INL/MIS-23-73205-Revision-0

Flexpower and Hydro-Hybrids

June 2023

Hill Balliet, Thomas Michael Rowe Mosier

Changing the World's Energy Future

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Flexpower and Hydro-Hybrids

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GMLC Flexpower

Vahan Gevorgian, Juan Gallego Calderon, Hill Balliet, Thomas Mosier, Caitlin Murphy, Bikash Poudel, Binghui Li, Soumyadeep Nag

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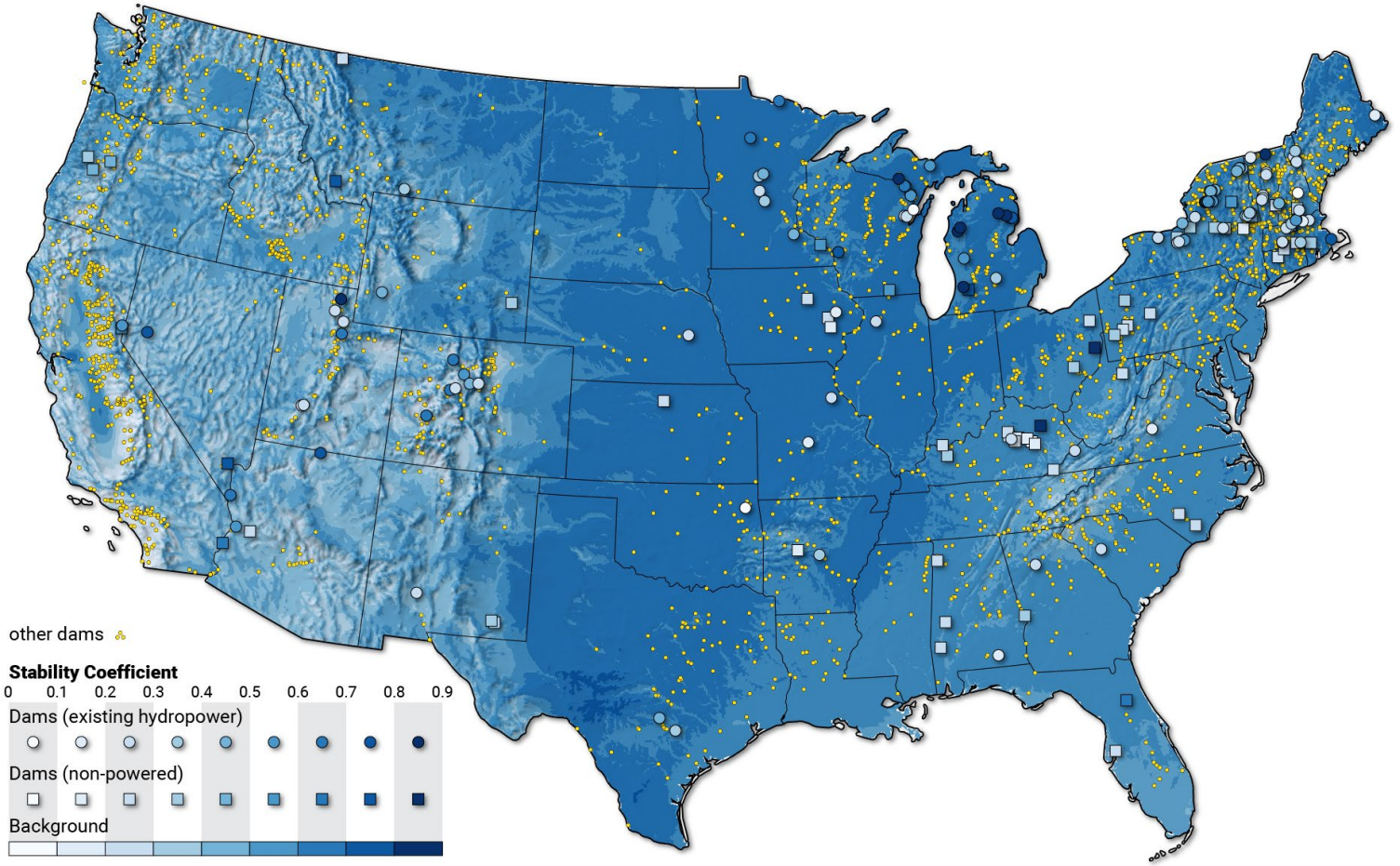
Complementarity is regional and more apparent over shorter timescales with solar

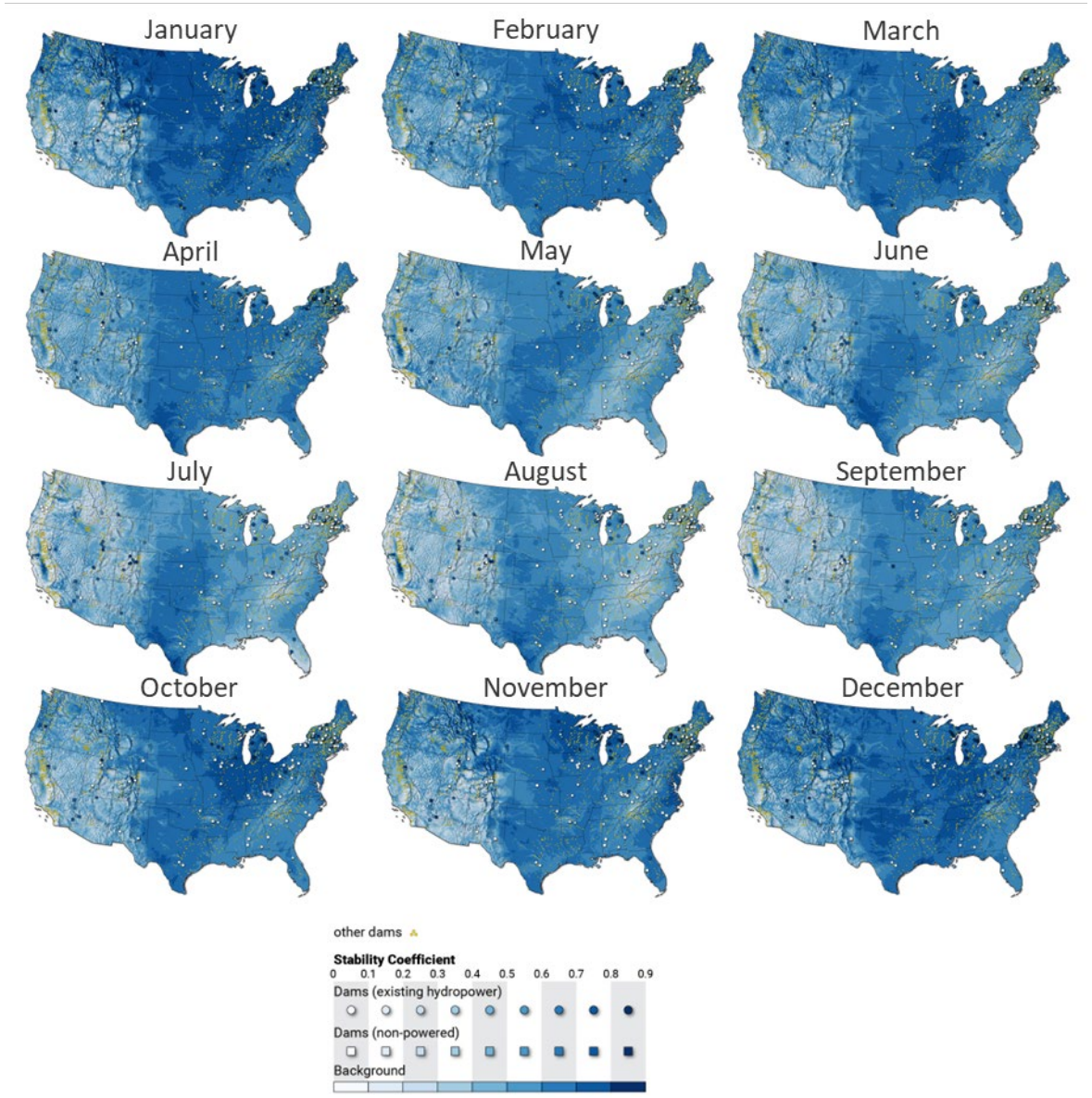
- Hourly complementarity is higher than daily complementarity
- Hydro-wind complementarity is not as strong as pairs that include solar
- Complementarity varies regionally for wind-solar and by site with hydro



Circles and squares indicate complementarity between hydropower and solar. Background color indicates complementarity between wind and solar. Yellow dots indicate dams with insufficient data.

