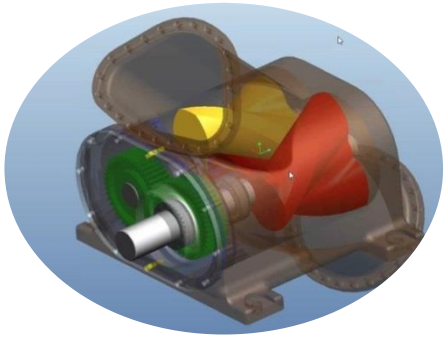
Eaton Roots Rotor Technology

Roots-based Hydro Turbine for Low Head Dams



Cost-Optimized Modular Helical Rotor Turbine-Generator System for Small Hydro Power Plants

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Project Overview

Cost-Optimized Modular Helical Rotor Turbine-Generator System for Small Hydro Power Plants: Develop a cost-effective Roots-based turbine-generator package to cost effectively deploy hydropower generation at existing non-powered dams and constrained waterways

The Challenge: Cost-effective solution to harvest the potential energy in existing non-powered dams and constrained waterways with low heads and flows

Partners:

- Alden Research Laboratory: Fish passage and debris management studies; laboratory testing of prototype turbine
- Kettering University: computational fluid dynamics (CFD) modeling of various turbine designs
- Roush Industries: CAD and finite element analysis (FEA) modeling of turbine designs
- Oakridge National Laboratory: Hydropower cost modeling

Next Generation Hydropower (HydroNEXT)

Optimization

- Optimize technical, environmental, and water-use efficiency of existing fleet
- Collect and disseminate data on new and existing assets
- Facilitate interagency collaboration to increase regulatory process efficiency
- Identify revenue streams for ancillary services

Growth

- **Lower costs of hydropower components and civil works**
- Increase power train efficiency for low-head, variable flow applications
- Facilitate mechanisms for testing and advancing new hydropower systems and components
- Reduce costs and deployment timelines of new PSH plants
- Prepare the incoming hydropower workforce

Sustainability

- Design new hydropower systems that minimize or avoid environmental impacts
- Support development of new fish passage technologies and approaches
- Develop technologies, tools, and strategies to evaluate and address environmental impacts
- Increase resilience to climate change

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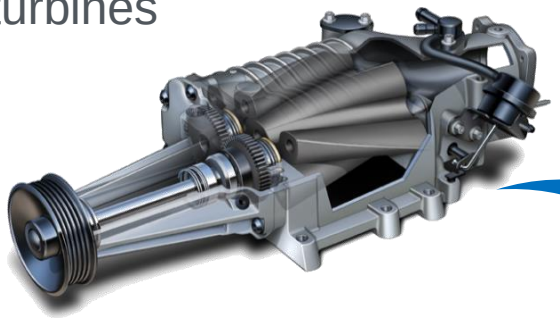
The Impact

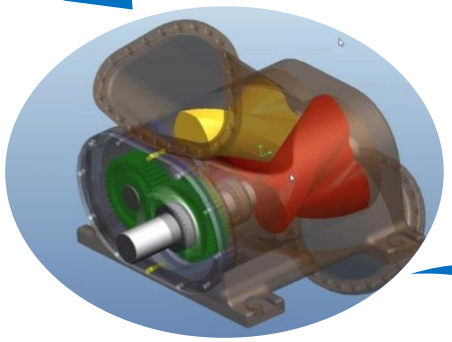
- Target >80% mechanical efficiency
- Target <$2,000 per kW initial capital cost (ICC)
- Target <0.056 levelized cost of energy (LCOE)
- Enable cost-effective hydropower generation at existing non-powered dams with low head and flow
- Project Endpoint:
  - Performance testing of a sub-scale Roots-based rotor turbine in a laboratory environment
  - Hydropower system cost modeling to evaluate the helical Roots-based turbine ICC and LCOE

