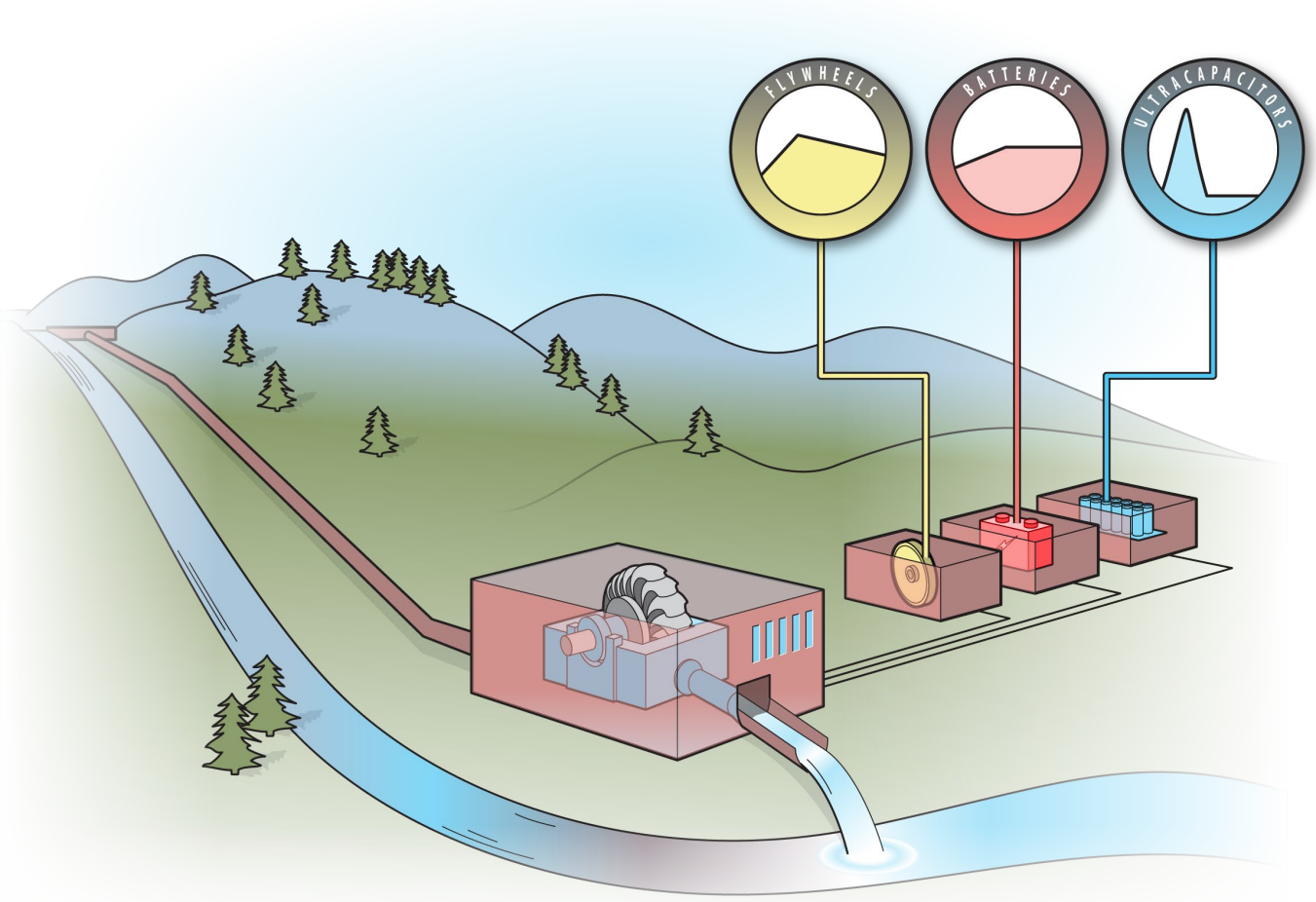
1.2.4.101 – Integrated Hydropower and Energy Storage: Providing Essential Reliability and Ancillary Services using Individual or Coordinated Hydropower Plants



Thomas Mosier, S M Shafiul Alam (INL)
Vahan Gevorgian (NREL)
Matt Mahalik (ANL)

Thomas.Mosier@inl.gov

28 July, 2022

Project Overview

Project Summary

- This project evaluated the feasibility and benefits of integrating hydropower plants and energy storage devices to enhance market participation and enable grid islanding. The approach is agnostic to the type and number of energy storage devices and hydropower generation assets used.
  - Conducted field demonstration Idaho Falls Power to demonstrate black start using their run-of-river hydropower plants and ultracapacitor energy storage system.
  - Developed a tool to recommend battery sizing for enhancing market participation in CAISO.

Intended Outcomes

- Increase competitiveness of hydropower plants as electricity markets evolve to favor higher amounts of flexibility. The status quo is that hydropower plant owners feel a high degree of uncertainty about value proposition of hybridization. This work helps them take the first step.
- Enable small hydropower plants to provide black start and grid islanding capabilities to local critical loads. The status quo is that diesel generators are typically used for initial black start and then small hydropower plants are brought online. Our approach enables black start without diesel generators.