Complementarity Varies Seasonally

- Monthly complementarity mirrors annual
- Seasonal variation does exist, especially in high complementarity areas
- Areas with mountain snowmelt have significant hydro complementarity variation



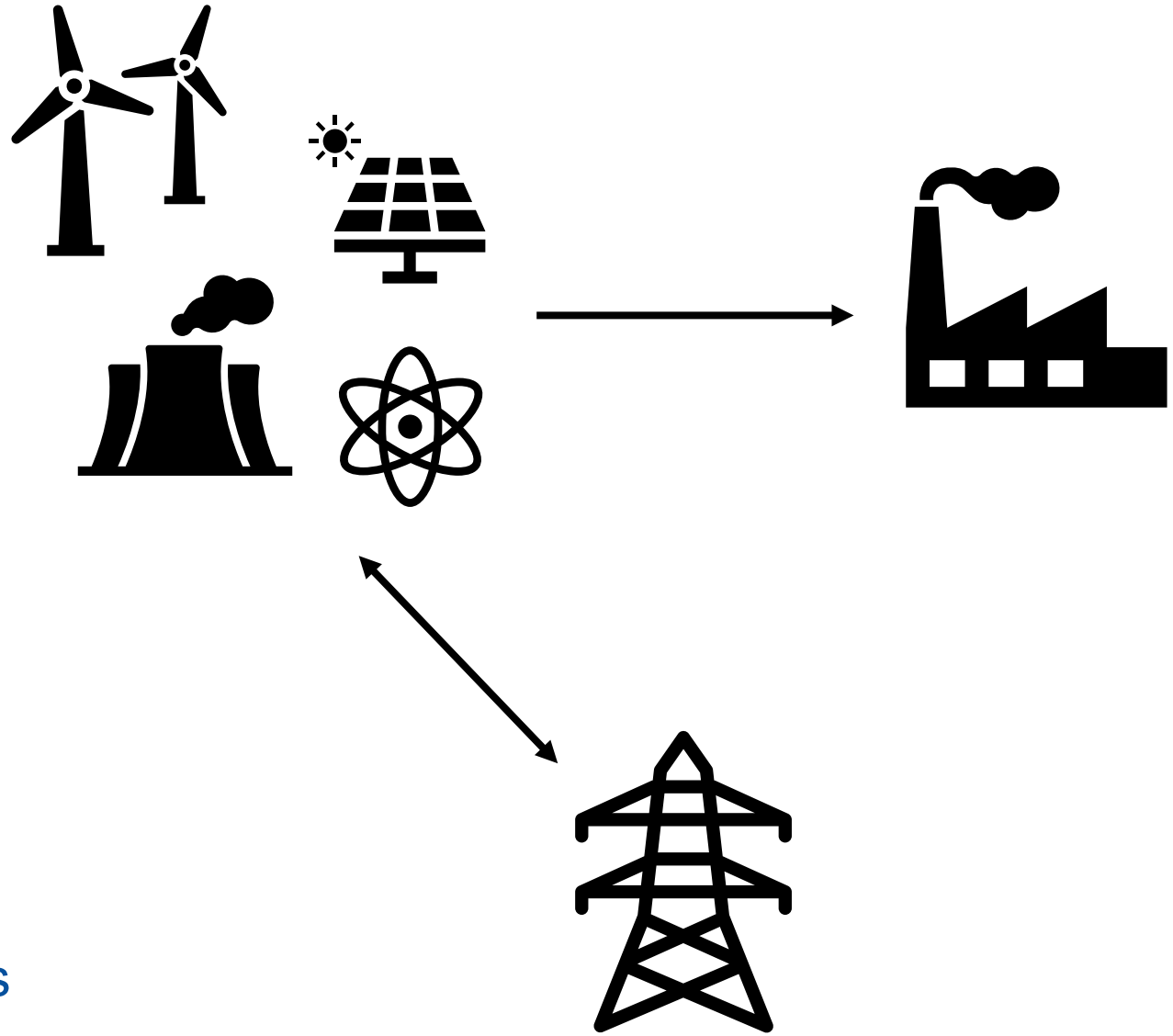
Circles and squares indicate complementarity between hydropower and solar. Background color indicates complementarity between wind and solar. Yellow dots indicate dams with insufficient data.

Other takeaways

- Capturing the temporal complementarity of resources does not require hybridization
  - Other strategies include regional resource balancing
  - Building out new transmission
- Transmission deferral benefits require sub-hourly complementarity analysis that considers seasonality
- Relative sizing of resources influences complementarity. These results use assets with the same nameplate capacity
- Complementarity measures how close the resources are to a flat output. This may not be optimal for specific use cases.

Thermal Integration

- Why renewables?
  - Affordable bulk electricity
  - Tax credits
  - Easily scalable
- Why clean thermal?
  - Affordable firm capacity
  - Affordable high-grade heat
  - Increases system inertia
- Use cases
  - Low complementarity areas
  - Rural co-ops
  - Industrial processes



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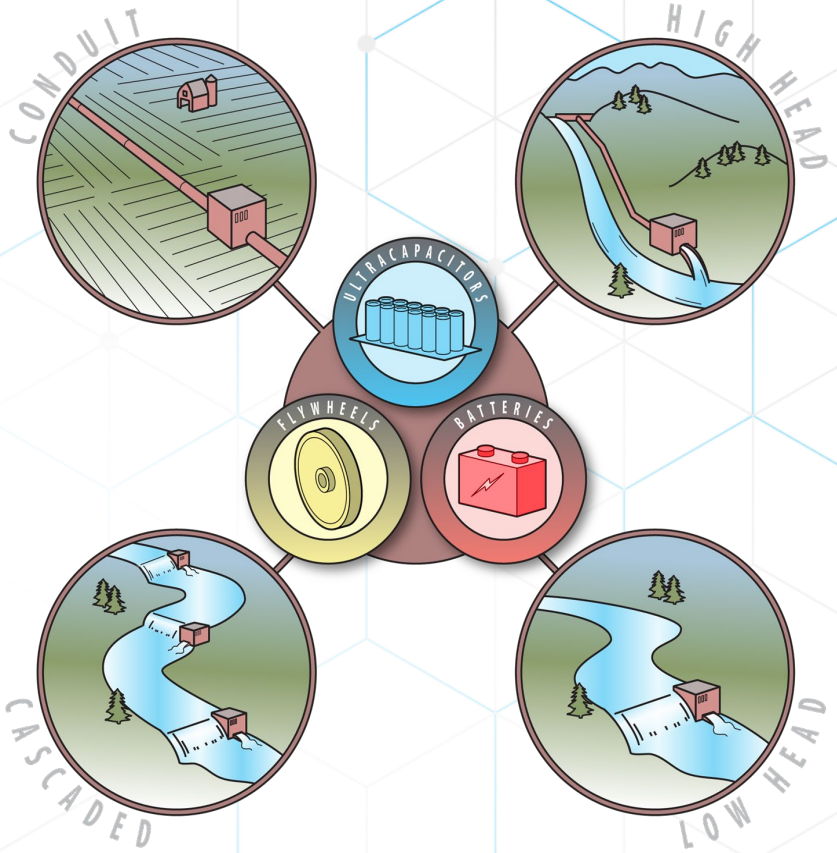
Mercury Governor

Hydro-Hybrids



Hill Balliet, S M Shafiul Alam, Thomas Mosier, Venkat Durvasulu, Vahan Gevorgian, Jonghwan Kwon, Binghui Li, Yingqian Lin, Matt Mahalik, Carlos Lopez, Weihang Yan

