Recent Advances in Wave Energy Generation

- from the perspective of the Wave Energy Research Group, Aalborg University

by

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Wave Energy Research Group

At Aalborg University,
Department of Civil Engineering,
Division of Water & Soil

- Staff: 10-15
- Profile:
  - Waves, Mechanics,
  - Hydro Dynamics, Control
- Experimentiel testing in lab. and at sea
- 2x 3-D wave tanks, wave and current flumes
- Key operator in Nissum Bredning
- Instrumentation for measuring “anything” 😊
- Numerical modelling
Wave Energy Research Group

- Have been involved in more than 40+ concepts/projects over the past 12-14 years
- Partner in 4 ongoing EU financed projects
- Involved in all primary Danish, and numerous international, concept developments within the sector
- National and international standardization efforts
- Teaching, courses (Ph.D./external)
Other relevant research units at AAU

The Wave Energy Research Group is in close cooperation with other research units at the university:

- Structures and geotechnics
  Division of Structures, Materials and Geotechnics
- Power take-off
  Department of Energy Technology, Section of Fluid Power and Mechatronic Systems
- Energy systems
  Department of Development and Planning, The Sustainable Energy Planning Research Group
- Control
  Department of Electronic Systems, Section of Automation & Control

Etc. …

A very interdisciplinary field
Keywords

• Why wave energy?
• Potential
• Concept developments – examples of technologies
• Generic national and international projects
• What’s happening now?
# Cost of Energy (in Denmark)

<table>
<thead>
<tr>
<th>ENERGY TYPE</th>
<th>€/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating Offshore Wind</td>
<td>400-1500</td>
</tr>
<tr>
<td>Wave Energy</td>
<td>~750</td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>~125</td>
</tr>
<tr>
<td>Offshore Wind</td>
<td>75-125</td>
</tr>
<tr>
<td>Onshore Wind</td>
<td>40-75</td>
</tr>
<tr>
<td>Coal</td>
<td>30-45</td>
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</tbody>
</table>

30% of our electricity comes from wind. Why?

We are interested in Wave Energy. Why?
Cost of Energy important but not essential

Energy policy is driven by politics

There is a growing demand for clean energy, the main drivers are not just **Jobs, Environment, Global Warming**

**Nations wants to secure energy supply**
Et energisystem uden fossile brændsler

Vindmøller
Vindmøller skal producere en stor del af den el, der skal bruges i 2050. De fleste af møllerne skal placeres på havet.

Solceller
Solceller kan evt. supplere vindmøllernes elproduktion.

El-bil
De fleste biler skal bruge el. En del større køretøjer som f.eks. lastbiler skal køre på biobrændstoffer.

Bølge-kraft
Bølgekraft kan evt. supplere vindmøllernes elproduktion.

El-kabler
Der skal bygges flere elkabler til udlandet, så vi kan eksportere og importere mere el.

Husene skal isoleres bedre, så de bruger mindre energi end i dag. En del huse skal opvarmes af små varmepumper, resten skal forsynes med fjernvarme.

Varmepumpe
Elapparater skal være mere energieffektive end i dag.

Biomasse
Der skal bruges biomasse både på kraftvarmeværkerne, til produktion af biobrændstoffer til transport og i industrien.
The Wave Energy Resource is Enormous.
~ 20 % of World's Energy Needs
Potential wave energy in Europe

Denmark's electricity consumption: 3,7 GW
Danish West coast (offshore):
- Up to 25 MW/km
- averagely 16 MW/km
- Around 150 km from the coast
  ~ 2,4 GW
In the European Atlantic/North Sea coasts:
  25 - 75 MW/km
Mediterranean sea: 4 - 11 MW/km
Total potential on European coasts: ca. 320 GW
Wave Energy has the potential to contribute significantly to the world's energy production.
Examples of activities (DK focus)

Concept developments
- Wave Dragon – Design study for a 1.5 MW device for deployment at DanWEC, Hanstholm
- Resen Waves – ’Standard’ lab. test
- Weptos – ’Large scala’ lab. testing conducted in CCOB, Santander, Spain
- Wavestar – Performance measurements on prototype at DanWEC, Hanstholm, cont.
- Floating Power Plant – Real sea scale testing, combined wind/wave

EU funded projects
- CORES
- EquiMar
- Marinet
- WaveTrain2
- Hydralab
- Marina
- DTOcean

National, cooperation projects
- SDWED
- Partnership for wave power
- DanWEC
- IEC – TC114 / DS S-614
- FLOAT2
Wave Dragon
- a slack moored wave energy device of the overtopping type

