIND.EU reference turbines of 10 MW
- Inter turbine distance is a variable between 3.6 and 10 D
- 20 parallel grid lines connecting 5 turbines to central substation
Annual Energy Production per row

Rows: 1 2 3 4 5 6 7 8 9 10

Annual Energy Production per row

E Farmnet (GWh/yr.)

Wind Farm Row

- 10.00D
- 7.29D
- 5.10D
- 3.65D
Main results

Net energy farm production (including aerodynamic and electrical losses)
- Increase with distance
- Increase levels off with distance

Investment costs of electrical infrastructure
- Linear increase with distance
Conclusions and Outlook

- Within the EERA-DTOC project a wind farm design tool is developed which combines existing wake models with electrical grid models.
- The integrated tool is demonstrated on basis of likely scenarios.
- A sequence of scenarios is defined ranging from a base scenario to a far future scenario with a near future scenario in between.
Conclusions and Outlook, ctd

• The near future scenario has been calculated with a combination of ECN’s aerodynamic tool FarmFlow and the electrical tool EEFARM

• The net energy yield increases with distance but the increase becomes less with distance

• The investment costs of the electrical infrastructure increase linearly with distance
The near future scenario has been calculated with a combination of ECN’s aerodynamic tool FarmFlow and the electrical tool EEFARM. An increase from 3.6 to 10 rotor diameters is earned back in 1.5 years with an energy price of 0.1 Euro/kWh. First results from an overall cost model (using the energy yield and investments costs of the present study) indicate a decrease in COE when distance is increased from 3.5 to 10 rotor diameters but decrease becomes less with distance. Work on a cost model which includes the actual FarmFlow/EEFARM parameters (energy yield and investment costs) is underway at ECN based on the former OWECOP model [1].

Thank you very much for your attention