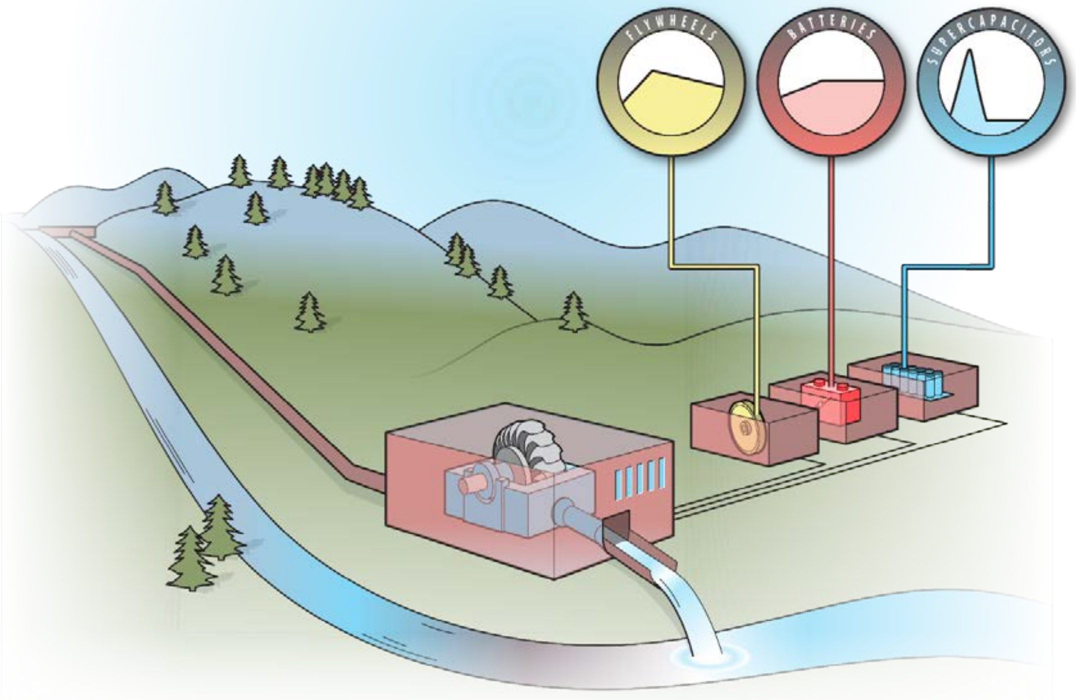
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Integrated Hydropower and Energy Storage Systems



Idaho National Laboratory
Argonne NATIONAL LABORATORY
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Agreement #30237

Hydropower Program

October 8, 2019

Thomas Mosier

Idaho National Laboratory

Project Overview

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Project Summary

This project evaluates the feasibility of integrating hydropower plants and energy storage devices. The approach is agnostic to the type and number of energy storage devices and hydropower generation assets. These capabilities are enabled through the Smart Energy Box, which was developed in partnership with Siemens. A case study based on Idaho Falls Power is used to demonstrate the increased market participation enabled by this technology.

Project Objective & Impact

- High penetration of variable renewables has increased the need for, and value of, ancillary services, a trend that is expected to continue.
- The major objective of this project is to enhance hydropower plants' ability to provide grid services.
- A hybrid combination of energy storage devices will act as a combined virtual reservoir to support the hydropower plant.
- This project advances the state-of-the-art by enabling the design of integrated virtual reservoirs and developing multi-level optimized control strategies to utilize a combination of different hydropower generation assets and energy storage devices.

Project Information

Project Principal Investigator(s)

Thomas Mosier (INL)
Vladimir Koritarov (ANL)
Vahan Gevorgian (NREL)

WPTO Lead

Marisol Bonnet

Project Partners/Subs

Idaho National Laboratory (INL), Argonne National Laboratory (ANL), National Renewable Energy Laboratory (NREL), Idaho Falls Power (IFP), American Governor, Siemens.

