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HydroVision International

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Demonstrating Black Start and Islanded Operation of a Small Hydropower Plant*

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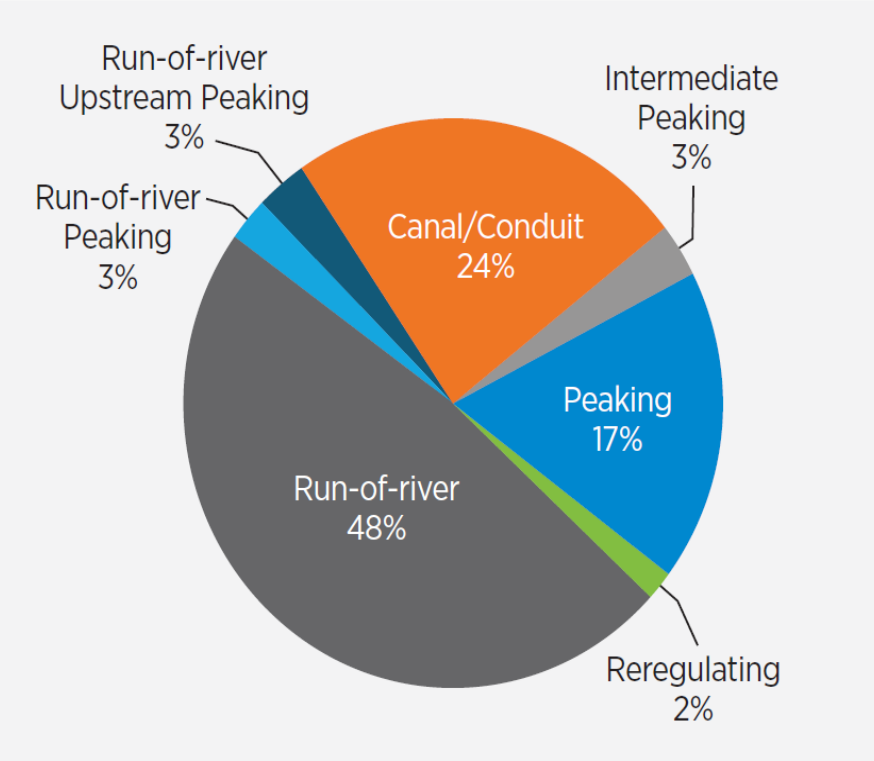
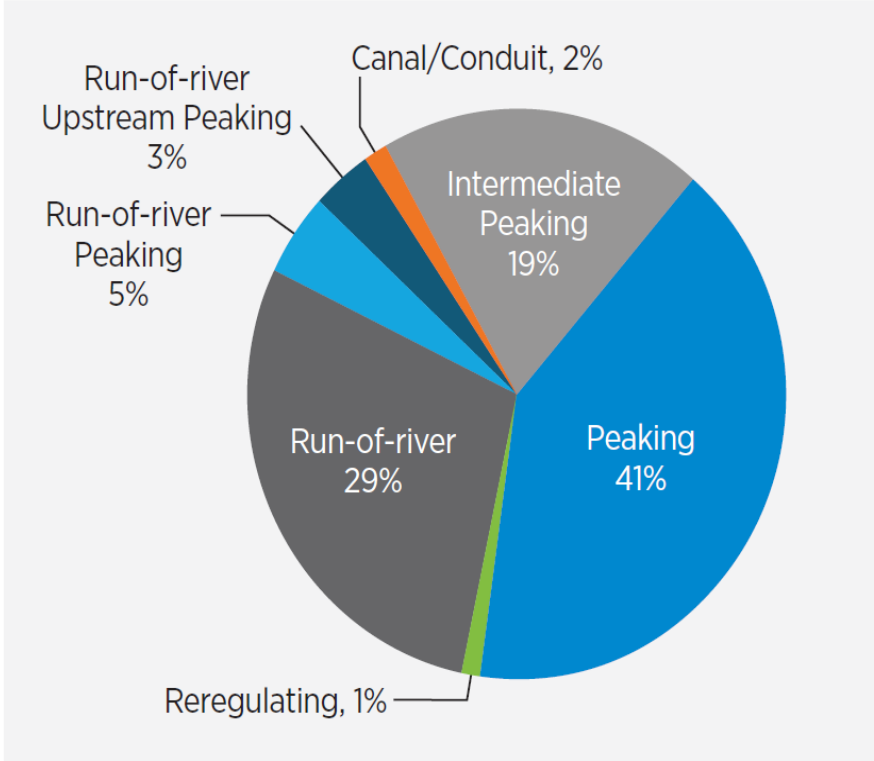
Hydropower in the US (as of 2016)



Source: National Hydropower Asset Assessment Program FY15 Plant Database [15]

Figure 2-8. Distribution of operating modes for hydropower facilities, by number of projects

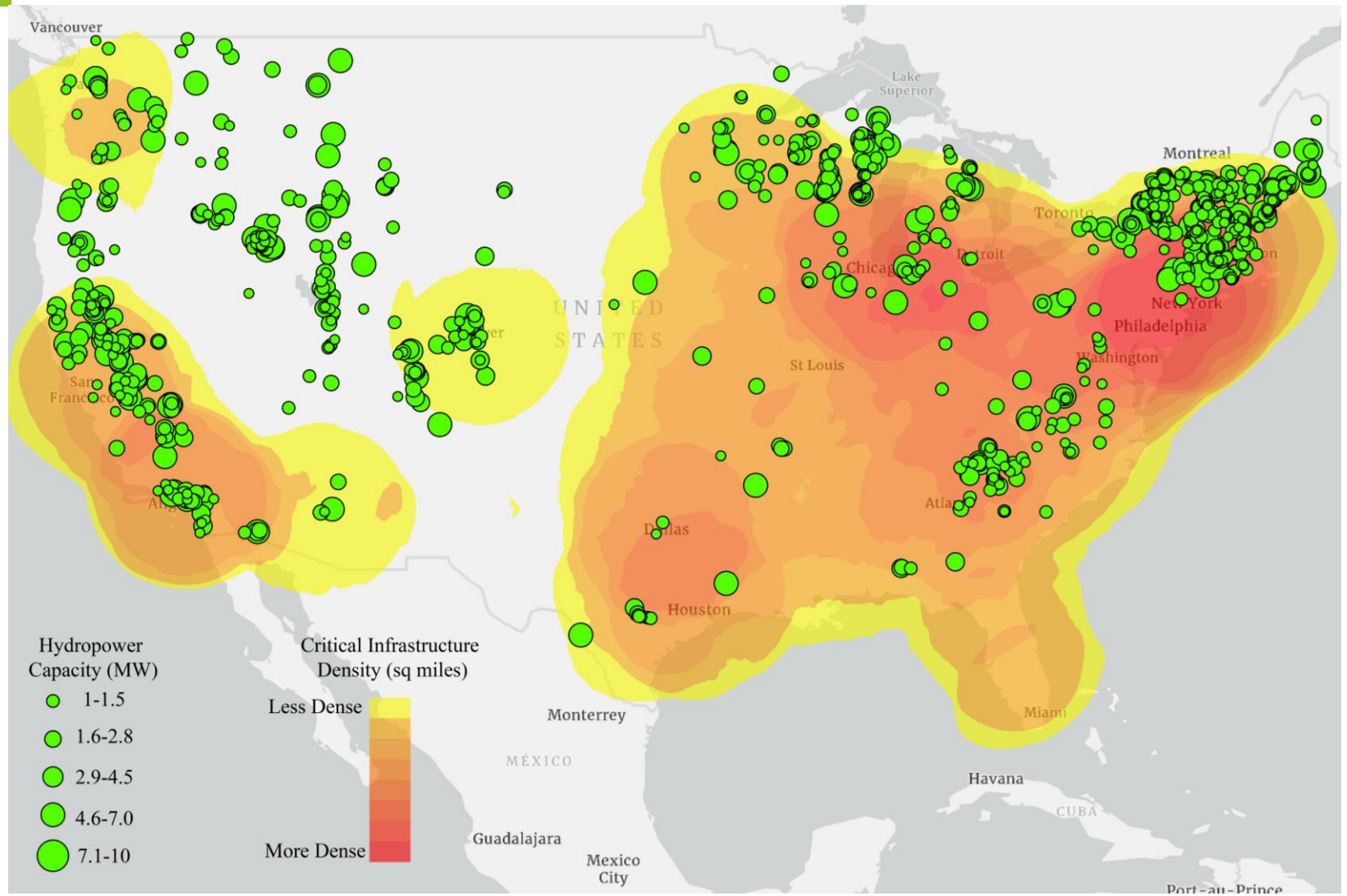


Source: National Hydropower Asset Assessment Program FY15 Plant Database [15]

Figure 2-9. Distribution of operating modes for hydropower facilities, by capacity

