Experimental Validation of Numerical Simulation of Tidal Power Plants (Deep Green) using ADCP Measurements

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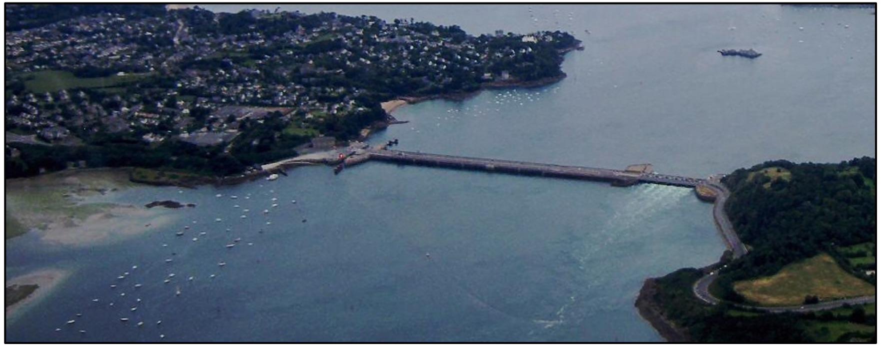
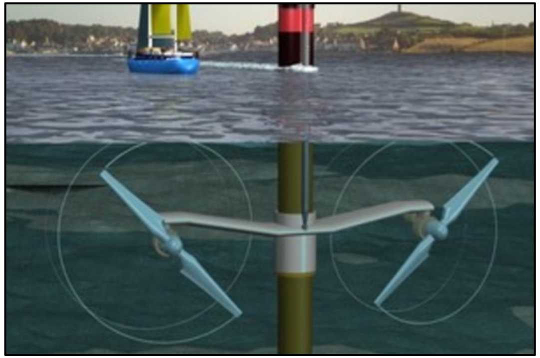
Tidal Power

- Tidal currents are caused by rise and fall of tides due to the effects of celestial bodies
- Tidal currents are more predictable than winds
- Commonly used axial flow turbines require velocities higher than 2 m/s to operate efficiently[1]



The sea wall (barrage – La Rance, France 1966 – 240 MW peak power)

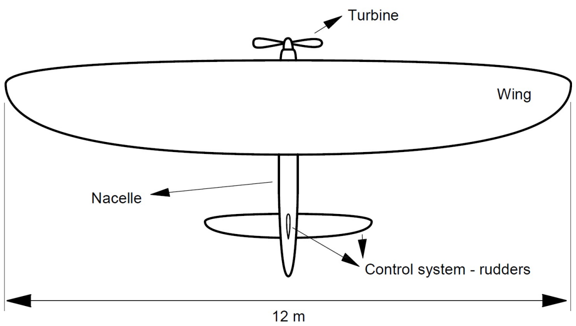


SeaGen (free-standing) in operation in Northern Ireland, UK [2]

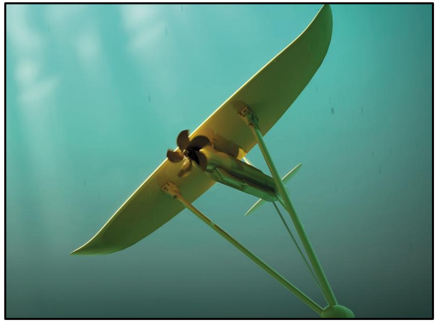
1. Electric Power Research Institute. (2006). Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices. USA
2. MCT (Marine Current Turbines)

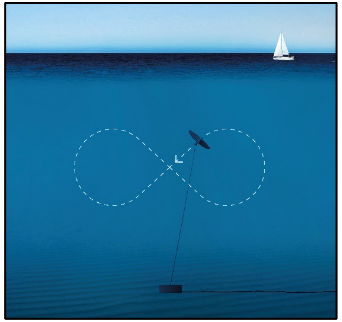
Deep Green by Minesto AB

- Novel solution for harnessing power from low velocity tidal streams[3]
- Tethered kite with a turbine attached
- The model **DG500** (wingspan 12m, rated power 500kW)
- Designed to operate in tidal current velocity of **1.6 m/s**
- DG500 is steered in a lemniscate (horizontal 8) trajectory **perpendicular to the flow** – trajectory width (D_y) of 60 m
- Flow velocity through the turbine reaches several times the tidal velocity