Project Duration

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

Alignment with the Program

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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

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Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

- Understand the needs of the rapidly evolving grid and how they create opportunities for hydropower and PSH.
- Investigate the full range of hydropower's capabilities to provide grid services, as well as the machine, hydrologic, and institutional constraints to fully utilizing those capabilities.
- Optimize hydropower operations and planning—alongside other resources—to best utilize hydropower's capabilities to provide grid services.
- Invest in innovative technologies that improve hydropower capabilities to provide grid services

This project:

- Enables existing hydropower plants to better contribute to evolving grid requirements, including over short time-scales (e.g. frequency regulation) to medium time-scales (e.g. load following). This solution also reduces ramping of hydropower plants, decreasing wear and tear of machines.
  - ➢ Demonstrated with hardware-in-the-loop simulations
- Optimizes operation of the integrated hydropower and energy storage system to achieve objectives, such as maximizing revenue potential.
  - ➢ Achieved with CHEERS model
- Develops technology paradigm and corresponding control structure to improve hydropower capabilities to provide grid services.
  - ➢ Achieved with Siemens Smart Energy Box

Project Budget

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Lab	FY17	FY18	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019)	
Lab	Costed	Costed	Costed	Total Costed	Total Authorized
ANL	$194K	$381K	$51K	$626K	$650K
INL	$556K	$489K	$98K	$1,142K	$1,217K
NREL	$171K	$163K	$115K	$449K	$621K
TOTAL	$921K	$1,033K	$264K	$2,217K	$2,488K

Milestones and Management Approach

FY17

Focus: Develop control structures and high-fidelity digital models

Milestones:
- Complete front end controller in Siemens Smart Energy Box
- Develop digital energy storage models
- Design verification of energy storage control topologies using high fidelity models in digital real time simulation environment
- Develop CHEERS model topology for case study

FY18

Focus: Analyze integrated hydropower and energy storage performance

Milestones:
- Perform CHEERS case study using Idaho Falls Power cascaded hydropower plants integrated with batteries and flywheels
- Test and optimize ability of integrated energy storage device and run-of-river hydropower plant to provide frequency support similar to that of conventional hydropower plant.

FY19 (Q1 and Q2)

Focus: Expand services to include black starts

Milestones:
- Demonstrate ability of supercapacitors to support black start support using real hardware
- Create black start valuation guidance.
- Prepare for Spring 2020 field demonstration.

Overarching management approach: utilize strength of teams to achieve common objective

- Control architecture, hardware testing, and integration – INL
- Generator technologies, advanced power electronics, coordinated network response – NREL
- Market participation and valuation approaches (e.g. CHEERS model development) – ANL
- Hydropower operational requirements – IFP
- Industry best practices for control structures – Siemens in partnership with INL
- Validated hydropower governor systems – American Governor