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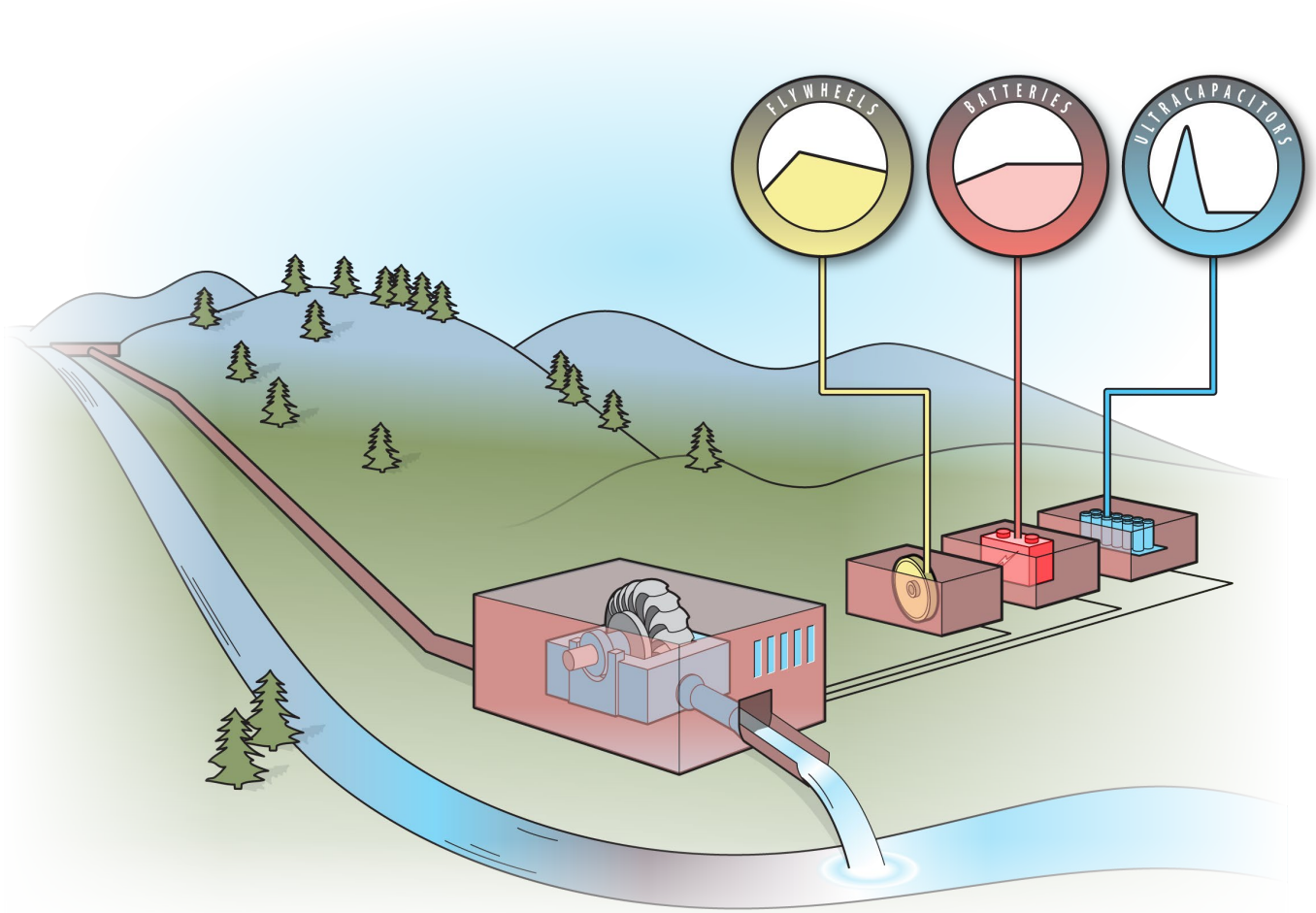
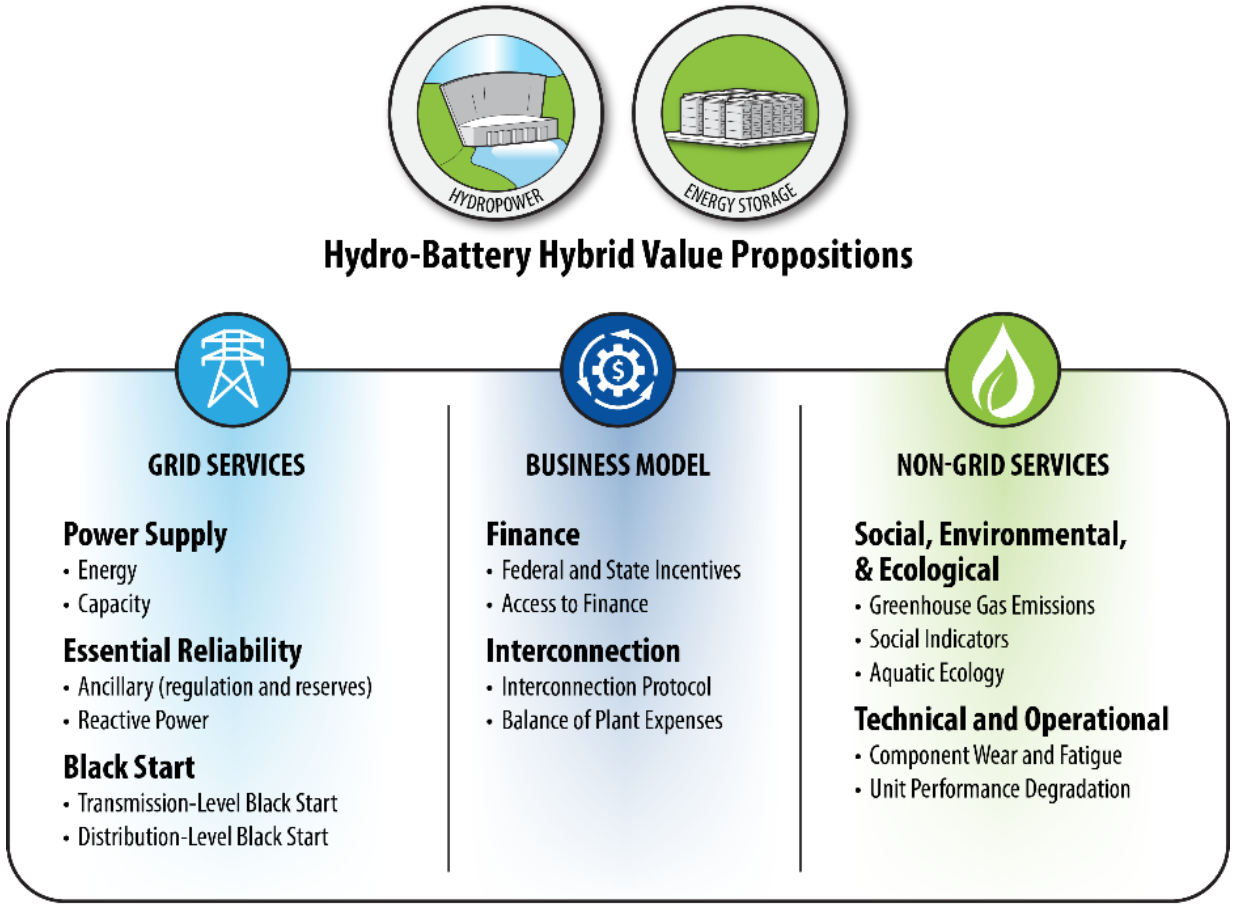
Hydropower Hybrids: Objectives

- Deployment ready technology for powering local loads during emergencies
- Tools that lower the barrier to hybridization of existing plants

