Tidal power plant simulations using large eddy simulation (LES) and the actuator line method (ALM)

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Abstract

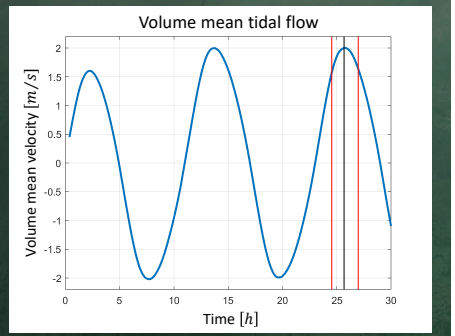
The share of the renewable energy in the global energy mix is to be increased according to the sustainable development goals of the UN. Tidal energy potentially can here play a substantial role for the electric power generation. The tidal power plant Deep Green developed by Minesto uses a novel technology with a "flying" kite that, with its attached turbine, sweeps the tidal stream with a velocity several times higher than the mean flow. Eventually these power plants will form arrays requiring knowledge of (1) the interaction between individual power plants as well as (2) how the power plants and the arrays will influence the surrounding environment.

The tidally oscillating turbulent boundary layer flow is in the present study analyzed using Large Eddy Simulations (LES) utilizing two different modeling techniques (pseudo-spectral and finite volume method). The boundary layer flow is analyzed both undisturbed and with a sweeping tidal power plant. The power plant is modeled using the Actuator Line Method (ALM). This method has been reformulated in order to be able to take arbitrary pathways of the actuator line into account.

The results for the undisturbed flow simulations show, e.g., variations of the turbulence intensity depending on pre- or post-tidal peak flow for equivalent volume mean flow. The results for the modeled power plant show, e.g., that the wake flow downstream of the power plant that can be related to the size of the pathway size.

Model Setup

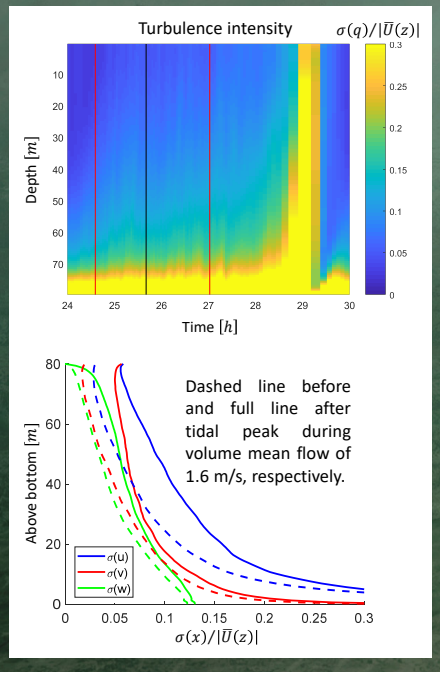
The LES model is setup to resemble the conditions at a site, west of Holy Island along the north wet coast of Wales, where the first Deep Green is to be deployed. The depth is 80 m and a bottom roughness length is used to model bottom roughness following the observations of frequent boulders with dimension roughly 2x2x2 m^3 at the bottom. The model is forced using a full tidal cycle (12 h) sinusoidal varying body force, and the body force amplitude is adjusted to fit the maximum tidal peaks present at the site (1.6, 2.0, and 2.4 m/s respectively). For the Coriolis force we assume that the force perpendicular to the main flow is balanced by a pressure gradient. The volume mean flow in the LES model during a number of tidal cycles are shown below for the case with a maximum tidal peak of 2.0 m/s.



The instance for the third tidal peak (between 25 and 26 h) and where the volume mean flows of 1.6 m/s are indicated with a black line and red lines, respectively. The instantiations field at time the first red line (approx. 24.5 h) is used as initial conditions for the simulation with the Deep Green.

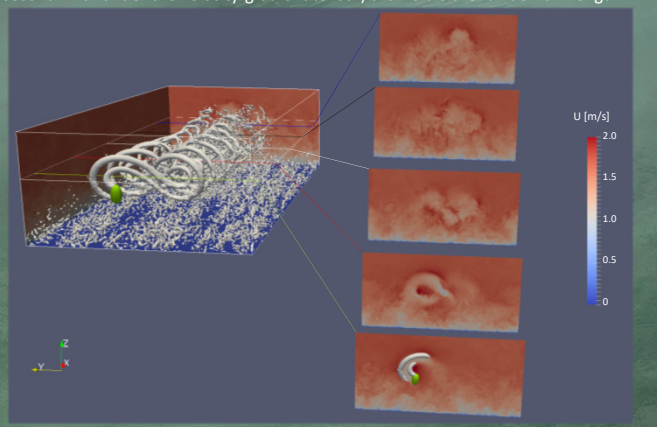
Turbulence Intensity

The turbulence intensity $I = \sigma(q)/\bar{U}(z)$ is shown below for the case with a maximum tidal peak of 2.0 m/s. Here $\sigma^2(q) = Var(q)$, Var is the variance, q is the velocity fluctuation, and $\bar{U}(z)$ is the horizontal mean velocity. The instance for the third tidal peak (between 25 and 26 h) and where the volume mean flows of 1.6 m/s are indicated with a black line and red lines, respectively. It is seen that the turbulence intensity varies strongly with time and is asymmetric around the tidal peak. It is further noticed that it is anisotropic in different directions.



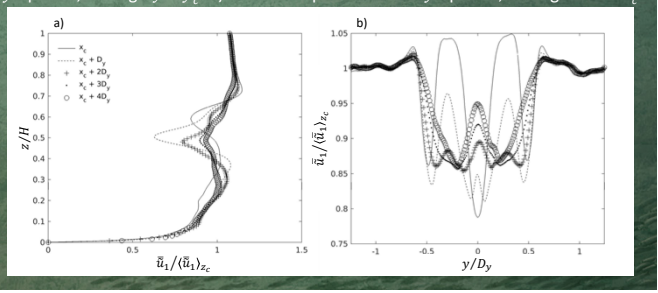
Velocity Field and Vortices

The instantaneous velocity fields after approximately 15 trajectories have been run after the mean current of 1.6 m/s at approximately 24.5 h. The Deep Green (visualized by the green isosurface of the force field) clearly affects the velocities here given at domain boundaries and at yz-planes at $x = x_c$, $x_c + D_y$, $x_c + 2D_y$, $x_c + 3D_y$, and $x_c + 4D_y$ where x_c is the center and D_y is the width of the trajectory, respectively. The induced vortices (indicated by isosurfaces of a positive value of a second invariant of the velocity-gradient tensor) are visible the full domain length.



Velocity Deficit

Comparison of mean flow velocities, at locations downstream of the Deep Green trajectory center (x_c, y_c, z_c), show the downstream wake. a) Vertical profiles at the yz-planes, through $y = y_c$. b) Horizontal profiles at the yz-planes, through at $z = z_c$.



References: Fredriksson et al. (2016). http://iopscience.iop.org/article/10.1088/1757-899X/276/1/012014
Broström et al. (2018), Some modelled characteristics of tidal turbulence in medium depth water, Ocean Science meeting, AGU, Seattle, USA.

Acknowledgement: This project is financed by the Swedish Energy Agency.

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