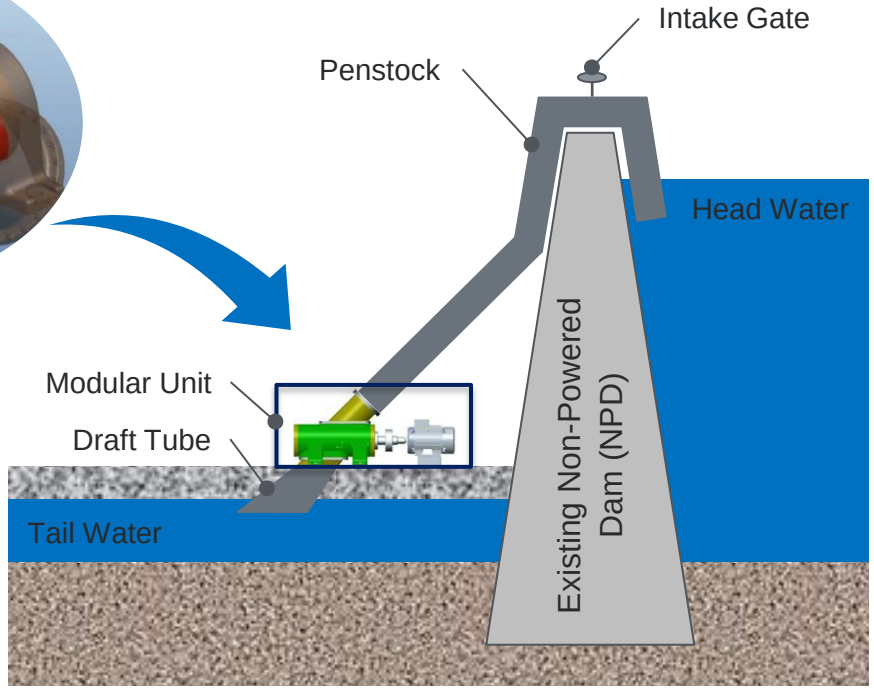
Technical Approach

- Leverage Eaton's technology, manufacturing and commercial experience with Roots-based compressors and expanders to create value in Roots-based hydro power turbines



- Develop a Roots-based hydro power turbine that has a broad efficiency range to maximize power generation benefit





- Integrate the turbine-generator into small modular units that can be installed above the tail water to reduce system and civil costs

Technical Approach

Value = Benefit – Cost

Increase Benefit by:

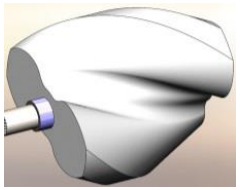
- CFD to develop a Roots-based turbine design with a broad efficiency range to maximize power generation through the seasonal head and flow cycles of a non-powered dam
  - CFD methodology proven through design of air compressors for engine intake, air management systems for fuel cells and expanders for Rankine cycle waste heat recovery

Decrease Cost by:

- Leveraging Eaton's supercharger rotor manufacturing expertise to develop a low-cost method to manufacture the hydro turbine rotors in commercial volumes
  - Solid polymer rotor versus hollow metal rotor
- Eaton's Electrical Sales and Services division to develop a cost-effective modular turbine-generator package

Accomplishments and Progress

- Developed a 2-lobe Roots-based rotor design through CFD that is predicted to achieve the target 80% mechanical efficiency
  - Stresses and strains are reasonable
  - Bearing forces are manageable
  - Specifications for fish and debris management intake screens are commercially available.



- System Architecture Study of the turbine-generator system to develop an understanding of the trade-off in performance, versatility and cost for non-powered dam applications in the United States
  - 750mm diameter rotor, ~50kW at 12m head
- Preliminary manufacturing costs estimates suggests the Roots-based turbine-generator is cost comparable to bulb turbine-generator
  - Refine manufacturing process and cost estimates during Budget Period 2 (BP2)

Project Plan & Schedule

	DOE FY2015		DOE FY2016				DOE FY2017				DOE FY2018	
Key Milestones	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Project Initiation	▲											
Go/no-go Decision							▲					
Project Planned Completion											▲	

- Schedule includes 6-month no-cost time extension due to:
  - Delay due to sub-recipient contract negotiations
  - Additional turbine design effort required to achieve 80% efficiency target.

Project Budget

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

Budget History					
FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
		$89K	$25K	$516K	$144K

- Variances: BP1 material costs savings for 3D printing of concept models by leverage resources in Eaton's new Additive Manufacturing Center of Excellence
- Project budget expended through FY2016: 36%
- Other funding sources: None.

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

- Alden Research Laboratory: Greg Allen, Ben Coleman, George Hecker
- Kettering University: Bassem Ramadan
- Roush Industries: Jim Strid, Nitin Talekar, Matt Van Benschoten, Rich Wineland
- Oakridge National Laboratory: Patrick O'Connor

Communications and Technology Transfer:

None

Next Steps and Future Research

FY17/Current research:

- Build and test a sub-scale prototype to validate CFD predicted performance and measure indications of cavitation – 8/2017
- Develop turbine cost inputs for Oak Ridge National Laboratory's (ORNL's) Hydropower Cost Model – 3/2017
- ICC and LCOE using ORNL's Hydropower Cost Model – 8/2017
- Commercialization analysis report to assess commercial viability – 10/2017

Proposed future research:

- Perform full-scale field installation and operation to validate turbine performance, ICC, and LCOE.