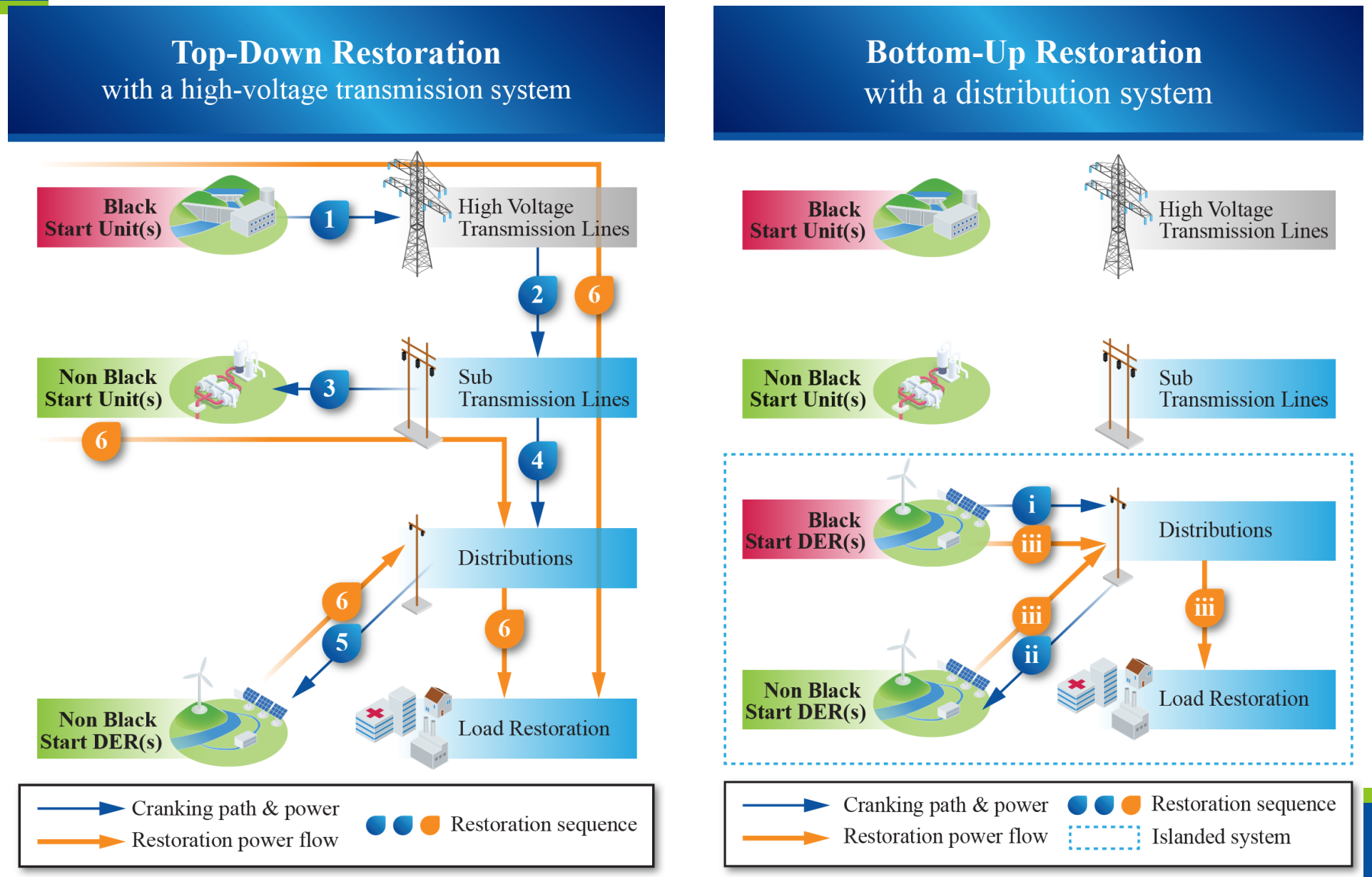
Image Source: DOE, Hydropower Vision Report, 2016

US Small Hydro (<10MW) Fleet

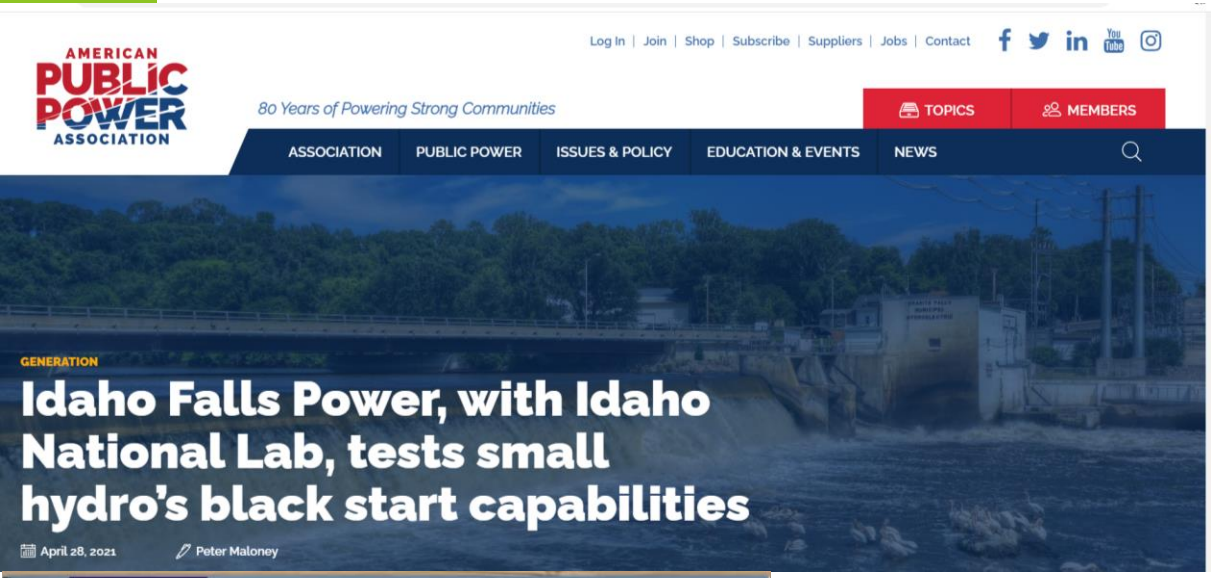


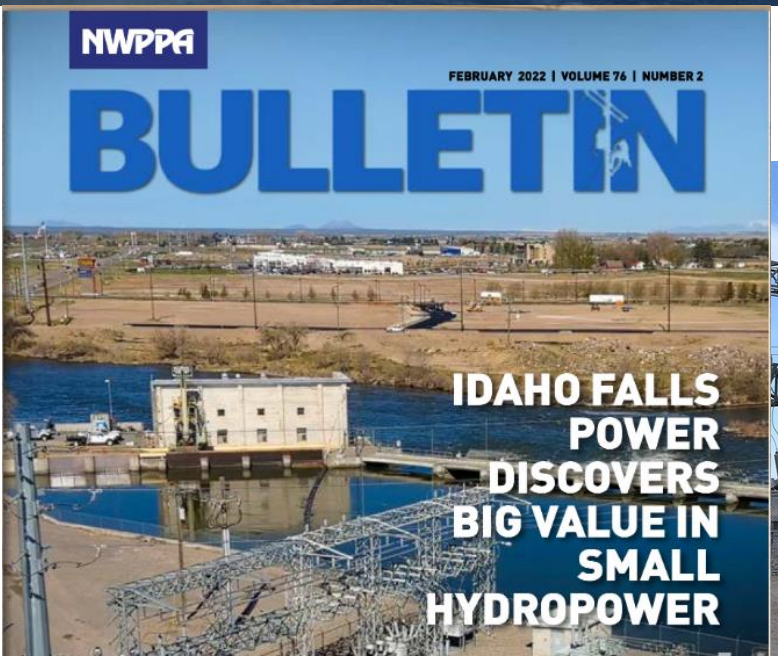
- Can small hydropower form microgrid during
  - Public safety power shutoff?
  - Load-shed in the winter?
  - Bulk grid black out?

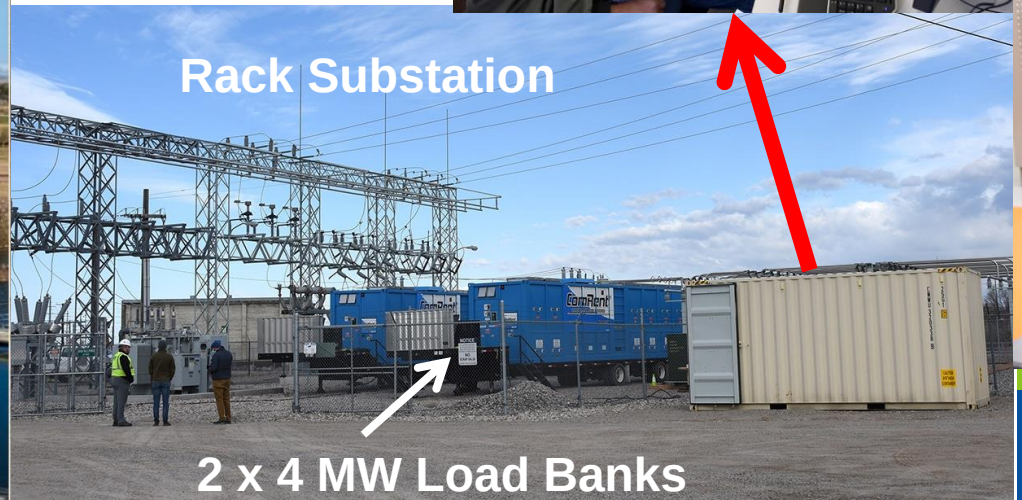
Black Start and Restoration



Islanded Distribution Grid Black Start: Successful Field Demonstration with Idaho Falls Power