End-User Engagement

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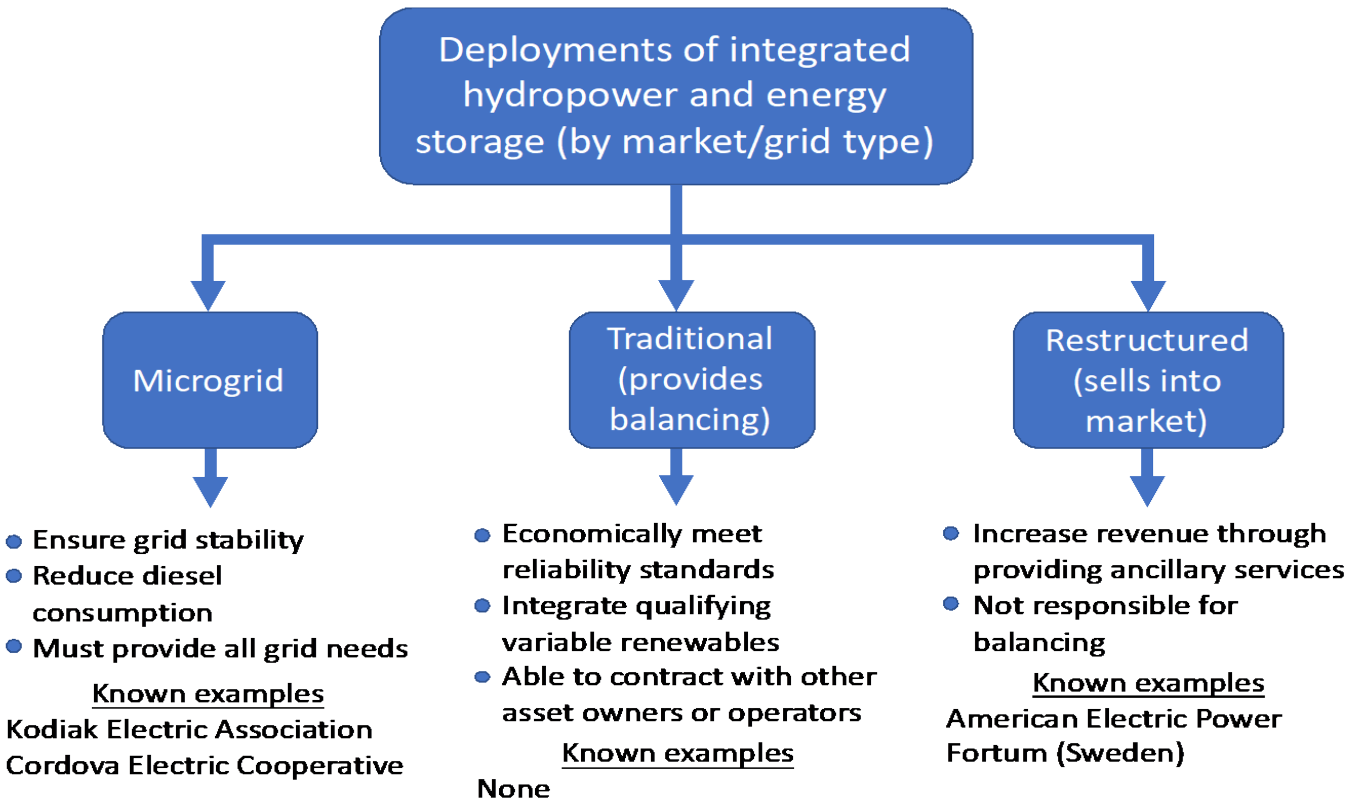
- Primary project beneficiaries are hydropower plant owners and operators, who:
  - would like the opportunity to participate in ancillary services markets
  - desire greater operational flexibility or contribution to reliability services
  - desire to reduce ramping speed and frequency



Dissemination Strategy

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- Hydropower industry very interested in these topics, as expressed by increasing prevalence of panels on the topic.
- Project dissemination includes:
  - Presentation at several industry events (National Hydroelectric Association and HydroVision conferences)
  - Feature story for industry publications
  - General audience video
  - Conference papers and technical reports (HydroVision and DOE reports)
- This dissemination strategy chosen to broadly increase knowledge on topic and solicit engagement by motivated industry partners (e.g. to identify partners for future case studies).
- A technical advisory group will be setup in next fiscal year as we transition from conceptual development to industry deployment.

