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:

\[ \Delta V_i(x) = \frac{V_{i\text{inc}}}{\sqrt{1 - C_i}} \left( \frac{D_i}{x} \right)^{0.5} \]

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

\[ V_{j\text{inc}} = U_{j\text{inc}} - \sum_{k} \Delta V_k(x_{kj}) \frac{A_{kj}}{A_{jk}} \]

U_{j\text{inc}}: free wind speed, i.e. hypothetical wind speed had the wind farm not existed

\( D_{i\text{inc}} \): rotor diameter of turbine “i”

\( D_i \): diameter of wake from turbine “i”

\( x_i \): down wind coordinate of turbine “i”

\( V_{i\text{inc}} \): incident wind speed at turbine “i”

\( C_i \): thrust coefficient of turbine “i” as a function of hub-height wind speed.

\( A_{i\text{inc}} \): model wake expansion coefficient

\( A_{i\text{area}} \): rotor area of turbine “i”

\( A_{\text{overlap}} \): 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_{i\text{inc}} at the turbine considered (not on free wind speed U_{j\text{inc}} 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_{k}\text{inc} 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.

- Lilgrund: production data 2008-Jan.01 – 2012-Dec.31

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.

Validation

Modelled turbine production deficit profile downwind in a wind farm compared to observed data. Examples are presented below. Horns Rev 222° Horns Rev 270° Nysted 278° Lilgrund 180°

Results: Calibration – Onshore

Calibration onshore wake expansion coefficient k was performed vs. wind farm production calculations by Park1 with standard parameters, for 14 wind farms.

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