Coaxial dual-rotor turbine farm layout optimization

Mehedi Hassan, Matthew Bryant, Andre Mazzoleni, Praveen Ramaprabhu, Kenneth Granlund

INTRODUCTION

A coaxial dual-rotor turbine has the potential to be one of the most efficient technologies for extracting energy from ocean currents when deployed in large numbers in the resource site. To obtain the highest amount of power output from a farm the turbines must be positioned in a way that they avoid the wake interactions among them as much as possible [1]. The objective of this study is to achieve the optimal layout of the farm using genetic algorithm with a newly-developed wake model that can predict the velocity downstream of a coaxial dual-rotor turbine.

WAKE MODEL

Wake equation derivation

The wake model [2] utilizes simple momentum balancing and Bernoulli's principle in the near- and far-wake to calculate the velocities in those regions in terms of rotor diameters (D_1, D_2), axial induction factors (e_1, e_2), and the freestream velocity (U_∞).

Considering the momentum balance in the inner control volume we obtain

$$d_0 = D_2\sqrt{\frac{1-e_2}{1-2e_2+2e_1}} \quad (13)$$

In a similar manner, from the outer control volume, we can show

$$D_0 = \sqrt{\frac{1-e_1}{1-2e_1}D_1^2 - \frac{2(2e_1-e_2)(1-e_2)}{(1-2e_1)(1-2e_2+2e_1)}D_2^2} \quad (14)$$

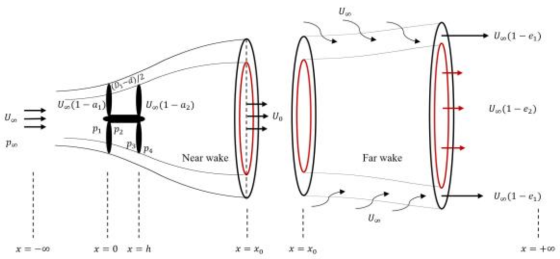

Fig. 1 Control volumes in the near- and far-wake regions.

Obtain power coefficients ($C_{p,1}$, $C_{p,2}$) from BEMT

↓

Calculate axial induction factors e_1, e_2 by solving:

$$C_{p,1} = 4[e_1(1-e_1)^2]$$

$$C_{p,2} = 4(e_2-2e_1)(1-e_2)^2$$

↓

Estimate diameter of inner annulus (d_0) using Eq. (13) at transition location (x_0)

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Obtain near wake diameter (D_0) from Eq. (14)

↓

Get near wake distance (x_0) from curve fitting

↓

Estimate wake expansion constant (α) from

$$\alpha = \frac{1}{2}\left(\frac{D_0-D_1}{x_0}\right)$$

↓

Calculate $U(x)$ using Eq. (15) or Eq. (17)

Fig. 2 Flow chart describing the wake model.

The flow velocity in the near- and far-wake can then be expressed, respectively, as

If $x < x_0$ (near wake):

$$U(x) = \left[\frac{(1-e_2)D_2^2 + \left(D_0^2 - \frac{1-e_2}{1-2e_2+2e_1}D_2^2\right)(1-2e_1)}{(D_1+2\alpha x)^2}\right]U_\infty \quad (15)$$

If $x > x_0$ (far wake):

$$U(x) = \left[1 + \frac{(1-e_2)D_2^2 - (D_1+2\alpha x_0)^2}{(D_1+2\alpha x)^2} + \frac{\left(D_0^2 - \frac{1-e_2}{1-2e_2+2e_1}D_2^2\right)(1-2e_1)}{(D_1+2\alpha x)^2}\right]U_\infty \quad (17)$$

Model validation

The proposed model was validated against a steady-state RANS simulation with *k-ω* SST turbulence closure performed at a flow speed of 1.5 m/s with turbulence intensity of 12%.

Figure 3 shows the nondimensionalized axial velocity distribution on a plane passing through the central axis and validation of the model prediction with the CFD results.