Project Information

Principal Investigator(s)

- Thomas Mosier, INL
- Vahan Gevorgian, NREL
- Matthew Mahalik, ANL

Project Partners/Subs

- Idaho National Laboratory (INL)
- National Renewable Energy Laboratory (NREL)
- Argonne National Laboratory (ANL)
- Idaho Falls Power (IFP)
- Emerson

Project Status

Completed

Project Duration

- Project Start Date: October 01, 2016
- Project End Date: September 30, 2021

Total Costed (FY19–FY21)

$2,213,287.93

Project Objectives: Relevance

Relevance to Program Goals:

- Aligns with Hydropower Program Activity 2 – Grid Reliability, Resilience, and Integration (HydroWIRES).
- Enables existing hydropower plants to better contribute to evolving grid requirements over short (e.g., frequency regulation) to medium (e.g., load following) time-scales.
- Enables small hydropower to execute grid islanding action.
- Can reduce ramping of hydropower plants, decreasing wear and tear of components.
- Optimizes operation of the integrated hydropower and energy storage system to achieve multiple competing objectives (e.g., balancing environmental flows and revenue maximization).

Project Objectives: Approach

- Market participation
  - Conducted suite of simulations for variety of hydropower plant and battery configurations.
  - Trained machine learning model to predict revenue for novel hydropower plant and battery configurations.
  - Modelled battery degradation and calculated financial performance.
  - Developed public-facing tool.
- Black start
  - Created testbed for de-risking technology and approach in INL's lab facility.
  - Conducted field demonstration with Idaho Falls Power to prove concept in the field.
  - Produced outward facing report to document outcomes and guidance for interested parties.

Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

- Market participation
  - Web-based battery sizing tool for hydropower plants in CAISO.
  - Case study with PG&E.
  - Patent application filed on use of variational mode decomposition in splitting dynamic regulation signal for hybrid system.
- Black start
  - Field validated H6E hydrogovernor model in Simulink and RSCAD.
  - Power hardware-in-the-loop testbed for hydropower hybrid system.
  - Report on field demonstration.

Outcomes:

- Helped hydropower owners in CAISO to take the first step in considering hybridization to enhance market participation.
- Proved the concept of using small hydropower and energy storage to perform local grid black start and restoration.

Project Timeline

FY 2019

Scoped market participation tool.

Demonstrated ability of ultracapacitor to support black start using real hardware.

Created black start valuation guidance.

FY 2020

Conducted suite of market participation simulations to assess ability of batteries to increase revenue in CAISO.

Prepared for Spring 2021 field demonstration.

FY 2021

Completed battery sizing tool for hydropower hybrid.

Conducted case study with Pacific Gas and Electric evaluating batteries to enhance market participation.

Demonstrated Idaho Falls Power's small hydro black start with ultracapacitor support.

Project Budget

	FY19	FY20	FY21	Total Actual Costs FY19–FY21
	Costed	Costed	Costed	Total Costed
INL	$531,325.96	$447,954.57	$384,329.49	$1,363,610.02
NREL	$203K	$115K	$105K	$423K
ANL	$153,365.19	$113,942.31	$159,370.41	$426,677.91
Total	$887,691.15	$676,896.88	$648,699.9	$2,213,287.93

End-User Engagement

- Stakeholder and end-user engagement strategy
  - Hydropower operators will benefit from the enhanced operational flexibility and resilience that energy storage can offer.
  - Energy storage vendors will benefit by learning new business cases of integrating energy storage with hydropower.
- Energy I-Corps – Interviewed 75 personnel across industry and heard diverse insights:
  - Industry thinks there is the highest potential for enhancing market participation in CAISO and PJM.
  - ISO participation models are important for monetizing benefits.
  - An important value proposition is being able to use existing interconnection.

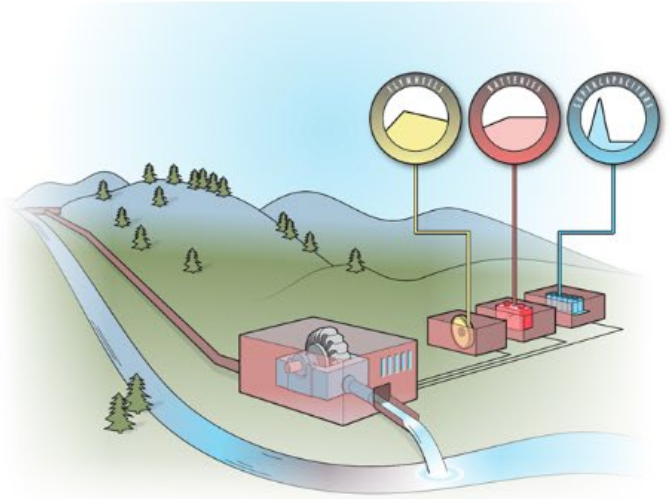
Utilities	9
Hydropower owners/operators/developers	14
ISO's and regulatory bodies	8
Trade and advocacy organizations	6
Industry consultants	19
Energy storage developers	3
Researchers	9
Investors and commercialization gurus	4

