Wake Modelling with the Actuator Disc Concept in Complex Terrain

Ansgar Johan Ladstein[1], Arne Reidar Gravdahl[1,2]
1 Norwegian University of Life Sciences, Universitetstunet 3, 1430 Ås, Norway
2 WindSim, Fjordgaten 15, 3125 Tønsberg, Norway

Norwegian University of Life Sciences

windsim

Abstract

A wind turbine operating downwind of another will stand in the wake of the upstream turbine, resulting in decreased power generation and increased loads. In order to keep wake losses at a minimum, wind farm designers rely on wake models to optimize the wind farm layout. Therefore, accurate wind turbine wake modelling is essential for developing cost efficient modern wind farms.

The aim of this study was to perform a comparative analysis of a new implementation of numerical wake model referred to as the Actuator Disc Concept (ACD), against two commonly known analytical wake models, the Jensen- and Larsen model.

The performance of the wake models was evaluated using large sets of SCADA data from Nygårdsfjellet wind farm located in complex terrain. The simulations were performed in the Computational Fluid Dynamics (CFD) based software, WindSim, which solves the Reynolds Averaged Navier-Stokes (RANS) equations.

Methods

Nygårdsfjellet wind farm is located 30 km north-east of Narvik, Norway. It consists of 14 Siemens SWT-2.3-93 wind turbines with hub height of 80 m, adding up to a total installed capacity of 32.2 MW. Based on the location of the met mast and the quality of the SCADA data, exclusively wake cases with westerly winds are selected for the validation study.

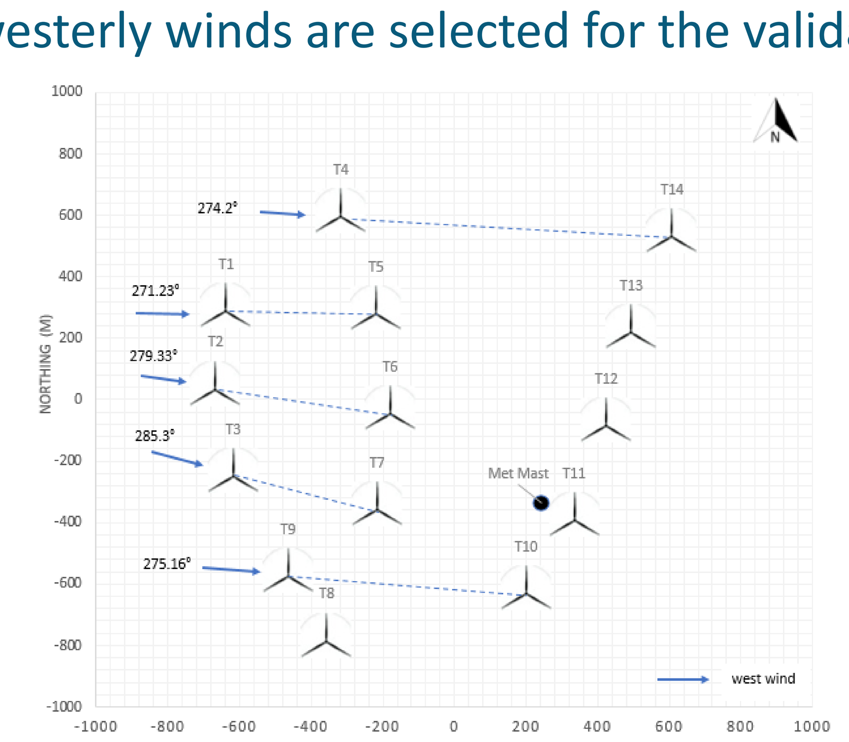

Fig 1. Selected single wake cases.

