Water Power Technologies Office Peer Review
Marine and Hydrokinetics Program

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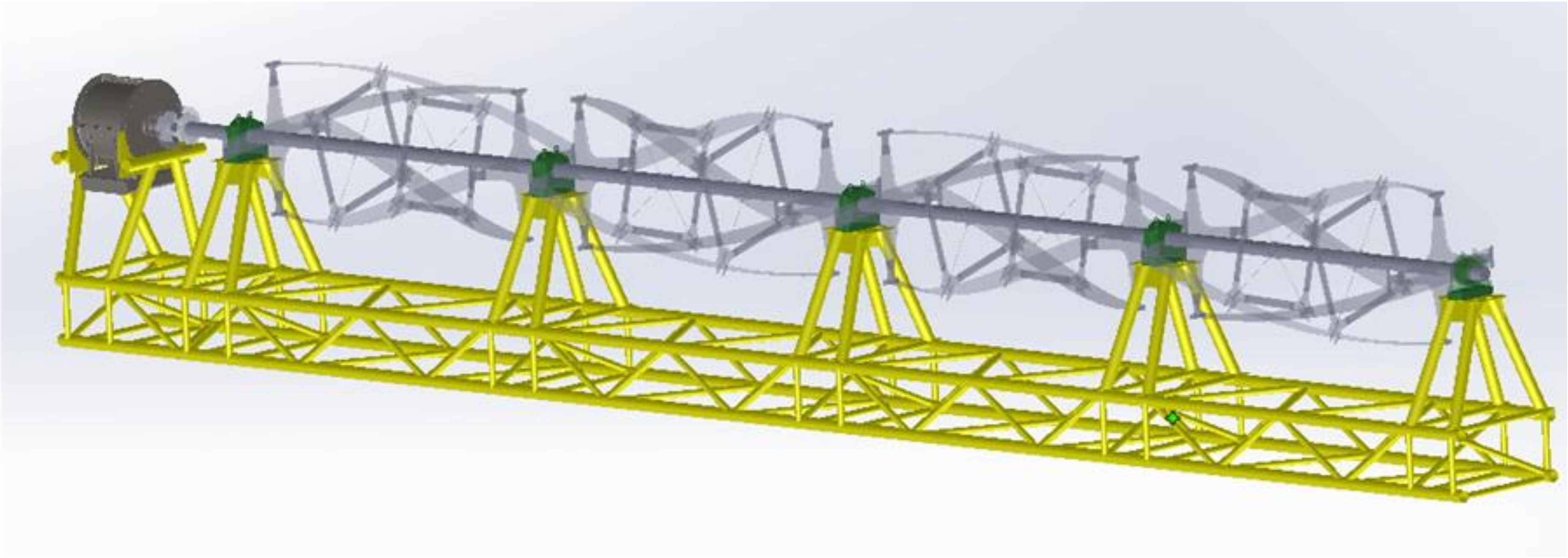

Power Take-off System for Marine Renewable Devices

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Project Overview

Power Take-off System for Marine Renewable Devices

- Operating conditions for subsea marine and hydrokinetic (MHK) bearings are known to the industry to be particularly challenging
  - Ocean Renewable Power Company (ORPC) has identified approaches to a bearing solution and proposes to evaluate different options to determine which solution promises the lower levelized cost of energy (LCOE).
- To provide reliable electrical generation, it is crucial to develop a generator that can withstand water intrusion
  - ORPC will design a high-reliability electrical generator system for application in MHK devices. ORPC expects that this design will comprise a pressure-compensated, fluid-filled generator with improved insulation. In the event of seawater intrusion into the generator, this design will maintain operability. With decreased repair times, availability will be increased as a result.

Project Overview

The Challenge:

- Bearings
  - Sliding bearings are subject to wear
  - Roller bearings require lubrication and seals
    - Seals are subject to wear and failure
  - Insufficient life for unattended operation (five years) subsea

- Generator
  - Salt water intrusion into generators damages insulation
  - Seals are wear/failure elements
  - Ability to tolerate any leakage is extremely limited

Project Overview

Partners:

- Ted Lesster, RCT Systems, Switched Reluctance Design
- Scott Jenne, National Renewable Energy Laboratory (NREL), Economic Advancement Impact
- Rick Fontana, Fontana Engineering, Bearing Design
- Hal Youngren, AeroCraft, Loads analysis using computational fluid dynamics (CFD)
- Eduard Muljadi, NREL, Generator Review and Guidance
- Espen Schuller, Rolls-Royce Marine, Permanent Magnet (PM) Machine Design

Program Strategic Priorities

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Technology Maturity

- Test and demonstrate prototypes
- Develop cost effective approaches for installation, grid integration, operations and maintenance
- **Conduct R&D for innovative MHK systems & components**
- Develop tools to optimize device and array performance and reliability
- Develop and apply quantitative metrics to advance MHK technologies

Deployment Barriers

- Identify potential improvements to regulatory processes and requirements
- Support research focused on retiring or mitigating environmental risks and reducing costs
- Build awareness of MHK technologies
- Ensure MHK interests are considered in coastal and marine planning processes
- Evaluate deployment infrastructure needs and possible approaches to bridge gaps

Market Development

- Support project demonstrations to reduce risk and build investor confidence
- Assess and communicate potential MHK market opportunities, including off-grid and non-electric
- Inform incentives and policy measures
- Develop, maintain and communicate our national strategy
- Support development of standards
- Expand MHK technical and research community

