WP 3 – PTO-Systems

Generator systems for WED

Jochen Bard, Peter Kracht; Fraunhofer IWES
Overview

- Design of rotating generator system
- Use case ¼-OWC
- Simulation technologies
- Ongoing Research on linear generators
Key part / Impact on:
- Reliability,
- Efficiency,
- O&M costs etc.

=> Project success depends on good generator design!

Research aims at:
- Knowledge base on requirements and characteristics
- Improved design process
- Simulation technologies etc
Generator system design

Requirements on generator system

- Control
- Grid connection
- Hull
- Marine Environment
- Maintenance
- Mooring
- Turbine

Structural Design of Wave Energy Devices – www.sdwed.civil.aau.dk

Generator system design

AALBORG UNIVERSITY

Department of Civil Engineering

Fraunhofer IWES

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Generator system design

Design process

Tools:
- Knowledge base,
- Simulation software,
- HIL-tests etc.
Turbine characteristics

Impulse-Turbine
- Low operational speed,
- High starting torque,
- High efficiency over wide flow range
- Expectable power range 0.5 – 1 MW
- ...

Characteristics of an example air-turbine

Generic requirements:
- Variable speed operation
- Low operational speeds
- Possibly no gear box
- High part load efficiency
- High overload capacity
- High mechanical reliability
- ...

Similar requirements for other frequently used turbine types
Generator system design

Candidate systems
- Doubly fed induction generator (DFIG)
- Asynchronous generators (ASG)
- Permanent magnet synchronous generators (PMG)
- Separate excited synchronous generators (SG)

Diagram: Frequency converter - generator system
### Generator system design

#### Performance of FC-generator systems

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>~ 90-95% (full load)</td>
</tr>
<tr>
<td>Overload Capacity</td>
<td>Torque_max/...rated</td>
</tr>
<tr>
<td>Control time constants</td>
<td>~ 2-4</td>
</tr>
<tr>
<td>Power factor</td>
<td>0...1 Independently controllable</td>
</tr>
<tr>
<td>Fault-ride-through</td>
<td>Good performance</td>
</tr>
<tr>
<td>Transient short circuit torques</td>
<td>Up to 15 times the rated torque</td>
</tr>
</tbody>
</table>

**Torque vs speed curve (source: DiracDelta)**

**Time history of short circuit moment**

- Torque Limited (Current Limit)
- Peak Rating
- Power Limited
- Continuous Rating
Benchmarking of generator systems

<table>
<thead>
<tr>
<th></th>
<th>DFIG</th>
<th>ASG</th>
<th>PMG</th>
<th>SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency (full-load)</td>
<td>+++</td>
<td>-</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Efficiency (part-load)</td>
<td>-</td>
<td>-</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Maintenance</td>
<td>--- (slip ring)</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Investment costs</td>
<td>-</td>
<td>+</td>
<td>+ (magnets?)</td>
<td>+</td>
</tr>
<tr>
<td>Reliability</td>
<td>--- (slip ring)</td>
<td>++</td>
<td>++</td>
<td>+ (?)</td>
</tr>
<tr>
<td>Range of rated speeds</td>
<td>-</td>
<td>-</td>
<td>+++</td>
<td>++</td>
</tr>
<tr>
<td>Availability</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Comparison of generator systems at 1MW rated power

DFIG: no option due to slip-ring wear out
ASG: transitional technology, demonstration projects
SG & PMG: most promising for future full-scale WECs
Use case ¼-scale OWC

CORES – EU / FP7 - Project

(source: HMRC)
### Use case ¼-scale OWC

(source: OceanEnergy Ltd.)

<table>
<thead>
<tr>
<th>Device characteristics</th>
<th>Requirements from dynamic simulations</th>
<th>Generator specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>- OWC</td>
<td>- Rated power: 11kW</td>
<td>- 8-pole Asynchronous generator</td>
</tr>
<tr>
<td></td>
<td>- Rated speed: 785 RPM</td>
<td>- Rated power 11kW</td>
</tr>
<tr>
<td></td>
<td>- Operating speed: 300 – 1300 RPM</td>
<td>- Overload capacity 300%</td>
</tr>
<tr>
<td>- Floating structure</td>
<td>- Run-away speed: 1600 RPM</td>
<td>- Rated speed: 769 RPM</td>
</tr>
<tr>
<td>- Backward Bent Duct</td>
<td>- Overload capacity: 20%</td>
<td>- Operating speed: 0 – 3000 RPM</td>
</tr>
<tr>
<td>- ¼-scale</td>
<td>- ...</td>
<td>- Marine version (certified by DNV, GL)</td>
</tr>
<tr>
<td>- Impulse-Turbine</td>
<td>- ...</td>
<td>- Standard frequency converter (IP21)</td>
</tr>
<tr>
<td>- ...</td>
<td>- ...</td>
<td>- ...</td>
</tr>
</tbody>
</table>

**PMG turned down mainly due to delivery time and costs!**
Use case ¼-scale OWC

OEBuoy in storm event (source: OceanEnergy LTD.)

Results of 3-month sea trial period

- No mechanical or electrical faults in fc-generator system
- 100% availability
- Peak power up to 25kW delivered to the onboard grid
- ...

Lessons learned

- Starting torque underestimated
- Hardware-in-the-Loop test significantly reduced commissioning time
- ...

Design process would significantly benefit from further simulation!
Simulation technologies

Modelling by set of characteristic curves, limits

- Torque limit
- Max speed
- Control response time
- ...

Suitable for investigations on:
- Control schemes
- Annual yield
- PTO-hull interaction
- Generator system specifications
- ....

Sufficient model grade for most use cases
Integration in Wave to Wire model

Tools:
- Adams
- Matlab/Simulink
- Modelica
- ....

Physical connection
Signal path
Ongoing research

- Matlab/Simulink model of PTO and hydrodynamics
- Aiming at investigations on PTO-system layout and control schemes
Ongoing research

Linear generator technologies

NEMOS WEC (source: Nemos)