Rapidly Deployable Advanced Integrated Low Head Hydropower Turbine Prototype

EE0006928
## Project Overview

### Project Summary

- Develop and test a rapidly deployable advanced modular hydropower turbine-generator design targeting low LCOE.
- Fabricated and tested a 0.2m prototype model in ARL’s 0.305m diameter water tunnel facility under variable flow conditions.
- Developed and tested additive manufacturing capability
- Performed a cost-assessment feasibility study for advanced manufacturing including 0.9 m diameter scale IGV and rotor blade builds.

### Project Objective & Impact

- The primary objective of this project is to develop and demonstrate a rapidly deployable, modular advanced integrated hydropower turbine-generator system with the potential to lower Levelized Cost of Energy (LCOE) through:
  - Design for advanced manufacturing
  - Scalability of design for wide range of site conditions
  - Modularity to simplify installation as well as reduce costs and environmental impact
  - Incorporation of CBM system to impact OpEx costs

## Project Information

### Project Principal Investigator(s)

- PI: Dr. Arnold Fontaine
- Co-PI: Jeffery Banks
- Co-PI: Wesley Mitchell
- Dr. Nicholas Jaffa

### WPTO Lead

- Rajesh Dham
- Michael Carella
- Erik Mauer

### Project Partners/Subs

- General Atomics

### Project Duration

- Project Start Date: July 1, 2015
- Project End Date: June 30, 2019
Alignment with the Program

Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

- Technology R&D for Low-Impact Hydropower Growth
- R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet
- Understand, Enable, and Improve Hydropower’s Contributions to Grid Reliability, Resilience, and Integration
Alignment with the Hydro Program

Environmental R&D and Hydrologic Systems Science

- Develop better monitoring technologies to evaluate environmental impacts
- Develop technologies and strategies that avoid, minimize, or mitigate ecological impacts
- Support development of metrics for better evaluating environmental sustainability for new hydropower developments
- Assess potential impacts of long-term hydrologic variations to hydropower generation and flexibility
- Improve abilities to assess potential methane emissions from reservoirs
- Better identify opportunities and weigh potential trade-offs across multiple objectives at basin-scales

Reduced Environmental Impact Through:

- Modular in-line axial flow design allows for deployment with minimal flow passage civil works.
- Hub-less design features an open centerline designed to be self cleaning.

Self cleaning feature verified during water tunnel test
Alignment with the Hydro Program

Technology R&D for Low-Impact Hydropower Growth

- Enable the design and development of new Standard Modular Hydropower (SMH) technologies for both existing water infrastructure and new stream-reach development. This new approach to systems design for hydropower projects incorporates ecological and social objectives for river systems earlier in design processes
- Leverage new advancements in manufacturing and materials to dramatically lower costs of SMH components and systems designs
- Support development of necessary testing infrastructure for new technologies

Reduce LCOE through:

- Modular design with scalable components for reduced initial capital costs
- Turbine designed for wide range of operating conditions for maximizing power generation
- Condition based maintenance (CBM) for reduced operations costs
- Designed for reduced O&M costs
- Design for advanced manufacturing (AM) to reduce initial capital costs
  - Blades designed and tested for metal AM processes
  - Inflow and outflow components identified as likely for potential cost reduction using AM
Alignment with the Hydro Program

R&D to Support Modernization, Upgrades, and Security for Existing Hydropower Fleet

- Create mechanisms to classify diverse hydropower plants by mechanical and cyber-physical systems, providing better characterization of the fleet and allowing identification of exemplary facilities / practices
- Advanced instrumentation and data evaluation to improve equipment longevity and condition based repair
- Creation of cybersecurity tools and studies which help enhance the security of critical dam infrastructure by articulating the cybersecurity target, risk and recovery landscape
- Develop cross-cutting digitalization systems and advanced sensor suites to empower data driven decisions on O&M and asset management

Condition Based Maintenance (CBM) Designed and Tested:
- CBM system integrated into turbine water tunnel test over range of operating conditions and with simulated faults
- Implemented with advanced instrumentation and data analysis
## Project Budget

### Total Project Budget – Award Information

<table>
<thead>
<tr>
<th></th>
<th>DOE</th>
<th>Cost-share</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY17</td>
<td>2,200</td>
<td>550</td>
<td>2,750</td>
</tr>
<tr>
<td>FY18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY19 (Q1 &amp; Q2 Only)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### FY17 – FY19 Q1 & Q2 (October 2016 – March 2019)

