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Modelling Tidal Power Plants (Deep Green) with Large Eddy Simulations and Actuator Line Model in a Narrow Domain

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Tidal energy sector has the potential of becoming a considerable source of sustainable energy. In terms of operation, many tidal power plant designs share many similarities with wind power plants, whilst the latter uses air currents to generate power, the former makes use of tidal currents. Tidal flow is much more predictable than wind currents due to the cyclic nature of the tides. Convectional tidal power plants typically require strong currents to operate efficiently. Since strong tidal flow is only found in specific locations, the number of deployment sites of such tidal power arrays is limited.

Deep Green by Minesto AB is a novel tidal power concept that harnesses power from low velocity tidal flows (design speed of DG500 is 1.6 m/s). The concept utilizes a kite-like mechanism, with a flying wing attached to the sea floor via a tether cable and three struts. A turbine is attached to a nacelle that in turn is attached to the wing contains and houses the generator, control system and power electronics. In the tidal flow, the wing generates lift as it starts to move almost perpendicular to the flow. The Deep Green is steered in a lemniscate trajectory (∞) by the horizontal and vertical rudders in the trajectory of the kite, the local axial velocity is several times the tidal flow speed. The Deep Green version here studied, DG 500, has a wingspan of 12 m and a rated power of the generator of 500 kW.

In previous studies by Fredriksson et al (2016), a single Deep Green was simulated using Large Eddy Simulations (LES) in a tidal flow using OpenFOAM v1712. The Deep Green was modelled using a modified actuator line model following the lemniscate trajectory. In the current phase of the project, multiple Deep Greens are studied in different arrangements to study the flow interaction between Deep Greens and find efficient layouts of an array. Since these simulations are to be carried out in a smaller domain compared to the scales used for tidal flow simulations, a sensitivity study of different ways of representing the tidal forcing including appropriate boundary conditions in these shorter domains is required and is the focus of this research paper.

Here, a comparison of how different tidal forcing models to be used for the Deep Green array simulations affect the flow conditions, will be carried out. One of the methods of forcing is to use a momentum source that maintains a constant volumetric mean flow velocity at a certain time of the tidal cycle and the other is to use a time varying force following the tidal cycle. The issue with using the latter is that during the tidal cycle the flow parameters differ which makes statistical analysis challenging. Fredriksson et al (2016) showed that the turbulence intensity varies between the accelerating and decelerating phases of the tidal cycle at the same flow velocity. The first alternative with a constant volumetric mean flow can be solved either by setting a specific Ubar with the 'meanVelocityForce' model in OpenFOAM and using cyclic boundaries in the flow direction, or by using a prescribed areal time varying upstream boundary condition still maintaining the area mean flow constant. In the first case adding tidal power plants later on, implies an infinite array configuration whereas the other case implies a specific number of rows in the array. For the latter, first a precursor analysis without any powerplant is used both to generate the undisturbed flow field and to get the input to the time varying upstream boundary condition that will be specified using timeVaryingMappedFixedValue. These two different forcing alternatives will then be investigated by studying parameters such as the horizontal velocity profile, turbulence intensity etc. In continuation of the two cases, a Deep Green will be added in the domain to study the impact of the different forcing on the turbine in terms of the velocity deficit and the turbulence intensity.

Finally, the modelling of the bottom boundary, which is a rough wall, needs to be further evaluated. In the current studies, nutkRoughWallFunction is used to put a constrain on the turbulent viscosity to simulate a rough surface. The site of instalment, Holyhead Deep, contains boulders of characteristic size 1-3 m with a prevalence density of 1.6 boulders per hundred square metres and hence a sand grain roughness height (K_s) of 0.3 is used. The value of K_s will be reinvestigated and its impact on the velocity profile and bottom shear stresses will be studied. This study of the tidal forcing in smaller domains together with roughness modelling will provide a solid ground to conduct experiments on the array design of Deep Greens.