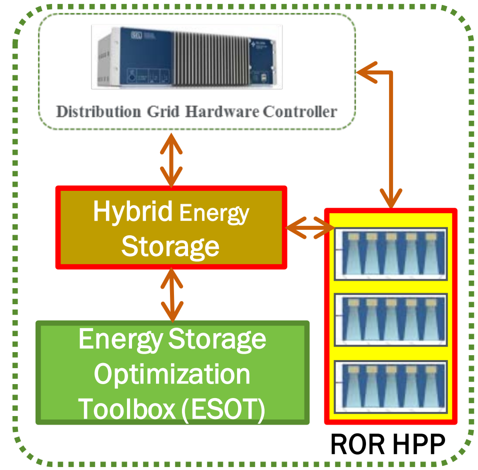
Technical Approach

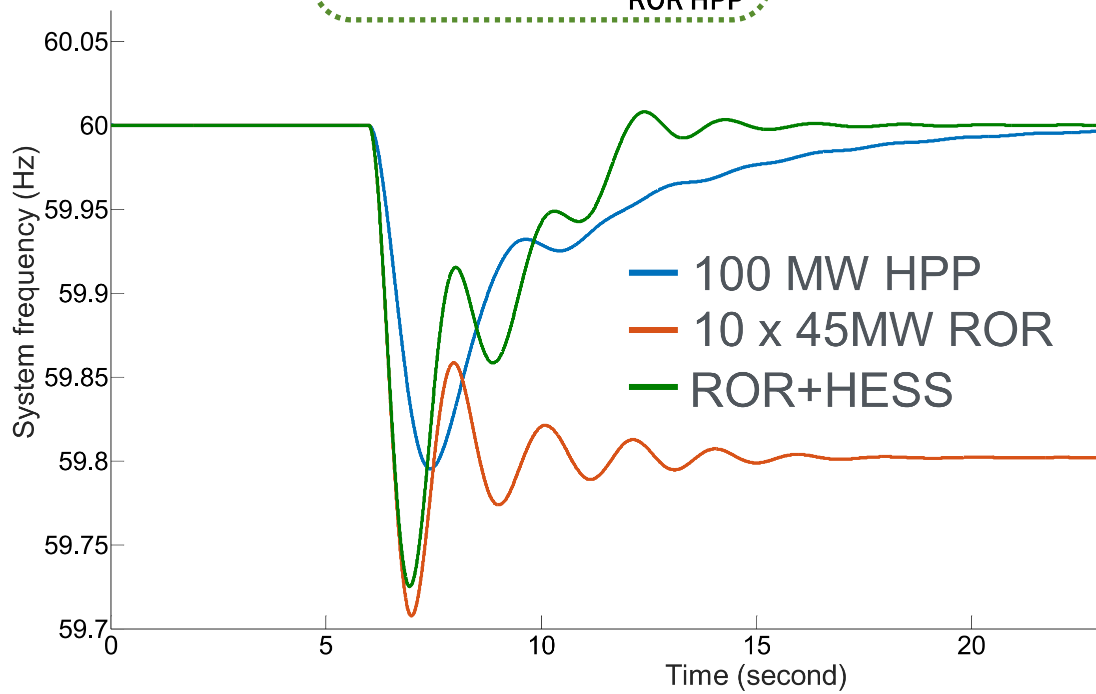
- **Virtual Reservoirs:** Demonstrate the feasibility of co-locating and coordinating hydropower plants with one or more energy storage devices to create "virtual reservoirs." These virtual reservoirs enable the integrated system to contribute essential reliability services and participate in ancillary services markets.
  - As a starting point, the project focused on demonstrating that energy storage can enable a run-of-river (ROR) hydropower plant to perform like a hydropower plant with reservoir storage.
  - For reservoir-based hydropower plants, integration with energy storage can also provide benefits such as enabling the facility to better meet multiple plant objectives (e.g. flexibility and license constraints).
- **Control Architecture:** Design a control structure to coordinate utilization of multiple generating units/plants and energy storage devices.
- **Cost-Benefit Analysis:** Evaluate financial viability of the system by utilizing system costs, real-world control signals, usage patterns, and financial factors considered by industry.
- **Use Cases:** Upon demonstrating concept feasibility, evaluate unique use cases with industry partners.