Dimensions of DG 500





Model and trajectory of the DG 500

3. Minesto AB https://minesto.com/

Numerical Modelling

- Deep Green is modelled using computational fluid dynamics (CFD) methods[4] in OpenFOAM
- Large Eddy Simulation (**LES**) for the free stream
- Actuator Line Model (**ALM**) for representing the Deep Green wing and turbine using source terms[5]
- Time varying tidal forcing used with a time period of 12 hours

$$F_{tidal} = F\cos(\frac{2\pi}{T}t)$$

Deep Green wing showing the actuator line elements

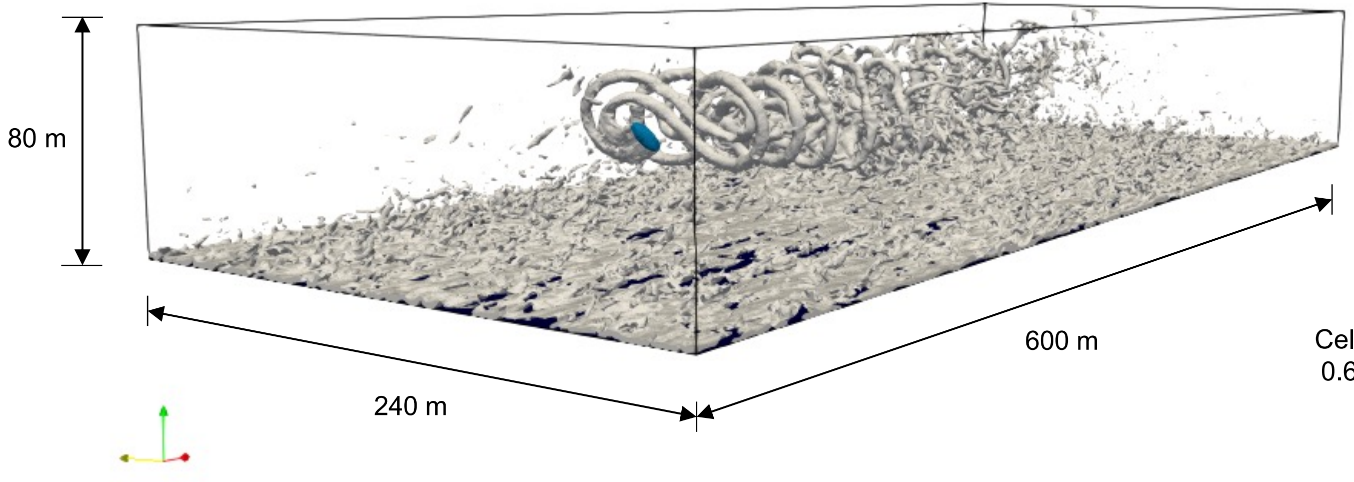
ALM Source term added to the momentum equations[5]

$$F_{DG}(\mathbf{r}) = \frac{F_i}{\varepsilon^3\pi^{2/3}}\exp\left[-\left(\frac{|\mathbf{r}|}{\varepsilon}\right)^2\right]$$

4. Fredriksson, S. T., Broström, G., Jansson, M., Nilsson, H., & Bergqvist, B. (2017). Large eddy simulation of the tidal power plant deep green using the actuator line method. *IOP Conference Series: Materials Science and Engineering*, *276*(1). https://doi.org/10.1088/1757-899X/276/1/012014

5. Sorensen, J. N., & Shen, W. Z. (2002). Numerical Modeling of Wind Turbine Wakes. *Journal of Fluids Engineering*, *124*(2), 393–399. https://doi.org/10.1115/1.1471361

Numerical Modelling



Cell size
0.625m

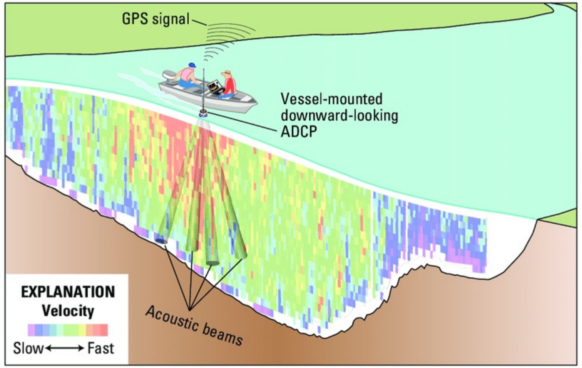
Vorticity isosurfaces (grey) of the Deep Green wake[4]
The Deep Green forces (F_{DG}) represented using the light blue iso surface

Vorticity is defined as the curl of the velocity vector and is a measure of flow rotation

4. Fredriksson, S. T., Broström, G., Jansson, M., Nilsson, H., & Bergqvist, B. (2017). Large eddy simulation of the tidal power plant deep green using the actuator line method. *IOP Conference Series: Materials Science and Engineering*, *276*(1). https://doi.org/10.1088/1757-899X/276/1/012014

Acoustic Doppler Current Profiler (ADCP) Measurements

- Measures 3D current velocity profile by multibeam SONAR
- Measurements on the Deep Green was carried out by Minesto AB, by a **vessel mounted ADCP, 70 m downstream of the Deep Green**
- Test site at Holy head, coast of Wales