<table>
<thead>
<tr>
<th></th>
<th>Costed</th>
<th>Costed</th>
<th>Costed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY17</td>
<td>DOE $781.933</td>
<td>Cost Share $253.3</td>
<td>DOE $501.223</td>
<td>DOE $1,565.856</td>
</tr>
<tr>
<td></td>
<td>Cost Share $0</td>
<td></td>
<td>Cost Share $0</td>
<td>Cost Share $253.3</td>
</tr>
<tr>
<td>FY18</td>
<td>DOE $501.223</td>
<td>Cost Share $0</td>
<td>DOE $282.7</td>
<td>Cost Share $0</td>
</tr>
<tr>
<td>FY19 (Q1 &amp; Q2 Only)</td>
<td>DOE $282.7</td>
<td>Cost Share $0</td>
<td>DOE $1,565.856</td>
<td>Cost Share $253.3</td>
</tr>
</tbody>
</table>

- **Project scope realignment:**
  - Model scale testing performed at 0.305m diameter scale vs proposed 0.9m scale due to cost overruns associated with large scale AM construction
Management and Technical Approach

• **Management Approach**
  – PI led the program and coordinated with task leads – bi-weekly and monthly update meetings
  – Four graduate students assisted with project activities on related research topics
  – Monthly progress update calls with DOE
  – Go/No-Go decision meeting (M12) webinar with DOE
  – Presentations at program reviews and hydro conferences

• **Technical Approach**
  – Task 1: Turbine hydrodynamic design
  – Task 2: Additive manufacturing feasibility study
  – Task 3: Rim-drive generator design
  – Task 4: CBM implementation
  – Task 5: Hybrid multi-material concept study
  – Task 6: Validation testing of turbine and CBM systems
End-User Engagement and Dissemination Strategy

• Interacted with Voith Hydro relative to possible field test installation
  – Voith Hydro personnel visited PSU to see water tunnel test
  – Discussions underway relative to possible licensing and future teaming relative to possible field installation
  – Exploring incorporation of commercially available Voith Marine rim-drive motor/generator into modular design

• Presented at NHA Hydro Week 2018 and 2019
• Presented at PSU Energy Days 2019
• Presented at NHA Speaker Series September 2019
• Planning on writing journal papers with results from water tunnel test
Technical Accomplishments

Turbine Design

Curve of constant specific speed (i.e. similar design). Diameter held constant and operating rpm allowed to vary.

Curve of constant specific speed (i.e. similar design). Operating rpm held constant and diameter allowed to vary.

Prototype
Full Scale Turbine
Scale Turbine
Operation

Turbine Power
Specific Speed = 2.16


Technical Accomplishments

Advanced Manufacturing

Design for Hybrid AM → Additive and Subtractive Toolpath Generation → Laser Deposition → CNC Machining → Final Part
Technical Accomplishments

Rim-Generator Design

Geometric Scaling

Variable RPM
Technical Accomplishments

Condition Based Maintenance (CBM)

CBM System Design and Implementation

Advanced Diagnostic Development Process

- Develop Condition Indication Algorithms
- Test and Validate Diagnostic Algorithms
- Gather System and Platform Sensor Test Data
- Hardware and Software Design
- Develop Failure Prediction Models
- Test and Validate Prediction Models
- HMS Information Interface
- HMS Data Acquisition Requirements

Turbin Generator
- Sensor Requirements
- Sensor Integration
- Sample Rate

CBM System Validation Testing

Accelerometer 1, PCA faceted by Turbine Speed

- Test Setup
- Blockage
- Imbalance
- Normal
Technical Accomplishments

Hybrid Multi-Material Concept Study

Low iron content Inconel 625

High iron content Inconel 625

Nitrogen vs water atomized 316L stainless steel feed stock
Technical Accomplishments

Turbine Validation Test

- CFD Profile
- Measurement Planes
- Inlet Guide Vanes
- Seal
- Bearings
- Seal
- Clear Acrylic
- Bevel Gear
- Probe Traverse Planes
- Planetary Speed Reducer (Removed)
- Stator Blades
- Rotor Blades
- Ring Gear

Graphs showing data for:
- Measured
- CFD
- Reynolds Sweep

Tip Speed Ratio vs. Various Parameters

Normalized Radius vs. Normalized Axial Velocity

15 | Water Power Technologies Office
Progress Since Project Summary Submittal

• Submitted Final Report