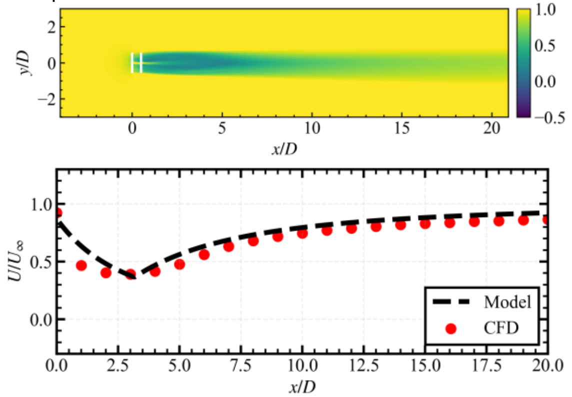

Fig. 3 CFD results (top) and model validation (bottom).

OPTIMIZATION RESULTS

Three tidal farms with 10x10, 16x16, and 21x21 cell configurations having 14, 36, and 62 turbines are considered for the optimization problem where the farm efficiency is maximized.

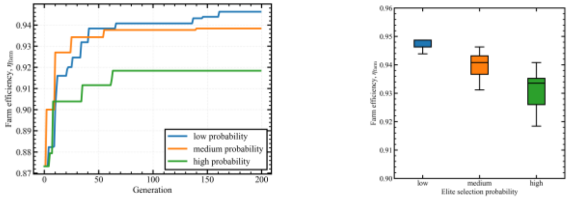

Fig. 4 10x10 farm efficiency convergence curves (left), and boxplot showing the statistics of 50 runs (right) for low, medium, and high elite selection rates.

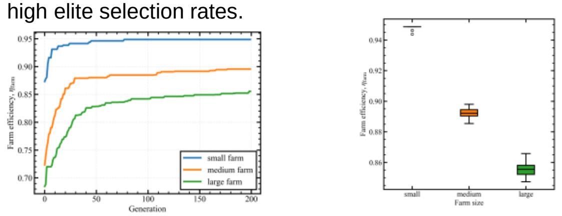

Fig. 5 Farm efficiency convergence curves (left), and boxplot showing the statistics of 30 runs (right) for small, medium, and large farms having numbers of turbines proportional to their sizes.

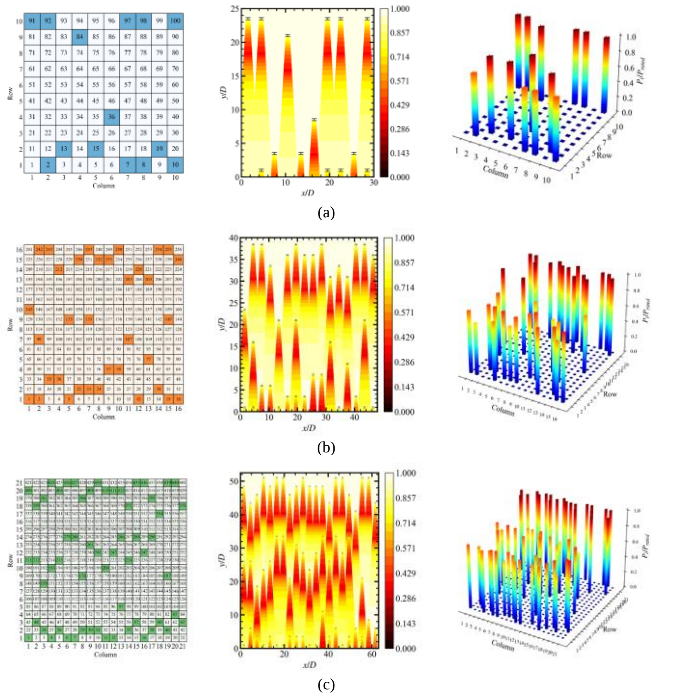

Fig. 6 Optimized farm layout (left), velocity field (center), and power output distribution (right), for a small (a), medium (b), and large (c) farm having numbers of turbines proportional to their sizes.

CONCLUSIONS

A new wake model for coaxial dual-rotor turbines is developed and utilized in solving tidal farm layout optimization problems using genetic algorithm. The proposed wake model shows a good agreement with the simulation results. The optimization results are useful for the assessment of the tidal power potential in tidal currents, ocean currents, and river currents.

REFERENCES

[1] Grady, S. A., M. Y. Hussaini, and Makola M. Abdullah (2005)
[2] Katic, I., Jørgen Højstrup, and Niels Otto Jensen (1986)

ACKNOWLEDGEMENT

This work was funded by a grant from the North Carolina Renewable Ocean Energy Program (NCROEP).