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Estimation of partial wake loads for wind farm control design

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Motivation and Context

Wind farm **optimization of power & loads**

Wind farm control design based on **simple surrogate model** (e.g. FLORIS)

Wind turbine characterization

- Power & thrust coefficients
- Damage Equivalent Loads

Combinations of:

- Ambient conditions (wind speed, TI,…)
- Operational control handles (yaw, derating)
- **Wake impingement??**

Pre-calculated simulation databases

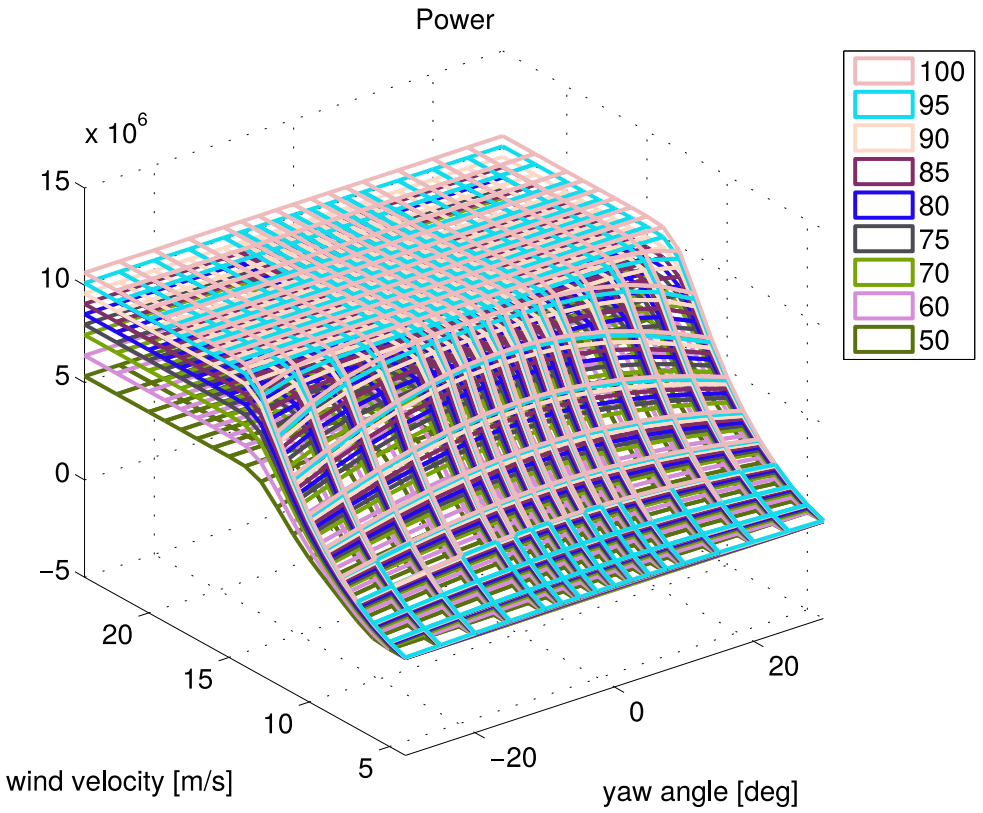
Objectives

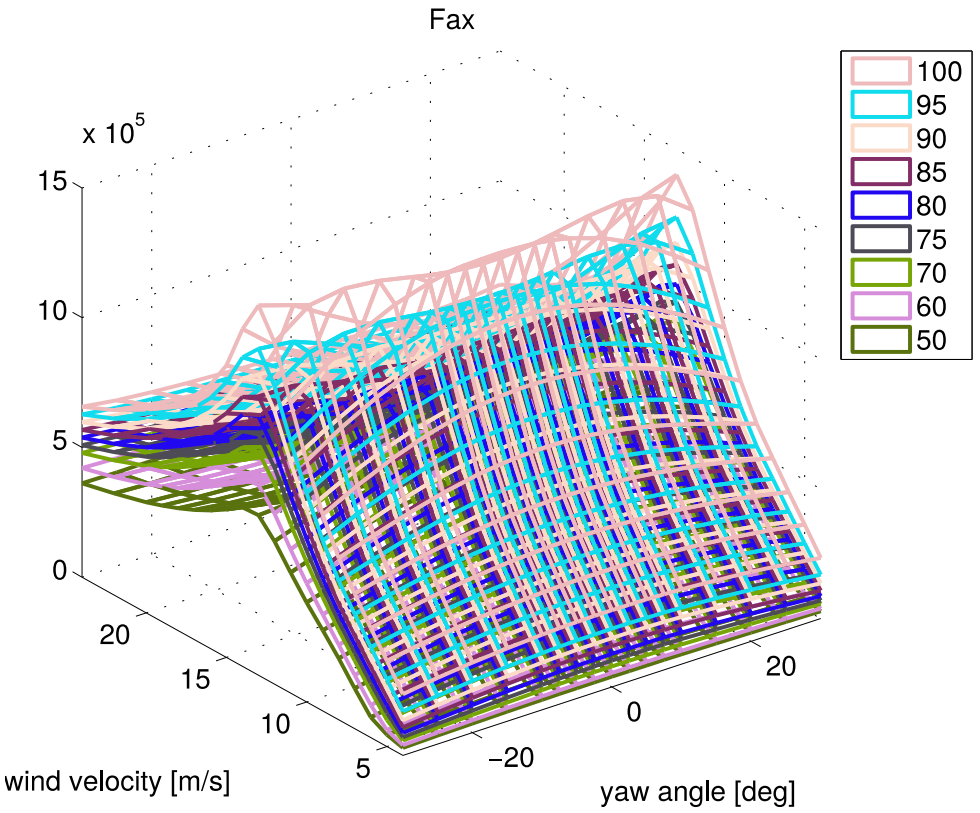
1. Verification of interpolation from pre-calculated databases for cases **without** partial wake
2. Determine the **need for specific partial wake considerations**
3. Method for **estimating DEL in partial wake impingement** based on databases of an unaffected turbine
4. **Validation** against virtual winds & FLORIS inflow conditions
   - ➢ Varied set of wake types (wake deficit & impact zone)

INNWIND 10 MW wind turbine
Blade root flapwise bending moment
OpenFAST simulations

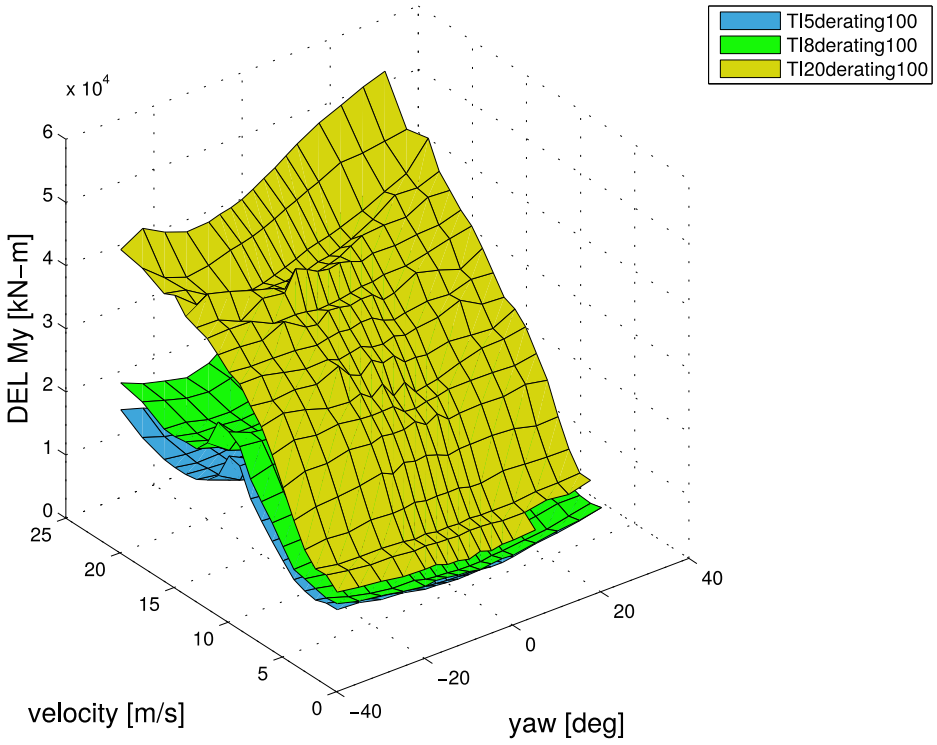
Interpolation from pre-calculated databases