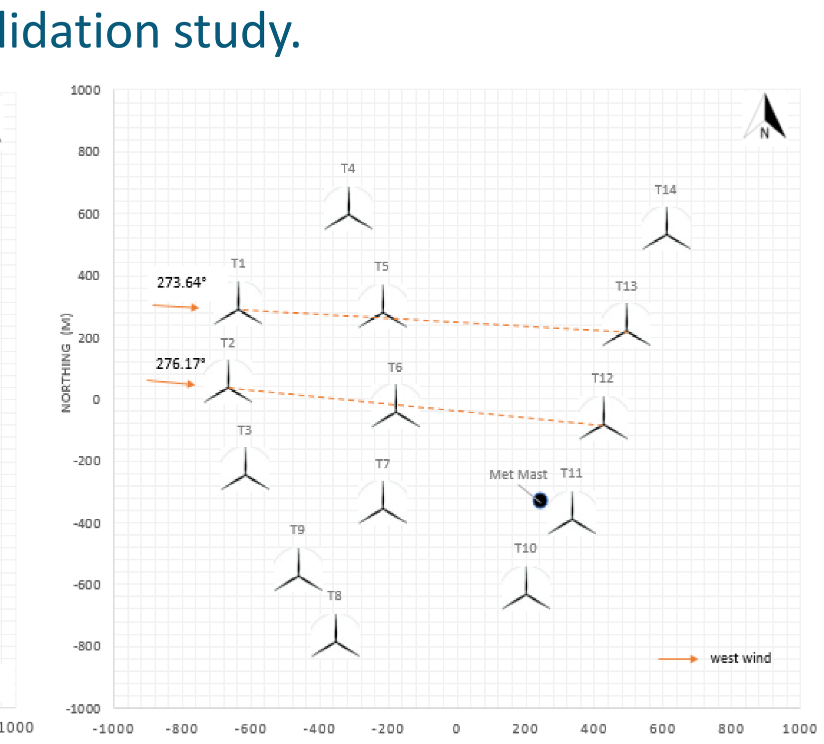

Fig 2. Selected multiple wake cases.

Analytical wake models calculates the wake effects after the CFD simulations are performed. The wind velocity deficit for the Jensen- and Larsen model is given as follow:

Jensen model[1]:

$$\delta V = \frac{1-\sqrt{1-C_T}}{\left(1+\frac{2kx}{D}\right)^2} \quad (1)$$

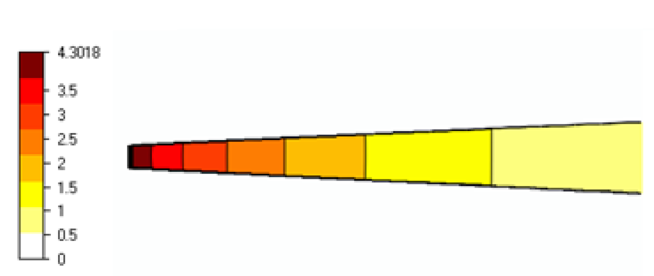

Fig 3. Jensen wake expansion.

Larsen model[2]:

$$\delta V = \frac{\left(C_T A_x^{-2}\right)^{\frac{1}{3}}}{9}\left[r_x^{\frac{3}{2}}\left(3c_1^{\,2} C_T A_x\right)^{-\frac{1}{2}} - \frac{35}{2\pi}^{\frac{3}{10}}\left(3c_1^{\,2}\right)^{-\frac{1}{5}}\right]^2 \quad (2)$$

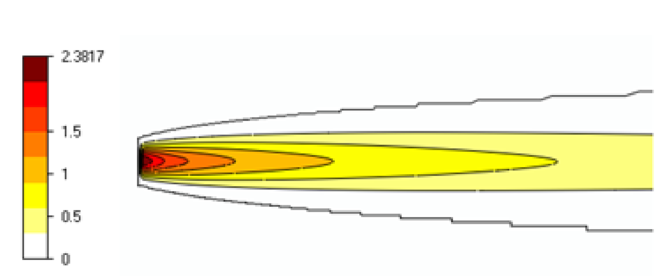

Fig 4. Larsen wake expansion.

The ACD concept is a numerical wake model which introduces the turbines directly into the CFD simulations enabling the model to reproduce wake-wake and wake-terrain effects. The turbines are modelled as porous discs with a resistive force being the thrust force of the turbine.

ACD method[3]:

$$T = C_T\left(U_{1,i}\right)\frac{1}{2}\rho\left(\frac{U_{1,i}}{1-\alpha_i}\right)^2 A_i \quad (3)$$

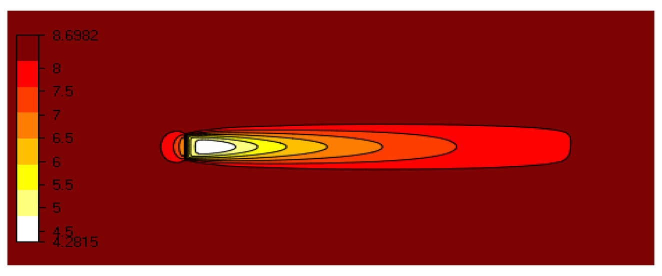

Fig. 5 ACD wake expansion.