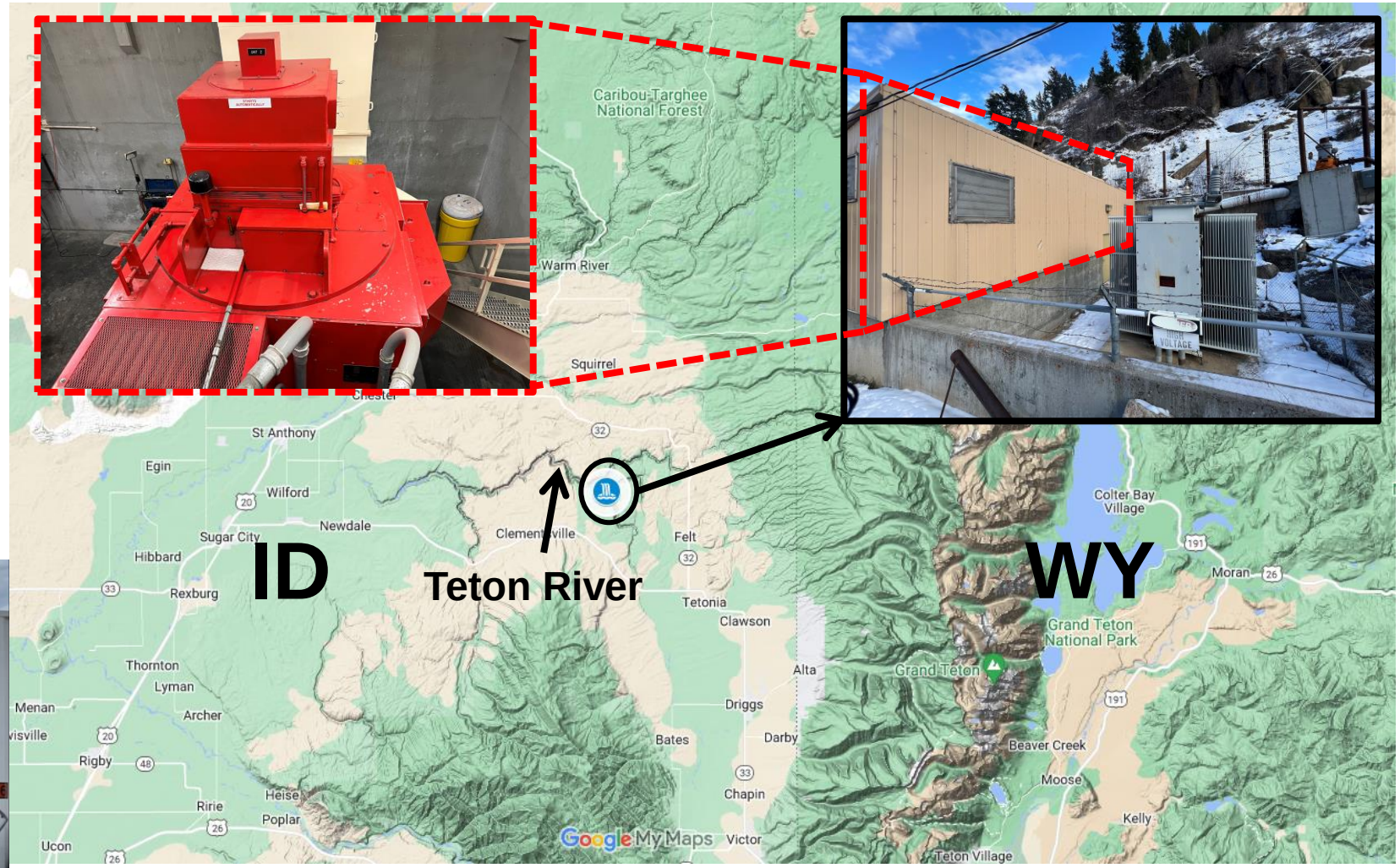




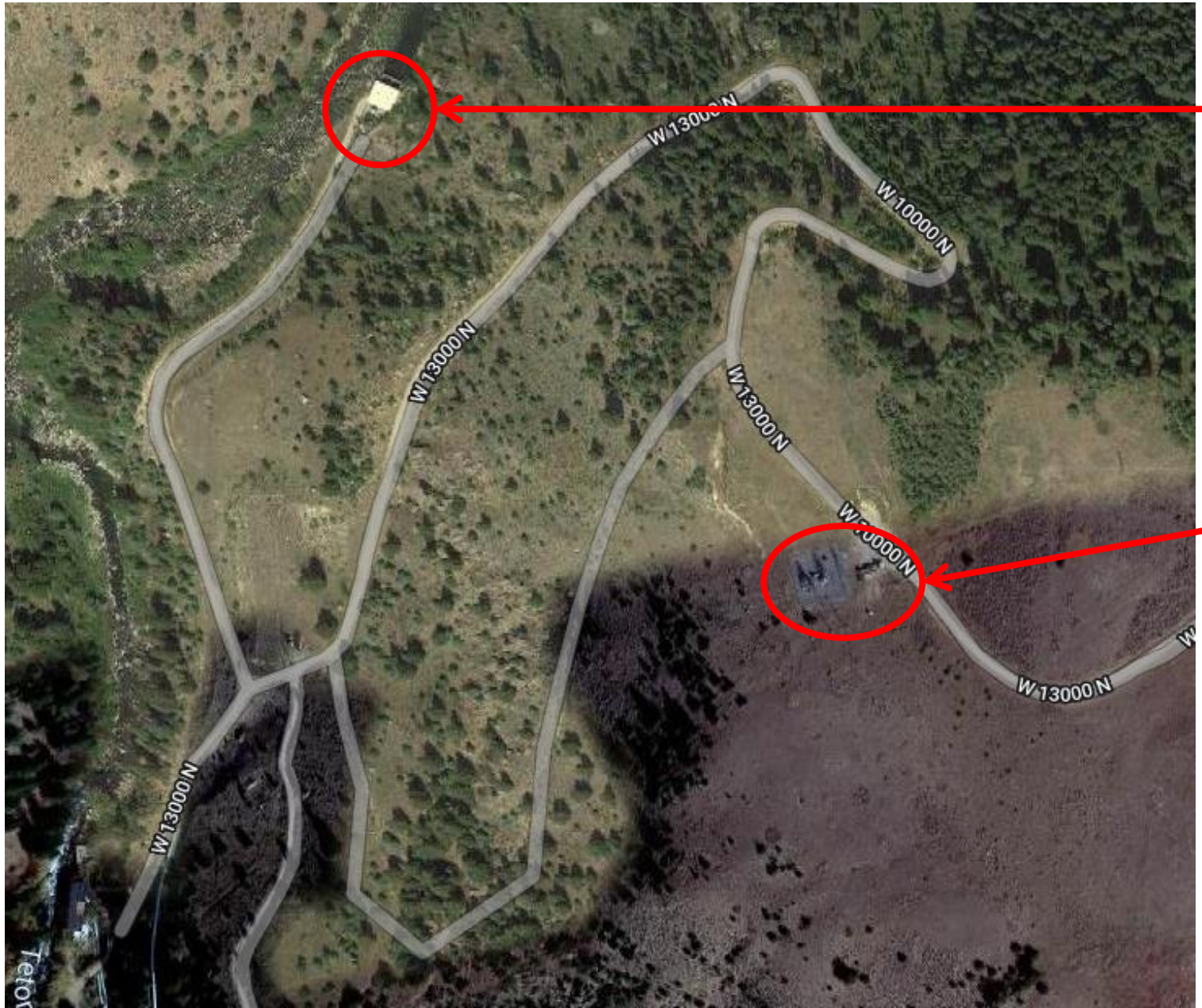


2nd Field Demonstration: Black Start Felt Plant

- Utility: Fall River Rural Electric (FRE) Cooperative.
- Remote site.
- Minimal retrofit to exiting flow control.
- Mobile energy storage support with automatic control.



Interconnection

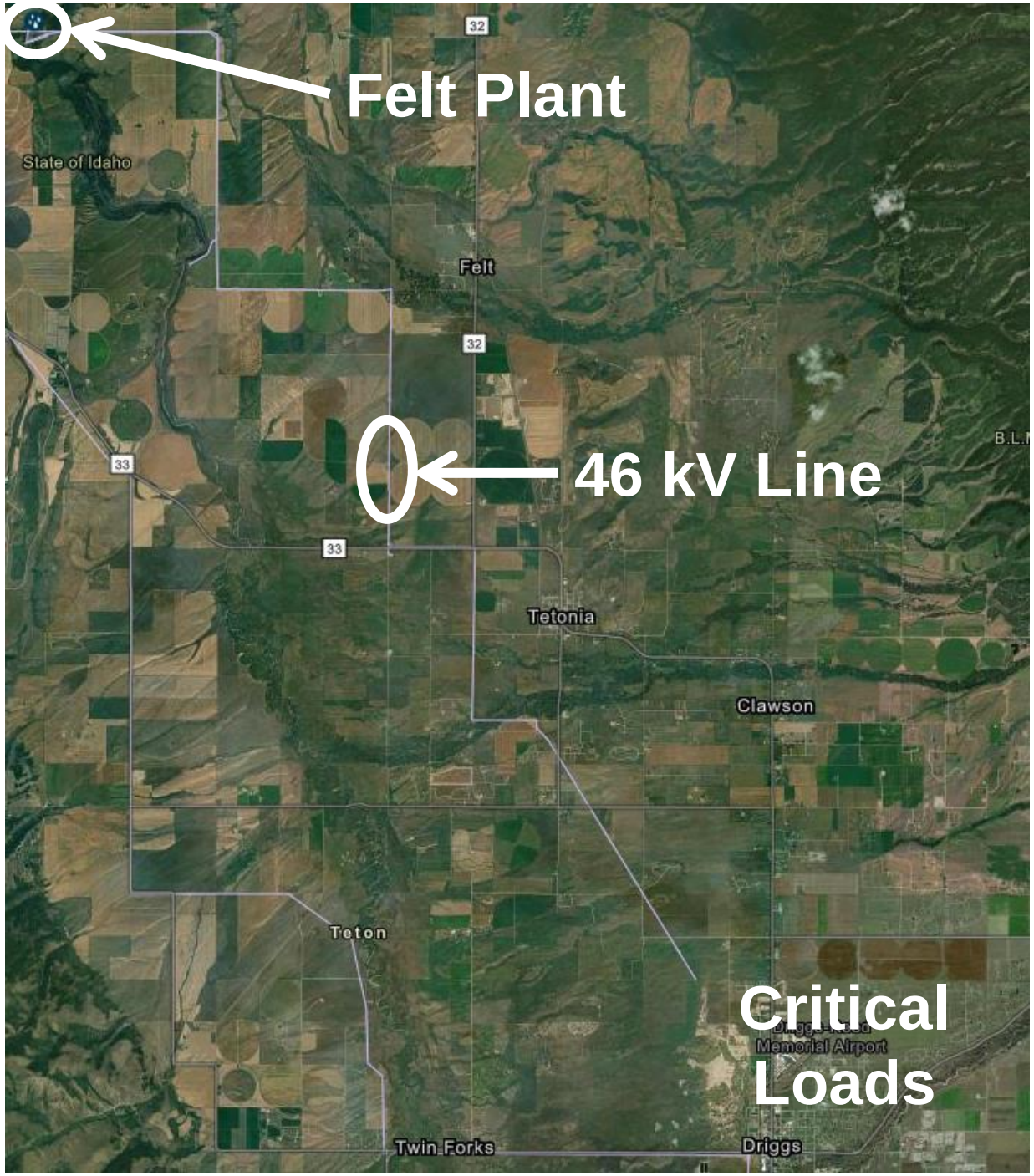


Felt plant

Badger Substation

Satellite Image Source: Google Maps

Winter Transportation: From Badger substation to Felt Plant (0.8 miles)



