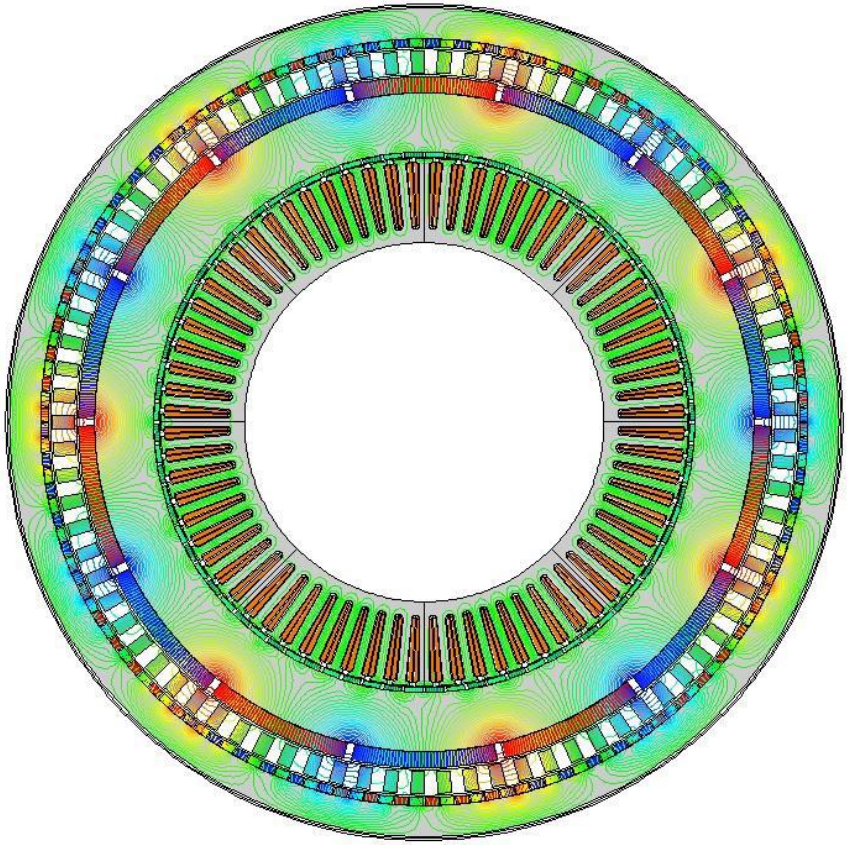

Advanced Direct-Drive Generator for Improved Availability of Oscillating Wave Surge Converter Power Generation Systems

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Project Overview

Advanced Direct-Drive Generator for Improved Availability of Oscillating Wave Surge Converter Power Generation Systems

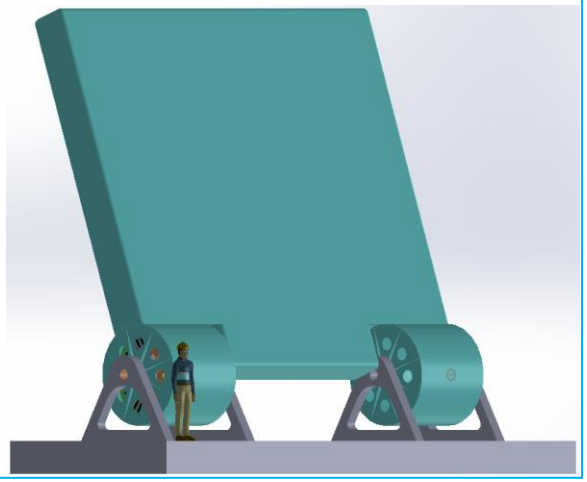
The Challenge: Economical ocean wave energy conversion

- Reliable, low-speed, high-torque electrical generation -

Partners:

Texas A&M – Magnetic Gear Design

Resolute Marine Energy – wave energy converter (WEC) System



Program Strategic Priorities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

Validate design and demonstrate enabling direct-drive generator technology for MHK applications

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

The Impact

- Significant improvements over existing PTO system
  - Reduction in levelized cost of energy (LCOE) (35%)
  - Increased energy generation (26%)
    - Increased peak power (100%)
    - Increased system efficiency (33%)
    - Increased availability expected
- Potential COTS component for MHK industry

Project Final Product

- Integrated magnetic-gear-generator
  - One of largest ever built
- Assembled and tested dry, lab prototype
  - 1/3 power, 15x speed
- Produced design for full-scale generator and PTO system

Project Value

- MHK industry lacking clear technology convergence
- System developers forced to (re)create their own solutions and components
  - Requiring significant time, expense, and expertise
- No direct-drive, low-speed, high-torque generators available
- This project enables commercial generators at the required low-speed and high-torque for MHK applications

- Partner Resolute Marine Energy supplied expertise on and specifications for wave energy conversion
  - Ensuring generator design is relevant to necessary power take-off (PTO) system
- Partner Texas A&M supported modeling and design of magnetic gears

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Technical Approach

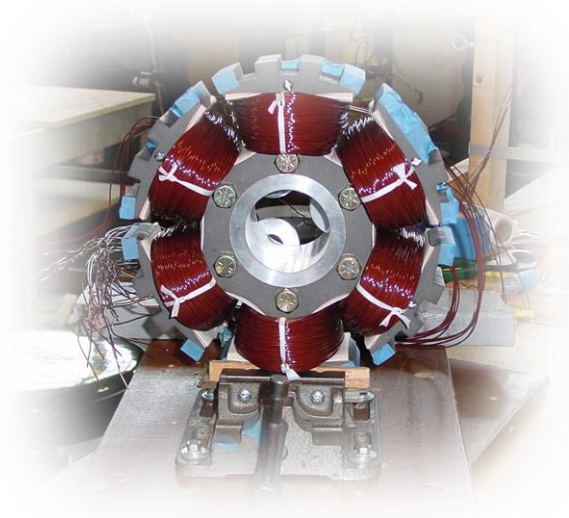
Major generator challenges:

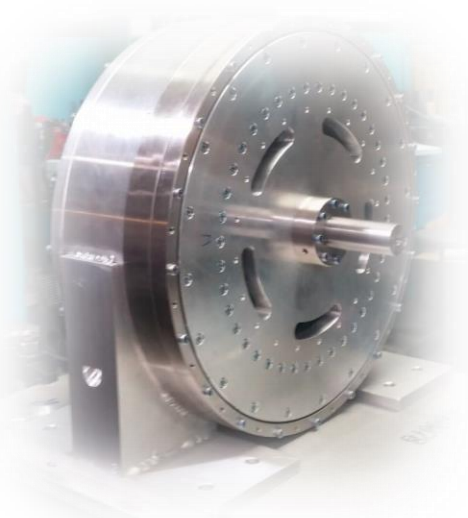
- Average speed from ocean waves less than 2 rpm
- More than 4 to 1 peak to average speed ratios

Design de-risked in 2 Stages: From 1 hp at 300 rpm, to 10 hp at 30 rpm

- Converged to integrated, magnetically geared generator

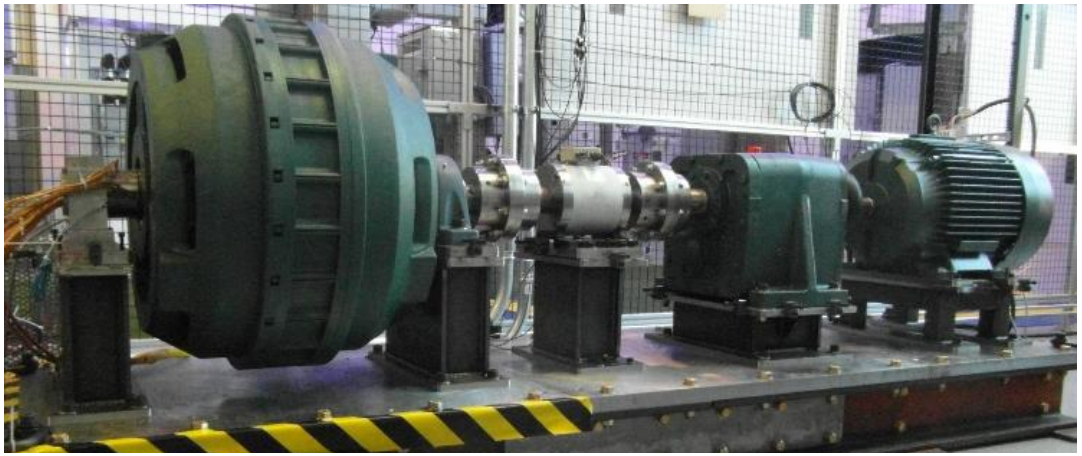
Design model assumptions validated at each stage, thus ensuring confidence in final design





Accomplishments and Progress

- Successfully built and tested one of the world's largest magnetically geared generators
  - 0.8 m diameter, 3800 Nm, 10 kW at 30 rpm
- Enabled 35% reduction in LCOE; efficiency and energy increased by 33% and 26%, respectively, versus baseline hydraulic PTO
- Tested torque limiting control to address peak torques with testing under oscillating ocean waveforms



Accomplishments and Progress

- Direct-drive electrical PTO also provides increased reliability, overload operation and protection, controllability for peak power and torque limiting
- Demonstrated generator performance under variety of waveforms enables broad, standardized application in industry
- Early commercialization possibilities for this low-speed, high-torque generator technology outside of marine and hydrokinetics (MHK)
  - Offshore and distributed wind energy
  - Marine propulsion

Project Plan & Schedule

- Project start date: 12/01/2013
- Phase 1: Evaluated three generator alternatives at 1 kW, 300 rpm scale
- Go/No-Go decision point passed June 2015
  - Following Phase 1 prototype demonstrations and model validation
- Phase 2: Design, build, and test 10kW, 30rpm prototype
  - Integrated radial-flux magnetic gear and generator topology selected
  - Full scale design delivered based on learning from Phase 1 and 2
  - Impact of new PTO evaluated compared to baseline WEC system
- Project completion date: 12/30/2016

Project Budget

Budget History					
CY2014		CY2015		CY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$356K	$152K	$996K	$354K	$1,745K	$493K

- No modifications to project plan
- 100% of project budget expended as of 2/2017
- No other funding sources used

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

Texas A&M – Magnetic Gear Design

Resolute Marine Energy – WEC System and Baseline PTO

North Carolina State University – Power Converter and Control

Baldor Advanced Technology – Mechanical Assembly

Communications and Technology Transfer:

IEEE and American Society of Mechanical Engineers (ASME) technical papers and conferences

Attended Wave Energy Prize Innovation Showcase

Various discussions with universities, national labs, and MHK developers on new in-water projects and/or additional developments

Next Steps and Future Research

FY17/Current research: Project completed 12/2016
All project milestones and deliverables complete

Proposed future research:

Strategy and technology development focusing on subsea operation that is durable and low cost

Improved cooling technologies (using seawater?)

Extension to marine propulsion and wind energy to enable efficiency and cost benefits similar to wave energy