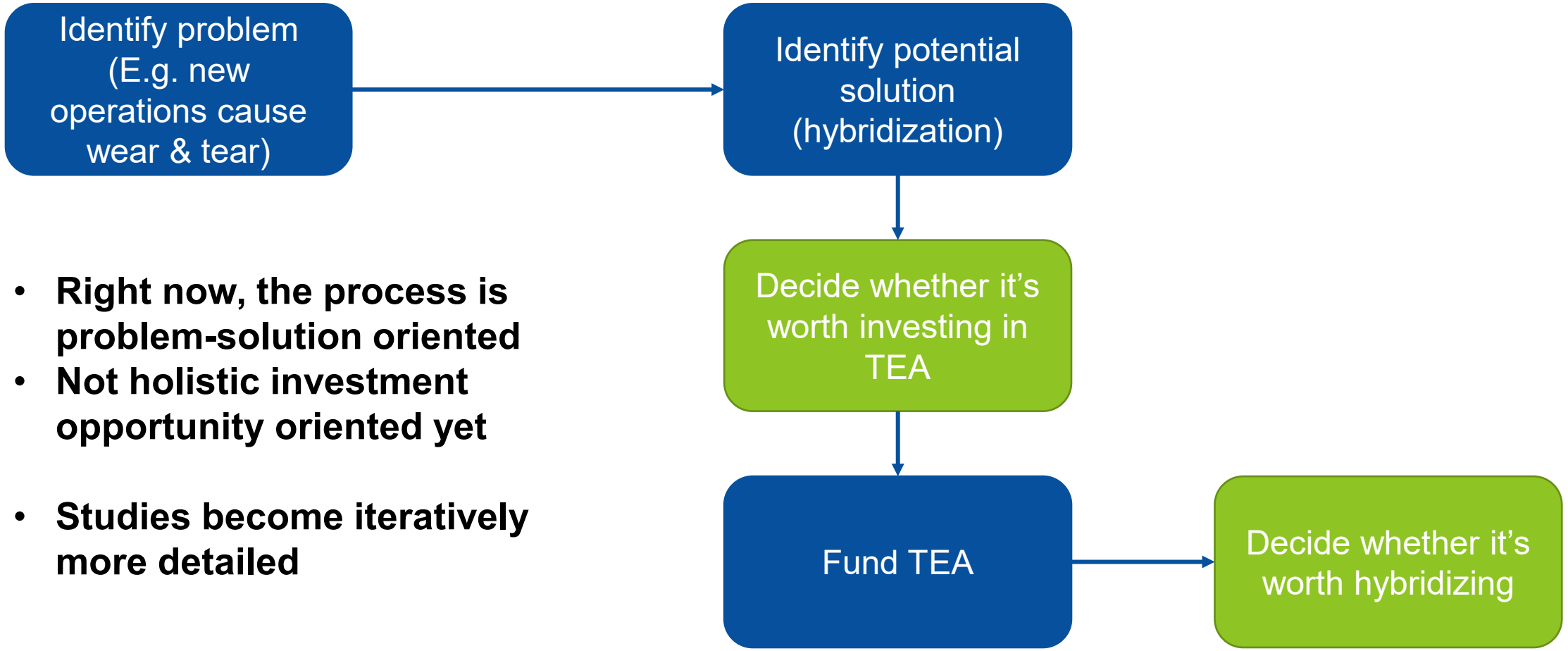


Competing Value Streams

- Review paper identifies value propositions that:
  - Affect the decision to hybridize a hydropower asset
  - Affect the operation of hydro hybrid assets
- Competing value streams should be pursued situationally
  - Hydropower owners don't know all value propositions
  - Don't have the tools to dynamically select which to pursue