Black start Felt plant and support the Teton basin critical loads over the 46kV line

Image Source:
US Energy Information Administration

Steps to De-risk the Field Demonstration

Modeling

- Collect hydrogovernor data in grid connected mode of operation
- Develop hydrogovernor model for ROR hydropower on Simulink

Simulation

- Set hydrogovernor in islanded mode
- Analyze response to load step change on Simulink
  - Without Storage
  - With Storage

Test

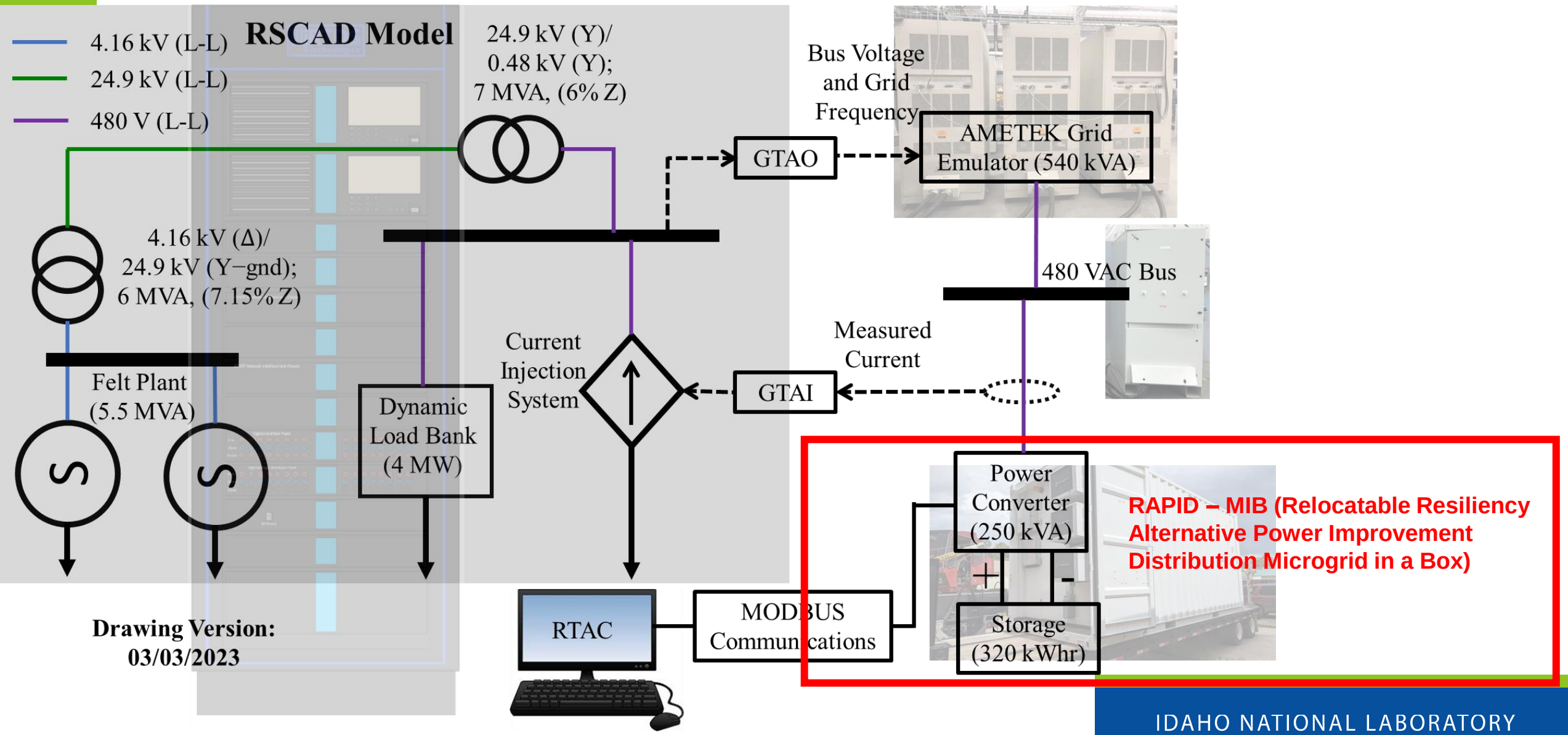
- Develop RSCAD model for digital real-time simulation (DRTS)
- Conduct power hardware-in-the-loop (PHIL) test

Felt Plant Technical Information

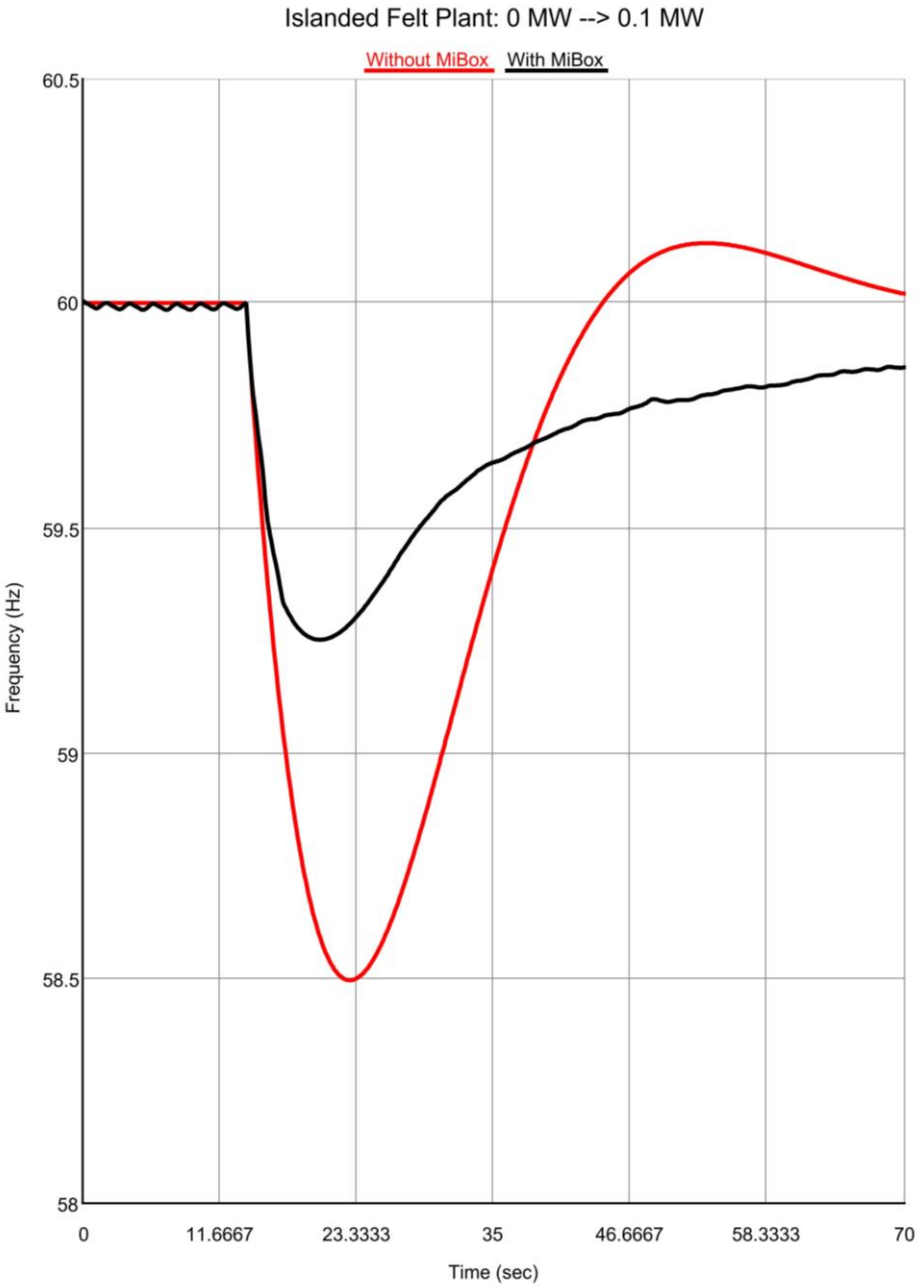
- Number of units: 2
- **Turbine: Francis**
- Rated head: 155 ft, maximum head: 156 ft, minimum head: 154 ft.
- Combined generation capacity of 2 units: 5.5 MW (156 ft head); 5.43 MW (154 ft head)
- Combined design flow rate for two units: 500 CFS, minimum: 125 CFS
- **Rated combined capacity of the two turbines: 2 x 3840 HP = 5.73 MW**
- Penstock length: 1750 ft
- Penstock diameter: 8ft
- Synchronous Speed: 600 RPM
- **Inertia constant of one unit (calculated): 2.264 sec**
- **Recommended Tw for testing: 0.75 ~ 1.5 sec**
- Power versus gate curve has been obtained through onsite test.

Information Source: FERC#5089, 08/31/2021; Tests performed by Mercury Governor, and FRE plant photo shoot.