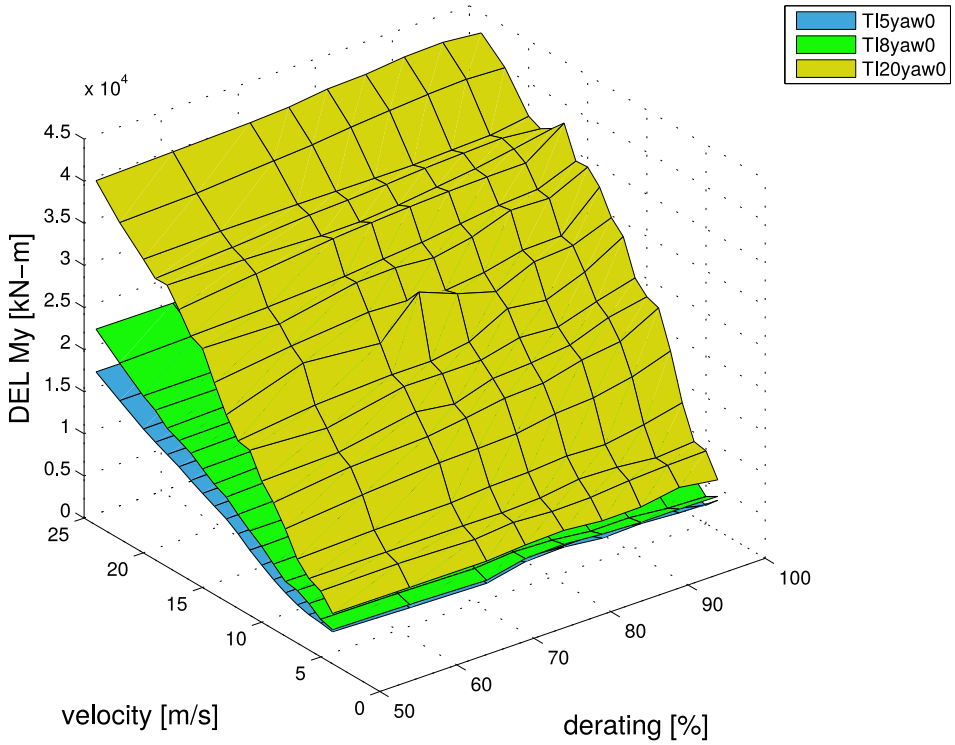
- Combination of conditions (wind speed, TI, derating, yaw angle)
- 8721 cases simulated in OpenFAST





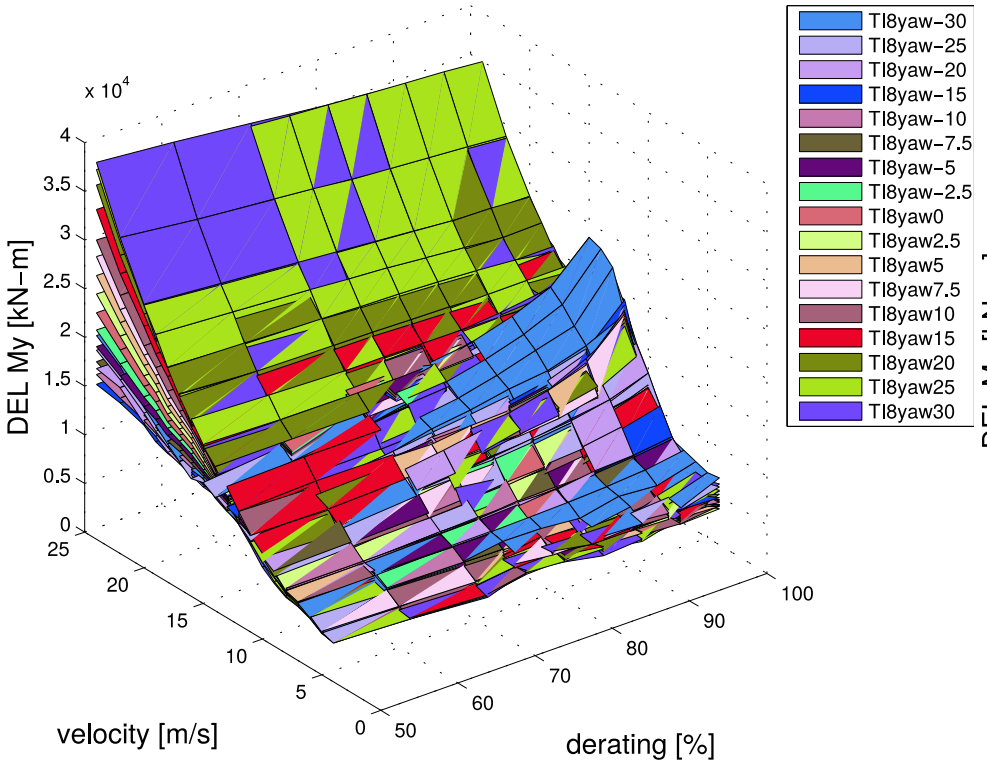
Interpolation from pre-calculated databases