Dissemination

- Battery sizing tool has been hosted as web app. Revenue prediction work published in the Journal of Energy Storage.
- The field demonstration with Idaho Falls Power has been featured by the Northwest Public Power Association (NWPPA), and appeared at the web portals of American Public Power Association, National Hydropower Association, and Microgrid Knowledge. Mentioned at the Senate Energy and Natural Resources Committee hearing on Hydropower.
- High fidelity models are released on GitHub. Technical publications and presentations made at HydroVISION, IEEE Power and Energy Society Transmission and Distribution Conference and General Meeting.

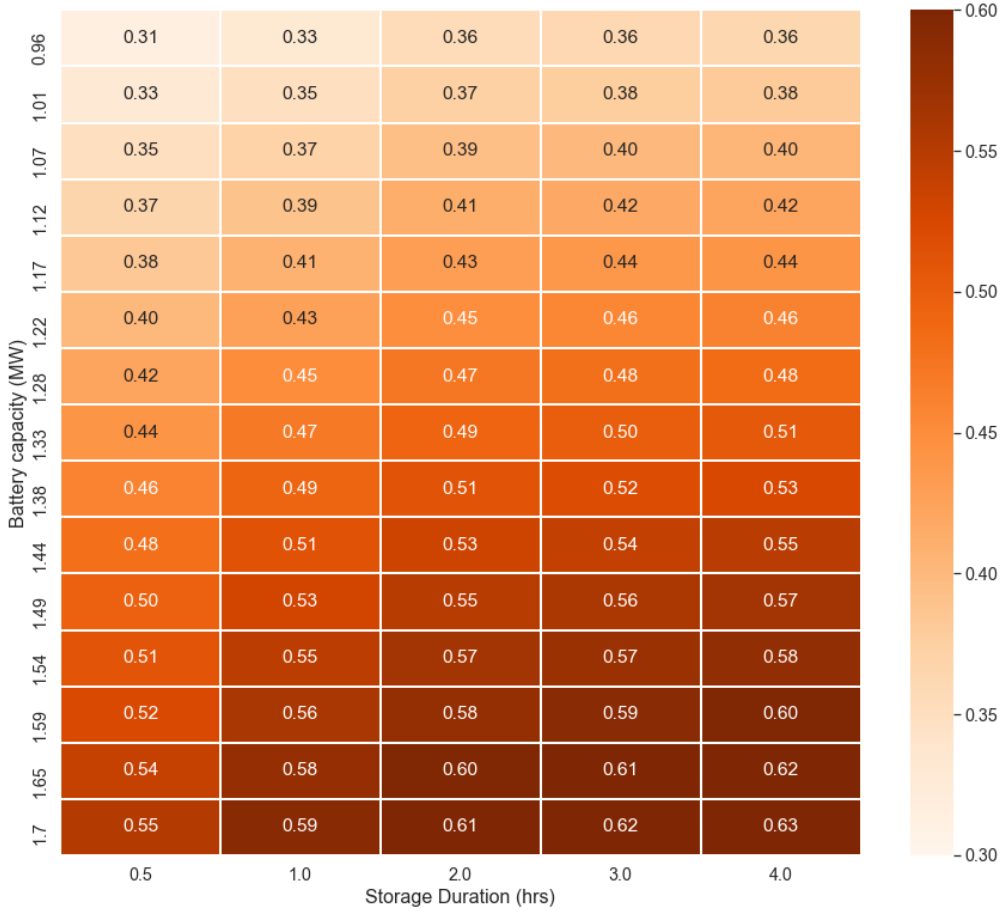
Accomplishments since 2019 WPTO Peer Review

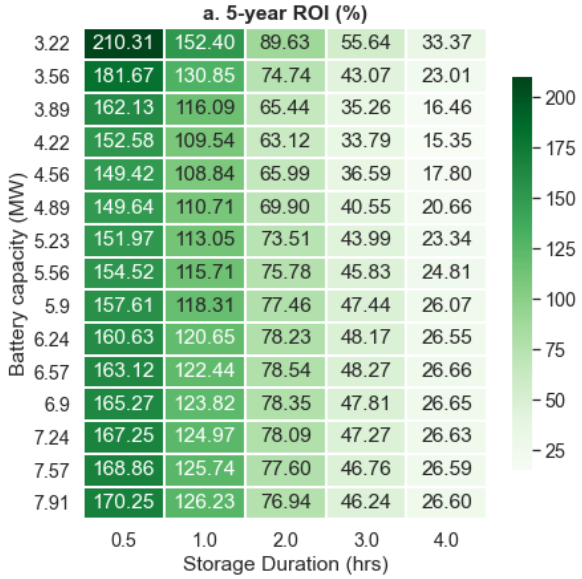
Developed web-based Hydro + Storage Sizing Tool (https://hydrohybrids.inl.gov/)

