Performance Evaluation of the Wavestar Prototype

Morten Kramer, R&D engineer, Wave Star A/S
Laurent Marquis, Head of Development, Wave Star A/S
Peter Frigaard, Head of Civil Engineering Department, Aalborg University

Presented by: Laurent Marquis

EWTEC 2011 conference in Southampton, UK. 2011-09-06.
Wavestar test machines

Test machine at Aalborg University
- Deployment: 2004-2005
- Scale: 1/40
- Float diameter: 0.25 m

Test machine at Nissum Bredning
- Deployment: 2006-2010
- Scale: 1/10
- Float diameter: 1.0 m

Prototype test section at Hanstholm
- Deployment: 2009->
- Scale: 1/2
- Float diameter: 5.0 m
The Wavestar prototype is a 2-float section of the full 20-float machine.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Hanstholm prototype</th>
<th>Commercial Wavestar 0.6 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of floats</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Float diameter</td>
<td>Ø5 m</td>
<td>Ø5 m</td>
</tr>
<tr>
<td>Arm length</td>
<td>10 m</td>
<td>10 m</td>
</tr>
<tr>
<td>Weight</td>
<td>1000 ton</td>
<td>1600 ton</td>
</tr>
<tr>
<td>Nominal electrical power</td>
<td>110 kW</td>
<td>600 kW</td>
</tr>
</tbody>
</table>
The Wavestar prototype was installed from a barge in September 2009 and it is accessible in any weather via a 300 m long access bridge.
Two years of experience at real sea

In general there have been no major problems with the design of the prototype. All structural and mechanical components in the WEC have proven functionality as intended. The WEC has survived two large storms with no damages and no service afterwards. Only minor design faults with the float design, the jacking-system, and some electrical problems have been identified and corrected.
Jackling system adjustments
Float damage
Operational time 2010-2011

Legend:
- Down time and transition states
- In storm protection
- Stopped due to calm sea
- Harvesting energy, below ForskVE curve
- Harvesting energy, above ForskVE curve
Operational time and waves in August 2011
Power measurements from the Hanstholm test unit

- Red data points are 30 minute average values of harvested power from one float (hydraulic power leaving one cylinder)
- 5740 red data points are shown corresponding to 120 days of full operation
- A typical wave period for the Hanstholm location is used for the simulated curve

\[ CWR \% = \frac{\text{Power [kW]}}{\text{Wave power [kW/m]}} \cdot \frac{\text{Float diameter [m]}}{100} \]

- Measured Sept 2010 to Sept 2011 (control generation 3)
- Measured June 2010 (control generation 2)
- Measured May 2010 (control generation 1)
- Simulation (control generation 3)
- ForskVE limit for subsidies

- Absorbed power [kW]
- Significant wave height \( H_{mo} \) [m]
- Wave power [kW/m]
- CWR [%]
Power matrix for a C5 Wavestar with 20 floats (Ø5 m, 10 m long arms)

Values are average electrical power to grid in kW.

<table>
<thead>
<tr>
<th>Wave height $H_{m0}$ (m)</th>
<th>Wave period $T_{0.2}$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 - 3</td>
</tr>
<tr>
<td>0.0 - 0.5</td>
<td>0</td>
</tr>
<tr>
<td>0.5 - 1.0</td>
<td>0</td>
</tr>
<tr>
<td>1.0 - 1.5</td>
<td>54</td>
</tr>
<tr>
<td>1.5 - 2.0</td>
<td>106</td>
</tr>
<tr>
<td>2.0 - 2.5</td>
<td>175</td>
</tr>
<tr>
<td>2.5 - 3.0</td>
<td>262</td>
</tr>
</tbody>
</table>

3.0 - Storm protection
Perspective: Wavestar performance in Europe

<table>
<thead>
<tr>
<th>Site</th>
<th>Belmullet, IR</th>
<th>Wave Hub, UK</th>
<th>Pilot Zone, P</th>
<th>EMEC, UK</th>
<th>Horns Rev 2, DK</th>
<th>SEM-REV, F</th>
<th>BIMEP, ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Power</td>
<td>1200 kW</td>
<td>1200 kW</td>
<td>1200 kW</td>
<td>1200 kW</td>
<td>600 kW</td>
<td>1200 kW</td>
<td>1200 kW</td>
</tr>
<tr>
<td>Storm protection</td>
<td>Hs &gt; 5 m</td>
<td>Hs &gt; 5 m</td>
<td>Hs &gt; 5 m</td>
<td>Hs &gt; 5 m</td>
<td>Hs &gt; 3 m</td>
<td>Hs &gt; 5 m</td>
<td>Hs &gt; 5 m</td>
</tr>
<tr>
<td>Annual production</td>
<td>4.29 GWh</td>
<td>2.64 GWh</td>
<td>2.87 GWh</td>
<td>2.88 GWh</td>
<td>1.41 GWh</td>
<td>2.37 GWh</td>
<td>2.21 GWh</td>
</tr>
</tbody>
</table>

C5-10 (10 m arm)  C5-16 (16.7 m arm)
Power curve for C5 WEC with 20 floats and 10 m arms.
80 % PTO efficiency. Power is average production to grid.

Power curve for C5 WEC with 20 floats and 16.7 m arms.
80 % PTO efficiency. Power is average production to grid.

From 600 kW to 6 MW

- **C5**
  - 70 m long
  - 20 floats of Ø 5 m
  - ~ 10-15 m water depth
  - 600 kW @ 2.5m Hs

- **C10**
  - 140 m long
  - 20 floats of Ø10 m
  - ~ 20-30 m water depth
  - 6 MW @ 5.0m Hs

Double size = 11 times more power
Wavestar machines in synergy with wind turbines