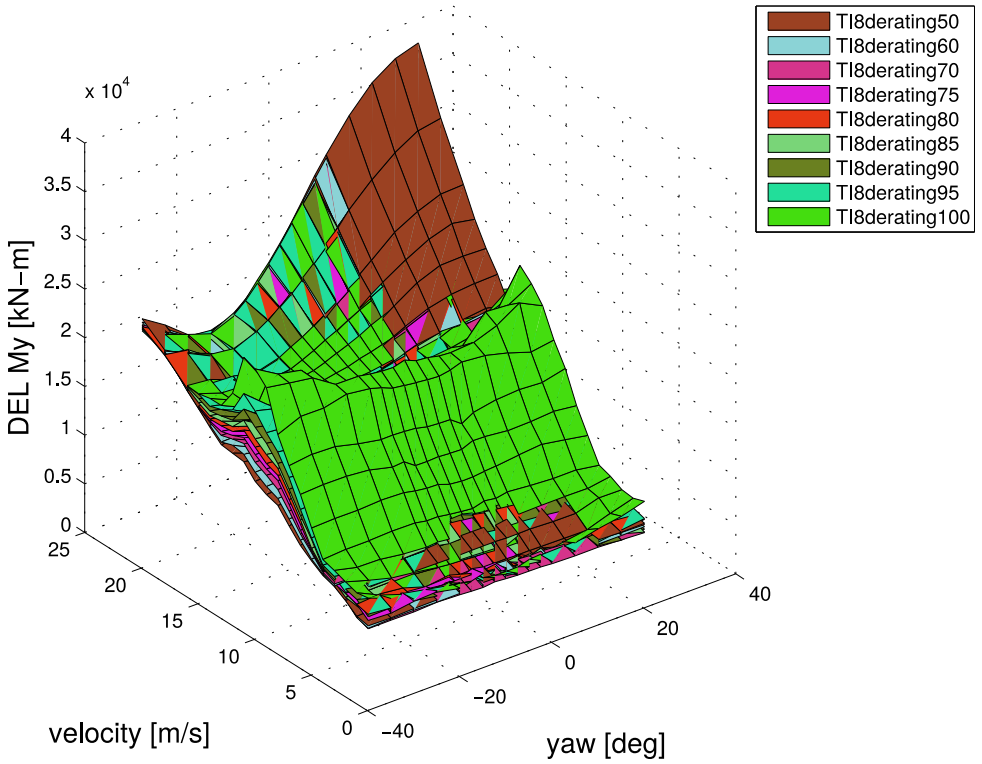




Effect of TI on DEL My

Interpolation from pre-calculated databases

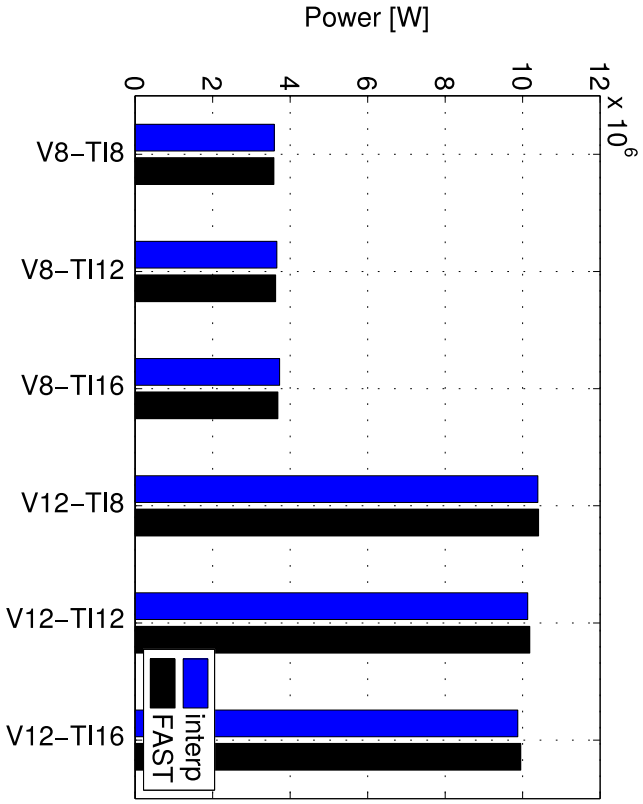


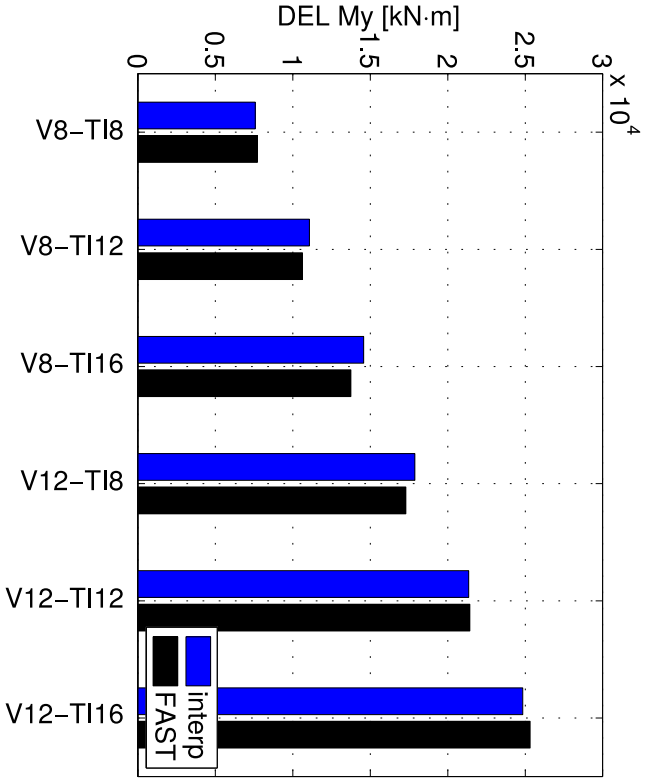


- Lower power setpoint ⇒ lower DEL My for most wind speeds & yaw angles
- Effect of derating more significant near rated wind speed
- Effect of yaw angle more evident for the highest wind speeds
- **Non-symmetric effect of yaw angle on DEL My for high wind speeds**

Interpolation from pre-calculated databases

- DEL estimation in cases w/o partial wake based on interpolation from database
- Comparison for 2 wind speeds and 3 TI:
  - Direct simulation of the case (black)
  - Result from the interpolation (blue), TI-based



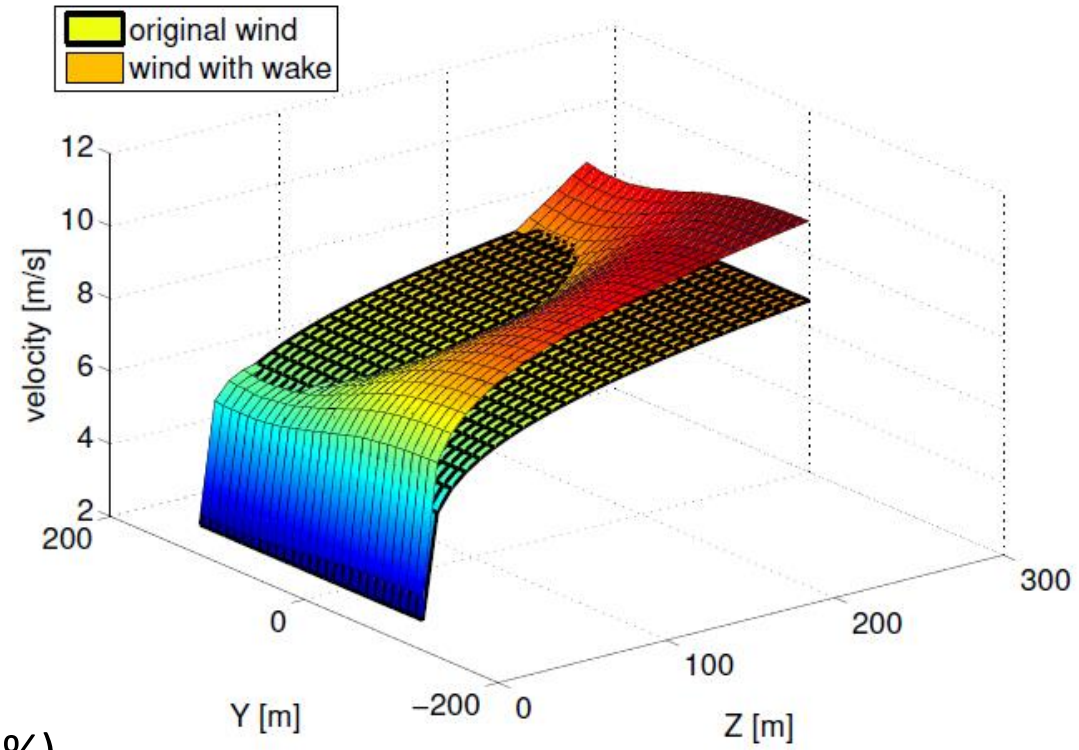


Slight effect of the seed in the turbulent wind

Need & effect of partial wake on DEL

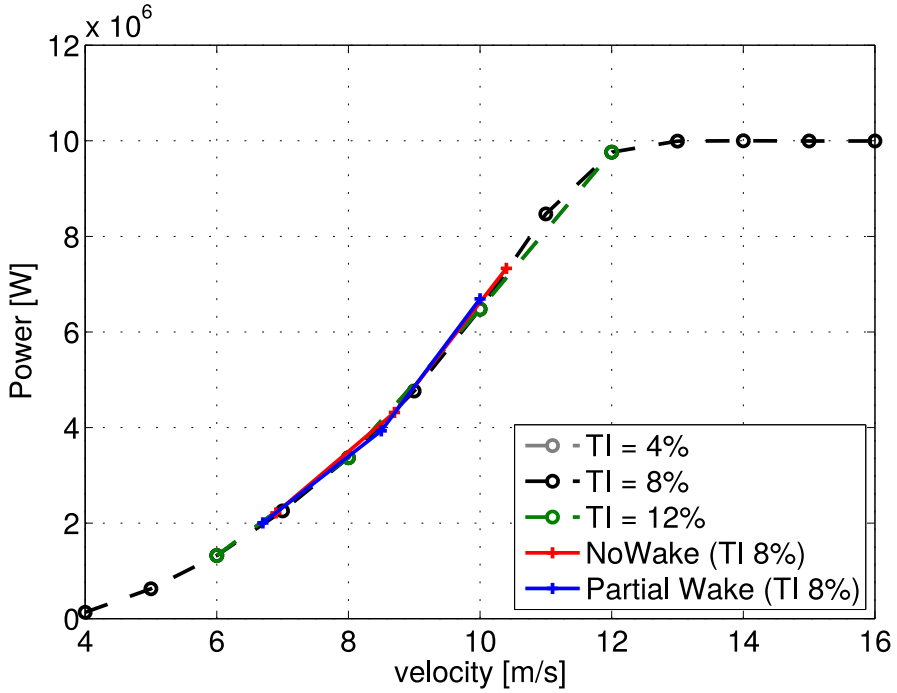
- Assumed that partial wake impingement will provoke greater imbalance in loads
- **Should we take this effect into account in DEL estimation?**