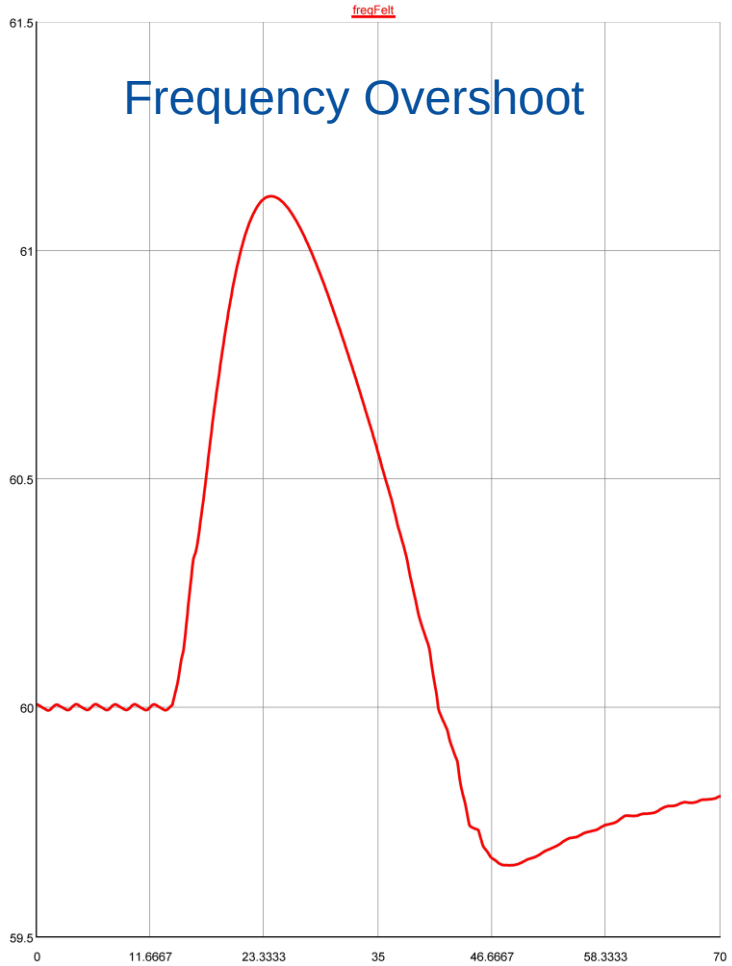
PHIL Test Set Up



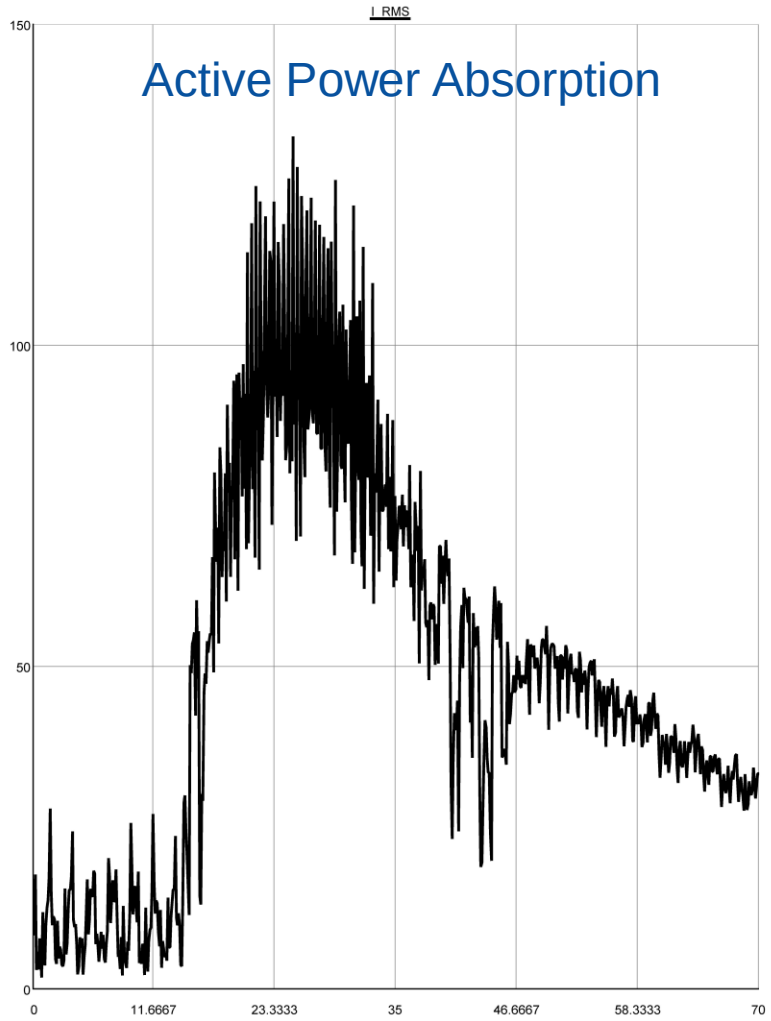
Felt Plant Transients with RAPID MIB



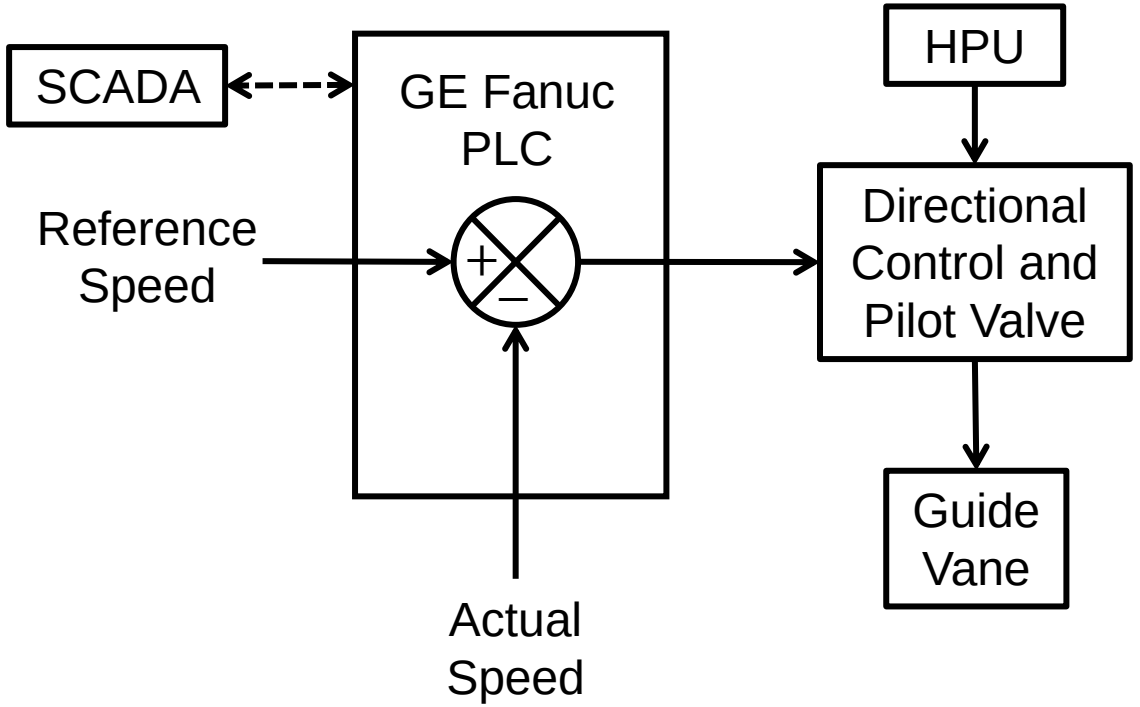
100 kW → 75 kW



100 kW → 75 kW



Felt Plant Existing Control



HPU: Hydraulic Power Unit
PLC: Programmable Logic Controller
SCADA: Supervisory Control and Data Acquisition
Guide Vane: Wicket Gate for Francis Turbine

Digital Governor Retrofit

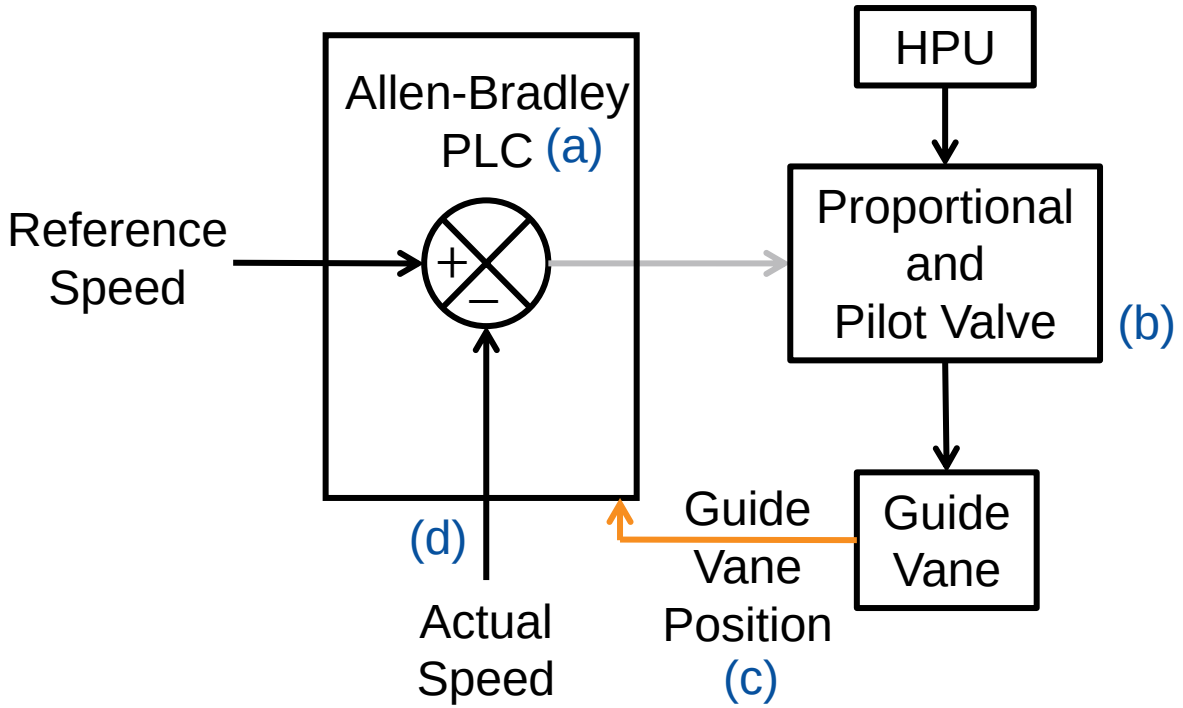
a) Installed PLC for each unit and interfaced start/stop sequence with existing wiring.

b) Replaced existing simple open/close directional valve with proportional valve.

c) Added a guide vane / gate position linear transducer.

