NREL and Sandia National Laboratories (SNL) Support of Ocean Renewable Power Company's TidGen™ Power System Technology Readiness Advancement Initiative Project

Cooperative Research and Development Final Report

CRADA Number: CRD-12-481

NREL Technical Contact: Al LiVecchi

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Cooperative Research and Development Final Report

In accordance with Requirements set forth in Article XI, A(3) of the CRADA document, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Ocean Renewable Power Company and Sandia National Laboratories

CRADA Number: CRD-12-481

CRADA Title: NREL and Sandia National Laboratories (SNL) support of Ocean Renewable Power Company's TidGen™ Power System Technology Readiness Advancement Initiative Project

Joint Work Statement Funding Table Showing DOE Commitment:

Estimated Costs	NREL Shared Resources
Year 1	$ 320,000.00
Year 2	$ 105,000.00
TOTALS	$ 425,000.00

Abstract of CRADA Work:

This document summarizes the tasks identified for National Laboratory technical support of an Ocean Renewable Power Corporation (ORPC) DOE grant awarded under the FY10 Industry Solicitation DE-FOA-0000293: Technology Readiness Advancement Initiative. The system that ORPC will deploy in Cobscook Bay, ME, is known as the TidGen™ Power System. Each Turbine Generator Unit (TGU) has a rated capacity of 150 to 175 kW, and they are mounted on bottom support frames and connected to an on-shore substation using an underwater power and control cable. This system is designed for tidal energy applications in water depths from 60 to 150 feet. In funding provided separately by DOE, National Laboratory partners NREL and SNL will provide in-kind resources and technical expertise to help ensure that industry projects meet DOE WWPP (Wind and Water Power Program) objectives by reducing risk to these high value projects.

Summary of Research Results:

See Attachment A

Subject Inventions Listing:

None

Report Date:

2/12/15

Responsible Technical Contact at Alliance/NREL:

Al LiVecchi

This document contains NO confidential, protectable, or proprietary information.

Sandia National Laboratories

Operated for the U.S. Department of Energy by

Sandia Corporation

Albuquerque, New Mexico

ATTACHMENT A TO FINAL REPORT

PROJECT ACCOMPLISHMENTS SUMMARY

Cooperative Research and Development Agreement (#1793.03)
between **Sandia National Labs** and The National Renewable Energy Laboratory and Ocean Renewable Power Company

Note: This Project Accomplishments Summary will serve to meet the requirements for a final abstract and final report as specified in Article XI of the CRADA.

Title:
NREL and Sandia National Laboratories (SNL) Support of Ocean Renewable Power Corporation (ORPC) TidGen™ Power System Technology Readiness Advancement Initiative Project

Final Abstract:
This document summarizes the work completed for National Laboratory technical support of Ocean Renewable Power Corporation (ORPC) DOE grant awarded under the FY10 Industry Solicitation DE-FOA-0000293: Technology Readiness Advancement Initiative. The system ORPC will deploy in Cobscook Bay, ME is known as the TidGen™ Power System. The Turbine Generator Unit (TGU) each have a rated capacity of 150 to 175 kW, and are mounted on bottom support frames and connected to an on-shore substation using an underwater power and control cable. This system is designed for tidal energy applications in water depths from 60 to 150 feet. Using funding provided separately by DOE, National Laboratory partners NREL and SNL will provide in-kind resources and technical expertise to help ensure that industry projects meet DOE (Wind and Water Power Program) WWPP Program objectives by reducing risk to these high value projects.

Background:
The probability of success of lengthy and very expensive device development and testing cycles in the nascent marine and hydrokinetic (MHK) industry is substantially increased by leveraging the experience gained and lessons learned in wind energy and marine engineering, through the combined experience of the national laboratories. These efforts aim to decrease risks for future device deployments, provide a faster path to technology maturation and device commercialization, and inform evolving international MHK standards. Areas of support generally include: Design review and guidance; modeling and analysis; component, sub-system and materials testing; and open-water testing, measurement, and monitoring.