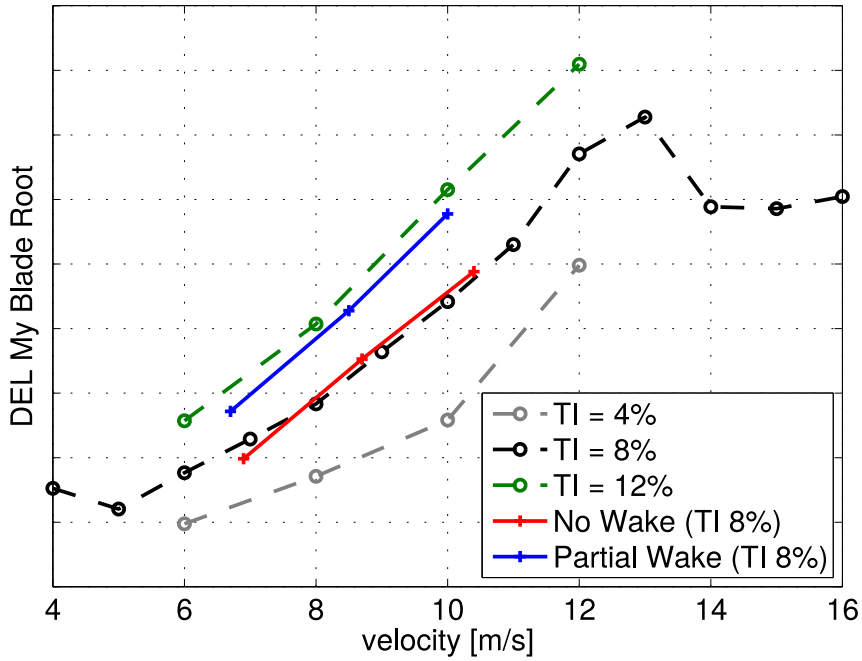
- Two types of inflow turbulent wind (with similar mean wind speed ; TI=8% ; shear exponent=0.2):
  - without wake
  - with **virtual partial wake** centered at blade tip (azimuth = 270 deg)



- ➢ 3 different mean wind speeds
- ➢ Reference of other TI (4% and 12%)

Need & effect of partial wake on DEL

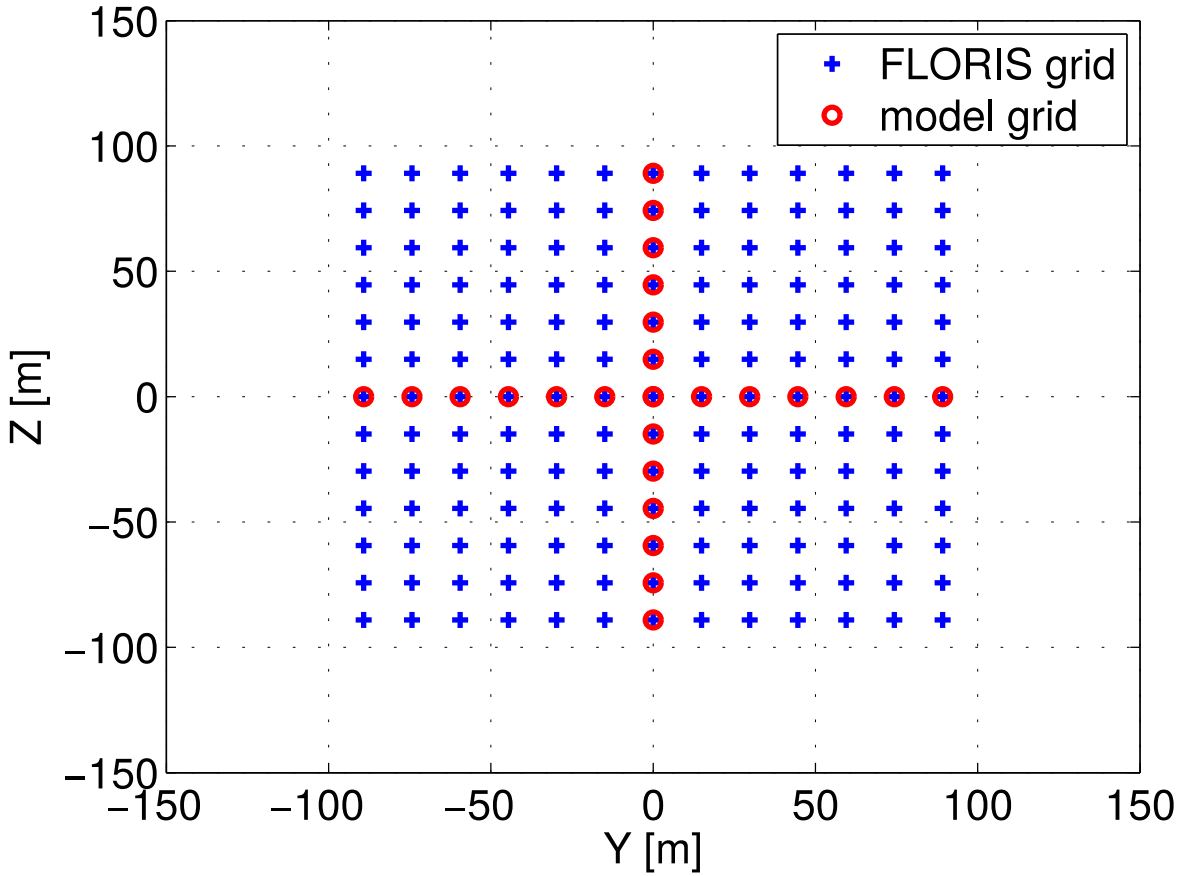




- Similar behaviour in power wrt mean wind speed, independent from TI
- **Partial wake has no effect in power estimation as long as mean wind speed remains the same**
- But **in DEL My partial wake presents DEL values similar to higher TI**
- Effect to definitely be taken into account in DEL estimation

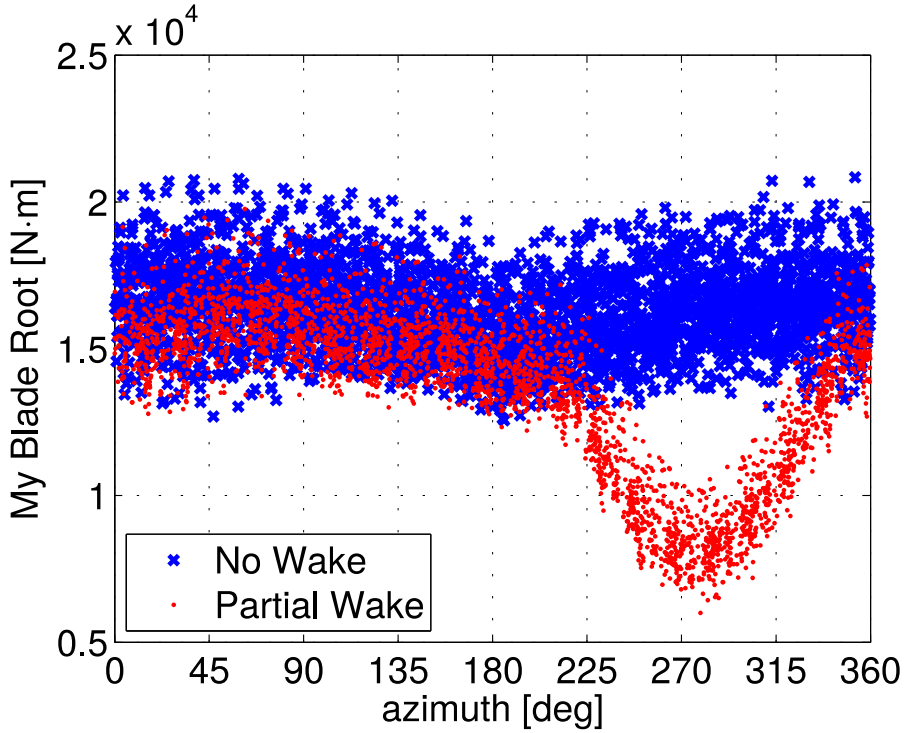
DEL estimation for cases with partial wake

- Estimation of power modified from FLORIS
  - Squared grid ⇒ points corresponding to 0, 90, 180 and 270 deg



DEL estimation for cases with partial wake

- Significant effect on the loads in determined regions of **azimuth depending on the wake impingement position**
- Using mean velocities for azimuth 0, 90, 180 and 270 deg is possible to **translate from velocities to cyclic loads** due to rotor sweep, apart from the turbulent variations