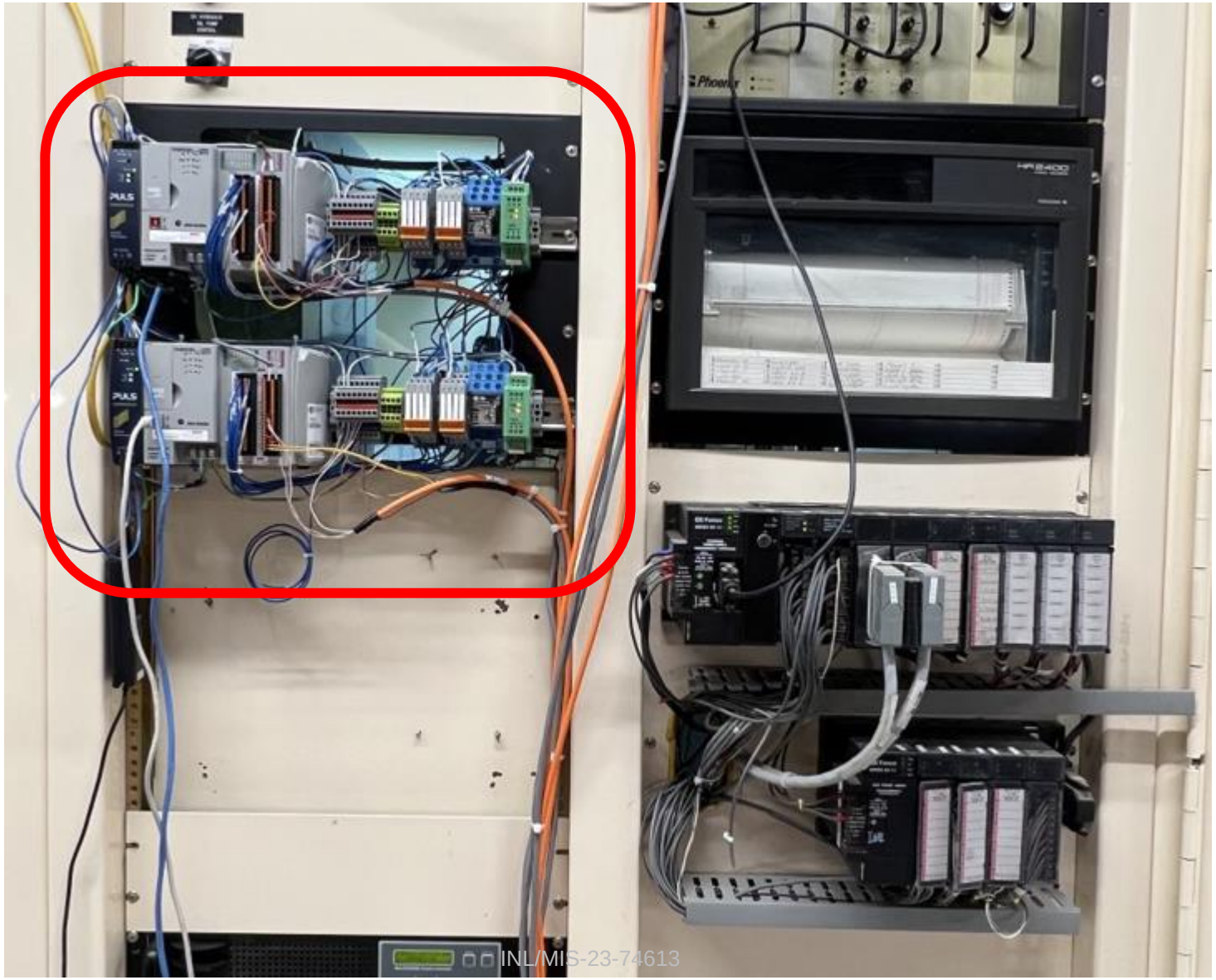
d) Added a generator PT speed sensing module.

Bypassed SCADA



HPU: Hydraulic Power Unit
PLC: Programmable Logic Controller
SCADA: Supervisory Control and Data Acquisition
Guide Vane: Wicket Gate for Francis Turbine

a) PLCs are installed for each unit



Cable retrofit for feedback and actuation

b) Proportional valve replaces directional valve

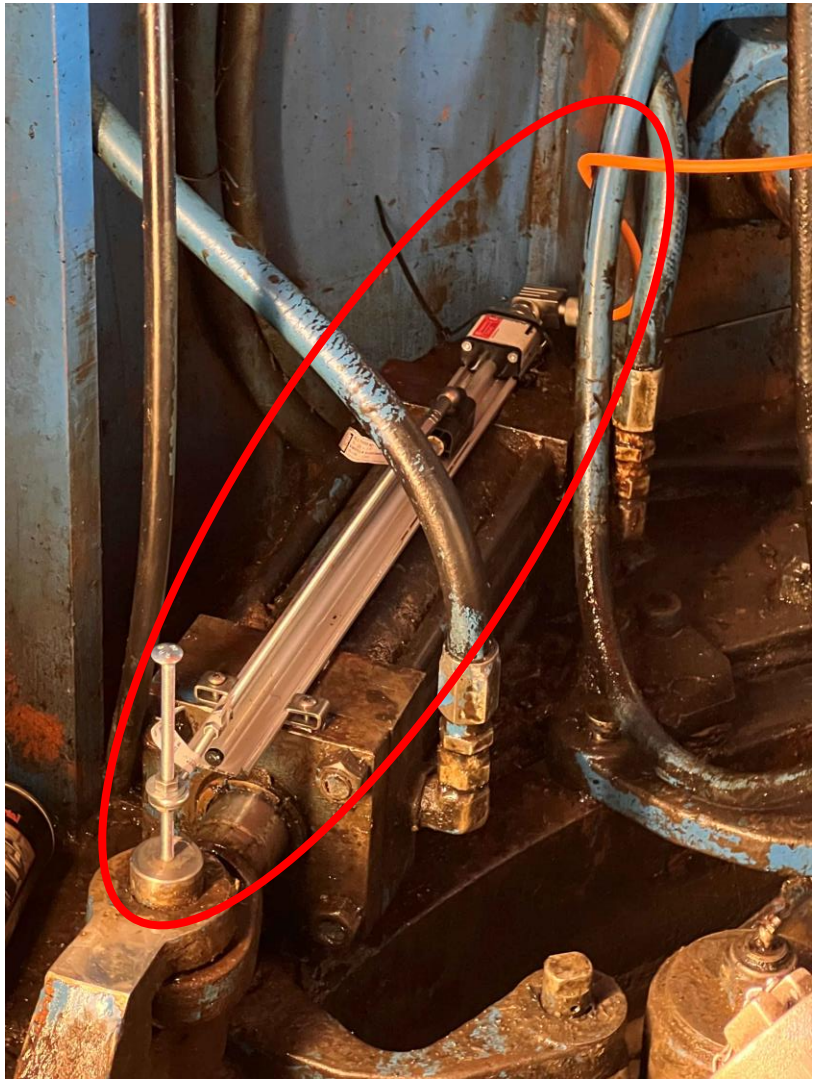
- Grey cable sends actuation signal from PLC.

