Validation of the Revised WAsP Park Model

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Abstract

The DTU Wind Energy wind-resource model WAsP contains a wind farm wake model Park (Park1). This Park model in has been revised, Park2, to improve prediction accuracy in large wind farms, based on sound physical and mathematical principles: consistent wake-modelling and perturbation theory for wake-wake-interaction.

Park2 has been validated and calibrated using a number of off-shore and on-shore wind farms. The calibration has resulted in recommended values for the wake-expansion coefficients of the Park2 model.

Objectives

Why revise the Park-model?: To some extent the original Park-model [2, 3] is based on empirics to a higher degree than on physics. Also, there have been doubts regarding the applicability to large wind farms.

What should Park2 fulfill?: Park2 should be based on sound physical modelling and on accepted mathematical principles. Park2 should be calibrated and validated against available wind farm operational data.

Methods of Park2

Single-turbine wake: The wake from a single-turbine “i” in a wind-farm is modelled, following the classical approach by N.O.Jensen [1], by a top-hat speed-deficit profile (constant inside, zero outside wake), as a function of the down-wind coordinate x:

\[ \Delta V(x) = V_i - V_{i(0)} = \begin{cases} 0 & \text{if } x < x_i, \\ V_i(V_i/V_c) & \text{if } x_i < x < x_i + D_{inc}, \\ 0 & \text{if } x > x_i + D_{inc}. \end{cases} \]

Combined wakes: speed deficit at turbine “i” by linear superposition of wakes from turbines upwind of turbine “j”, considering partial overlap between wakes and the rotor of turbine “j”:

\[ \Delta V_{ij} = U_i - \sum \Delta V_i(x) \frac{A_{inc,i}}{A_{inc,j}} \]

where:
- \( U_i \): free wind speed, i.e. hypothetical wind speed had the wind farm not existed
- \( D_{inc,i} \): rotor diameter of turbine “i”
- \( D_{inc,j} \): diameter of wake from turbine “j”
- \( x_i \): down wind coordinate of turbine “i”
- \( V_{ij} \): incident wind speed at turbine “i”
- \( V_i(V_i/V_c) \): thrust coefficient of turbine “i” as a function of hub-height wind speed.
- \( C_{T}(V_i) \): model wake expansion coefficient
- \( A_{inc,i} \): rotor area of turbine “i”
- \( A_{inc,j} \): partial overlapping area of wake “i” on rotor of turbine “j”

Consistent formulation: The wake speed deficit from a single turbine depends only on local incident wind speed \( V_{ij} \) at the turbine considered (not on free wind speed \( U_j \) as is the case in Park1).

Wake combination by perturbation: The speed deficits are considered to be small perturbations, so that linear superposition can be used (2nd and higher order effects of wake mixing can be disregarded).

Wake - surface interaction disregarded: The Park2 model is simple, thus wake interaction with surface is disregarded. The reflection model of the original Park model [2,3] was not considered to represent aerodynamics at the surface correctly [4, 5].

Simple terrain effects model: Terrain effects on wakes are disregarded. However, onshore free wind speed \( U_a \) is calculated individually for all turbines incl. terrain effects.

Results: Calibration and Validation – Offshore

Calibration and validation were performed vs. Danish offshore wind farm data sets.

Bayesian calibration [6, 7] was used for the wake expansion coefficient \( k \). Based on filtered wind farm production data (all turbines running) the PDF graphs show the probability distribution of the expansion coefficient \( k \).

Results: Calibration – Onshore

 Calibration

Modelled turbine production deficit profile downwind in a wind farm compared to observed data. Examples are presented below.

<table>
<thead>
<tr>
<th>Wind Farm</th>
<th>Onshore ( \sigma )</th>
<th>Offshore ( \sigma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horns Rev 1</td>
<td>0.06</td>
<td>0.09</td>
</tr>
<tr>
<td>Nysted</td>
<td>0.046</td>
<td>0.009</td>
</tr>
</tbody>
</table>

Conclusions

Park2 was found to produce predictions at least as close as Park1 to observed offshore wind farm productions. The calibration resulted in recommended wake-expansion coefficient values for both off- and on-shore wind farms.

References


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