Analysis of innovative concepts for WECs - Boris Teillant

27-03-2017

WavEC Offshore Renewables

GRANT AGREEMENT Nº: 607656
PROJECT: OceaNET
State-of-the-art & motivation

Status of wave energy

- No fully commercial Wave Energy Converter (WEC) after 30 years of intense R&D
- No evidence of technological convergence: still a wide variety of WEC concepts (design, working principle, location of interest) including new entrants
- Major industrial setbacks (OceanLinx, Pelamis, Wavebob, etc...) VS only few milestones achieved (Seabased, Carnegie, etc...)
- Many experts reckon the need for disruptive solutions and breakthroughs
- No standard method for holistic lifecycle performance analysis of WECs (power matrix, LCOE, NPV, IRR, EROEI, TPL etc...)

This project concerns the viability of implementing innovative concepts for wave energy conversion: e.g novel materials or PTO systems, innovative solutions for survivability, installation and O&M strategies
Methodology

Description of:
• PTO system
• Mooring system
• Control system

Strategies for:
• M&A
• T&I
• O&M (reliability)
• Decommissioning

Wave-to-wire model

Cost drivers
• System loads
• & dynamics
• Power matrix

Lifecycle model

CAPEX

OPEX

Energy production

Components & infrastructure data

Economic & risk model

Market data

Resource data

Design specs

Array layout

LCOE

Risk indicator
Lifecycle logistic model

Overview

• Model estimating CAPEX, OPEX and AEP over the project lifetime

• Time-based marine operation simulator -> DTOcean EU FP7 project:

• Focus on A&I and O&M phases:

  1. Characterization of the logistic requirements

  2. Selection of the suitable maritime infrastructure (port/vessel/equipment)

  3. Performance assessment of the feasible solutions in terms of time efficiency and costs
Lifecycle logistic model

Weather window

Example box-plot monthly accessibility
- Limit in Hs = 2m
- Limit in wind speed = 12 m/s

Waiting time depending on the total duration of the marine operation:
- Triple average waiting time if mission last 12 hours instead of 6 hours
Lifecycle logistic model

Sensitivity analysis & Gantt chart

- Schedule Sea Operation Time [h]
- Schedule Sea Transit Time [h]
- Schedule Waiting Time [h]
- Schedule Preparation Time [h]
- Schedule Total Time [h]

Vessel Positioning Time [h]
Schedule Sea Operation Time [h]
Schedule Sea Transit Time [h]
Schedule Waiting Time [h]
Schedule Preparation Time [h]
Schedule Total Time [h]

Installation of driven piles anchors/foundations
Installation of static export cables
Installation of collection point (surface piercing)
Installation of static array cables
Installation of devices
**Lifecycle logistic model**

**Verification**

<table>
<thead>
<tr>
<th>Optimal V&amp;E Solution</th>
<th>Installation Module Output</th>
<th>DBE Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity x Type [DB id]</td>
<td>Cost</td>
</tr>
<tr>
<td>Installation Vessel</td>
<td>1 x Cable Laying Vessel [9]</td>
<td>75.000€/day</td>
</tr>
<tr>
<td></td>
<td>1 x Cable Laying Vessel</td>
<td>80.000€/day</td>
</tr>
<tr>
<td>Support Vessel</td>
<td>2 x Multicat [55]</td>
<td>3.400€/day</td>
</tr>
<tr>
<td></td>
<td>2 x Multicat [55]</td>
<td>-</td>
</tr>
<tr>
<td>Installation Equipment</td>
<td>12460 x Split Pipes [1]</td>
<td>445€/unit</td>
</tr>
<tr>
<td></td>
<td>5000 x Iron Casing</td>
<td>300€/unit</td>
</tr>
<tr>
<td>Support Equipment</td>
<td>1 x Inspection ROV [2]</td>
<td>5.700€/day</td>
</tr>
</tbody>
</table>

- Comparison with a pilot farm of TEC against preliminary calculations of a maritime contractor
- Verification of the weather window calculation with Mermaid software (4 locations, various combinations of OLC)