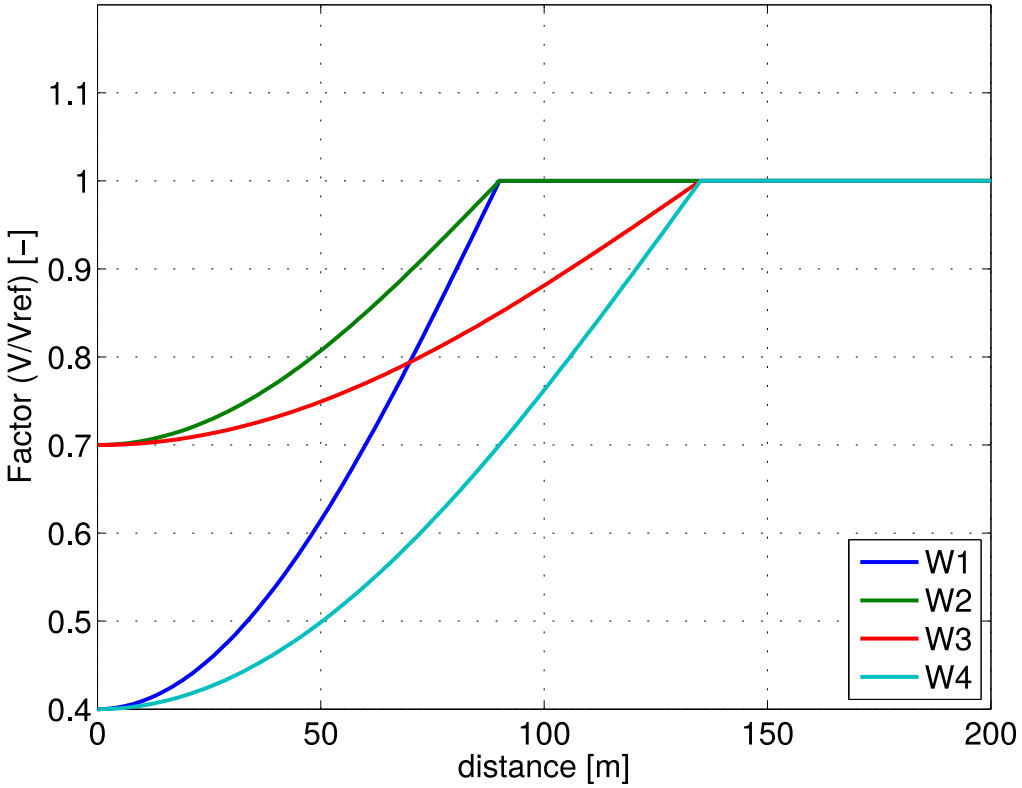


- **Complete time simulations** of the database are necessary for the modifications (not just the DEL result)
- Application of DEL computation to the modified data

Validation of the method

With virtual winds

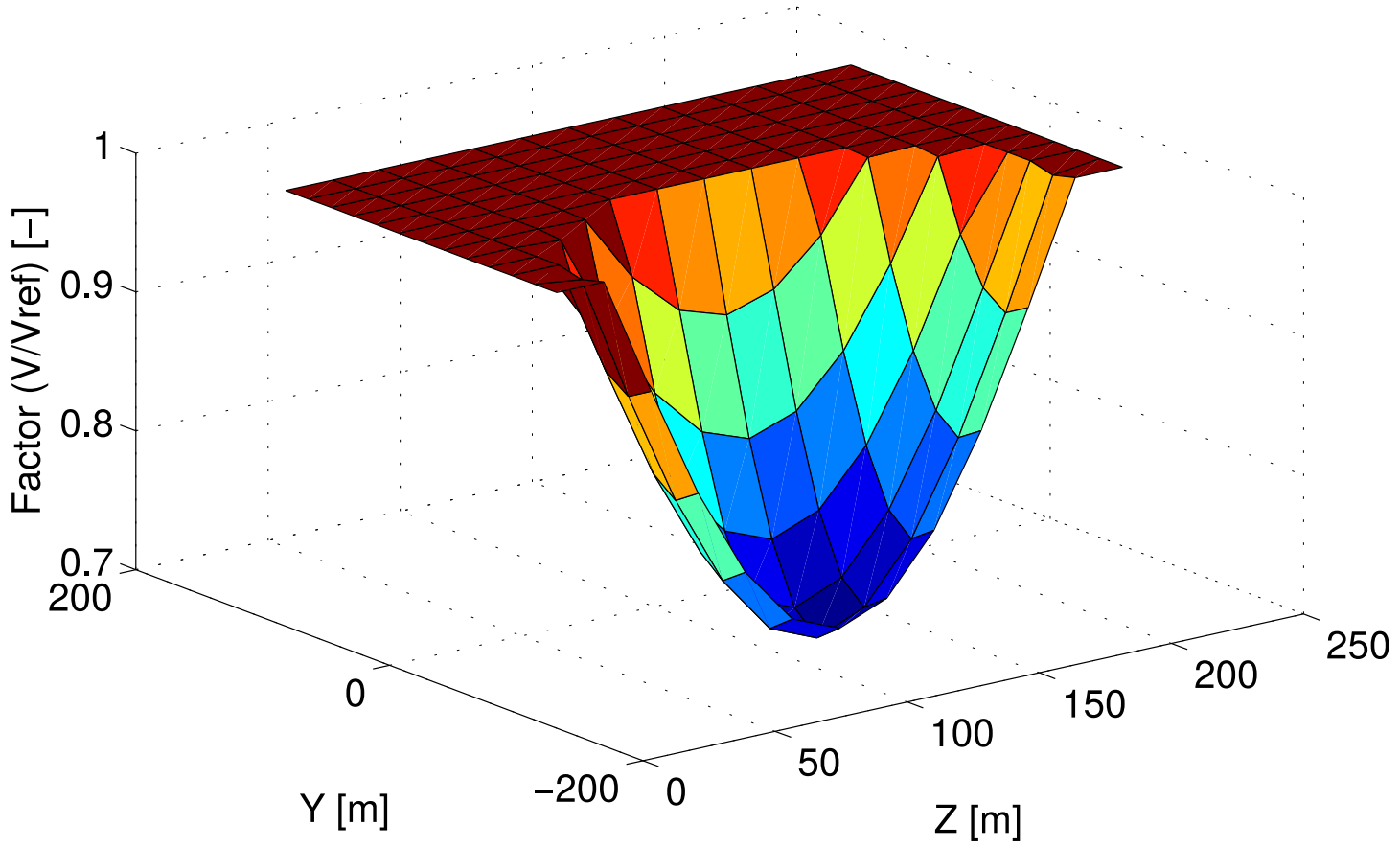
- 4 different wake deficits (W1-W4)
- **Reduction factor** applied for the generation of turbulent winds, dependent on the distance to the wake centre
- **Centre of the wake** defined by the y-coordinate
  - a (-90 m)
  - b (-50 m)
  - c (-20 m)
  - d (0 – full wake)



- Factor matrix applied to the original turbulent winds ⇒ “waked” winds

Validation of the method

With virtual winds



Wake W2, centered at y = -90 m (W2_a)