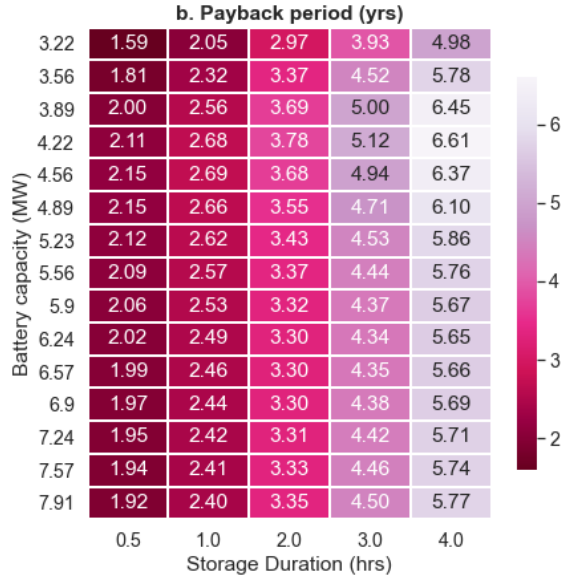


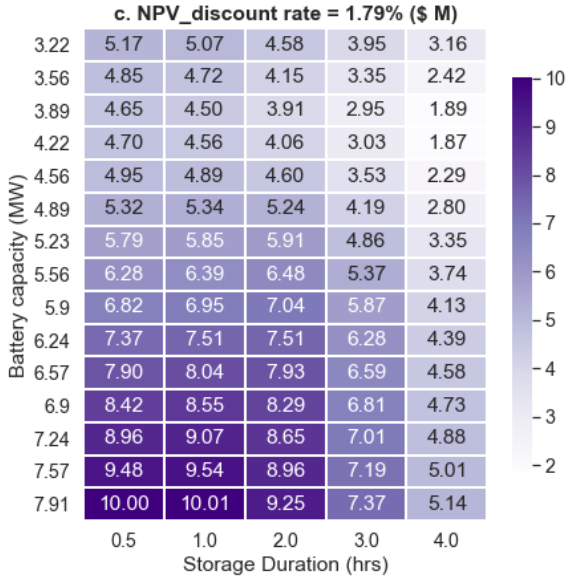
Example financial outputs from the Hydro + Storage Sizing Tool