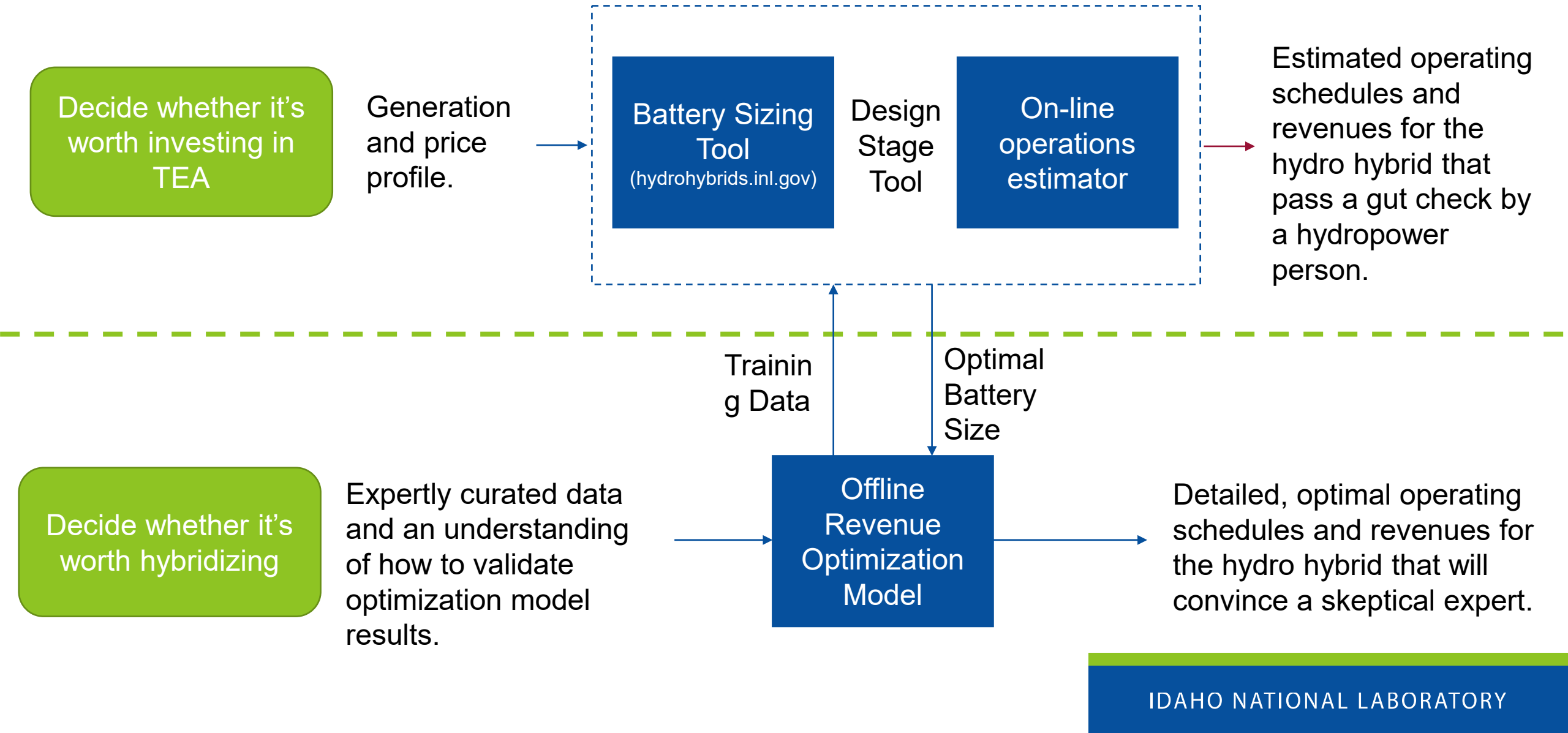
The Hybridization Decision Process



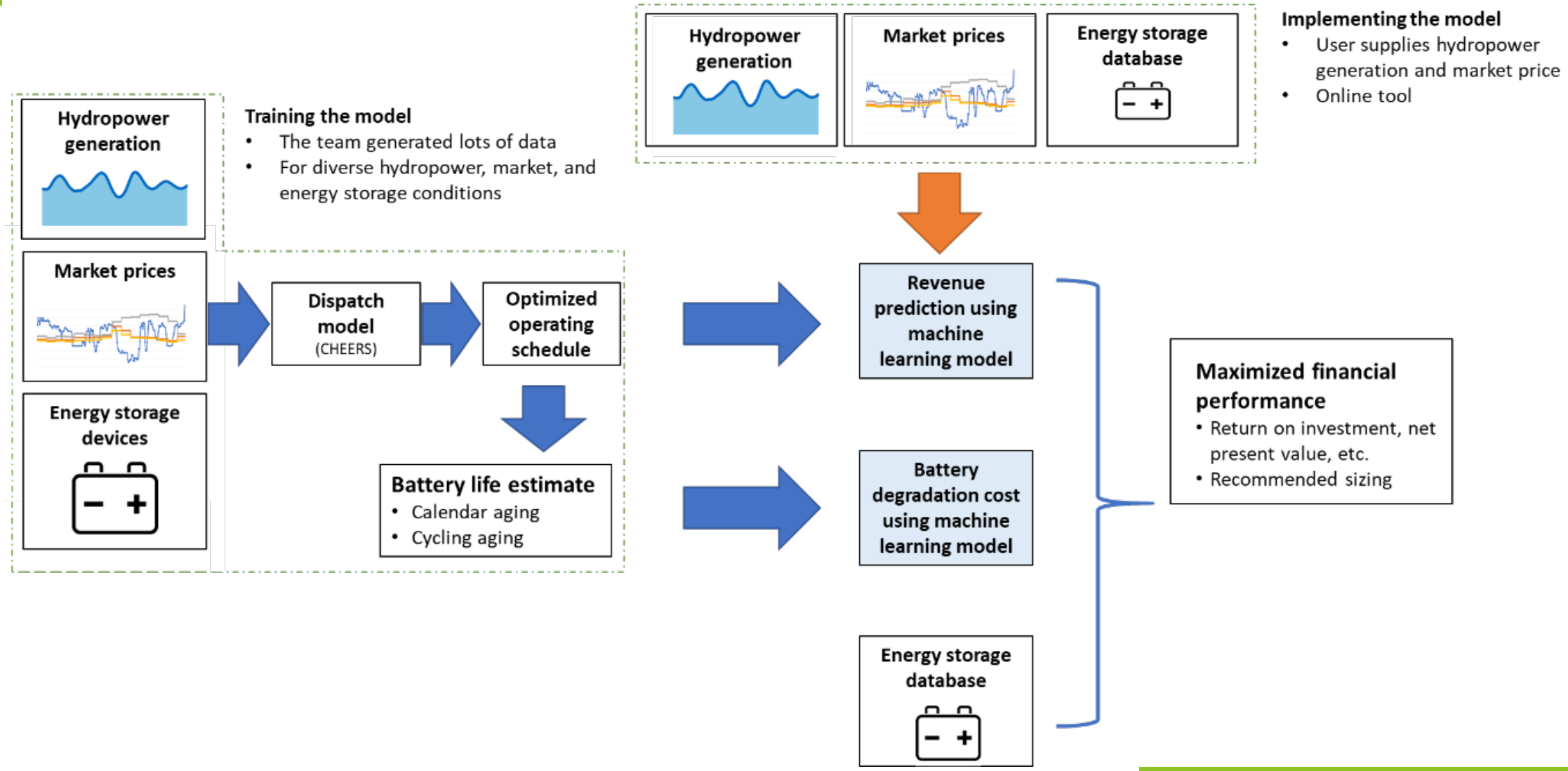
- **Right now, the process is problem-solution oriented**
- **Not holistic investment opportunity oriented yet**

- **Studies become iteratively more detailed**

How Our Tools Fit in

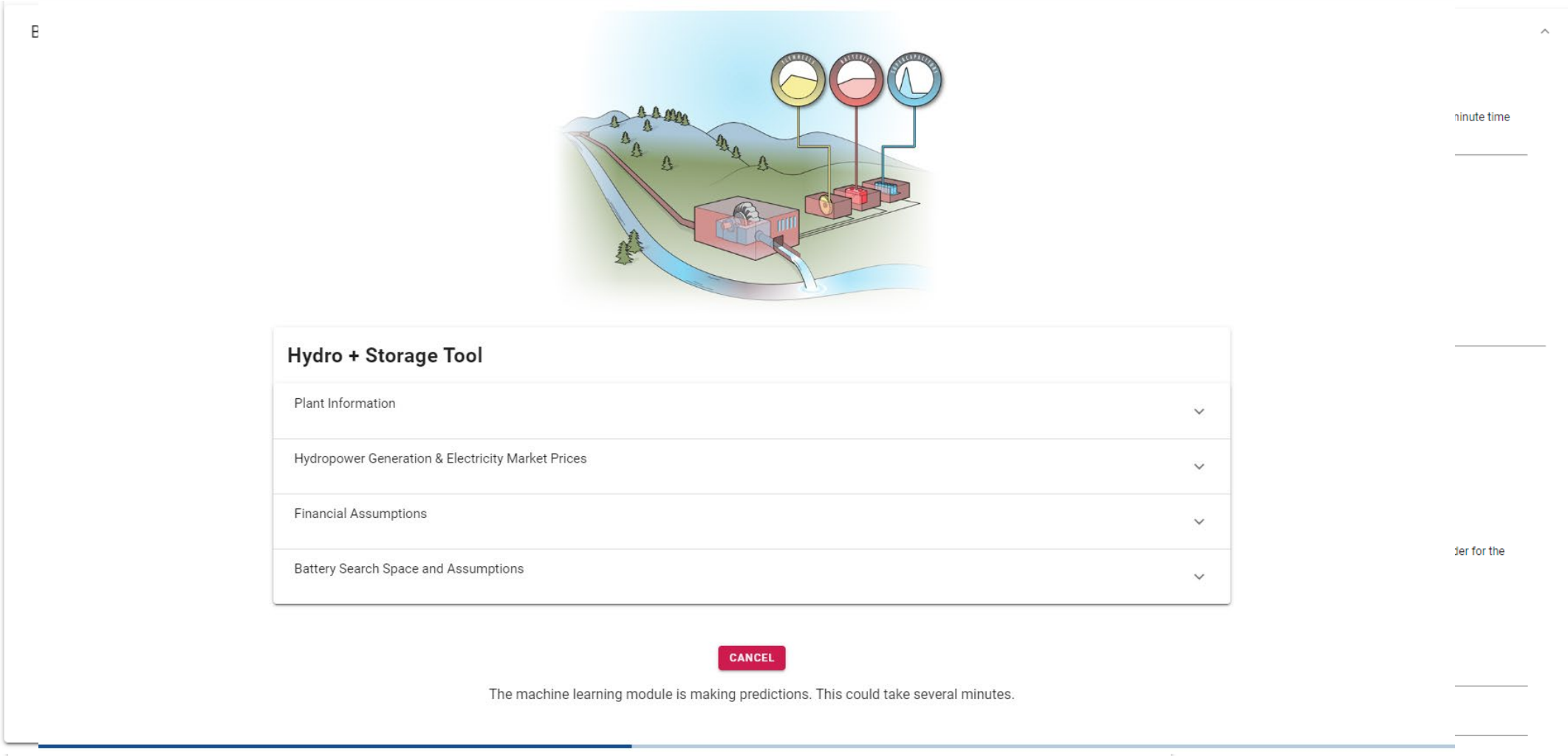


The Hydro + Storage Sizing Tool: sizing optimization of battery to increase financial performance



1. 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
2. M. Mahalik, T. Veselka, A. Mahajan, and F. T. Bui, "Application of a New Tool to Optimize Hydropower Day-Ahead Scheduling and Real-Time Operations," in Proceedings of HydroVision International 2012, Louisville, KY, July 2012 2012.

User interface of the Hydro + Storage Sizing Tool



Cold winters spurred Idaho Falls Power's interest in city electrical islandability