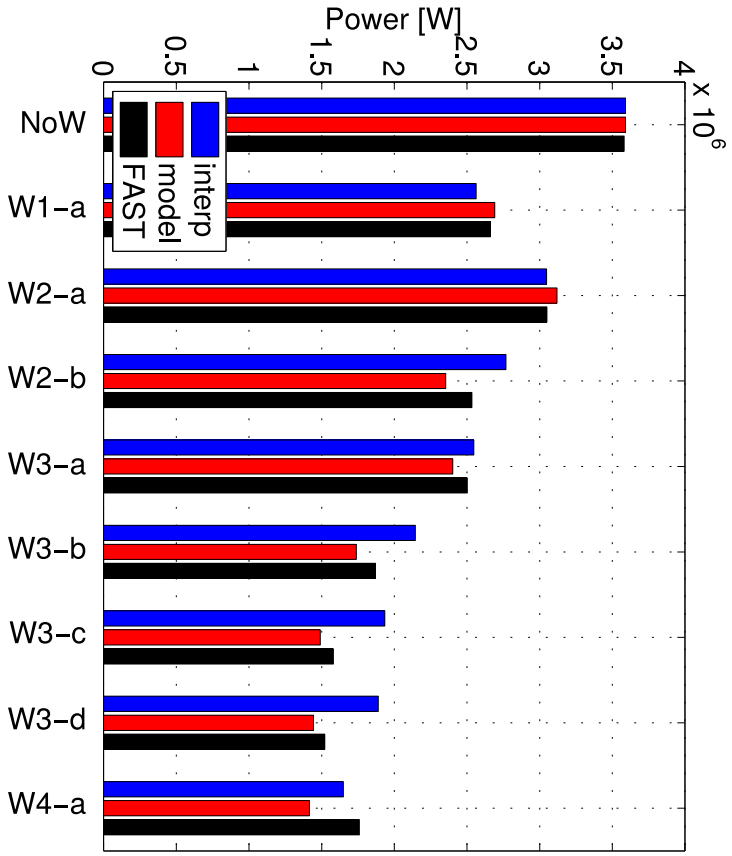
Validation of the method

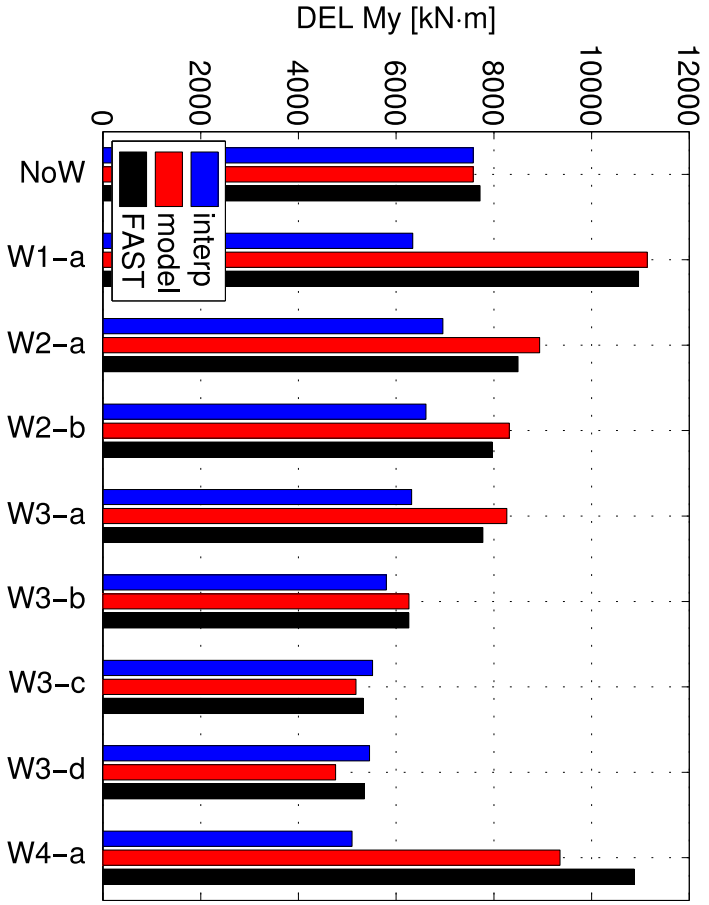
With virtual winds (V = 8 m/s)

OpenFAST simulations (black) – [FAST]

Estimation using new partial wake model (red) – [model]

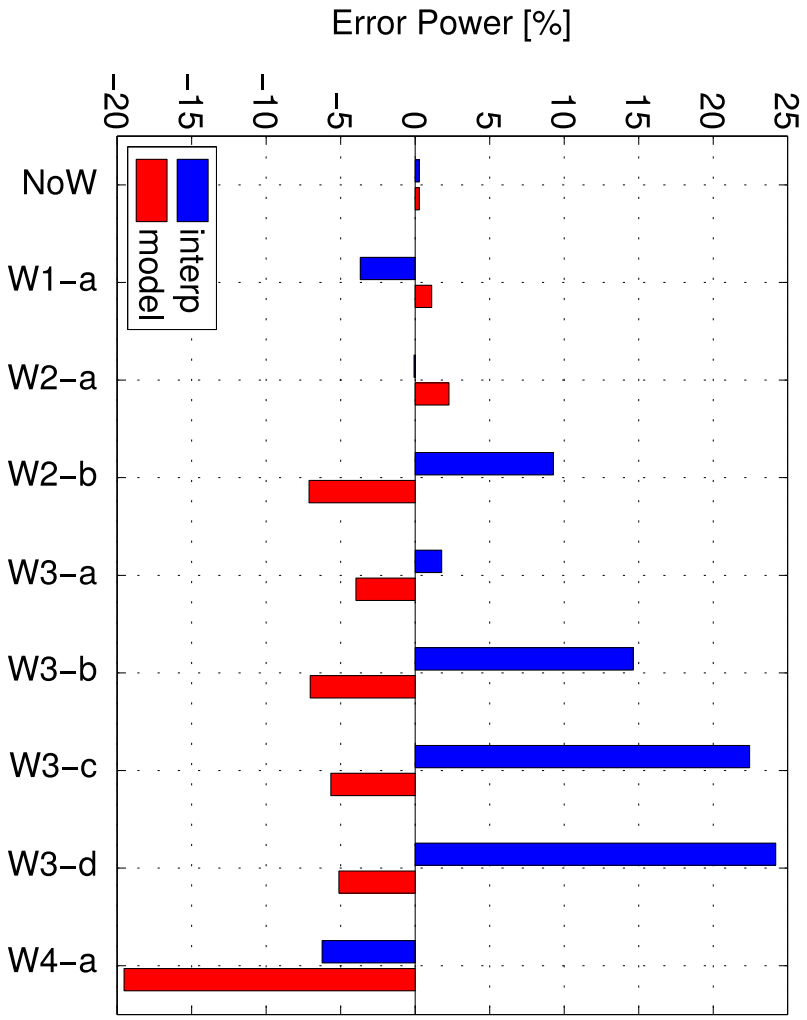
Estimation by direct interpolation w/o partial wake consideration (blue) – [interp]

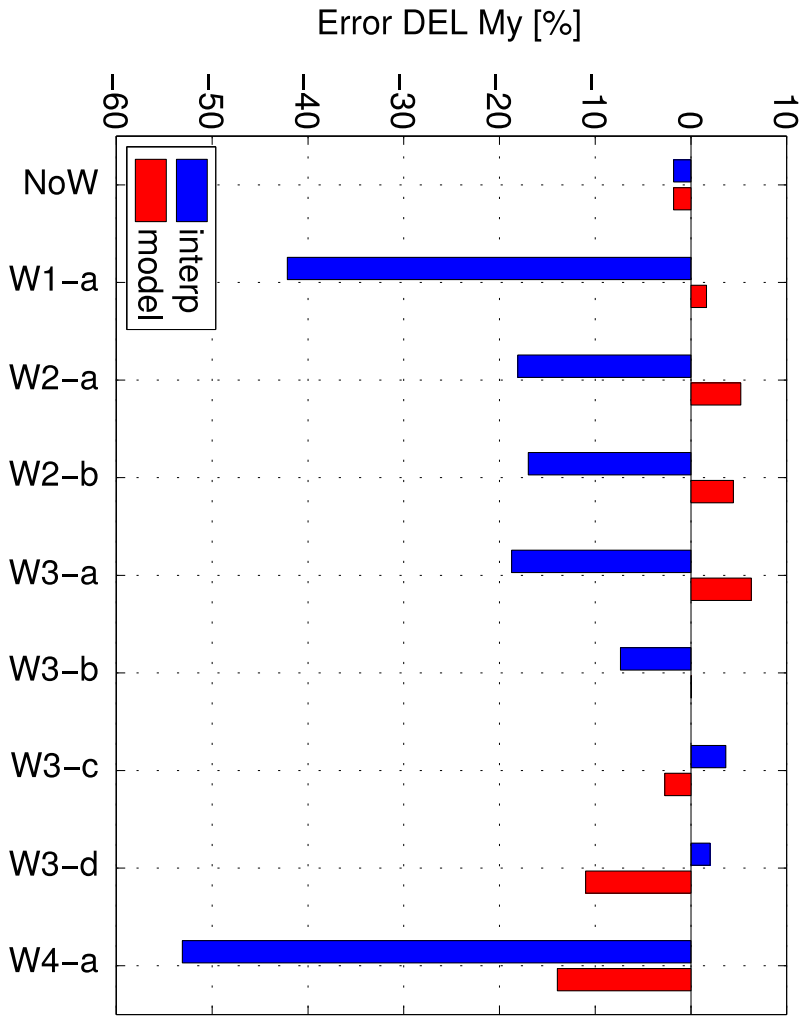




Validation of the method

With virtual winds (V = 8 m/s)