Results

The results are presented in normalized form after calibration. The directional bins are ± 2.5° wide and the velocity bins are ± 0.5 m/s. The ACD model uses wind speed above boundary layer, $U_{BL} = 10$ m/s as initial condition. Table 1 represent the wind speed extracted at 40 m height at met mast location $U_{met\ mast}$, using $U_{BL} = 10$ m/s. The analytical models uses $U_{met\ mast}$ as input value.

Table 1. Inflow wind speed and inflow wind direction for all wake cases.

	Wind speed at met mast location, 40 m height ($U_{met\ mast}$)	Inflow wind direction
Case #1	8.024 m/s	274.20°
Case #2	7.566 m/s	271.23°
Case #3	8.139 m/s	279.33°
Case #4	7.485 m/s	285.30°
Case #5	7.921 m/s	275.16
Case #6	8,021 m/s	273.64°
Case #7	8,156 m/s	276.17°

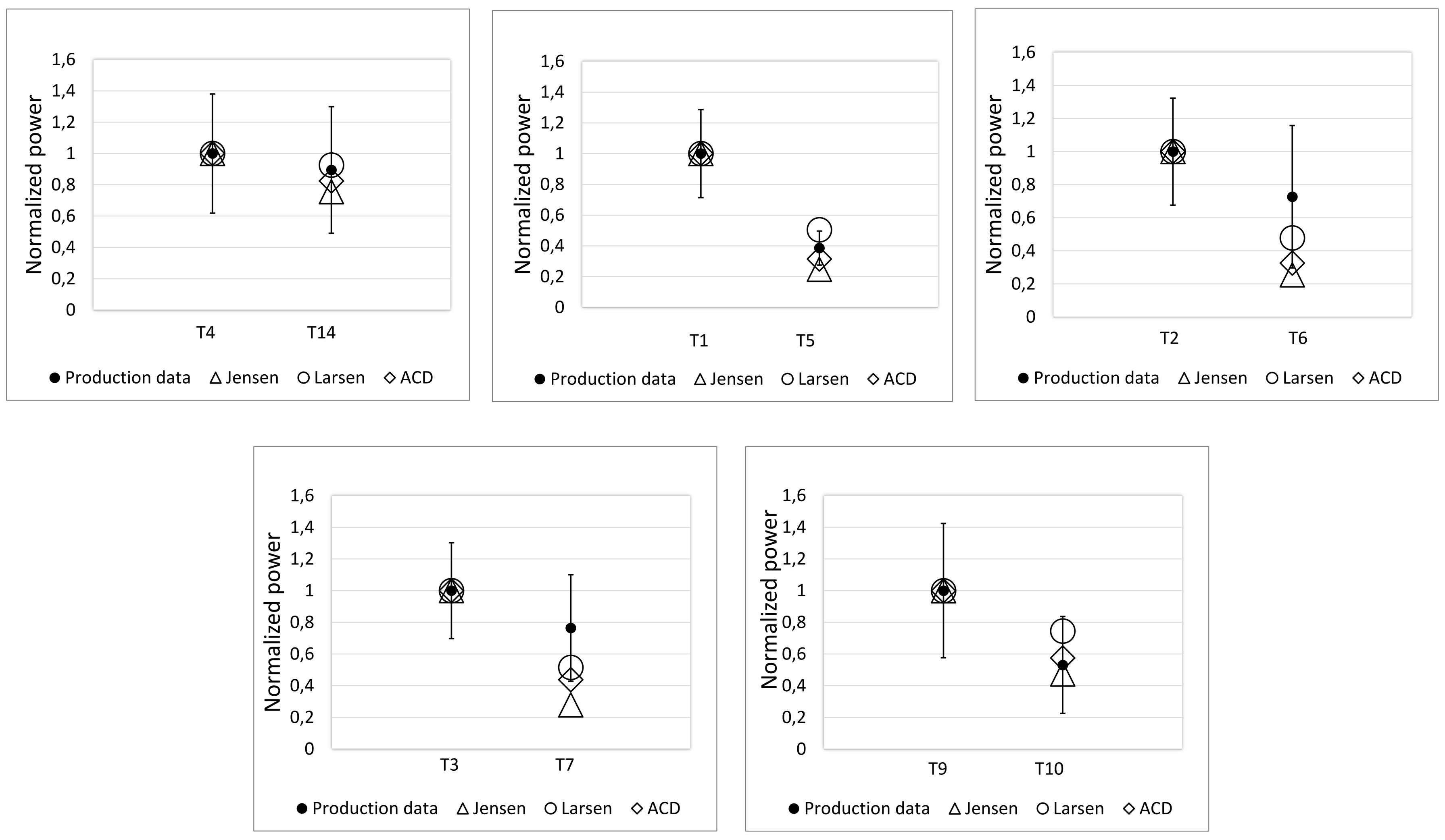

Fig 5. Results from single wake case #1 to case #5 .

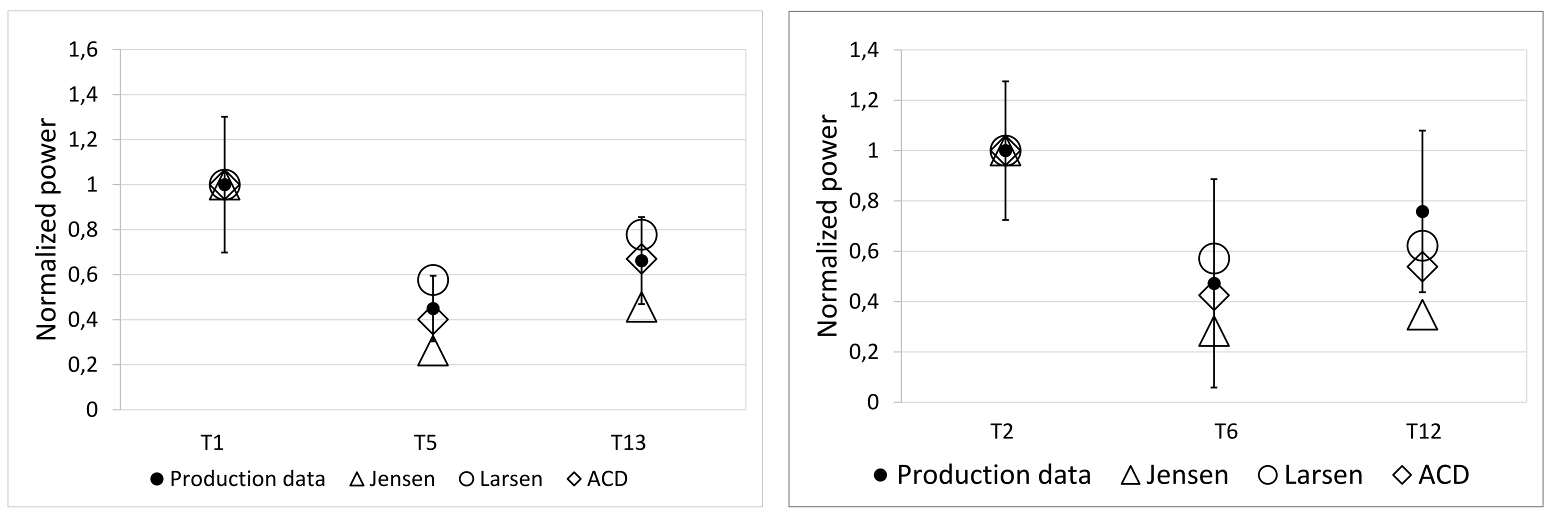

Fig 6. Results from multiple wake case #6 (left) and case #7 (right).

Conclusions

(i) The ACD method showed best results on cases with highest SCADA data quality, i.e. Case #2, Case #5 and Case #6.

(ii) The ACD model was able to reproduced wake-wake and wake-terrain on a higher level compared to the analytical models.

(iii) The study emphasizes the necessity of retrieving SCADA data of high quality in order to perform accurate validation studies.

References

1. Katic, I. (1986). A simple model for cluster efficiency: European Wind Energy Association Conference and Exhibition.
2. Larsen, C. G. (1988). A Simple Wake Calculation Procedure, 87-550-1484-4.
3. Simisiroglou, N., Polatidis, H. & Ivanell, S. (2018). Wind farm power production assessment: a comparative analysis of two actuator disc methods and two analytical wake models. *Wind Energ. Sci. Discuss.*, 2018: 1-13. doi: 10.5194/wes-2018-8.