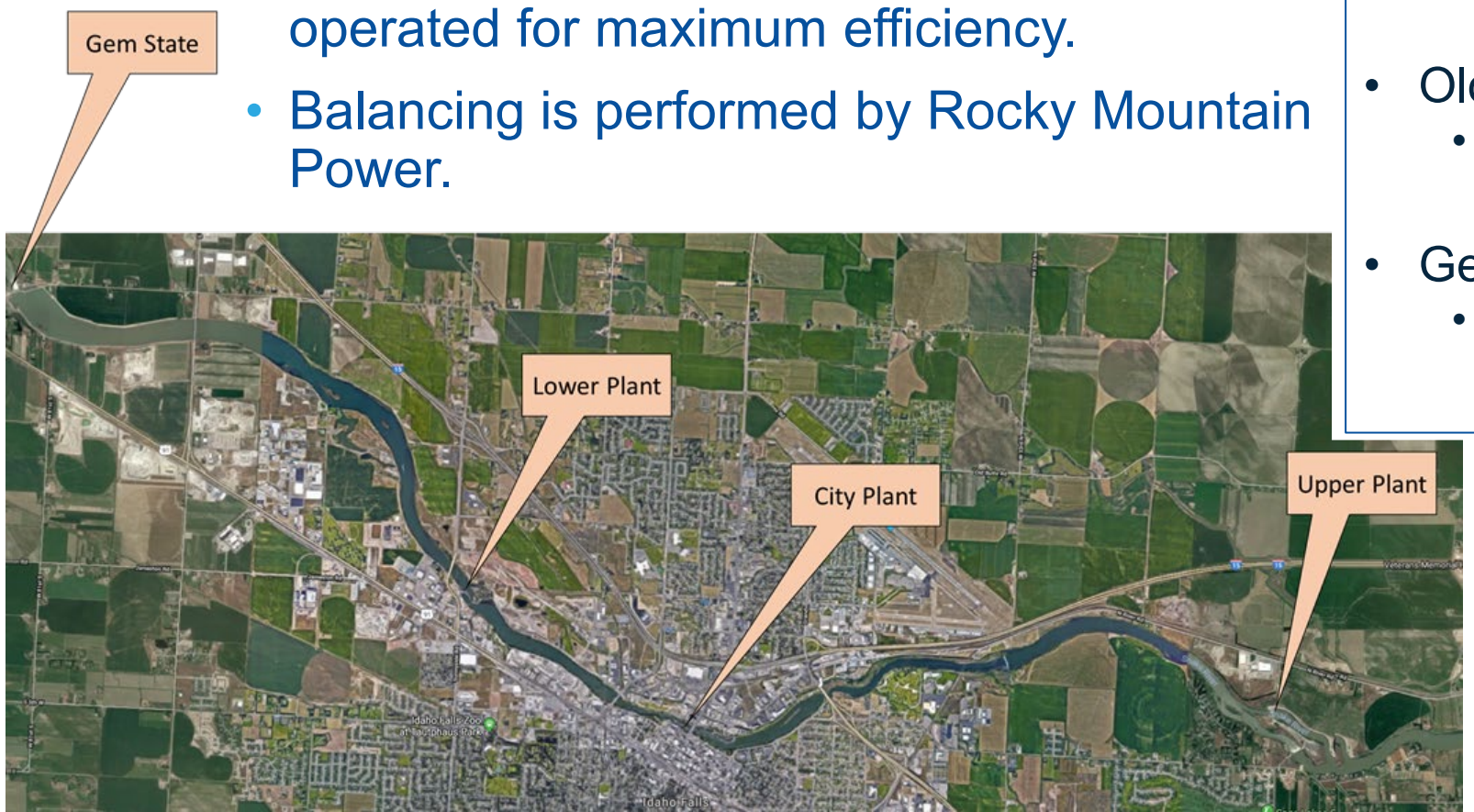
- IFP was disconnected from transmission during a cold winter storm
- At that time, had no experience operating system as temporary microgrid

IFP, INL, NREL, and Emerson performed April 2021 field demonstration to advance this capability

Source: Idaho Falls Magazine

Idaho Falls Power is municipal utility with five hydropower plants on upper Snake River

- Plants all connected to city's distribution and sub-transmission system.
- Under normal conditions, plants are operated for maximum efficiency.
- Balancing is performed by Rocky Mountain Power.

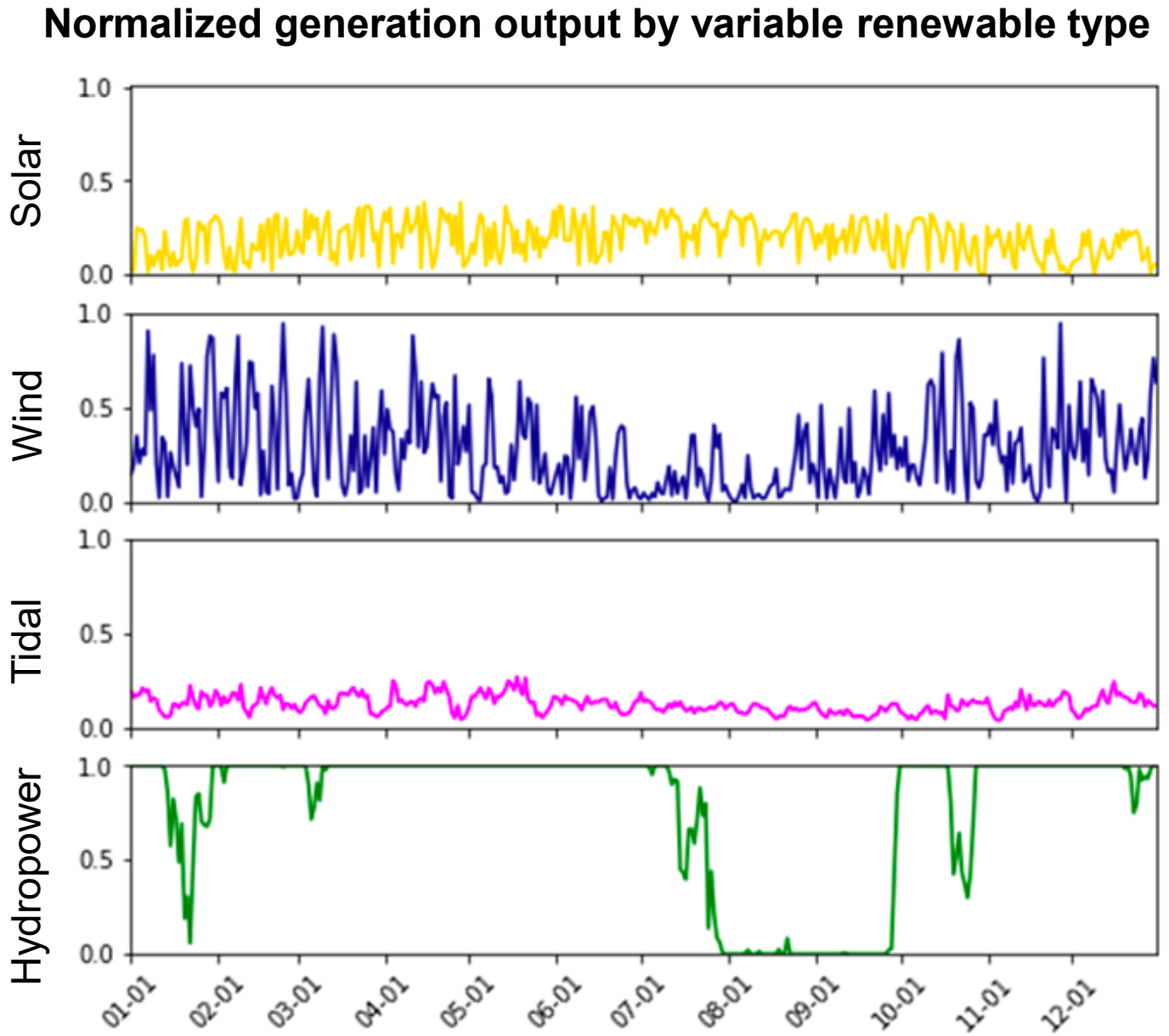


Hydropower plants

- Upper, City, and Lower
  - Bulb-style Kaplan units; 8.9 MW each; connected to distribution
- Old Lower
  - Two vertical Kaplan units; 1.8 MW each; connected to distribution
- Gem State
  - Single vertical Kaplan unit; 26 MW; connected to sub-transmission

Why hydropower for islanding?