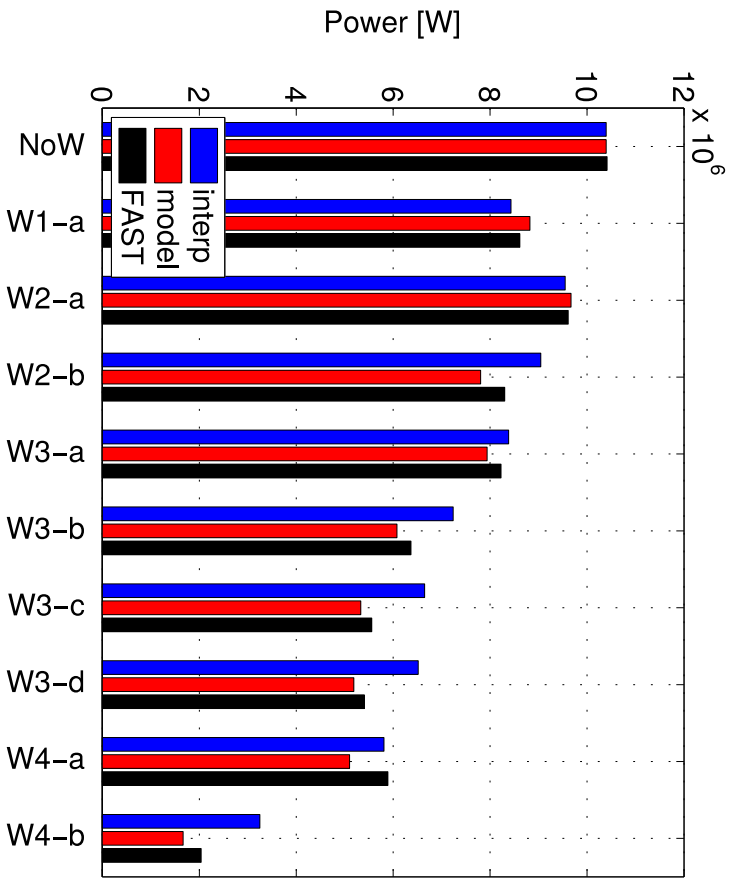
Validation of the method

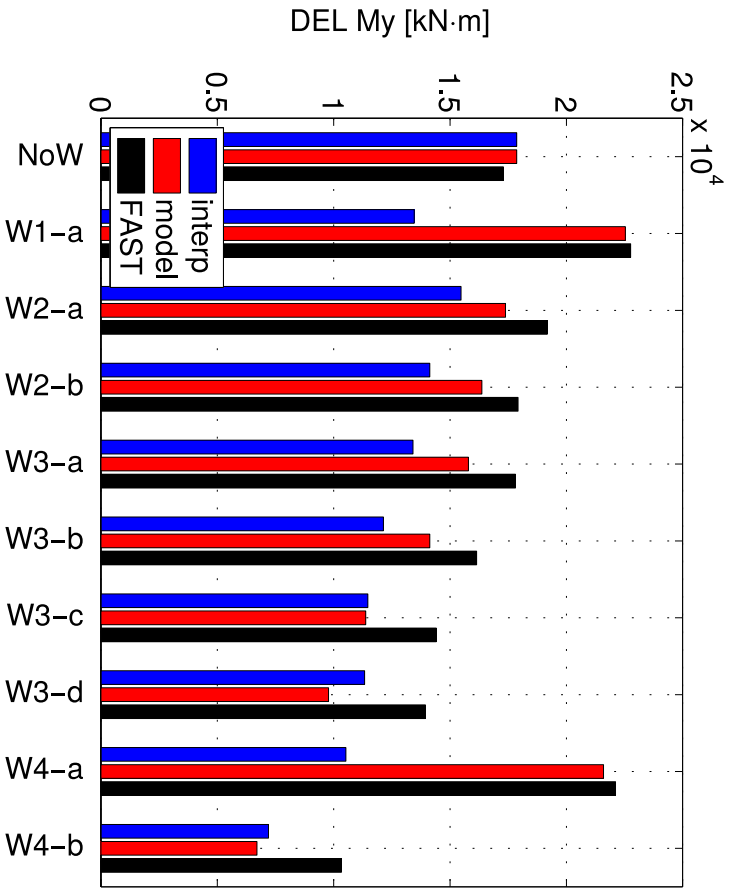
With virtual winds (V = 12 m/s)

OpenFAST simulations (black) – [FAST]

Estimation using new partial wake model (red) – [model]

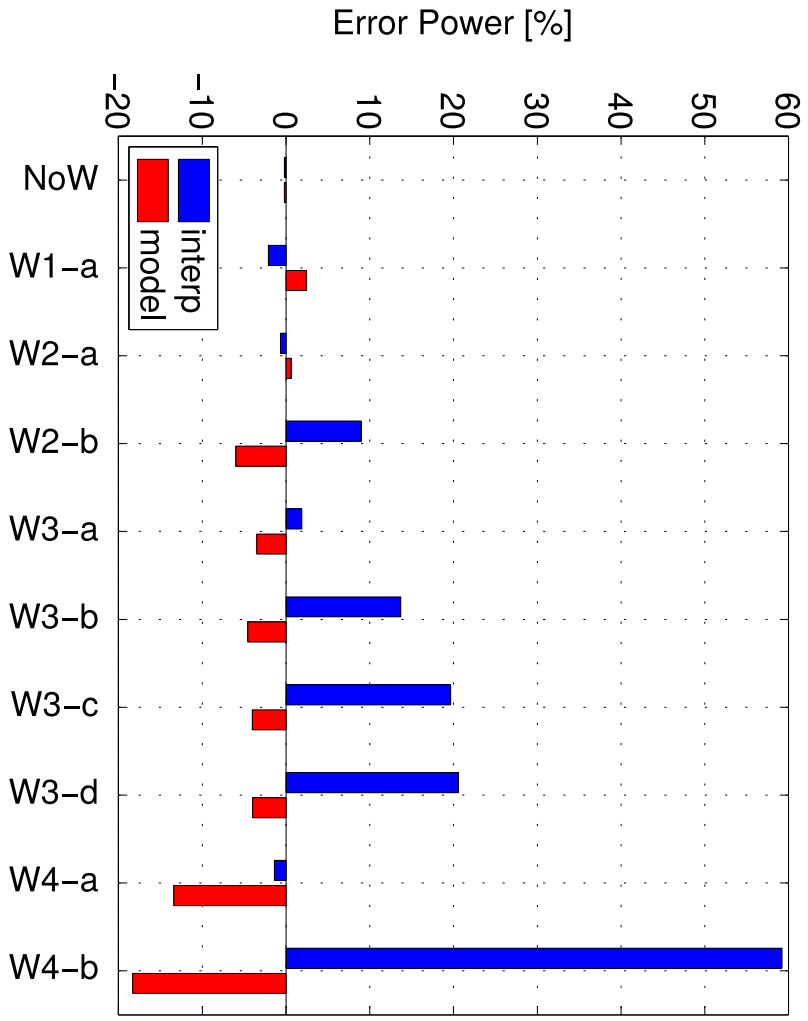
Estimation by direct interpolation w/o partial wake consideration (blue) – [interp]

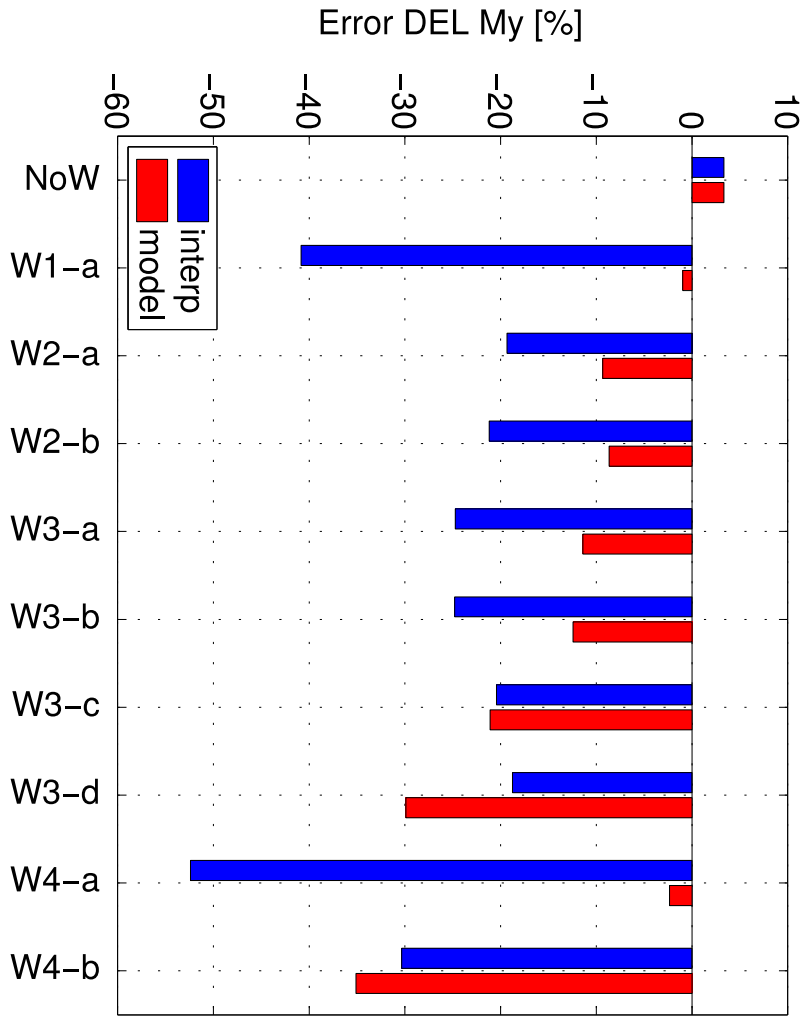




Validation of the method

With virtual winds (V = 12 m/s)