Existing directional control valve

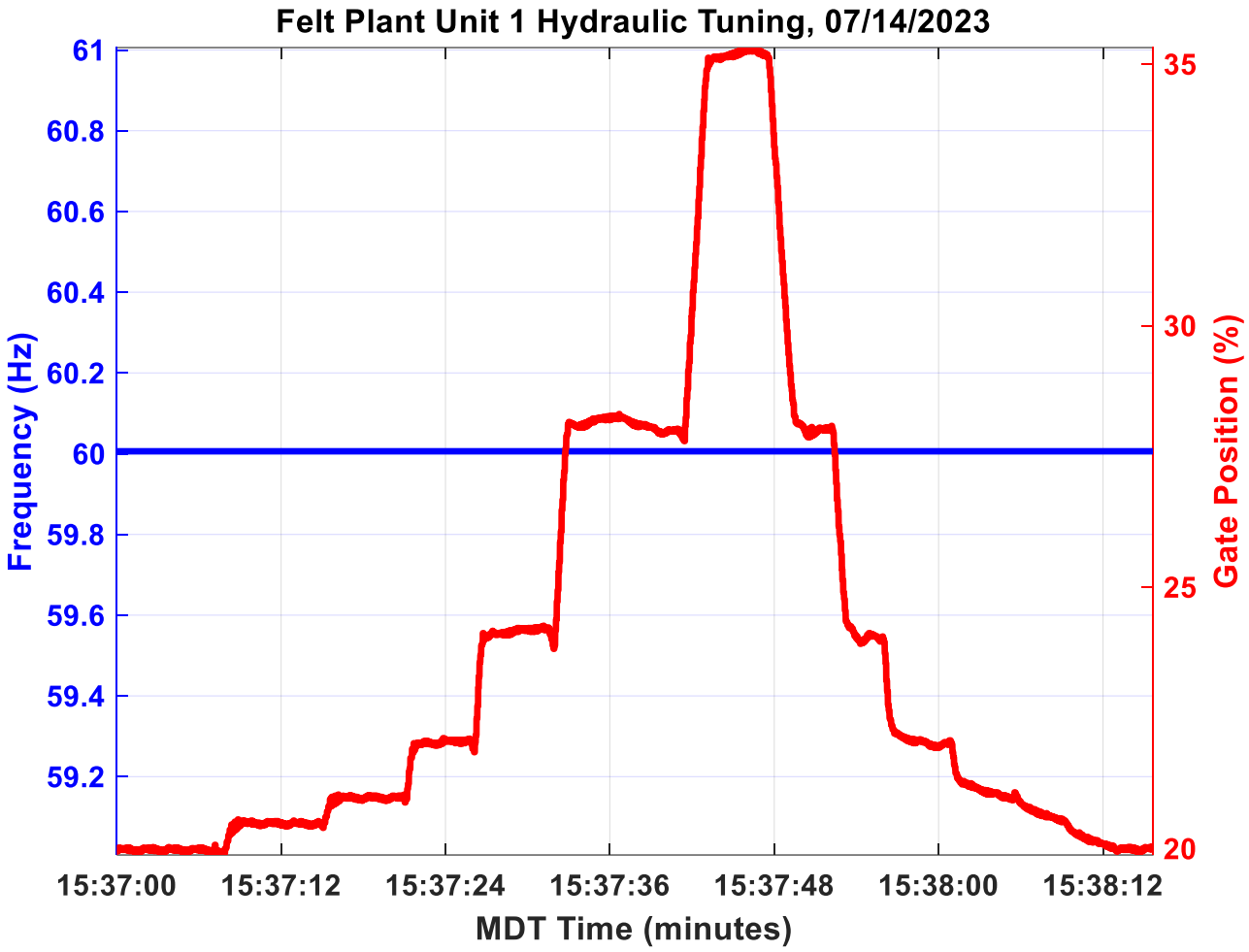
New proportional valve

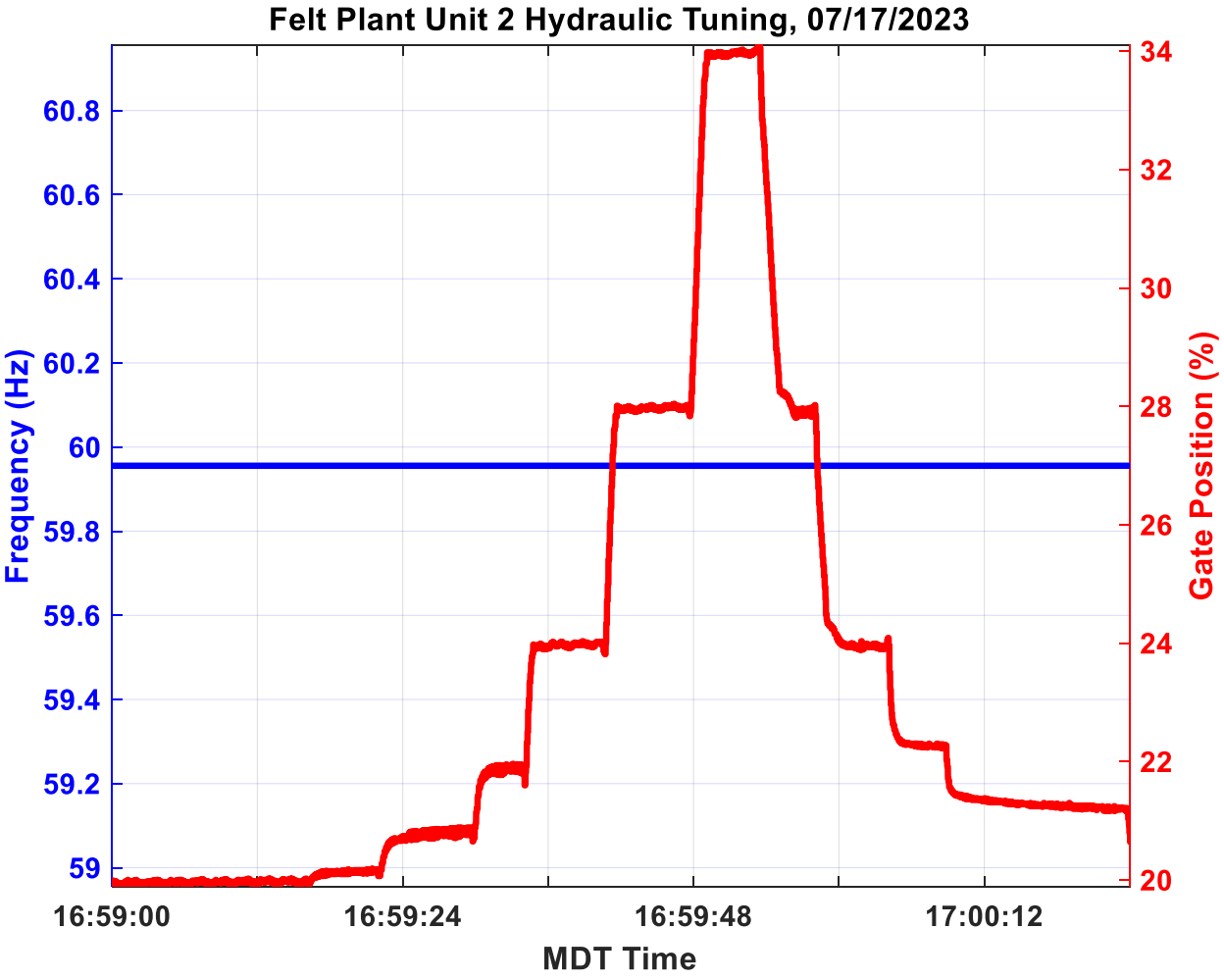
c) Gate position transducer is installed

- Orange cable sends position back to PLC.