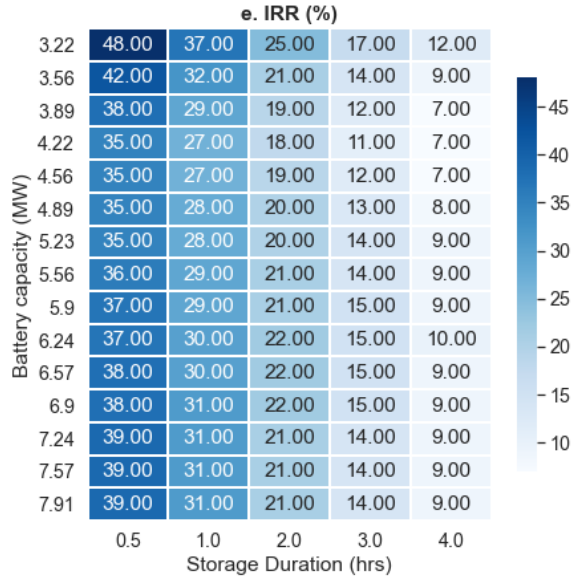
Revenue increase based on battery size





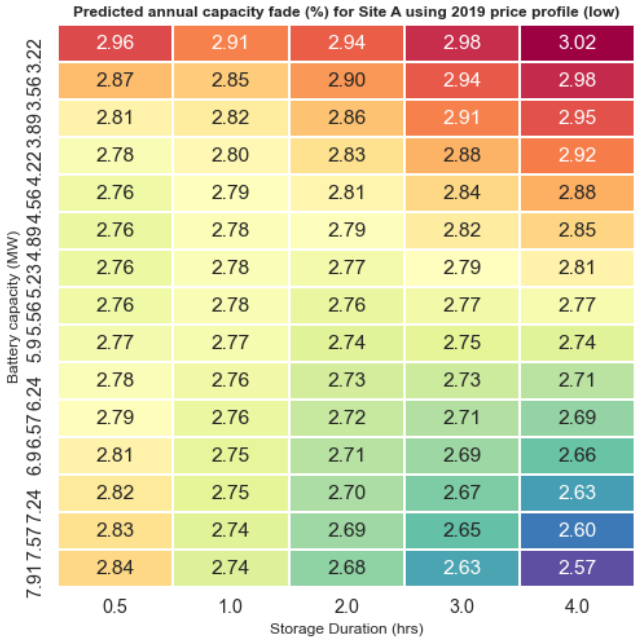


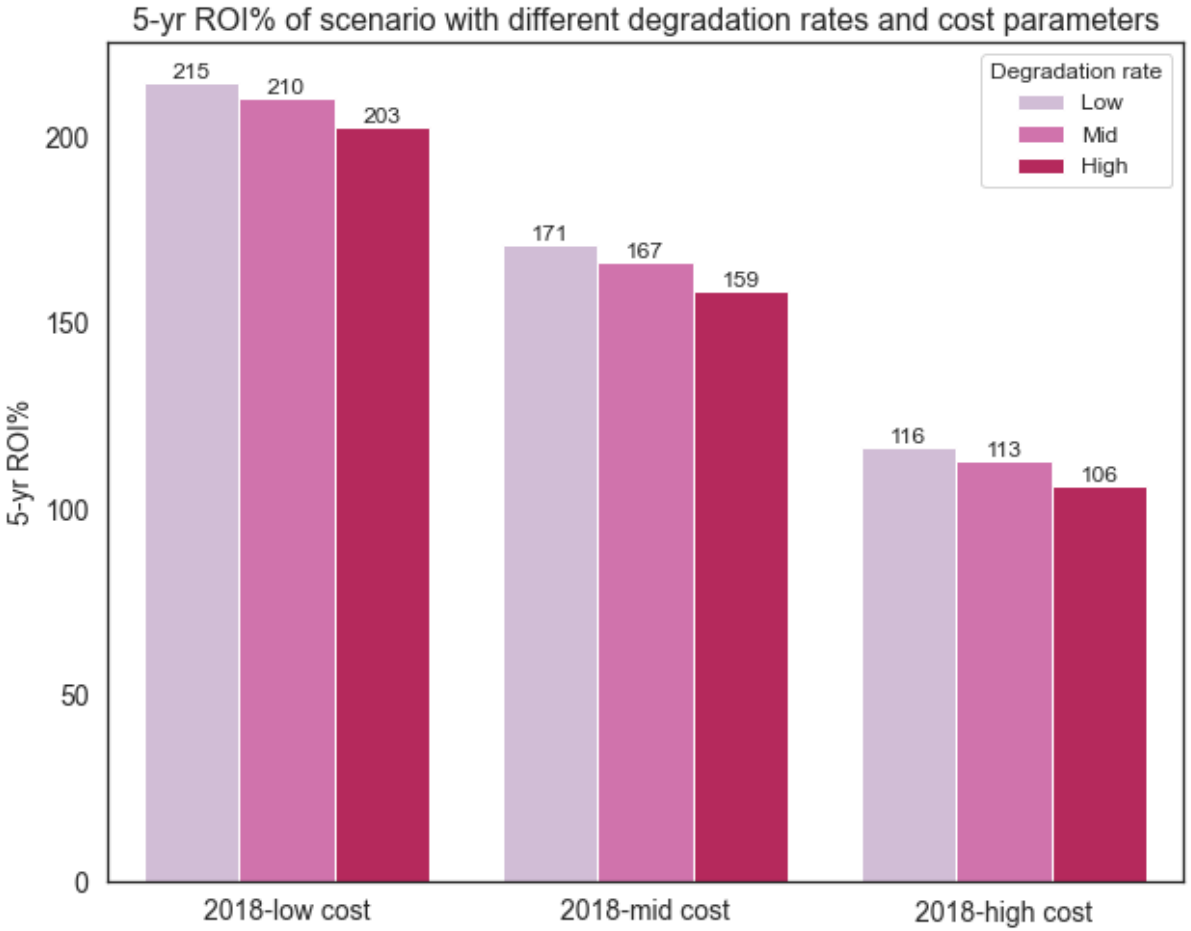




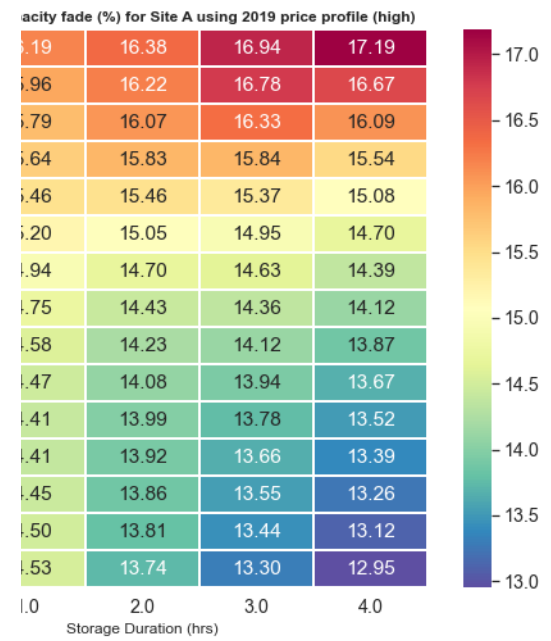
Estimated battery degradation within Hydro + Storage Sizing Tool

