DE-EE 8630 – An innovative SR-WEC for a market-disruptive LCOE

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Project Overview

Project Summary

• The objective is to develop and test a scaled prototype of Surface Riding Wave Energy Converter (SR-WEC) that can result in a market-disruptive Levelized Cost of Energy (LCOE) below 40 cents/kWh by combination of 1) extended operating window, 2) substantially lowered costs, and 3) amplified average power output by simple optimum control.
• The original objective also involves development of design methodology and proper simulation tools.

Intended Outcomes

• The project is 1) to complete optimum design of SR-WEC for the maritime market applications, 2) to confirm full performance of the SR-WEC using scalable wave tests of the scaled prototype in the wave basin and advanced global performance simulation, 3) to confirm the market disruptive LCOE less than 40 cents/kWh for single operation in the target application using the global performance simulation correlated with the scalable tests, and 4) identify remaining uncertainties and risks to be resolved in the larger scale prototype tests.

Project Information

Principal Investigator(s)

• PI: HeonYong Kang,
• Co-PI: Hamid Toliyat, Kuang-An Chang, Moo-Hyun Kim

Project Partners/Subs

• Dr. Toan Tran, Dr. David Ogden, Ms. Elena Baca from NREL.

Project Status

Ongoing

Project Duration

• Project Start Date: 9/1/2019
• Project End Date: 1/31/2023

Total Costed (FY19–FY22)

$504K
Project Objectives: Relevance to Program Goal (red boxes)

**Challenges**
- Difficult engineering to convert marine energy
  
**Foundational R&D**
- Installation and operation of reliable systems
  
**Technology-specific system design and validation**
- Difficult engineering to convert marine energy
  
**Approaches and Activities**
- Driven innovation in components, controls, materials, manufacturing, and systems
- Develop numerical and experimental tools and methodologies to understand fluid-structure interactions
- Improve MHK resource assessments and characterizations to optimize devices and arrays and understand extreme conditions
- Develop and apply quantitative metrics to identify and advance technologies with high ultimate techno-economic potential
- Validate performance and reliability systems through in-water tests of industry designed prototypes
- Improve methods for safe, cost-efficient installation, grid integration, operations, maintenance, and decommissioning
- Evaluate current and potential future needs for IO&M infrastructure
- Support the development and adoption of international standards for device performance and insurance certification
- Enable access to testing facilities to support the development and adoption of international standards for device performance and insurance certification

**Intermediate Outcomes**
- Use of improved resource assessments and characterization to effectively design and deploy devices
- Widespread understanding of fluid-structure interactions and use of advanced computational design tools and/or control strategies for new MHK device designs with improved energy extraction
- Dramatic LCOE reductions for MHK technologies driven by performance improvements and cost-reductions
- Increased private investment in and commercial demonstration of MHK technology designs and/or IO&M strategies for grid-scale, Power at Sea, and Resilient Coastal Community markets
- Widespread utilization of agreed upon international standards for device performance and insurance certification

**Long-Term Outcomes**
- Significant deployment of grid-scale cost-competitive MHK projects, driven by dramatic MHK technology LCOE reductions
- Increased growth of Blue Economy businesses and improved ability to monitor the world’s oceans through marine energy technologies
- Coastal/river community utilization of MHK technologies for improved energy independence and resilience

**Impact**
- Energy Affordability (e.g., reduced costs of energy/electricity)
- Energy Security (i.e., more resilient, flexible, and reliable energy systems)
- Economic Growth (e.g., jobs, supporting energy needs of new/growing sectors, export opportunities for new energy technologies)
Project Objectives: Approach

Approach: Development of Design Methodology

[Coupled Multi-Physics & Multi-Variables Design Optimization vs. segmented or decoupled]

Step 1. Out of the 4-variable parametric studies (10,000s to 100,000s cases), select a submerged volume that will ensure the first maximum energy conversion to a floating body in the form of hydrodynamics.

Step 2. From Step 1, the total mass of the linear generators is given, and specifications of linear generators are optimally designed through the 4-variable parametric studies (10,000s to 100,000s cases).

Step 3. Out of the fixed system design, determine the natural frequency for each sea state's peak period to result in the maximum conversion to the rotational motion's mechanical energy.

