Integrated wind plant simulator for layout and control optimization

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Wind Plant Optimization Tool Framework

**WINDFARMER: ENERGY ANALYST**

- WINDFARMER EA handles wake and energy calculation
- Interface with Python based-codes for aero-elastic load and cost modelling
- User-defined optimisation algorithm
- Steady state only (10-min average conditions)
- Multi-variable sub-models of environment and costs

Levelized **Cost of Energy** Optimization
**Offshore Sub-Structure Engineering Cost Model**

- **Initial tower assumption**
- **Footprint calculation**
- **Jacket outline design**
- **Frequency within tolerance?**
  - Yes
  - **Wind & Wave load calculation**
    - **Member ULS, FLS & Pile checks**
      - **Does the structure pass code checks?**
        - Yes
        - **Frequency within tolerance?**
          - Yes
          - **Final jacket cost**
          - **Jacket cost calculation**
            - Pricing properties
        - No
          - **Section re-design**
    - No
Offshore Sub-Structure Engineering Cost Model

- Automated sub-structure design as function of turbine size, loading, water depth and ground conditions

Jump at water depth where extra jacket storey is added

Jacket mass ~20% increase from class C to class A. ~20-30% increase from 26m to 50m water depth
Multiple Variables Feed into Cost of Energy Function

**Levelised Cost of Energy** =

\[ \text{Levelised Cost of Energy} = \left( \sum (Cost_{\text{Turbine}} + Cost_{\text{Foundation}} + Cost_{\text{Installation}} + Cost_{\text{Electrical}}) \right) \times \text{Capex factor} + Cost_{\text{OPEX}} \times \text{Opex factor} \]
An objective assessment of layout value

Which layout has higher energy yield?
An objective assessment of layout value

Which layout has higher energy yield?

Energy with cabling losses: -0.3%
An objective assessment of layout value

What about cost?
An objective assessment of layout value

What about cost?

Levelised cost (due to cabling mainly): -0.4%
An objective assessment of layout value

Therefore...
Cost of Energy:

LCoE: -0.1%
Energy yield - LCoE correlation
Example: Attempt to refine a ‘baseline’ offshore plant layout

- Baseline layout generated through:
  - Initial energy optimisation deriving best array geometry
  - Manual assessment of project costs considering ‘offline’ cost functions and constraints
  - Manual bridge between energy optimisation and cost optimisation
Baseline conditions

Deep energy deficit due to upstream turbines in prevailing directions
Example: Attempt to optimise a baseline layout

LCoE: -1.42%
Example: Attempt to optimise a baseline layout

- Energy
- Reduction in row length in N-S direction

Energy: +1.16%
Example: Attempt to optimise a baseline layout

- Levelised cost:
- 0.20% reduction composed of 82% array cabling, 18% reduced jacket costs
Removing manual interventions...

- The Southerly tip (high wind speeds) was blocked out due to high water depth perceived to be too costly for installation.
- Provided cost models are of suitable fidelity, the automated tool could make these value decisions directly trading off the benefit of the energy against the increase in project costs.
Removing manual interventions...

LCoE: -1.85%
Removing manual interventions...

- Energy

Wake affected energy yield

Energy: +1.61%
Removing manual interventions...

- Levelised cost:
- 0.19% reduction composed of 84% array cabling, 16% reduced jacket costs

Cost: -0.19%
What price uniformity?

- When irregularly arranged, turbines tend to hug boundaries with gaps forming internally reducing wake losses

3 movements of each turbine, LPC change of **-2.18%** relative to baseline
Wind plant-wide control strategies

- Consider wind farm as a power station, not a collection of autonomous turbines
- Turbines interact through their wakes
- When some turbines are wake-affected, optimize power set-points rather than shut down turbines completely

- Goal: Optimise farm-wide control strategies to balance the effects on energy capture and the accumulation of fatigue damage across the wind farm
Consider a simple example...

- Row of six 2MW turbines, regular spacing, wind direction from North.
Optimization variables & simple benefit function

- **Optimisation variables**: de-rating level, $\delta_i$, $i = 1, 2, \ldots, N$ (N turbines)
  - Notation: $\delta = (\delta_1, \delta_2, \ldots, \delta_N)$

- "Ideal" scenario: no turbines are wake affected

- "Base" scenario: wakes, but no turbine is de-rated, i.e. $\delta^{base} = (0, 0, \ldots 0)$

- 'Simple' **benefit function**: maximised in relation to the ideal scenario ($E^0_i, L^0_i$)

\[
\Delta J(\delta) = \sum_{i=1}^{N} \Delta J_i(\delta), \quad \Delta J_i(\delta) = \frac{(E_i(\delta) - E^0_i)}{E^0_i} - 0.1 \frac{(L_i(\delta) - L^0_i)}{L^0_i}
\]
3D spacing results (1)

- 3D spacing
- Average 10 m/s wind speed, 10% turbulence, from North

**Optimal set-points [kW]**

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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>50</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>300</td>
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</tbody>
</table>

**Base Net Power [kW]**

**Optimal Net Power [kW]**

3.7% power increase
3D spacing results (2)

**Power:**
- Ideal Net Power [kW]
- Base Net Power [kW]
- Optimal Net Power [kW]

**Fatigue Load:**
- Ideal Tower Base My [Nm]
- Base Tower Base My [Nm]
- Optimal Tower Base My [Nm]
Concluding remarks

- An integrated wind-plant system model has been demonstrated to aid cost of energy optimization. “Maximum energy yield” still appears to be a fair indicator of global optimal for at least some design scenarios, but further local optimisation is possible by considering more system effects.

- Simple plant-wide control example suggests there is potential to nuance turbine de-rating/shut-down policies and improve both energy and loading.

- Results clearly depend on the nature of the benefit functions, and the fidelity of wake model.

- The potential to optimize layout and plant-control policies simultaneously pre-construction could result in significant synergies – but this has yet to be demonstrated.
Thank you

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