Low degradation rate case

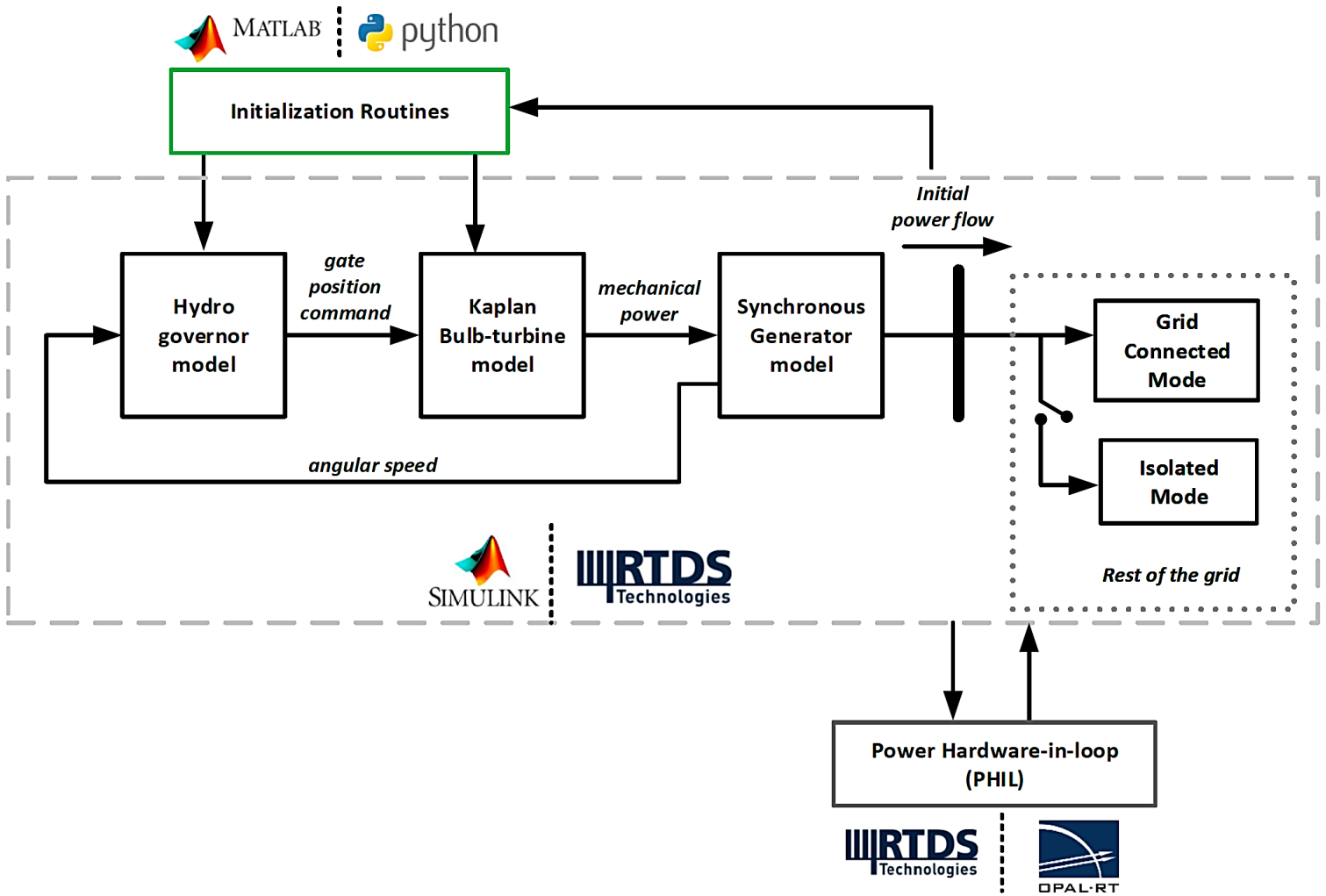




adation rate case

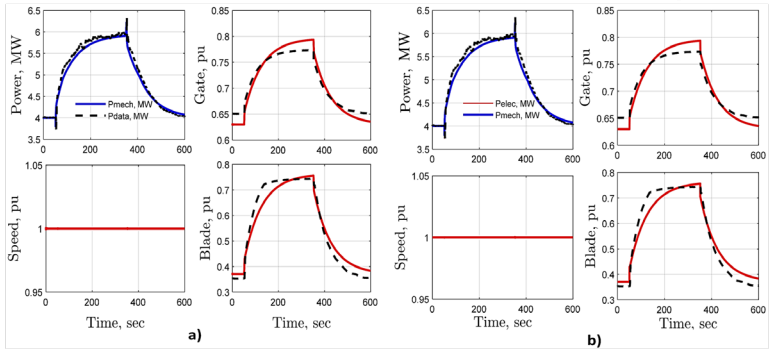


Developed real-time simulation compatible hydrogovernor dynamic model, validated through field measurements