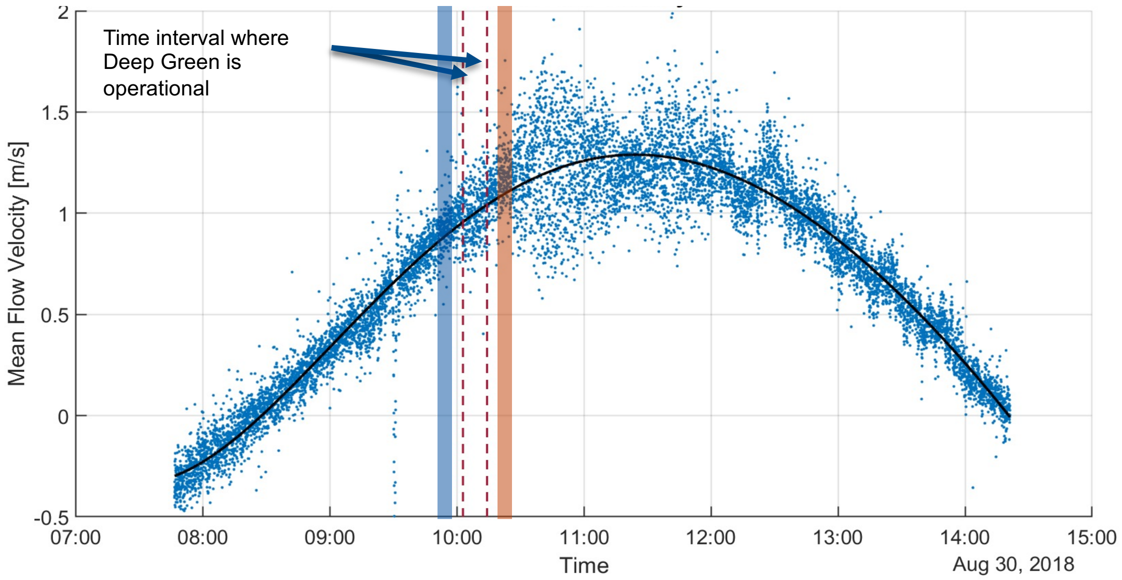
Vessel mounted ADCP[6]

ADCP Measurement Location

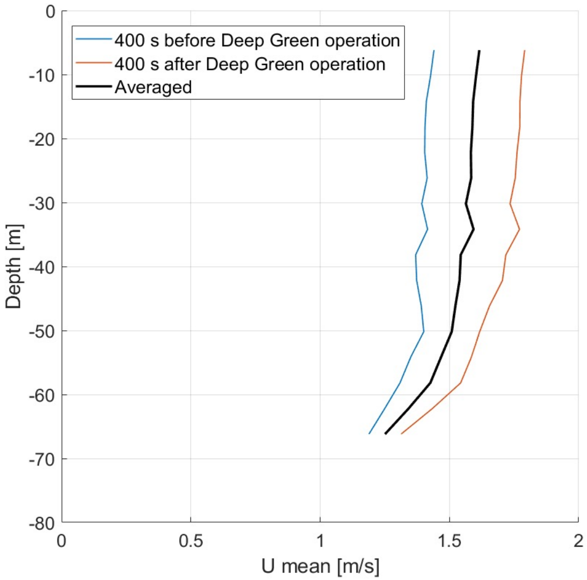
6. Mueller, David & Wagner, C.R.. (2013). Measuring discharge with acoustic Doppler current profilers from a moving boat.

ADCP Measurements – Mean Tidal Flow

Current Profile recorded for approximately 6:30 hours during which the Deep Green was operational for around 10 minutes