Waves overtopping the doubly curved ramp

Turbine outlet

Reservoir

www.wavedragon.net
Prototype Test Location

Nissum Bredning

- A benign site in Northern Denmark

- 1:4.5 scale (compared DK North Sea) prototype in situ at Test Site 1, 2003 – 2005

- Grid connected, Full control system, Highly instrumented
Resen Waves - LOPF
The wave energy converter *Wave Star*

*A multi point absorber system*

Scale 1:10 testing in Nissum Bredning

Scale 1:40 testing at AAU

Numerical modelling

www.wavestarenergy.com
Scale 1:10 Real Sea Tests in Nissum Bredning
Power measurements from Roshage test unit

Notes:
- Power is 10 minute average values of harvested power from one float (hydraulic power leaving one cylinder)
- A typical wave period for the Roshage location is used for the simulated curve

- Online data at http://wavestarenergy.com/concept
Weptos

**Wave Energy**
Floating Power Plant - Combined wind and wave
Very large numbers of ideas....

• Hundreds of concepts for utilization of wave energy – and even more patents!
• Still new concepts coming and being tested
• Some promising concepts, but the race is still open!
• No convergence so far...

And large challenges...

• Valley of death – spec. private cap.
• Very cap. intensive
• Small vs. large installations
• Market
• Externalities
MERMAID, Belgium

- OTARY RS (65%) and Electrabel, Group GDF SUEZ (35%)
- 450 MW wind / 20 MW wave
- Creation of a market!
Examples of activities (DK focus)

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- Wavestar – Performance measurements on prototype at DanWEC, Hanstholm, cont. Developments in lab.
- Floating Power Plant – Real sea scale testing, combined wind/wave

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The Alliance – The Project:
Structural Design of Wave Energy Devices

Objective of the project

Strengthen and consolidate Denmark’s position as one of the leaders in wave energy research, through the formation of a strategic international research alliance focusing on the structural design of Wave Energy Devices

Project granted by the Danish Council for Strategic Research
Call: Strategic Research in Sustainable Energy and Environment
Theme: Energy Systems of the Future

5 years (2010-2014)

12 Partner organizations - 6 Danish (73 %), 6 International (27 %)

Budget: 25 mil. dkr. (19.6 DSF, 5.4 Co-fin.)
Anticipated main results

A novel advanced wave-to-wire model synthesized from the following results related to wave energy devices to be generated in the project:

- Advanced knowledge on wave loadings
- Advanced knowledge on loads from and behaviour of mooring systems
- Advanced knowledge on loads from and behaviour of PTO systems
- New advanced knowledge on the interaction of the mentioned elements
- Advanced knowledge on the structural reliability of the devices
Challenges ...

- Large device variations
- Multiple disciplines involved
- Heavy interactions

Need for a ‘JPEG’ approach!

Get a coarse overview

Refine the details

To get the full picture
Challenges ...

Incorporation of experiences from associated more established fields

- Often same tools but opposite goals:
  - e.g. maximize motions or overtopping rather than minimizing, as in e.g. ship and breakwater design
- Need for more complex models (include non-linearities and interactions)

Need to consider both power production and extreme conditions

- Balance structural loads in both conditions

  - Balance maximizing power production through advanced control against structural wear
  - Balance overall power production against installed generator capacity
What do we want to achieve?

Overall: Reduce cost of energy....
Need tools for WED design and optimization
Different needs in
• Operating conditions
• Extreme conditions
Focus on
• Power production optimization
• Structural design
Many different WED types
• Provide ’building blocks’
Complex systems, non-linear behavior and interactions
• Need to balance computational speed and accuracy
Project test cases

Wavestar:
Operating cond.:
HD – lin./non-lin.
Moorings – N.A.
PTO – time dom. adv. control
Extreme cond.:
Simple – floaters out of water

Dexawave:
Operating cond.:
HD – lin.
Moorings – important, interaction
PTO – simple, passive damping
Extreme cond.:
CFD for structural loading

Weptos:
Operating cond.:
HD – multibody, highly non-linear, hydrostatics, variation of geometry
Moorings – important, weak interaction
PTO – highly non-lin.
Extreme cond.:
CFD for structural loading
Moorings – dyn. analysis
To date 33 ECTS (~150 lectures) given
Publication and dissemination

66 papers published

294 LinkedIn group members

38 press clips

Project website

46 invited lectures and public presentations

6 first and 2nd place SDWED Symposia

1st: 46 participants

2nd: 70 participants
Questions - comments?

Thank you!