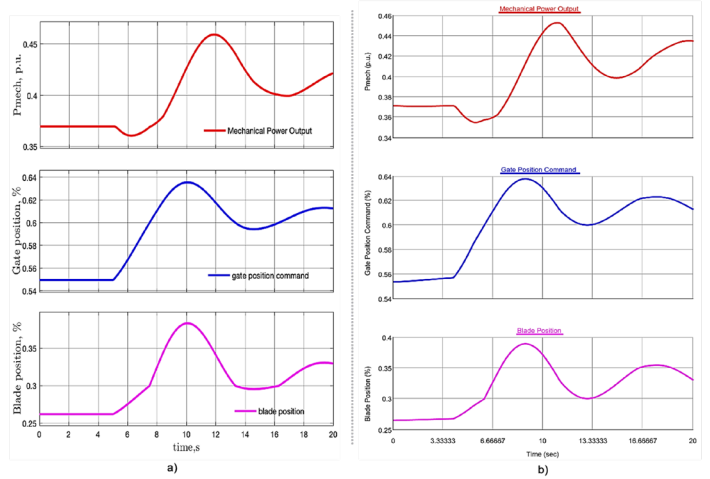
Model Validation in Grid Connected (Load Control) Mode

Simulink Matlab Scripts

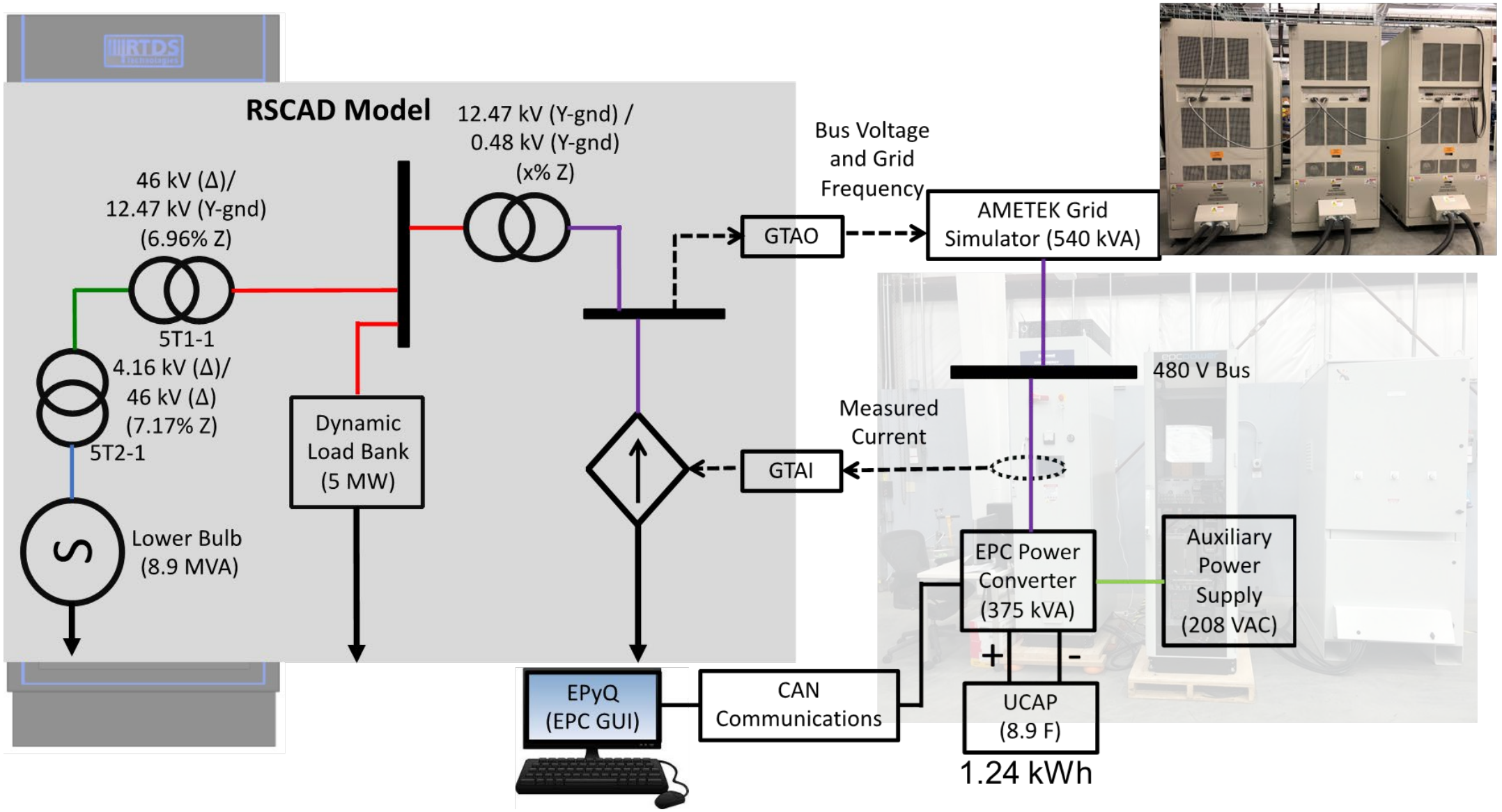


Isolated (Speed Control) Mode Simulation

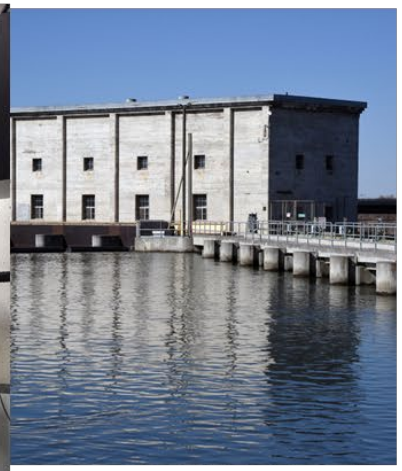
Simulink RTDS

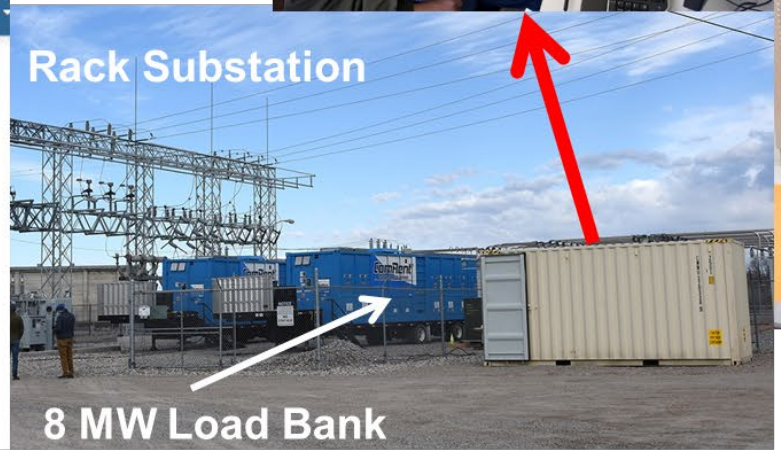


Developed “closed-loop” testbed and demonstrated hydro + storage black start concept in lab with real hardware



Conducted successful black start field demonstration with Idaho Falls Power





Performance: Accomplishments and Progress (cont.)

- Identify any patents, awards, or other important recognition that have resulted from this project.
  - Nina Rydalch, “Idaho Falls Power Discovers Big Value in Small Hydropower”, Cover Story, NWPPA Bulletin, February 2022.
  - S M Shafiul Alam, Abhishek Banerjee, Cliff Loughmiller, Brion Bennett, Nicholas Smith, Thomas M. Mosier, Vahan Gevorgian, Ben Jenkins, and Matthew Roberts, “Idaho Falls Power Black Start Field Demonstration - Preliminary Outcomes Report”, INL/EXT-21-63855, April, 2021.
  - Abhishek Banerjee, S M Shafiul Alam, Thomas M. Mosier, and John Undrill, “Modeling a Bulb-Style Kaplan Unit Hydrogovernor and Turbine in Mathworks-Simulink and RTDS-RSCAD”, 2022 IEEE PES T&D Conference and Exposition.
  - S M Shafiul Alam, Abhishek Banerjee, and Thomas M. Mosier, “Power Hardware-In-the-Loop Hydropower and Ultracapacitor Hybrid Testbed”, IEEE PES GM 2022 (Accepted).
  - GitHub Repository: https://github.com/IdahoLabResearch/Hydropower_Unit_Models
  - “Enhancing Local Grid Resilience with Small Hydropower – Proving the concept through demonstration, simulation, and analysis with Idaho Falls Power” (Being reviewed by WPTO).