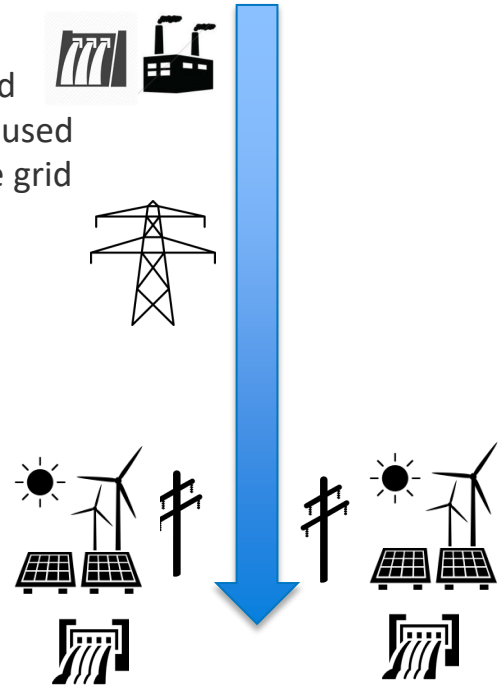
- It's less variable and more predictable over minute to daily timescales compared to wind and solar
- Has inertia, and pressure from water column, to help stabilize frequency



Source: Shafiul Alam (INL), Michael Emmanuel (NREL)

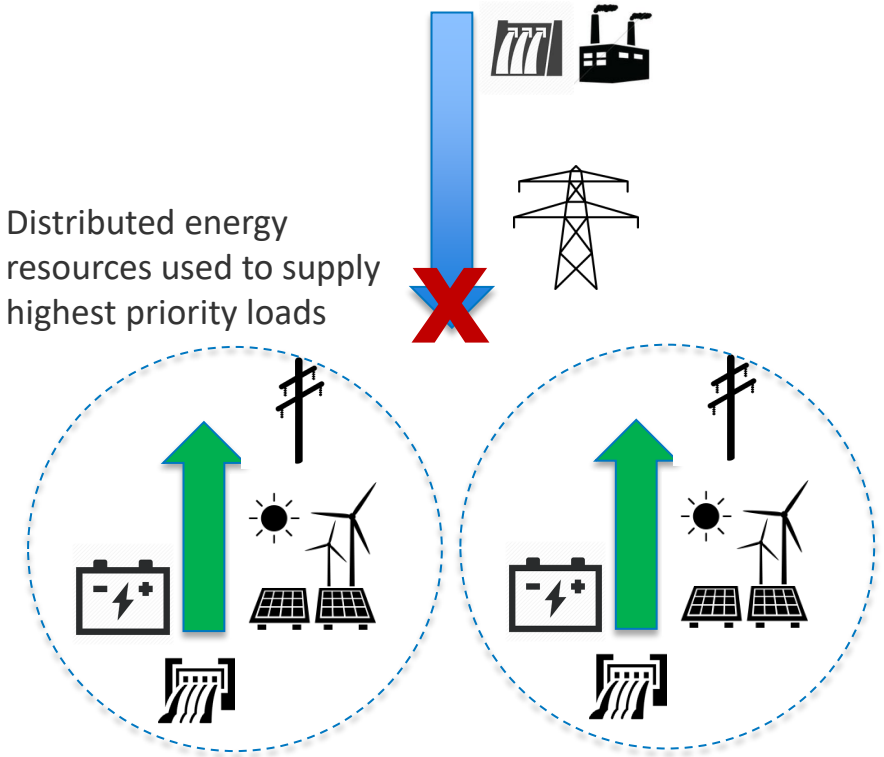
A shifting paradigm for distributed energy resources

Conventional top-down balancing



Distributed energy resources used to offset centralized power requirements

Use of local resources for balancing

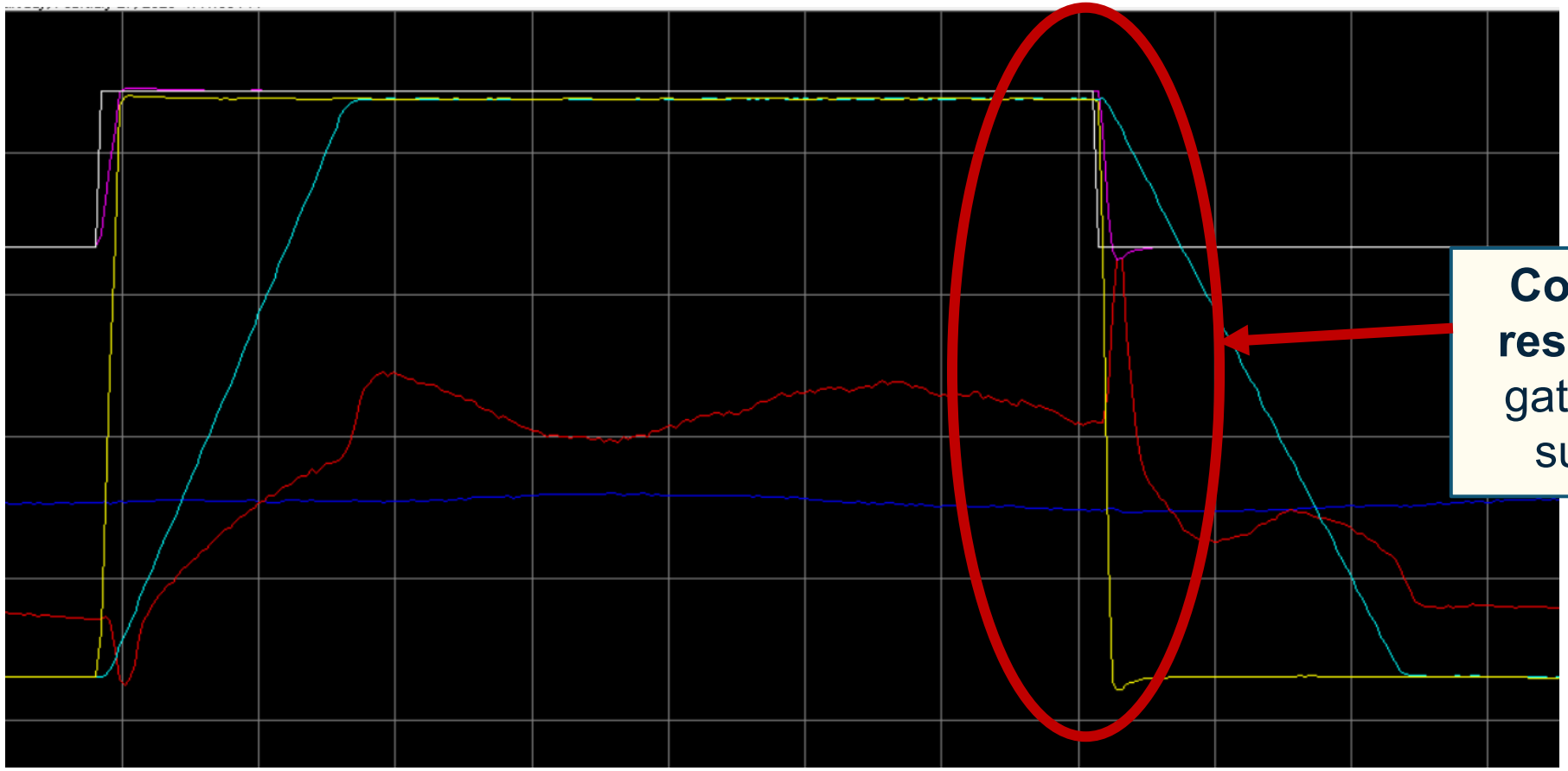


Enabling temporary grid islanding requires increased investment

- Automatic switching
- Distribution system controls
- Individual unit controls
- Operator training

Source: adapted from Vahan Gevorgian (NREL)

At approximately 40% capacity and above, bulb-style Kaplan units have strong counterintuitive response



Aqua line = gate position
Red line = power output

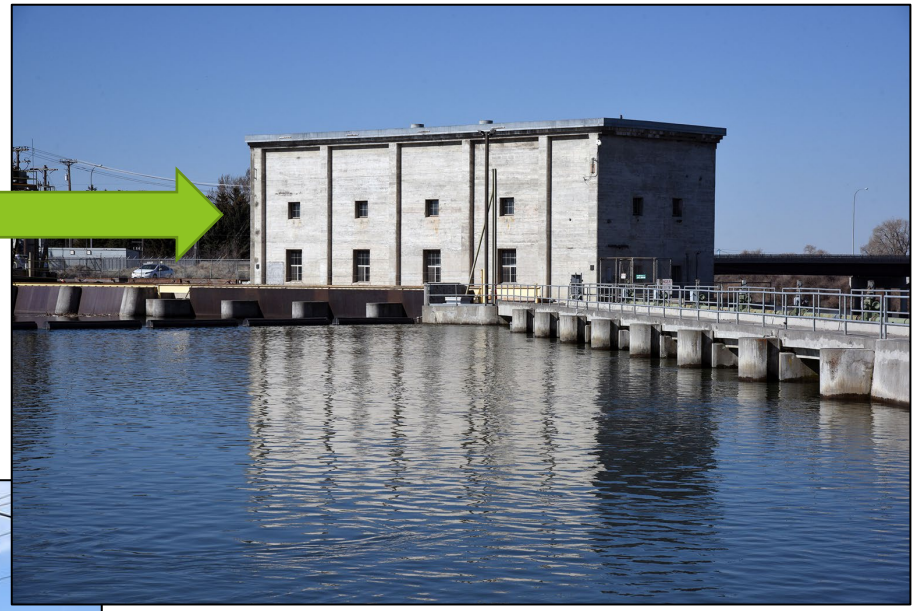
Counterintuitive response: closing gate causes short surge in power

Field demonstration evaluated three solutions to enable islanding

- **Adding energy storage**
  - Provide fast response with ultracapacitor and inverter systems (lessens requirement for hydropower units).
- **Optimizing governor controls**
  - Implement improved governor controls, optimized for maximizing stability of variable pitch Kaplan units.
- **Synchronizing multiple plants**
  - Additional rotating mass, ramping, and generation capacity.