Step 4. Out of the 3-variable parametric studies (1000s cases), find the optimum PTO parameters to maximize average power output.
Approach: Development of Innovative Wave Energy Conversion Mechanism

[Adaptive Resonance for Varying Random Waves vs. targeting few frequencies]

Developed a Wave Energy Conversion Mechanism that achieves “effective energy capture for much wider sea state range” by “Adaptable Resonance” featuring

- In-situ Tp Measurements
- Individual Resonance for In-situ Tp

resulting in the maximum conversion to the mechanical power

Variation of $T_p$  
Changing $\omega_n$
## Project Objectives: Expected Outputs and Intended Outcomes

### Outputs:
- New Design Methodology integrating multi-physics and multi-variables
- New Wave Energy Conversion Mechanism effective for varying irregular waves
- Scaled-prototype of I/S-SR-WEC
- Deep-learning Fully Nonlinear Simulation
- Validation data from physical wave tests and correlated simulation models
- Full Prototype Design of I-SR-WEC validated for average power 5 kW with LCOE below 40 ¢/kWh
- Journal Publications(2-2/5-2/+), Patent(2+)

### Outcomes:
- Guidance to design a WEC
- Design and performance improvement of other WECs
- Commercial applications in powering the Blue Economy at the average power scale up to 5 kW.
- Promote more accurate prediction using fully nonlinear simulations accelerated through deep learning
Project Timeline

FY 2019-21
- Design Methodology Development
- Optimum Design Development
- Performance Assessment (AEP, LCOE)

FY 2021
- Go/No-Go Decision
- Presented the milestones and deliverables
- Received GO

FY 2022-23
- Prototype Fabrication & Validation
- Performance Assessment Update
- Correlated Simulation (Linear and Fully Nonlinear)
Project Budget

Total Project Budget – Award Information

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<tr>
<th>DOE</th>
<th>Cost-share</th>
<th>Total</th>
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<td>$752K</td>
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<td>$940K</td>
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FY19-21 | FY21-22 | Total Actual Costs FY19–FY22

<table>
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<tr>
<th>Costed</th>
<th>GNG Meeting in August 2021</th>
<th>Costed</th>
<th>Total Costed</th>
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<td>$414K</td>
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<td>$90K</td>
<td>$504K</td>
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- Before GNG Meeting in August 2021, we had 6-month of No Cost Time Extension.
End-User Engagement and Dissemination

• Stakeholder and/or end-user engagement strategy
  – Target End-User Group: diverse offshore operations that require remote energy supply up to average 5 kW from the single unit, including ocean observation, exploration, aquaculture, and integration with existing offshore platforms.
  – Commercialization initiative with individual end-users (ABS, Navy NAVFAC EXWC): shared technical details including benefits to end-users, communicating specific applications to develop for the end-users.
  – Plan to form or engage End-user Advisory Group when prototype tests start to specify required functionalities for the commercial applications.
  – Research outputs disseminated through invited talks, training program, and research outreach for underrepresented groups.

• Dissemination: along with publications in journals and proceedings, TEES Office of Commercialization and Entrepreneurship will manage technology transfer as well as commercialization.
Performance: Accomplishments and Progress

- Sequential Design Optimization
  - Time-domain floating body dynamics by Cummins' Equation
  - Time-domain generator dynamics for nonlinear power-take-off
  - Decoupled floating body dynamics with the generator dynamics
  - Uncertainties in OpEx

- LCOE Calculation using NREL SAM

<table>
<thead>
<tr>
<th>Location</th>
<th>NOAA Buoy Location</th>
<th>Linear Generator</th>
<th>Average Power</th>
<th>Average Annual Power Production (kWh)</th>
<th>LCOE (¢/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Coast</td>
<td>41002</td>
<td>6 m, 14 units</td>
<td>5 kW</td>
<td>38,092</td>
<td>37.68</td>
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<tr>
<td></td>
<td></td>
<td>4 m, 20 units</td>
<td></td>
<td>38,119</td>
<td>47.12</td>
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</table>

I-SR-WEC
35.84 vs kW/MN

Refinement of the Optimum Design using Fully Nonlinear Simulation
Fabrication and Wave Basin Test of a Scaled Prototype
Update Performance Metrics
Performance: Accomplishments and Progress (cont.)

Publications

Simulation or Computation Tool
1. Development of Fully Nonlinear Simulation accelerated by GPU parallelization and Deep Learning
2. Development of Control of National Frequency to adapt the resonance for a given in-situ sea state
Future Work

• Refinement of Final Optimum Design using Accelerated Fully Nonlinear Simulation

• Fabrication of Scaled-Prototype and Test Gradually from Subsystems
  ✓ 3D Printing + Generator Fabrication and Assembly
  ✓ Dry Actuator Tests for regular/irregular waves
  ✓ 2D Wave Basin Tests for regular/irregular/varying regular & irregular waves

• Performance Metrics Validation & Update

• Correlation of Simulations with Experiment Data

• Continuous Design Evolution
Q&A