  - Vivek Kumar Singh, Abhishek Banerjee, S M Shafiul Alam, and Thomas M. Mosier, “Dynamic Frequency Regulation Improvement in Hydropower-Hybrid System using Variational Mode Decomposition” 2022 IEEE PES T&D Conference and Exposition, April 25 - 28, 2022, New Orleans, LA, USA.
  - Vivek Kumar Singh, S M Shafiul Alam, and Thomas M. Mosier, “Generating control signals for energy sources”, US Provisional patent application: 63/333998, patent pending, filed 04/22/2022.
  - Lin, Yingqian, Binghui Li, Thomas M. Moiser, L. Michael Griffel, Matthew R. Mahalik, Jonghwan Kwon, and SM Shafiul Alam. "Revenue prediction for integrated renewable energy and energy storage system using machine learning techniques." Journal of Energy Storage 50 (2022): 104123.

Future Work – Accelerate Industry Deployment of Hydropower Hybrids

- Build and implement a framework for assessing the value of hydropower hybrids based on location and plant specific criteria (e.g., plant operations and maintenance requirements, license requirements, market conditions, and regulatory context).
  - Understand the decision to hybridize an asset.
  - Identify value propositions/benefits of hybrid asset.
  - Formulate the objective function to optimize total benefits.
- Develop operator training module for islanded operation of hydro hybrids.
  - Investigate frequency and voltage stability of islanded hydropower units across different capacity, and turbine types. Develop energy storage sizing to resolve identified issues.
  - Develop coordinated control scheme among islanded hydropower unit and energy storage.
  - Conduct field demonstration with a geographically and technically diverse hydropower operator.

Q&A