Crosscutting Approaches

- Enable access to testing facilities that help accelerate the pace of technology development
- Improve resource characterization to optimize technologies, reduce deployment risks and identify promising markets
- Exchange of data information and expertise

Project Strategic Alignment

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Technology Maturity

- Test and demonstrate prototypes
- Develop cost effective approaches for installation, grid integration, operations and maintenance
- **Conduct R&D for Innovative MHK components**
- Develop tools to optimize device and array performance and reliability
- Develop and apply quantitative metrics to advance MHK technologies

The Impact

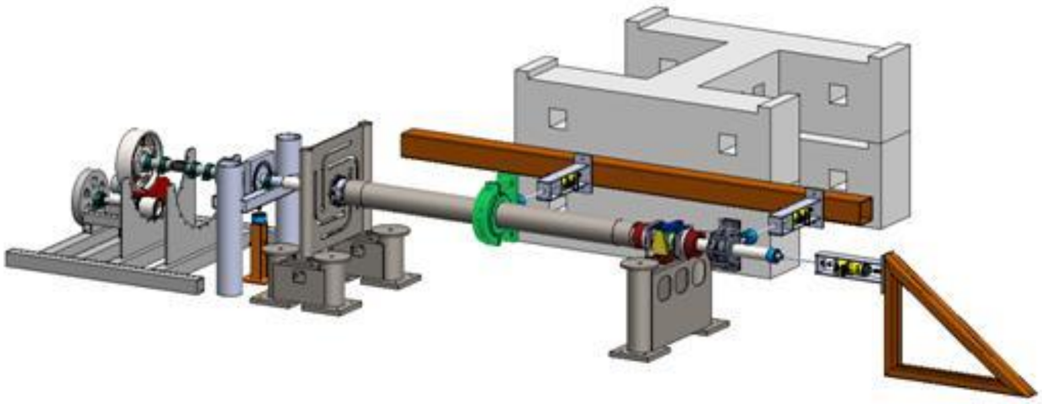
- Increase of the power-to-weight ratio (PWR) for the TidGen® TGU by an estimated 23% to 4.9kW/ton
- Availability target to 94%
- Reduction in LCOE of 25%
- High-availability electrical generator and bearings will have cross-industry applications
- Project end point are lab-tested generator and driveline subsystems

Generator Development

- Original hypothesis was that a switched reluctance electrical machine design would be preferred. A trade study found the switched reluctance (SR) design to be heavier, more complex, with no technical benefits over a permanent magnet design. The project team determined that a PM architecture was preferred over the SR design.
- Rolls-Royce Marine will produce the PM machine and use a newly developed encapsulation technology to seal the stator windings, which acts as a step closer to a fully “wet-gap” solution.
- ORPC is developing bearings capable of performing in a wet gap version of this generator.
- Final design showed improvements from 10,500 kg to 7,500 kg and from 1.3m to 1.1m length.
  - The total system efficiency is 90% at 32C, and better at typical market, operating conditions.
- Rolls-Royce Marine submitted the completed design package to vendors to begin the manufacturing process. Delays in winding of stator components have occurred. Final acceptance testing expected complete by February 2017.

Driveline Bearing Development

- Computational models were used to assess loads upon individual bearing components.
- ORPC has pursued two alternative bearing selections. Flume testing and laboratory analysis has shown a reduction in friction for these. Early test results anticipate low wear rates, supporting a five-year service life target.
- ORPC will construct a section of the TidGen® TGU driveline with novel bearings and test it with appropriate loads applied.
- Testing will occur at Advanced Structure and Composites Center (ASCC) at University of Maine. Initial assembly of the test-rig, shown below, is scheduled to begin at the ASCC in January 2017, with testing occurring in February.



Technical Approach

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Issues

- Change of course from SR to PM generator mid-project
- Delays in manufacturing of stator due to factory issues
- Change of location of driveline testing

Unique Aspects of approach

- Leak-tolerant generator design
- Long-life bearings
- Long maintenance interval

Accomplishments and Progress

Technical Accomplishments

- Bearing wear proven to be extremely small in testing
- Bearing friction very low

Original Technical Targets

- Increase of PWR by 23% to 4.9kW/ton
  - On target
- Increase availability to 94%
  - On target
- Reduction in LCOE of 25%
  - On target

Project Plan & Schedule

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- Original Project Period
  - 02/01/2014 – 04/30/2015 (BP1)
  - 05/01/2015 – 04/30/2016 (BP2)
- Extension approved for BP2
  - 05/01/2015 – 11/30/2016.
  - Go/No-Go decision point for BP2: Approved, June 23, 2015
- Extension request pending for BP2
  - 05/01/2015 – 03/31/2017
  - Delay in manufacturing generator components and driveline testing

Project Budget

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Budget History					
FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$506.8K	$175.6K	$554.7K	$204.2K	$922.1K	$110.6K

- BP2 budget had planned for driveline test work to be performed by generator manufacturer
  - Test work will now be performed by University of Maine
- 66% of the budget has been expended to date. Equipment procurement began in October 2016. Corresponding budget will be expended through the end of the year, about $200k. Deliverable payments to Rolls-Royce Marine, about $550k, will be expended in Q2, FY 2017.

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- NREL, Eduard Muljadi
- Fontana Engineering
- AeroCraft
- Rolls-Royce Marine

Communications and Technology Transfer

- One NREL Technical Report
- Three peer-reviewed technical papers

Next Steps and Future Research

FY17/Current research:

- Complete generator build and test
- Complete driveline build and test
- Systems Integration Report
- Finalize Impact Analysis
- Final Report

Proposed future research: In-water testing of the generator and driveline system is the next logical progression