### TIME VARIABLES

<table>
<thead>
<tr>
<th>Port – Preparation Time</th>
<th>59 h</th>
<th>72 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port – Waiting time</td>
<td>6 h</td>
<td>0 h</td>
</tr>
<tr>
<td>Sea – Installation Time</td>
<td>17 h</td>
<td>44 h</td>
</tr>
<tr>
<td>Sea – Transit Time</td>
<td>10 h</td>
<td>12 h</td>
</tr>
<tr>
<td>Total Time</td>
<td>101 h</td>
<td>119 h</td>
</tr>
</tbody>
</table>

### COST VARIABLES

- **Vessel Cost**: €439,000 - €419,000
- **Equipment Cost**: €1,500,000
- **Port Cost**: €667,000 - €192,000
- **Total Cost**: €2,111,000 - €6,672,000
Lifecycle logistic model

Ongoing work (journal paper)

- Investigate the potential lifecycle benefit of enabling technologies for the electrical and mechanical connections of arrays of WECs e.g:
  - Wet-mate connectors,
  - Modular gravity based anchors such as rocky bags & metallic blocks,
  - New tools such as vibro-drivers & robotic arms
  - Fit-for purpose vessels,
  - Novel attachment and disconnection systems and processes
Dielectric elastomer generator

Overview

Techno economic analysis of PolyWECs
EU FP7 PolyWEC project
Dielectric elastomer generator

Pico plant LCOE comparison

- Even with very conservative assumptions for the failure rates (i.e. full replacement every 6-months) or on the cost of the DEG (15€/kg), LCOE is between 20 and 50% lower LCOE
Dielectric elastomer generator

Other PolyWECs

Poly-Surge

Poly-U-OWC

Drum-WEC

Poly-Surge

Dielectric Elastomer Generator

Oscillating Flap

Parallellogram Mechanism

Seabed

Water Surface

Dielectric Elastomer Membrane

Poly-U-OWC

Air chamber

DEGs

Control volume

Foundation
Dielectric elastomer generator

Sensitivity analysis on the Poly-U-OWC

<table>
<thead>
<tr>
<th>Indicator</th>
<th>CAPEX</th>
<th>OPEX</th>
<th>$AEP_{WEC}$</th>
<th>$P_{WEC}$</th>
<th>$f_{cap}$</th>
<th>$f_{load}$</th>
<th>CW</th>
<th>CWR</th>
<th>LCOE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit</strong></td>
<td>[€/MW]</td>
<td>[€/MW/year]</td>
<td>[MWh]</td>
<td>[kW]</td>
<td>[%]</td>
<td>[%]</td>
<td>[m]</td>
<td>[%]</td>
<td>[€/MWh]</td>
</tr>
<tr>
<td><strong>Reference case:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- currently realistic rubber</td>
<td>4,30E+06</td>
<td>2,39E+04</td>
<td>1,13E+07</td>
<td>40,48</td>
<td>13%</td>
<td>11%</td>
<td>1,12</td>
<td>16%</td>
<td>514,17</td>
</tr>
<tr>
<td>DEG-PTO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- collector structure (a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Structural case (b)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicone based DEG-PTO</td>
<td>4,30E+06</td>
<td>2,39E+04</td>
<td>1,13E+07</td>
<td>40,48</td>
<td>13%</td>
<td>11%</td>
<td>1,12</td>
<td>16%</td>
<td>519,32</td>
</tr>
<tr>
<td>Enhanced rubber DEG-PTO 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhanced rubber DEG-PTO 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Impact of material unit cost on LCOE - tornado diagram

- DEG
- Concrete
- Steel

DEG lifetime

Project lifetime

Availability

Impact of material unit cost on LCOE - tornado diagram

- Minimum value
- Maximum value
Dielectric elastomer generator

Comparative study between Poly-U-OWC & Drum-WEC

- Performance metrics: AEP, average power, capacity factor, CWR, etc...