Technical Accomplishments

Virtual Reservoirs

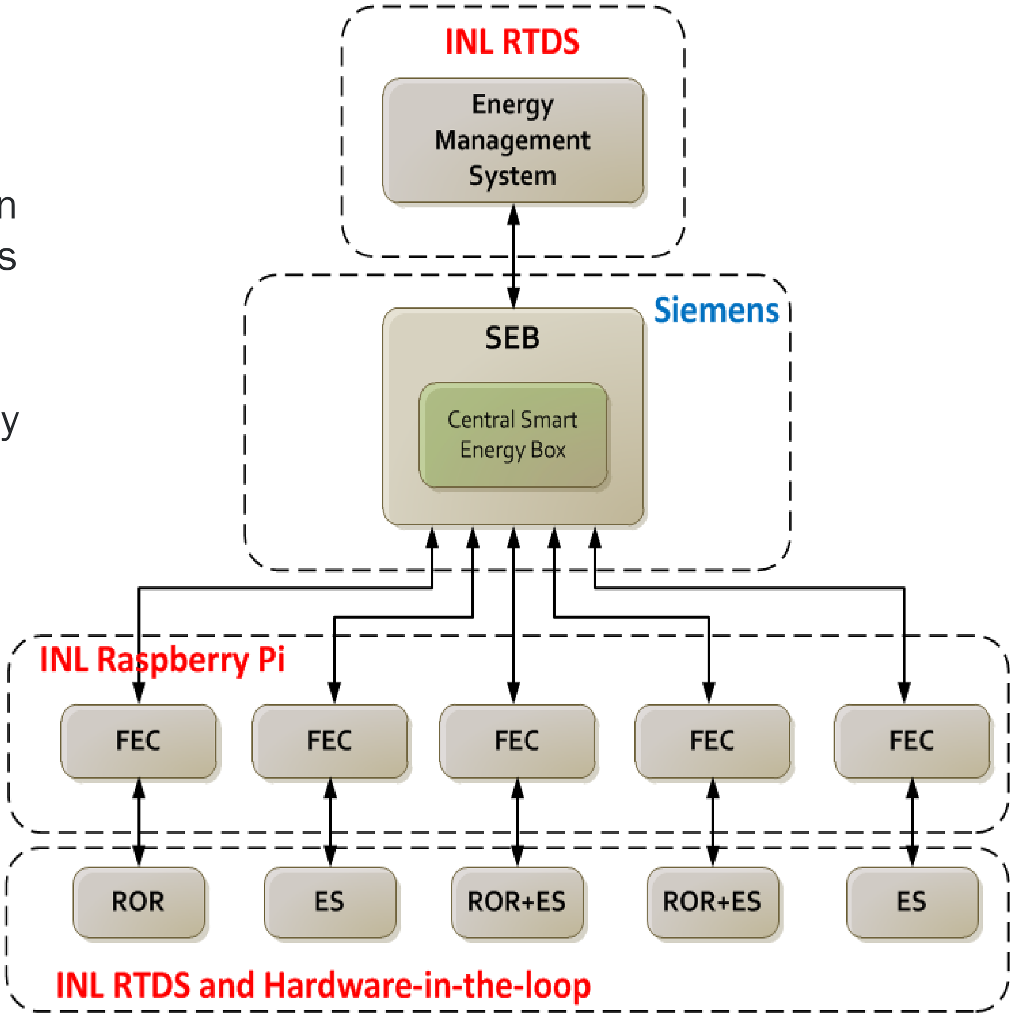
- Demonstrated ability of integrated ROR hydropower plants and energy storage to provide frequency support analogous to reservoir-based hydropower plant.
- Used digital real-time simulation environment with high-fidelity grid, hydropower, and energy storage models.
- Energy storage increases flexibility of hydropower over short to medium time-scales, enabling it to provide frequency regulation, energy arbitrage, and black start services.





Technical Accomplishments
Control Architecture

- Developed a control architecture, Siemens Smart Energy Box, to coordinate utilization of multiple hydropower units and energy storage devices.
- Control architecture includes:
  - Front-End Controller (FEC): Translates requests from SEB into local optimization problem and coordinates with other FECs for distributed optimization and to generate control signals for next level.
  - Low-Level Controller (LLC): Independently receives FEC control signals from respective FECs and maps to necessary parameter settings (e.g., proportional, integral gain, duty cycle, etc) for PEI. Multiple LLCs can interact with a single FEC.
  - Power Electronic Interface (PEI): Adjusts voltage and current settings for the hardware to be controlled. A single PEI interacts with a single LLC.
- Digital real-time simulations used to validate control structure.



