Wind Farm Effects

Exercise to Lecture #12
"Controller Design for Wind Turbines and Wind Farms"

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A 2×2 wind farm with $5\,\mathrm{MW}$ onshore wind turbines is operating at $10\,\mathrm{m/s}$ (undisturbed wind). The rotor diameters are $126\,\mathrm{m}$. The wind turbines have a North-South distance of 5 rotor diameter and a East-West distance of 7 rotor diameter distance on a regular grid, see Figure 1. In the partial load region (from $7\,\mathrm{m/s}$ to $10.6\,\mathrm{m/s}$), the power coefficient is 0.48 and the thrust coefficient is 0.8 and the air density is $1.225\,\mathrm{kg/m^3}$. The wake deficit parameter of the Jensen Wake Model from [1] is here 0.075.

a) In case of westerly wind direction, what is the wind speed at the downwind row?
b) How wide is then the wake impacted area?
c) How large are the wake losses in percent in this situation for the full wind farm?
d) How do wind speed, wake impacted area, and wake losses change for southerly wind direction?
e) What are the coordinates of all 4 wind turbines in the inertia coordinate system? The origin of the inertia coordinate system is the turbine in the South-West, $x_\mathcal{I}$ is pointing to the east, and $y_\mathcal{I}$ is pointing to the north.
f) What are the coordinates of all 4 wind turbines in the wind coordinate system for westerly wind? And for southerly wind? The origin of the wind coordinate system is the turbine in the South-West, $x_\mathcal{W}$ is pointing downwind, and $y_\mathcal{W}$ is pointing to the left.
g) How can the coordinates in the wind coordinate system be calculated with a transformation from the inertial coordinates depending on the wind direction (North is $0\,\mathrm{deg}$, East is $90\,\mathrm{deg}$)? For the mathematics of the coordinate transformation, following website might be helpful: https://en.wikipedia.org/wiki/Active_and_passive_transformation.
h) What are in general the mathematical conditions for wake interactions for two wind turbines with the coordinates $(x_{\mathcal{W}1}, y_{\mathcal{W}1})$ and $(x_{\mathcal{W}2}, y_{\mathcal{W}2})$? Use the differences $\Delta x_\mathcal{W} = x_{\mathcal{W}2} - x_{\mathcal{W}1}$ and $\Delta y_\mathcal{W} = y_{\mathcal{W}2} - y_{\mathcal{W}1}$.
i) How large are the overall wake losses assuming equally distributed wind directions for this wind speed? Use 1 deg steps in Matlab. What would you need to calculate the AEP of the wind farm?

References

[1] A. Peña, P.-E. Réthoré, and M. P. van der Laan. "On the application of the Jensen wake model using a turbulence-dependent wake decay coefficient: the Sexbierum case". In: *Wind Energy* 19.4 (2016), pp. 763–776. DOI: 10.1002/we.1863.

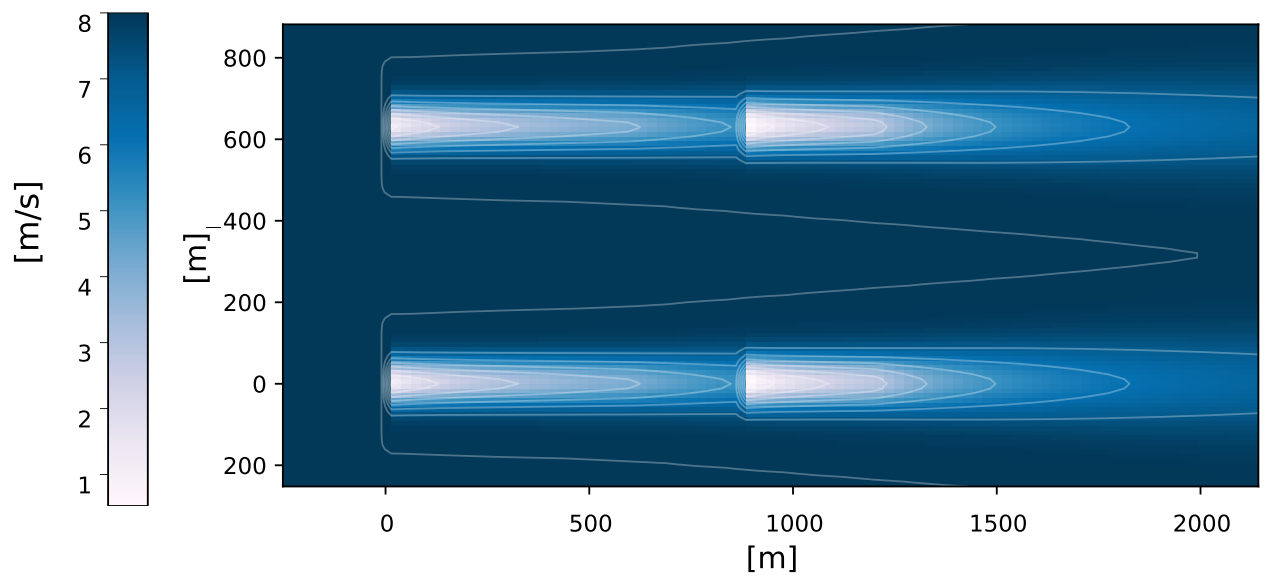[2] F. Novais, D. Schlipf, and S. Raach. *A Low Computational Framework for Testing Wind Farm Controllers.* 2021. DOI: 10.5281/zenodo.5008772.

Figure 1: 2×2 wind farm under westerly wind [2].