Array Optimization of Marine Hydrokinetic (MHK) Turbines
Using Blade Element Momentum Theory (BEMT)

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Goals
- Developing a numerical methodology to simulate the flow field for a single and array of MHK turbines.
- Investigating the wake-wake and wake-turbine interactions in a farm of MHK turbines.
- Finding mathematical relations between turbine spacing parameters and integral variables (i.e. efficiency, power, moments on blades and etc.)
- Applying the developed methodology for turbine array optimization.
- Suggesting an optimized turbine arrangement and estimating the overall efficiency of a turbine farm with minimum computational time and cost.

Numerical Methodology
- Virtual Blade Model (VBM), an implementation of BEMT in ANSYS FLUENT.
- Lift and Drag forces are calculated for each blade element.
- Calculated forces are averaged over a cycle of rotation.
- Effect of rotating blades is simulated on the fluid through a body force.

Methodology Validation
- Development of a methodology for array optimization of MHK turbines.
- For optimum operating conditions (constant TSR) local efficiency does not change significantly.
- For specific constrains (i.e. channel dimensions, number of turbines and etc.) the developed methodology was applied to suggest an optimized turbine arrangement and the overall efficiency of the farm was estimated with an acceptable accuracy (see following examples).

Summary & Applications

<table>
<thead>
<tr>
<th>X/R</th>
<th>Calculated Power by VBM [kW]</th>
<th>Available Kinetic Energy Flux on Turbine Plane [%]</th>
<th>Local Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.08</td>
<td>30.40</td>
<td>29.66</td>
</tr>
<tr>
<td>2</td>
<td>6.88</td>
<td>50.00</td>
<td>28.36</td>
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<tr>
<td>3</td>
<td>8.10</td>
<td>70.00</td>
<td>27.52</td>
</tr>
</tbody>
</table>

Simulated velocity deficit decay trend from VBM matched the self-similar solution for the axisymmetric wake.

<table>
<thead>
<tr>
<th>X/R</th>
<th>Min. AOA [°]</th>
<th>Max. AOA [°]</th>
<th>Calculated Power by VBM [kW]</th>
<th>Available Kinetic Energy Flux on Turbine Plane [%]</th>
<th>Local Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>5.08</td>
<td>6.88</td>
<td>106.21</td>
<td>378.15</td>
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<td>8.10</td>
<td>204.54</td>
<td>576.31</td>
<td>29.50</td>
</tr>
</tbody>
</table>

Efficiency of Downstream Turbines at Constant Tip Speed Ratio (T.S.R=4.9)

- Constant local efficiency (slope of the line)
- Linear trend between the available kinetic energy 2 radii upstream the device and the extracted power.

Available Kinetic Energy Flux at a Plane 2R Turbine Upstream [kW]

- Optimum offset ~ 1.75R

Dependent variables (i.e. efficiency, power, moments on blades and etc.)

Calculated Power via VBM vs. Estimated Power from the Available Kinetic Energy Flux

Optimised turbine arrangement and estimating the overall efficiency of the farm was estimated with an acceptable accuracy (see following examples).

Optimum offset ~ 1.75R

Staggered – 8R
Aligned – 8R
Staggered – 4R
Aligned – 4R

Overall Calculated Power via VBM vs. Estimated Power from the Available Kinetic Energy Flux

Staggered – 8R
Staggered – 4R
Aligned – 8R
Aligned – 4R