Technical Accomplishments
Revenue Potential

- Demonstrated market participation of integrated hydropower and energy storage system using CHEERS model to optimize charging and discharging based on water availability and price signals.
- Utilized real-world CAISO market data and Idaho Falls Power water and hydropower plant specifications. Case study setup included four cascaded ROR plants owned by IFP and integrated with either battery or flywheel energy storage devices.
- Simulations demonstrated increased revenue of 13 to 16 percent.

Revenue increases due to energy storage

Battery storage: +12.2% to +15.8%

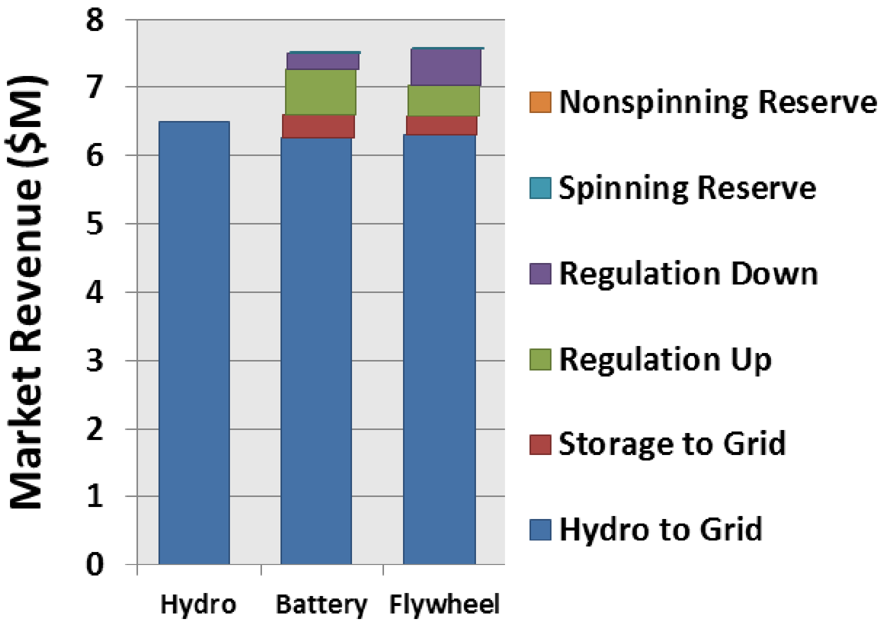
Flywheel: +12.0% to +16.3%

Investment Payback Period (years)

Battery, 2018 low cost: 10.1 – 13.3

Battery, 2025 low cost: 8.2 – 10.9

Flywheel, low cost: 12.8 – 17.8



(Based on data for Idaho Falls Power; range due to price profile assumptions)

Technical Accomplishments

Value of distribution-level black start

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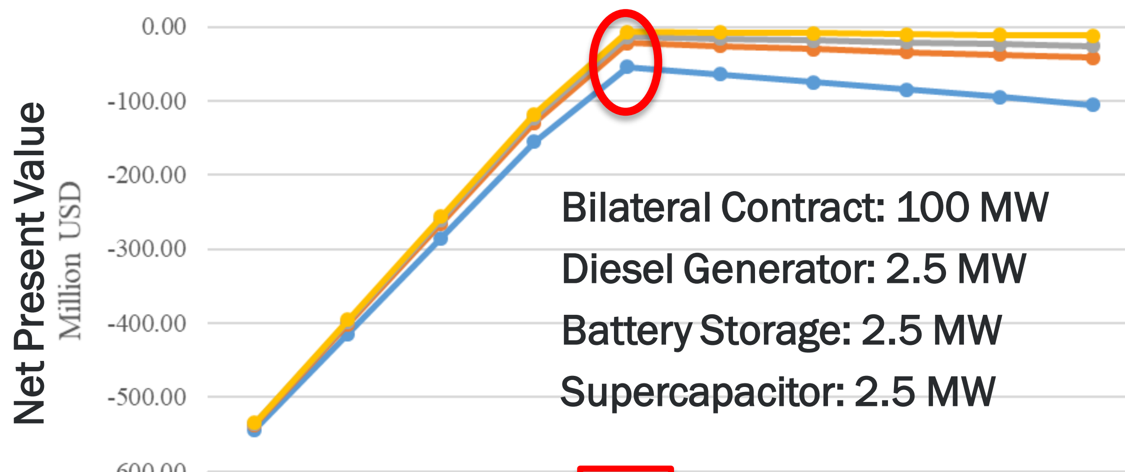
- Integration with energy storage enhances ROR hydropower plants ability to provide black start services.
- The project team developed distribution-level black start valuation guidance to inform this use case. Valuation compares cost of several mechanisms for achieving distribution-level black start capabilities.
- Preliminary findings suggest this technology may have higher value compared to diesel generators for enabling low-head ROR hydropower plants to provide black start services.
- This work is currently being developed into a tool. It includes mechanisms for providing valuation in traditional and restructured markets.



