Power Take-off System for Marine Renewable Devices

Cooperative Research and Development Final Report

CRADA Number: CRD-14-566

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In accordance with Requirements set forth in Article X: REPORTS AND PUBLICATIONS A.(2), of the CRADA agreement, 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

CRADA number: CRD-14-566

CRADA Title: Power Take-off System for Marine Renewable Devices

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1 Year 2	$ 149,416.00 $ 165,623.00
TOTALS	$ 315,039.00

Abstract of CRADA Work:

Ocean Renewable Power Company (ORPC) proposes a project to develop and test innovative second-generation power take-off (PTO) components for the U.S. Department of Energy's 2013 FOA: Marine and Hydrokinetic System Performance Advancement, Topic Area 2 (Project). Innovative PTO components will include new and improved designs for bearings, couplings and a subsea electrical generator. Specific project objectives include the following: (1) Develop components for an advanced PTO suitable for MHK devices; (2) Bench test these components; (3) Assess the component and system performance benefits; (4) Perform a system integration study to integrate these components into an ORPC hydrokinetic turbine. National Renewable Energy Laboratory (NREL) will participate on the ORPC lead team to review design of the generator and will provide guidance on the design. Based on inputs from the project team, NREL will also provide an economic analysis of the impacts of the proposed system performance advancements.

Summary of Research Results:

The research results are reported in the following technical papers and reports:

1. Eduard Muljadi, Alan Wright, Vahan Gevorgian, James Donegan, Cian Marnagh, Jarlath McEntee. "Dynamic Braking System of a Tidal Generator: Preprint.": 7 pp. 2016. http://www.nrel.gov/docs/fy16osti/66396.pdf.

Description: Renewable energy generation has experienced significant cost reductions during the past decades, and it has become more accepted by the global population. In the beginning, wind generation dominated the development and deployment of renewable energy; however, during recent decades, photovoltaic (PV) generation has grown at a very significant pace due to the tremendous decrease in the cost of PV modules. The focus on renewable energy generation has now expanded to include new types with promising future applications, such as river and tidal generation. The input water flow to these types of resources is more predictable than wind or solar generation. The data used in this paper is representative of a typical river or tidal generator. The analysis is based on a generator with a power rating of 40 kW. The tidal generator under consideration is driven by two sets of helical turbines connected to each side of the generator located in between the turbines. The generator is operated in variable speed, and it is controlled to maximize the energy harvested as well as the operation of the turbine generator. The electrical system consists of a three-phase permanent magnet generator connected to a three-phase passive rectifier. The output of the rectifier is connected to a DC-DC converter to match the rectifier output to the DC bus voltage of the DC-AC inverter. The three-phase inverter is connected to the grid, and it is controlled to provide a good interface with the grid. One important aspect of river and tidal generation is the braking mechanism. In a tidal generator, the braking mechanism is important to avoid a runaway condition in case the connection to the grid is lost when there is a fault in the lines. A runaway condition may lead to an overspeed condition and cause extreme stresses on the turbine blade structure and eventual disintegration of the mechanical structure. In this paper, the concept of the dynamic braking system is developed and investigated for normal and abnormal operations. The main objective is to optimize the performance under emergency braking while designing the system to be as simple as possible to avoid overdesigning the power electronics or exceeding the target budget.

- **Publication Date:** August 2016
- **Source:** NREL Publications Database

2. Eduard Muljadi, Alan Wright, Vahan Gevorgian, James Donegan, Cian Marnagh, Jarlath McEntee. "Turbine Control of a Tidal and River Power Generator." *Proceedings of the 2016 North American Power Symposium (NAPS), 18-20 September 2016, Denver, Colorado*: 5 pp. Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE). 2016. https://doi.org/10.1109/NAPS.2016.7747912.
Description: As renewable generation has become less expensive during recent decades, and it becomes more accepted by the global population, the focus on renewable generation has expanded to include new types with promising future applications, such as river and tidal generation. The input variations to these types of resources are slower but also steadier than wind or solar generation. The level of water turbulent flow may vary from one place to another, however, the control algorithm can be adjusted to local environment. This paper describes the hydrokinetic aspects of river and tidal generation based on a river and tidal generator. Although the information given in this paper is not that of an exact generator deployed on site, the data used is representative of a typical river or tidal generator. In this paper, the hydrokinetic and associated electrical controller

of the system were not included; however, the focus of this paper is on the hydrodynamic control.

- **Publication Date:** November 2016
- **Source:** NREL Publications Database

3. Eduard Muljadi, Alan Wright, Vahan Gevorgian, James Donegan, Cian Marnagh, Jarlath McEntee. 2016. *Power Generation for River and Tidal Generators*. NREL/TP-5D00-66097. http://www.nrel.gov/docs/fy16osti/66097.pdf.
Description: Renewable energy sources are the second largest contributor to global electricity production, after fossil fuels. The integration of renewable energy continued to grow in 2014 against a backdrop of increasing global energy consumption and a dramatic decline in oil prices during the second half of the year. As renewable generation has become less expensive during recent decades, and it becomes more accepted by the global population, the focus on renewable generation has expanded from primarily wind and solar to include new types with promising future applications, such as hydropower generation, including river and tidal generation. Today, hydropower is considered one of the most important renewable energy sources. In river and tidal generation, the input resource flow is slower but also steadier than it is in wind or solar generation, yet the level of water turbulent flow may vary from one place to another. This report focuses on hydrokinetic power conversion.

- **Publication Date:** June 2016
- **Source:** NREL Publications Database

4. Eduard Muljadi, Vahan Gevorgian, Alan Wright, James Donegan, Cian Marnagh, Jarlath McEntee. "Electrical Power Conversion of a River and Tidal Power Generator: Preprint.": 8 pp. 2016. http://www.nrel.gov/docs/fy16osti/66866.pdf.
Description: As renewable generation has become less expensive during recent decades, and it becomes more accepted by the global population, the focus on renewable generation has expanded to include new types with promising future applications, such as river and tidal generation. Although the utilization of power electronics and electric machines in industry is phenomenal, the emphasis on system design is different for various sectors of industry. In precision control, robotics, and weaponry, the design emphasis is on accuracy and reliability with less concern for the cost of the final product. In energy generation, the cost of energy is the prime concern; thus, capital expenditures (CAPEX) and operations and maintenance expenditures (OPEX) are the major design objectives. This paper describes the electrical power conversion aspects of river and tidal generation. Although modern power converter control is available to control the generation side, the design was chosen on the bases of minimizing the CAPEX and OPEX; thus, the architecture is simple and modular for ease of replacement and maintenance. The power conversion is simplified by considering a simple diode bridge and a DC-DC power converter to take advantage of abundant and low-cost photovoltaic inverters that have well-proven grid integration characteristics (i.e., the capability to

produce energy with good power quality and control real power and voltage on the grid side).

- **Publication Date:** September 2016
- **Source:** NREL Publications Database

Subject Inventions Listing:

N/A

Report Date:

See above

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