To the field: IFP islanded Rack substation and three hydropower plants

Lower Bulb and Old Lower hydropower plants

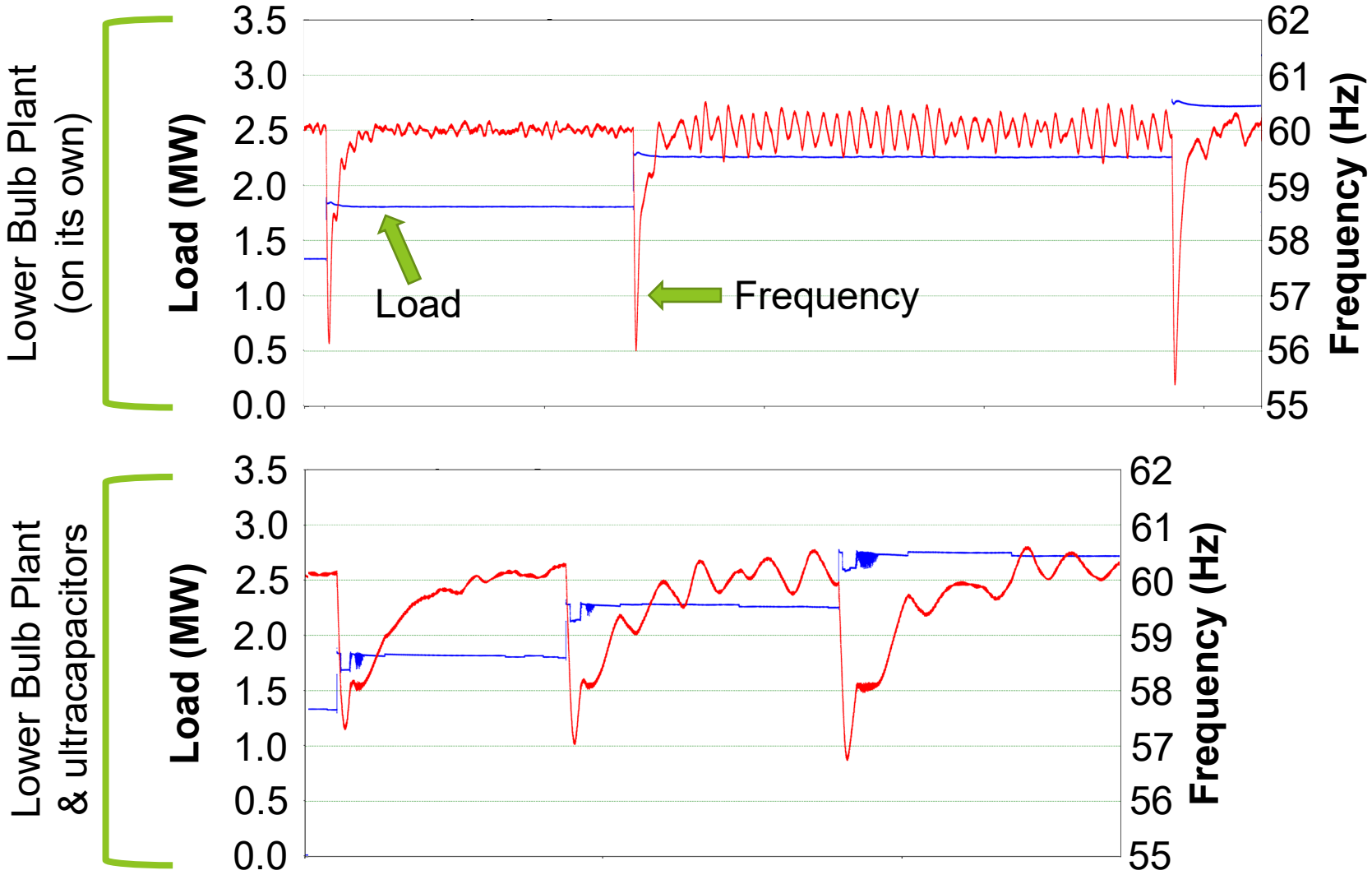


Rack substation

load banks (8 MW)

Ultracapacitor system

Ultracapacitors improved Lower Bulb Plant frequency excursions

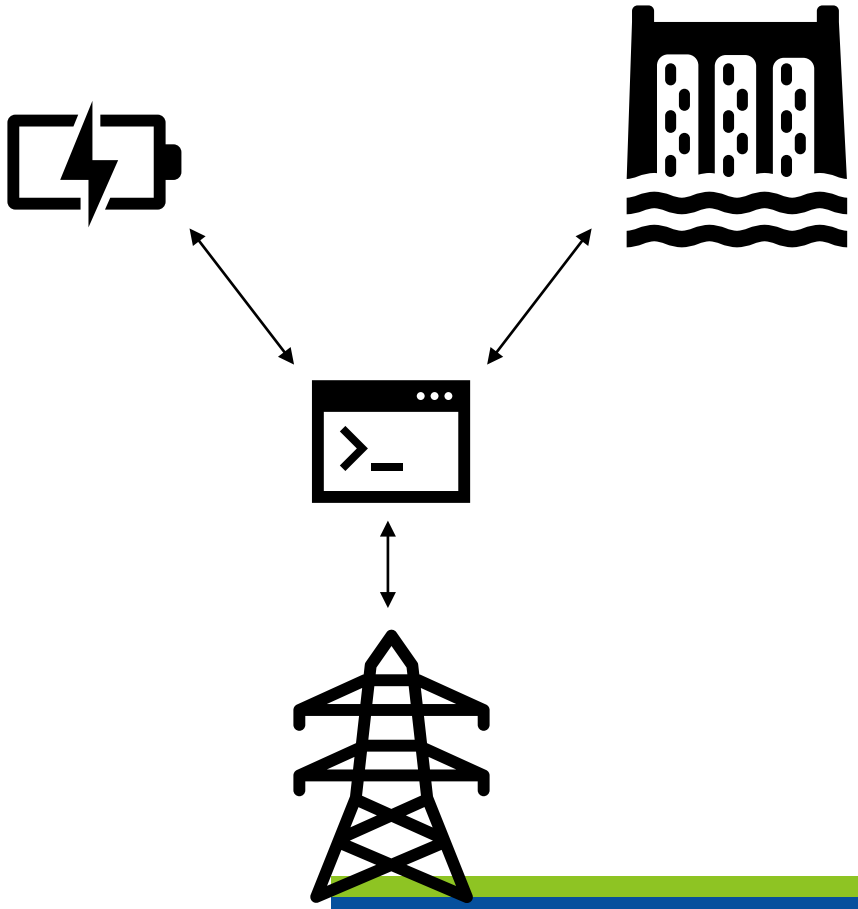


Ultracapacitor impacts:

- Improve frequency nadir
- Reduce high frequency oscillations
- Slow response time

Potential Innovations

- HIL test of entire system black start, including transmission and loads.
- Demonstrate minimal retrofit to existing flow control.
- Test with a Francis turbine, the most common type in the US.
- Demonstrate at a more remote site.
- Automate storage recharging during black start process. (low SOC battery)
- Automate operation mode-based control changes.



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