	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10
Bilateral Contract	-544.13	-414.65	-285.18	-155.70	-54.16	-64.36	-74.57	-84.77	-94.98	-105.18
Diesel Generator	-537.63	-401.66	-265.68	-129.71	-21.67	-25.75	-29.84	-33.92	-38.01	-42.09
Battery Storage	-536.05	-398.49	-260.94	-123.38	-13.76	-16.27	-18.77	-21.27	-23.77	-26.28
Super Capacitor	-534.65	-395.70	-256.75	-117.79	-6.78	-7.88	-8.99	-10.09	-11.20	-12.30

The team will test the technical ability of using hydropower plants with energy storage to provide black starts during a Spring 2020 field demonstration with Idaho Falls Power.

Progress Since Project Summary Submittal

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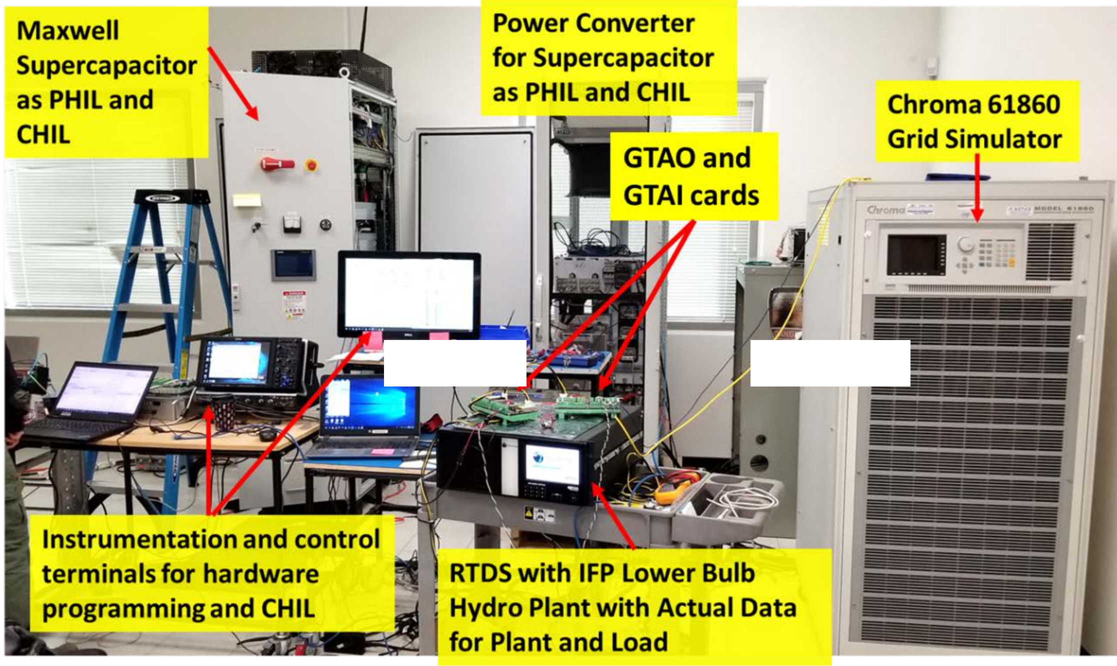
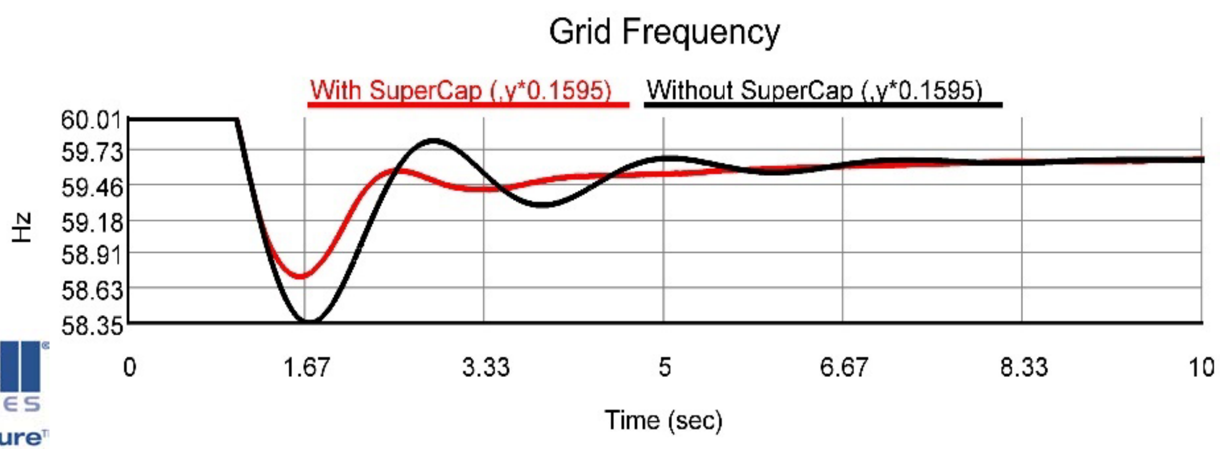
- The team procured and tested an ultracapacitor system that will be integrated with a low-head ROR hydropower plant to enable distribution-level black start services.
- This will be field tested with IFP during Spring 2020. The findings of the initial hardware testing were presented at the 2019 HydroVision International Conference in July.





IDAHO FALLS POWER

AMERICAN GOVERNOR

Maxwell TECHNOLOGIES Enabling Energy's Future

Progress Since Project Summary Submittal

- **Strengthening partnership with American Governor to develop validated hydropower plant models (capabilities, controls and hydrodynamics) for range of facilities.**
  - Enables assessment of “integrated technology” for examples representative of large segments of hydropower fleet.
  - Also developing validated model of Idaho Falls Power Lower Bulb Plant that will be used for field test of black start capability in Spring 2020.
- **Proposal for next two fiscal years accepted by WPTO.**
  - Focus is on translating conceptual work from this project phase to industry deployment.
  - External reviewers noted the interest by hydropower industry in integration of energy storage systems and gave overall very positive feedback.

Objectives of FY20 and FY21

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1. **Demonstrate the efficacy of integrated hydropower and energy storage for increasing the contribution of grid services through partnership with industry.**
   – Field demonstration focusing on a use case of the Siemens SEB to provide essential reliability services using hydropower integrated with energy storage.
   – *Partner TBD*
2. **Enable distribution-level black start services using integrated ROR hydropower plants and supercapacitors.**
   – Field demonstration focusing on providing black start services with a low-head ROR hydropower plant and supercapacitors.
3. **Develop guidance on sizing of energy storage systems, both batteries and hybrid energy storage systems, to provide a given set of services based on hydropower generation and utilization of the integrated system.**
   – Design will be based on cost, optimization of services, and degradation of energy devices. This guidance will take the form of a guidebook or open-source tool.