Dynamic Loading on Tidal Turbine Arrays (DyLoTTA)

Tim O’Doherty
Project Partners and Collaborators

Academic
Cardiff: Paul Prickett, Roger Grosvenor, Allan Mason-Jones, Carl Byrne
Strathclyde: Cameron Johnstone, Joe Clarke
Researchers: Matt Allmark, Stephanie Ordonez-Sanchez, Rodrigo Martinez, Cath Lloyd, Rob Ellis, Job Encarnacion, Song Fu

Industrial
Airborne Composites, ANSYS, Arup, Bosch Rexroth, Intertek, Lloyds Register, National Instruments, Nautricity Ltd, ORE Catapult, SKF, Tidal Energy Ltd.

International
Inha University – South Korea [experimental/numerical]
Mississippi State University – USA [numerical]
Dalhousie University – Canada [Material]
NREL – USA [Material and blade design]
1. Quantify the impact of wave-current interaction on the performance and integrity of TST devices when sited in an array.

2. Develop operational procedures to mitigate the impacts of extreme loading patterns. Specifically the dynamic loading patterns on the blade, blade root and eccentricity induced within the drive train.

3. Measure and mitigate such effects.

- Build 3 turbines to the same spec and test.
- Operate bench top rig with gear box.
- Use numerical tools to model turbine(s) under varying conditions of turbulence, waves and wakes – CFD, BEMT, LCOE software.
Turbine Design

3 x Ø 0.9 m Turbines – all to the same spec. Measures dynamic loads on 3 blades (flap and edge-wise), rotor thrust and torque, rotor position, rotational velocity, PMSM torque, stanchion loading and vibration through stanchion.

### Measurement Type

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Sample Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bladeroot bending moment (6 per turbine)</td>
<td>2 kHz</td>
</tr>
<tr>
<td>Rotor Thrust</td>
<td>2 kHz</td>
</tr>
<tr>
<td>Rotor Torque</td>
<td>2 kHz</td>
</tr>
<tr>
<td>Stanchion Bending Moment</td>
<td>2 kHz</td>
</tr>
<tr>
<td>Stanchion Vibration</td>
<td>10 kHz</td>
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</tbody>
</table>
Blade Design

Using the original Wortmann FX 63 –137.

- Chord length redistributed.
- Twist changed.
- Root modified for new turbines.
- New pitch angle

Good agreement between Expt, CFD and Strathclyde BEMT code.
INSEAN– Waves and Control Strategies

• Testing undertaken at INSEAN in November 2017.
• Looking at the effects that two control strategies have on the loading and performance of a tidal turbine when subjected to regular and irregular waves
• Measure data: Rotor torque and thrust and blade root bending moment of 2 blades.

✓ The control mode or the use of regular or irregular waves did not affect average values per test run.
✓ Thrust and torque fluctuations were substantial under both regular and irregular waves cases. Average peak loads 30% over the mean value under the conditions tested
✓ Torque control resulted in significantly larger thrust fluctuations per wave period than under speed control, for both regular and irregular waves.
## Experimental Testing Time Table

<table>
<thead>
<tr>
<th>Institution</th>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSEAN</td>
<td>2016</td>
<td>Initial turbine tested and calibration testing undertaken at different carriage velocities and wave cases.</td>
</tr>
<tr>
<td>IFREMER</td>
<td>2018</td>
<td>Joint project with Welsh NRN and EPSRC IAA funding. Testing with grid generated turbulence with and without wake generated turbulence. No grid (TI = ~2%) with waves and current.</td>
</tr>
<tr>
<td>INHA University</td>
<td></td>
<td>Blade design testing (ongoing)</td>
</tr>
<tr>
<td>ACRE Rd: 2019</td>
<td></td>
<td>Detailed testing of three turbines for comparison</td>
</tr>
<tr>
<td>FLOWAVE: 2019</td>
<td></td>
<td>3 turbine testing (+2 turbines with Southampton turbines (Myers, Allmark and Ordonez-Sanchez))</td>
</tr>
<tr>
<td>IFREMER: 2019</td>
<td></td>
<td>Additional testing of wave and current conditions</td>
</tr>
</tbody>
</table>
Overview of IFREMER Testing:

- Testing undertaken at IFREMER in April 2018.
- Looking at the impact of both grid generated turbulence and wake flows on dynamic loading and performance of 1/20th TST.
- Rotor torque and thrust, blade root bending moment on blade 2, rotational velocity, motor torque were recorded for 5 cases (Turbulence Intensity ~ 2 – 20 %):
  - 1 background turbulence
  - 2 grid generated turbulence cases with wake
  - 2 grid generated turbulence no wake cases.

- Inlet velocity 1.1 m/s
- LDA measurements 1m upstream of turbine, in-line with nose cone centre
Overview of IFREMER Testing:

- Inlet velocity 1.1 m/s
- LDA measurements 1m upstream of turbine, in-line with nose cone centre

<table>
<thead>
<tr>
<th>U</th>
<th>TI</th>
</tr>
</thead>
<tbody>
<tr>
<td>m/s</td>
<td>%</td>
</tr>
<tr>
<td>1.11</td>
<td>1.75</td>
</tr>
<tr>
<td>0.94</td>
<td>15.70</td>
</tr>
<tr>
<td>1.02</td>
<td>7.98</td>
</tr>
<tr>
<td>0.65</td>
<td>18.95</td>
</tr>
<tr>
<td>1.07</td>
<td>9.49</td>
</tr>
</tbody>
</table>
Overview of IFREMER Testing:

- Inlet velocity 1.1 m/s
- LDA measurements 1m upstream of turbine, in-line with nose cone centre
Wave models – Stokes 2\textsuperscript{nd} Order +

Modelling with uniform and sheared velocity profiles, different wave characteristics.
Publications to date:

**JOURNALS**


- S Salunkhe, S Bhushan, D Thompson, D. O'Doherty and, T. O'Doherty. Validation of hydrokinetic turbulent wake predictions and analysis of wake recovery mechanism. Submitted Renewable Energy June 2017

**12th EWTEC (2017)**


**4th AWTEC (2018)**


- K Porter, S Ordonez-Sanchez, M Allmark, T O'Doherty, C Johnstone. Laboratory study of tidal turbine performance in irregular waves. 4th AWTEC, Taipei.


- S Fu, C Johnstone. A sea-state based investigation for performance of submerged tensioned mooring supported tidal turbines. 4th AWTEC, Taipei.

**AIAA FLUID DYNAMICS CONFERENCE (2018)**


**13th EWTEC (2019) - 9 ABSTRACTS SUBMITTED including**

- 1 with NREL
- 1 with Inha
- 3 with MSU
- 1 with IFREMER
Acknowledgements

- EPSRC – Impact Acceleration Account funding for IFREMER access
- ARCCA and Supercomputing Wales – additional computing access
- Cardiff and Strathclyde Universities – PhD funding
- NRN – turbulence and wake data measurements
- MARINET 2 – INSEAN access
- Supergen plus - access to FLOWAVE.
SuperGen UK Centre for Marine Energy Research
Annual Assembly 2018

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Thank You