This CRADA allowed Sandia National Laboratories (SNL), in collaboration with the National Renewable Energy Laboratory (NREL), to leverage its experience in these areas and to provide in-kind resources and technical expertise to support the Ocean Renewable Power Corporation

(ORPC) project, Technology Readiness Advancement Initiative for the advancement of their TidGen™ Power System. This system was estimated at the start of the project to be at a technology readiness level of between 7 and 9. The system consists of four turbine generator units (TGU). Each TGU has a rated capacity of 150 to 175 kW. TGUs are mounted on bottom support frames and connected to an on-shore substation using an underwater power and control cable. This system was designed for tidal energy applications in water depths from 60 to 150 feet.

Funding for SNL and NREL was provided separately by DOE. Specific project objectives are detailed in the section below.

Description:
The National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL) collaborated with ORPC to support the development of ORPC's axial-flow current turbine technologies. This multi-party collaboration was conducted under a Cooperative Research and Development Agreement (CRADA) to define the collaborative tasks, and confidentiality and intellectual property provisions.

The efforts in this project directly support the development of specific MHK technologies and are proprietary and confidential in nature. However, this work does inform the development of MHK specific analyses and tools and enables direct national laboratory connection to evolving industry needs.

Specific collaborative tasks included:

1. TidGen™ Design Review
2. TidGen™ Failure Modes and Effects Analysis
3. Foil Joint Design and Performance Assessment
4. Model-to-Model Comparison
5. Array Optimization
6. Composite Fatigue Testing with Fiber-Bragg-Grating Sensors
7. High Fidelity Modeling of RivGen™ System

1. <u>Design Review</u>

A design review of the TidGen™ system by NREL and SNL experts in structural design, wind turbine design and operation, marine instrumentation, generators, fluid mechanics, modeling, and wind turbine SCADA and "field" testing identified and provided guidance and feedback on priority system refinement areas. The team then constructed specific collaborative work packages to advance high priority areas identified in the design review where significant relevant national laboratory expertise was applicable.

2. <u>Failure Modes and Effects Analysis</u>

A combined NREL/SNL team conducted a Failure Modes and Effects Analysis (FMEA) of the TidGen® system, including in-depth analysis of electrical, control, and structural sub-systems, to inform future design iterations and deployment and operations strategies. A risk assessment of failure modes was delivered to ORPC and actions were recommended to prevent/mediate risks. ORPC is directly incorporating these findings into TidGen® design refinement planning.

3. Foil Joint Design and Performance Assessment

A combined NREL/SNL team reviewed the designs and post-deployment assessment reports, engaged with ORPC engineers, and provided an assessment of the designs along with suggested actions and options to improve the designs. As part of this assessment, SNL performed a hydro-elastic analysis, using the CACTUS model, focusing on the joints in question.

4. Model to Model Comparison

SNL completed CACTUS modeling of the TidGen® device and preliminary comparisons were made with the ORPC stream tube model results provided by ORPC. SNL also completed an optimization study of the ORPC cross-flow rotor using CACTUS and DAKOTA. The optimization study expanded the design space by investigating straight vs. helical blades, the number of blades, and chord-to-radius ratios. The optimization study provided some useful qualitative comparisons between these different design configurations, along with exercising the CACTUS model to identify present limitations and areas for augmentation.

5. Array Optimization

SNL developed an optimization framework to identify optimal placement locations leading to array configurations of current energy converter (CEC) devices that will maximize energy production and minimize environmental effects. The framework utilizes a hydrodynamic modeling platform, known as SNL-EFDC, to investigate flow patterns before and after MHK array placements. In addition to maximizing device performance, the framework also considered potential environmental effects so that conditions which may alter fish behavior and sediment-transport trends could be avoided.

The array optimization framework was applied to Cobscook Bay, ME, the first deployment site of the ORPC's TidGen^{tm} device and ORPC's team was trained in its use and SNL has supported the ORPC model development team with their development of SNL-EFDC models of Cobscook Bay and Western Passage to inform future array deployments.