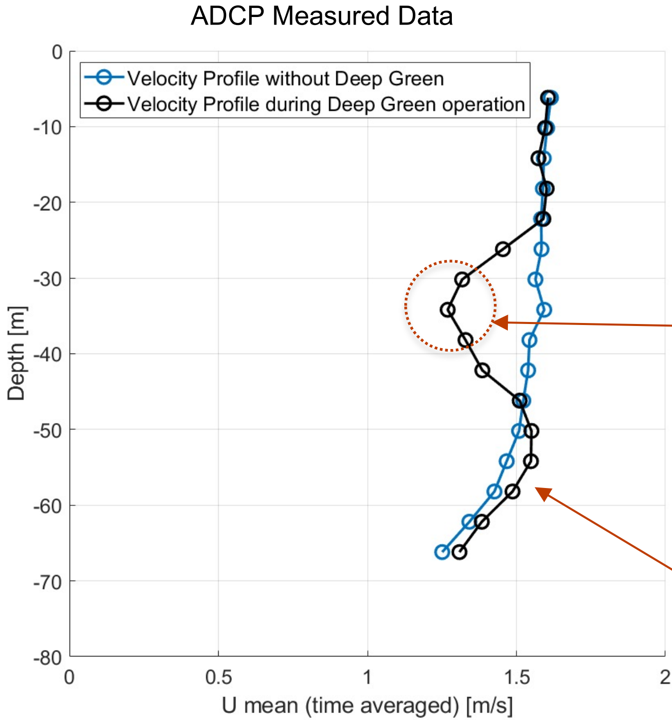


Flow velocity averaged over the vertical dimension – as a function of time



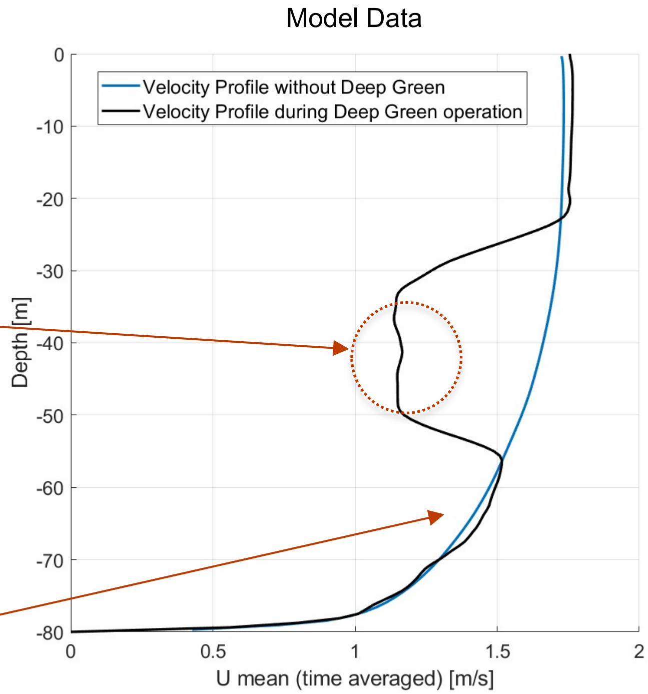
Time averaged vertical velocity profiles before, during and after the Deep Green operation

Comparing Model and Measurements – Velocity Profile with Deep Green



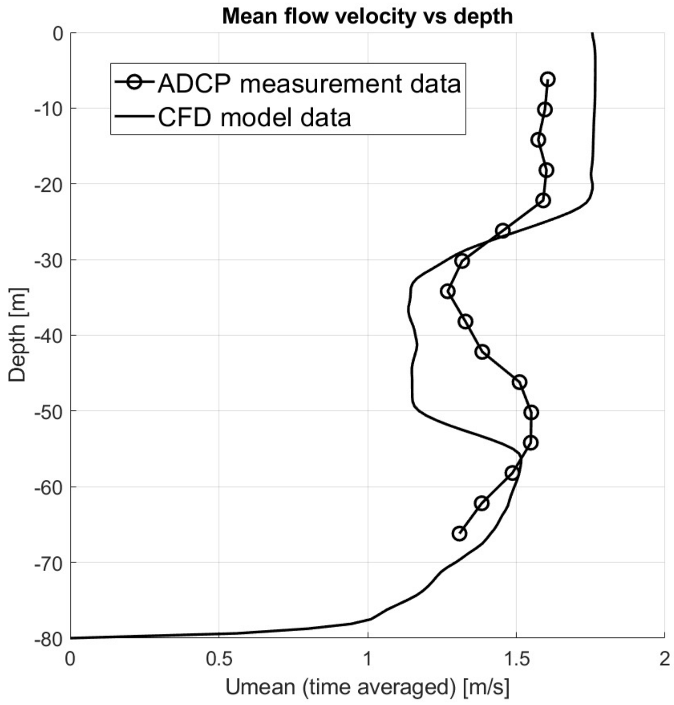
Velocity reduction in the region where the Deep Green operates

Flow acceleration below the Deep Green



Comparing Model and Measurements – Velocity Profile with Deep Green

- Numerical model predicts the flow features well
- In the model, the velocity deficit is stronger and wider than the measurements
- Could be due to some uncertainties in the measurements
  - Lower flow velocity
  - Lower forces on the Deep Green
  - Exact location of the ADCP relative to the Deep Green is unknown
  - Indications of higher turbulence in the measurements



Conclusions

- The numerical model was validated against measurements using ADCP
- The model predicted the flow features of the Deep Green wake quite well
  - Velocity reduction in the region of Deep Green operation
  - Flow acceleration below the Deep Green
- Could act as a proof of concept for wakes of tidal power kites
- A weaker and narrower wake was observed in the measurements – could be due to measurement uncertainties
- Validation of the model would aid in optimizing tidal power arrays