Validation of the method

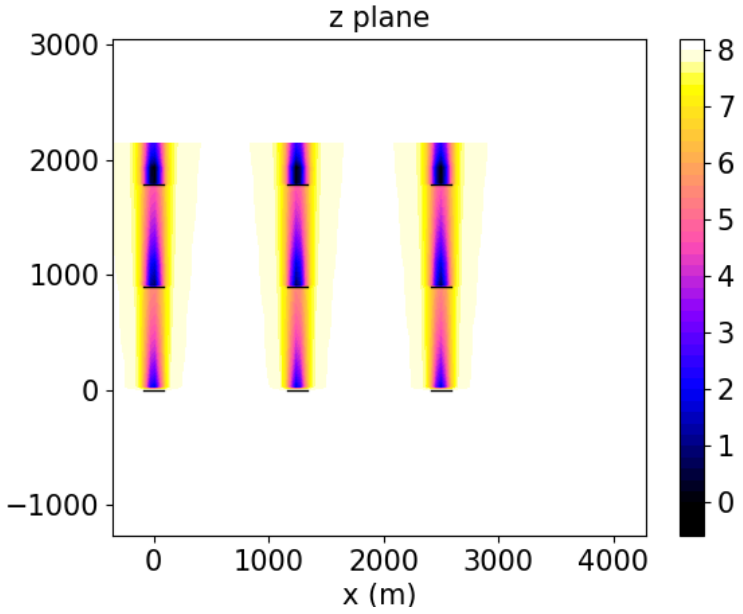
With virtual winds - Conclusions

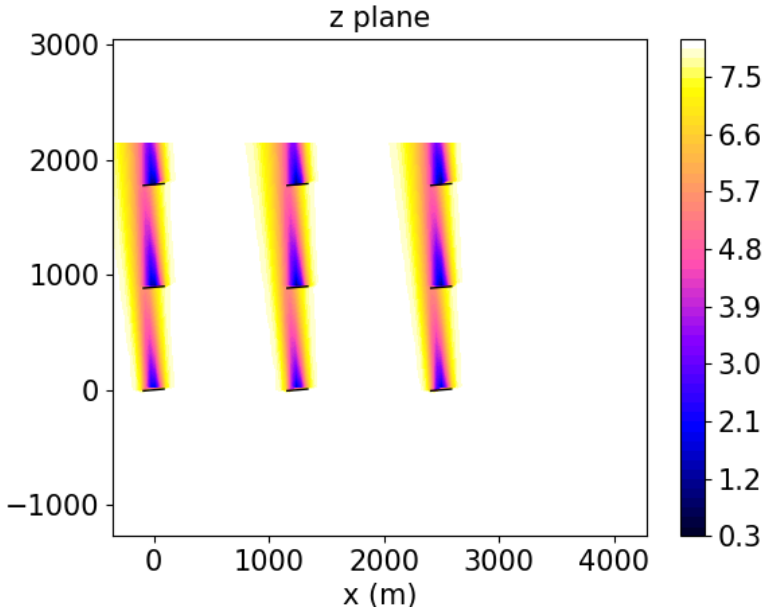
- New partial wake model improves DEL My and power estimation for most cases with respect to direct interpolation
- DEL My estimation:
  - significant improvement for a-cases (y = -90 m) and b-cases (y = -50 m)
  - Cases not improved are similar to full wake (centered at hub), or close to full wake
- Power estimation
  - Higher improvement in cases closer to full wake
  - Worse performance for a-cases

Validation of the method

With FLORIS data

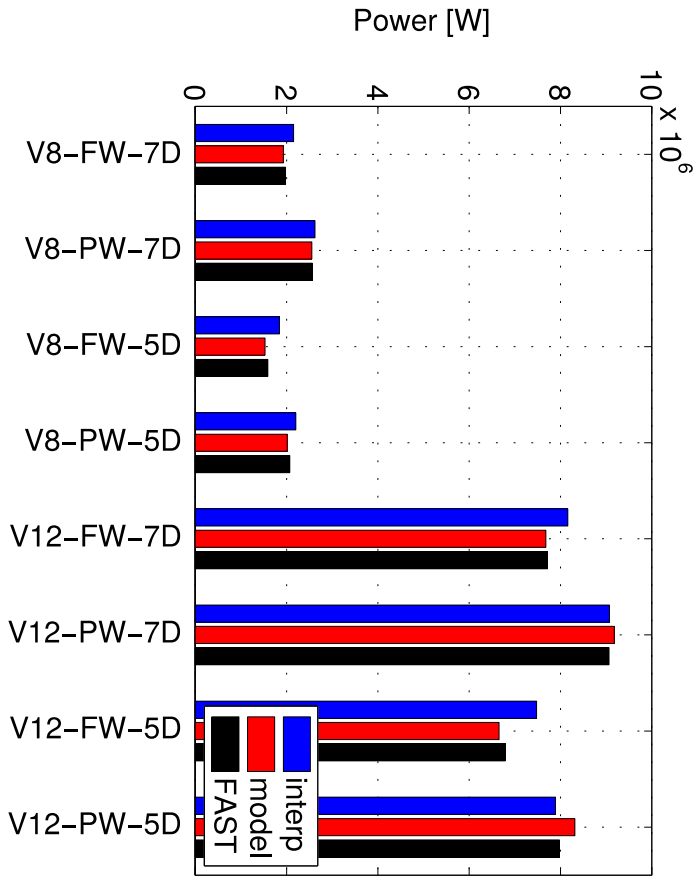
- Inflow wind values for downstream turbine with wake effect from upstream
- 8 FLORIS cases: 2 wind speed (8 m/s, 12 m/s), 4 inflow wind directions, TI = 8%
- Full wake and partial wake

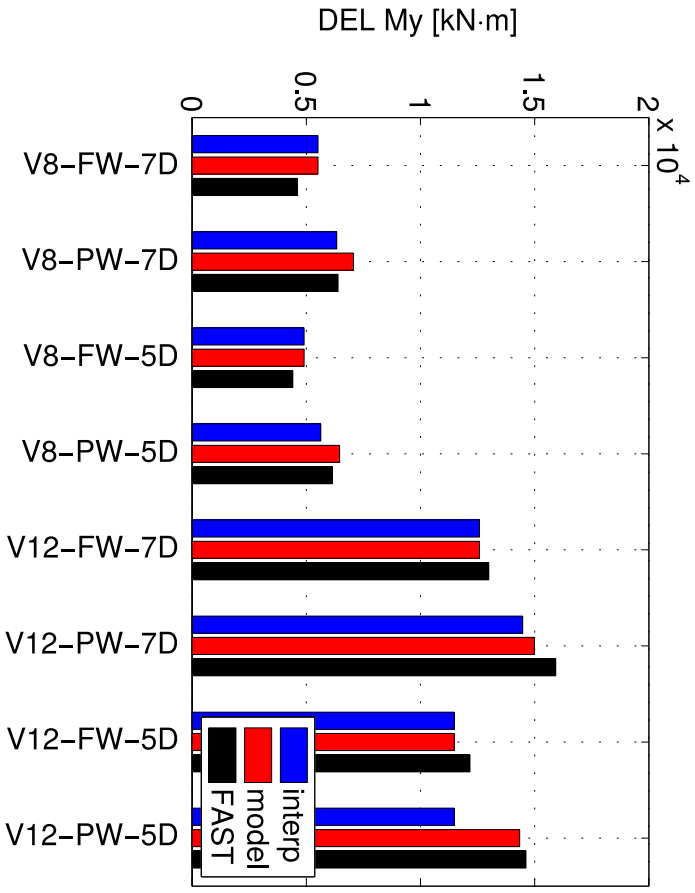




Validation of the method

With FLORIS data





Conclusions

- Effect of partial wake to be taken into account in DEL estimation for wind turbine characterization
- DEL My estimation affected vs power unaffected (same mean wind speed)
- Method for DEL estimation in partial wake occurrence demonstrated (cyclic loads)
- Improvement with respect to direct interpolation for most cases
- Future work
  - Computational time (time simulations)
  - Extension to other loads
  - Adjustments to the model for those specific cases without improvement

Thanks!

Q&A

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