<table>
<thead>
<tr>
<th>Performance metric</th>
<th>Unit</th>
<th>Poly-U-OWC</th>
<th>DrumWEC</th>
<th>Values in the literature [min, mean, max]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$AEP_{WEC}$</td>
<td>[kWh]</td>
<td>281630</td>
<td>492970</td>
<td>N/A</td>
</tr>
<tr>
<td>$\langle P_{WEC} \rangle$</td>
<td>[kW]</td>
<td>40.1</td>
<td>70.5</td>
<td>N/A</td>
</tr>
<tr>
<td>$f_{capacity}$</td>
<td>[%]</td>
<td>13.5</td>
<td>19.1</td>
<td>[5, 15, 60]</td>
</tr>
<tr>
<td>$f_{load}$</td>
<td>[%]</td>
<td>10.8</td>
<td>15.2</td>
<td>N/A</td>
</tr>
<tr>
<td>$CW$</td>
<td>[m]</td>
<td>1.1</td>
<td>1.9</td>
<td>N/A</td>
</tr>
<tr>
<td>$CWR$</td>
<td>[%]</td>
<td>16.0</td>
<td>16.2</td>
<td>[7, 29, 72]</td>
</tr>
</tbody>
</table>

- Techno-economic indicators: CAPEX (€/MW), OPEX (€/MW/year) & LCOE

<table>
<thead>
<tr>
<th></th>
<th>LCOE [€/MWh]</th>
<th>CAPEX [€/MW]</th>
<th>OPEX [€/kW/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poly-U-OWC</td>
<td>514</td>
<td>4296</td>
<td>23.9</td>
</tr>
<tr>
<td>DrumWEC</td>
<td>537</td>
<td>6421</td>
<td>27.2</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>100 – 250</td>
<td>3,000 – 3,500</td>
<td>80 – 120</td>
</tr>
<tr>
<td>Tidal</td>
<td>150 – 300</td>
<td>3,000 – 5,000</td>
<td>130 – 210</td>
</tr>
<tr>
<td>Wave (pre-commercial stage)</td>
<td>200 – 700</td>
<td>5,000 – 7,000</td>
<td>300 - 450</td>
</tr>
<tr>
<td>Wave (commercial stage)</td>
<td>100 – 300</td>
<td>3,000 – 4,500</td>
<td>200 – 300</td>
</tr>
</tbody>
</table>
Dielectric elastomer generator

Ongoing work (journal paper)

- On the techno-economic potential of DEG for wave energy conversion
- 4 different PolyWECs
- Comparative study with existing WECs or against literature data
- Extensive sensitivity analysis
- Current projections are positive but further R&D is required to strengthen the confidence in the results
- Implementing the TPL or related stage-gate metric system to complement this holistic appraisal
Early stage ideas

Overview

H2020 WETFEET project

- Apply the integrated techno-economic mode to the most promising breakthroughs:
  - Negative springs
  - Submergence for survivability
  - Structural membrane
  - Control cocoon
  - New PTOs (tetra-radial turbine, novel water turbine & DEG)
  - Array breakthroughs (rigid and non-rigid connections)
  - Alternative structural materials
  - Off-grid applications
Early stage ideas

Negative spring

- Extension of the bandwidth and a shift in the response to lower frequencies can be observed

- WaveSpring system embedded in a WaveStar-like, a pitching and a heaving WEC

- Tradeoff between increased efficiency (or reduced stiffness -> smaller structures) and added-complexity
Early stage ideas

Review paper on 2nd generation of PTOs for WECs

*Figure adapted from Têtu et al. Handbook of WE – Chapter 4
Early stage ideas

Overview

• Consolidate the framework for the TPL assessment and functional requirements
Dissemination

Conference papers


Dissemination

Project deliverables

 DemoWFloat: Deliverable D4.4

 DTOcean:
   D2.4,
   D4.5,
   D5.1, D5.2, D5.3, D5.4, D5.5, D5.6,
   D7.2, D7.3 & D7.5
   (D1.2, D2.1, D4.3, D6.1, D6.2 & D7.1)

 PolyWEC: Deliverables D1.3, D5.3 & D5.4

 WETFEET: Deliverables D2.1, D2.2, D2.3, D7.1, D7.2 & D7.3

Other activities

 INORE symposia 2014, 2015 (attendee) & 2016 (organization),
 IST PhD courses & ISSSD2 PhD course AAU
 Lecturing techno-economic analysis of offshore renewables for the EUREC master classes
 Supervising 4 MSc/MEng thesis: Tiago Rocha, Clara Vrousos, Eric Guardiola & Christian Lorenzo
Thank you for listening!

Boris Teillant
WavEC Offshore Renewables
boris.teillant@wavec.org