6. Composite Fatigue Testing with Fiber-Bragg-Grating Sensors

SNL, in collaboration with Montana State University and Micron Optics, investigated the feasibility of using Fiber Bragg Grating Sensors to enable future deployment monitoring of TidGen™ foil structural integrity. The laboratory study evaluated material health and performance for MHK devices by investigating the bond strength of externally adhered fiber optic strain sensors under static and fatigue loading. Fiber-optic Fiber Bragg Grating (FBG) sensors were selected as they provide a compact and robust sensor that has been successfully used within the marine environment to measure strains and temperatures of static objects made of metals and concrete, and have begun to be used with composite structures. The FBG sensors were externally adhered and conditioned in salt water prior to static and fatigue testing to mimic the marine environment. This work leveraged Sandia Wind Instrumentation and Sandia Advanced Materials & Manufacturing Program. The results provided data as to the longevity and accuracy of externally bonded sensors on dynamic systems operating within marine environments for MHK developers.

7. High Fidelity Modeling of RivGen™ System

The Sandia-ORPC team applied high fidelity modeling to evaluate the performance of the RivGen® prototype turbine generation unit, a cross-flow turbine, which exhibits more complex flow physics than the more common axial-flow turbine. The 3D unsteady Reynolds-averaged Navier-Stokes (URANS) models used to predict power performance were first validated using a unique set of field measurements collected by ORPC in Cobscook Bay in 2014. Numerical experiments, simulated on Glory, were then conducted to investigate and quantify parasitic drag effects on turbine performance and how these effects could be mitigated to improve performance. The results of this investigation provide a clear path for modifications to be made in the next design iteration of the RivGen® turbine.

This study also demonstrated the value of high fidelity modeling, and High Performance Computing (HPC) resources, when resolving the complex 3D flow effects on performance that are sometimes encountered with complex turbine architectures.

Benefits to the Department of Energy:
The project supports energy security through a diversified energy portfolio that includes energy sources derived from MHK technologies. It leveraged DOE investments and national laboratory core competencies in wind and water power technologies, as well as high performance computing (HPC) resources. It identified limitations of mid-fidelity models, including, CACTUS, for predicting the power performance of complex crossflow turbines; namely due to their failure to predict complex 3D flow and resulting parasitic drag effects, which were found by high fidelity modeling of the RivGen® system to significantly reduce performance.

Economic Impact:
The probability of success of lengthy and very expensive device development and testing cycles in the nascent MHK industry will be increased by leveraging the experience gained and lessons learned in wind energy and marine engineering, through the combined experience of the national laboratories. These efforts aim to decrease risks for future device deployments, provide a faster path to technology maturation and device commercialization, and inform evolving international MHK standards. Areas of support generally include: Design review and guidance; modeling and analysis; component, sub-system and materials testing; and open-water testing, measurement, and monitoring.

The technical support provided by SNL and NREL will accelerate the advancement of the TidGen™ and RivGen® Systems by identifying key areas for design iteration to improve structural performance, power performance, monitoring and array optimization. ORPC is using the analysis and recommendations provided by SNL and NREL to plan redesign and testing efforts for these systems.

Project Status:
Completed September 30, 2014

ADDITIONAL INFORMATION

Laboratory/Department of Energy Facility Point of Contact for Information on Project

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CRADA Intellectual Property

See CRADA. Trademark on TidGen™ System. Legal registration on RivGen® System.

Technology Commercialization

No. The results of the project indicate that the TidGen™ and RivGen® Systems will still require more design iterations before being commercialized.

Project Examples

The project highlighted value of leveraging DOE investments in wind power and ocean engineering, and high performance computing. The RivGen® work will be featured in an article published in Sandia's 2014 HPC Annual Report, "HPC Provides High Fidelity Evaluation of Tidal Turbine Performance for Industry Partner." However, it would be premature to present this project during a Congressional testimony because the technology still requires more design iterations before being commercialized.