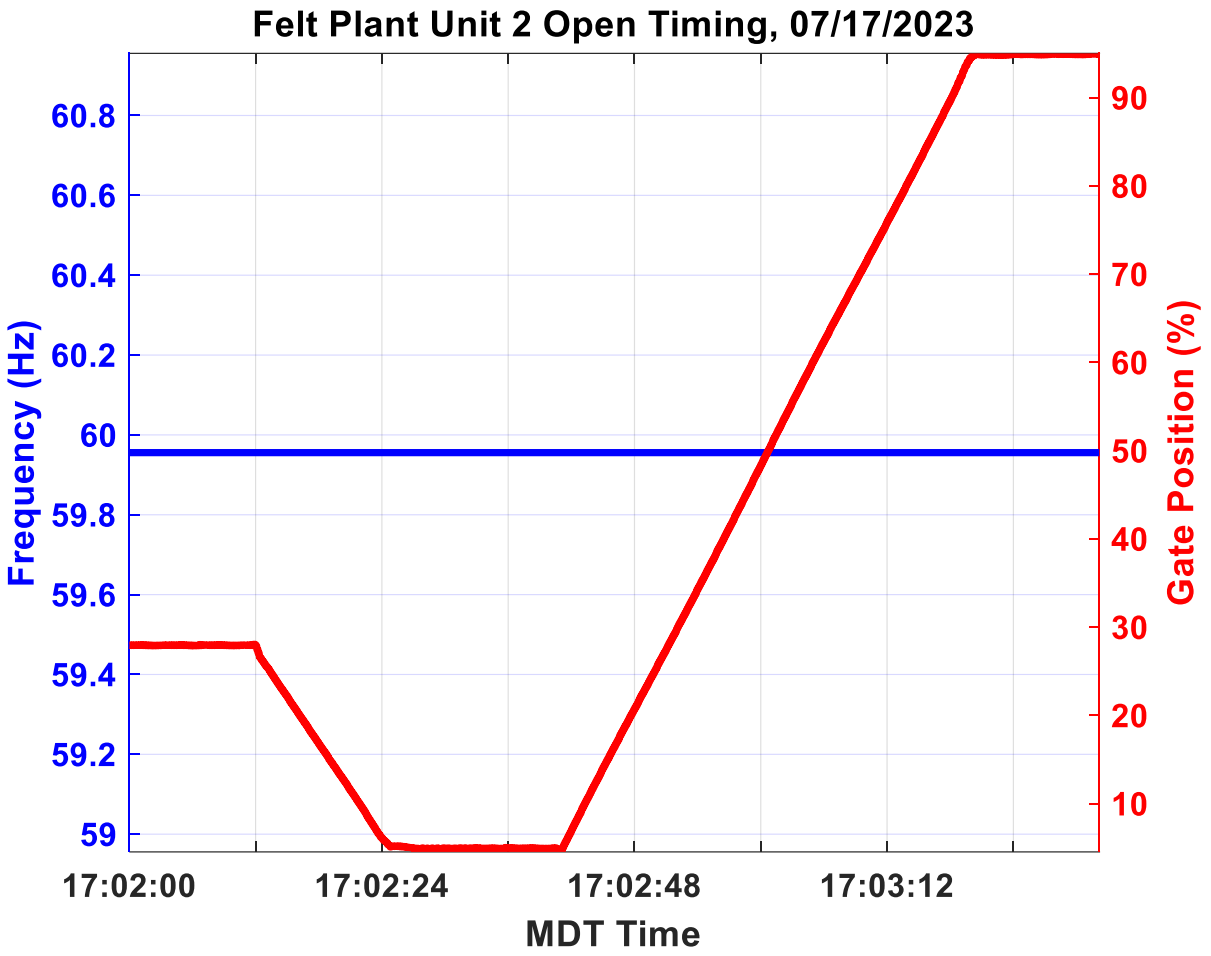


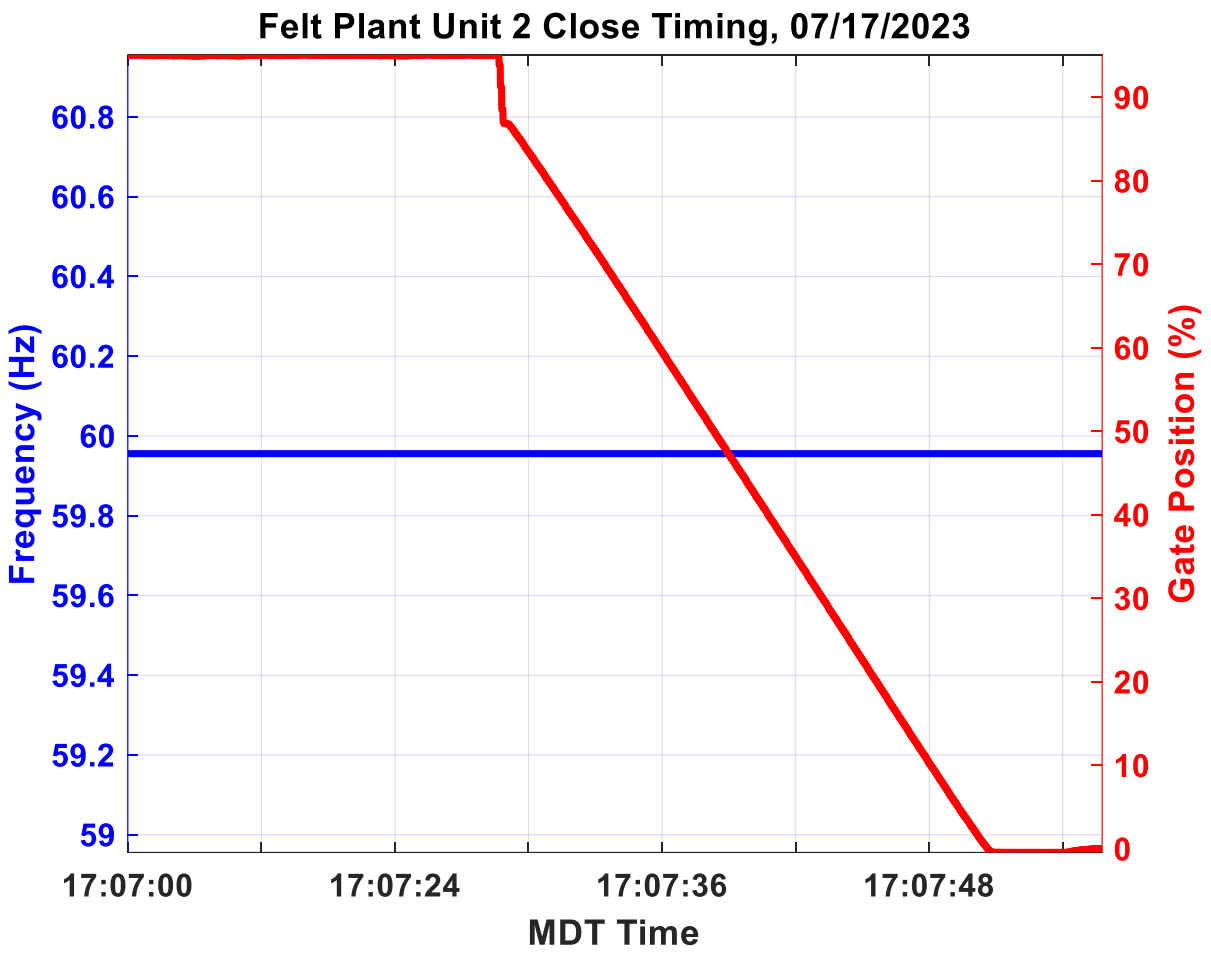
Hydraulic Tuning





Gate Opening and Closing Timing



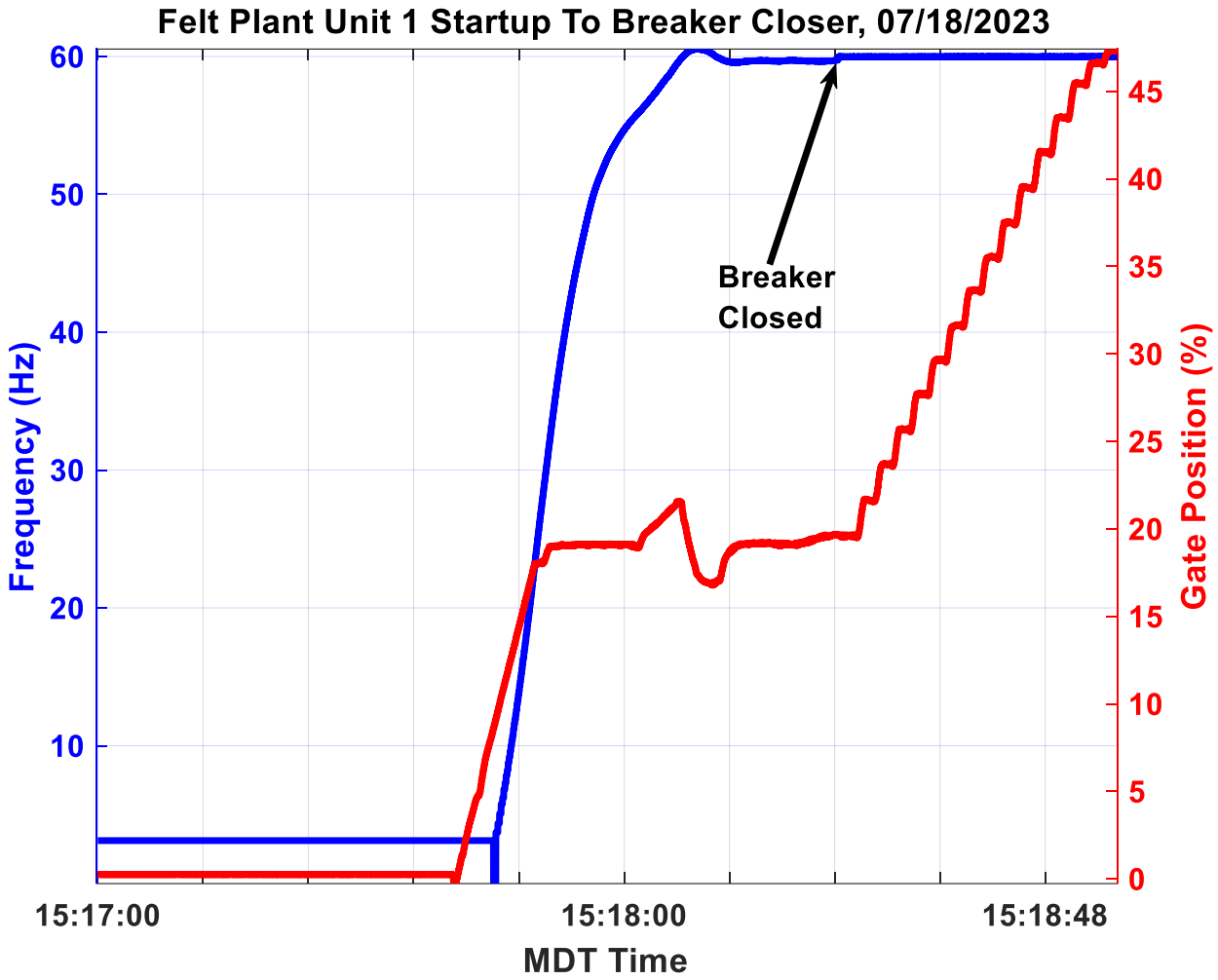


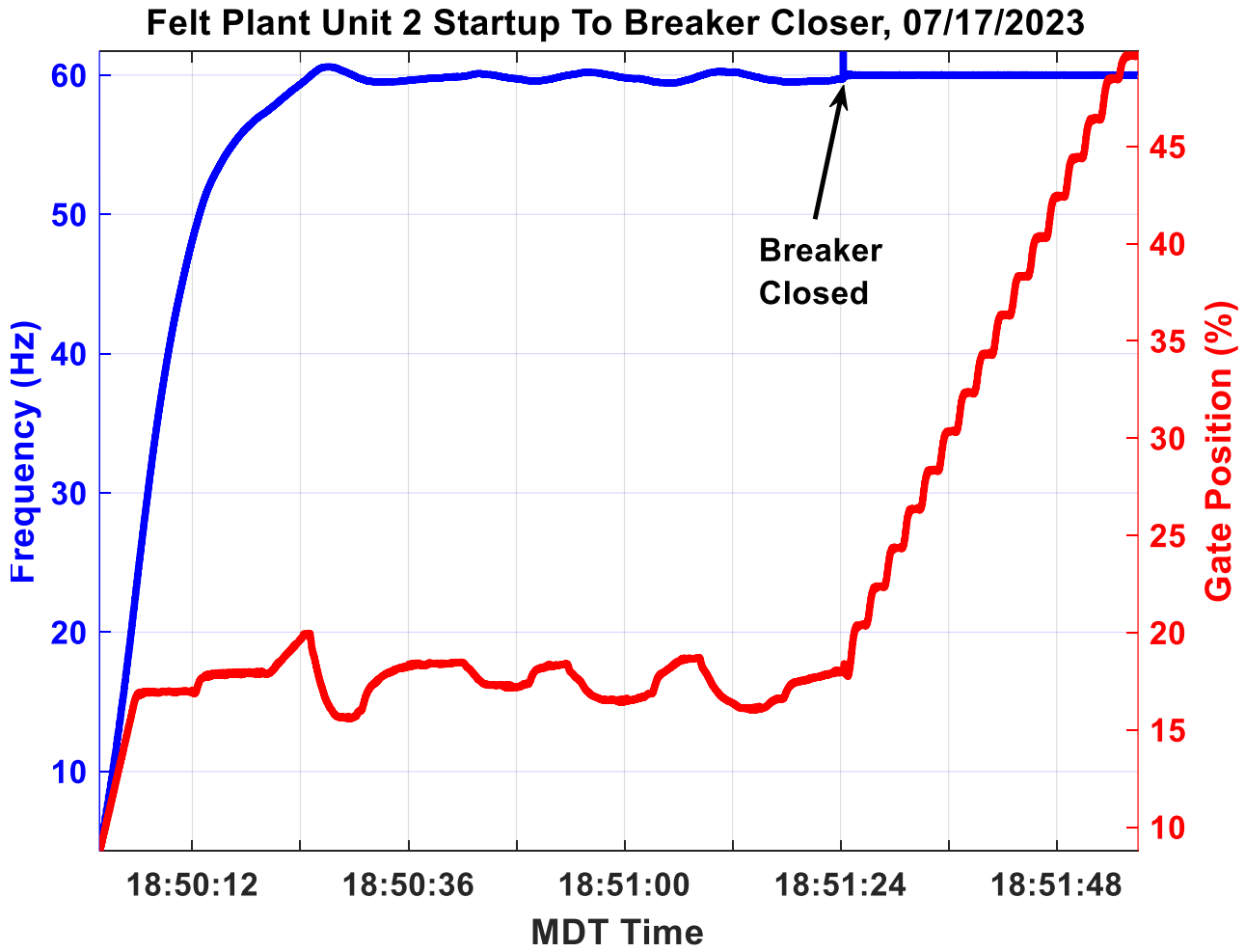
0 – 100% Gate opening time: 22 sec

0 – 100% Gate closing time: 25 sec

Response time before retrofit: 3~4 minutes

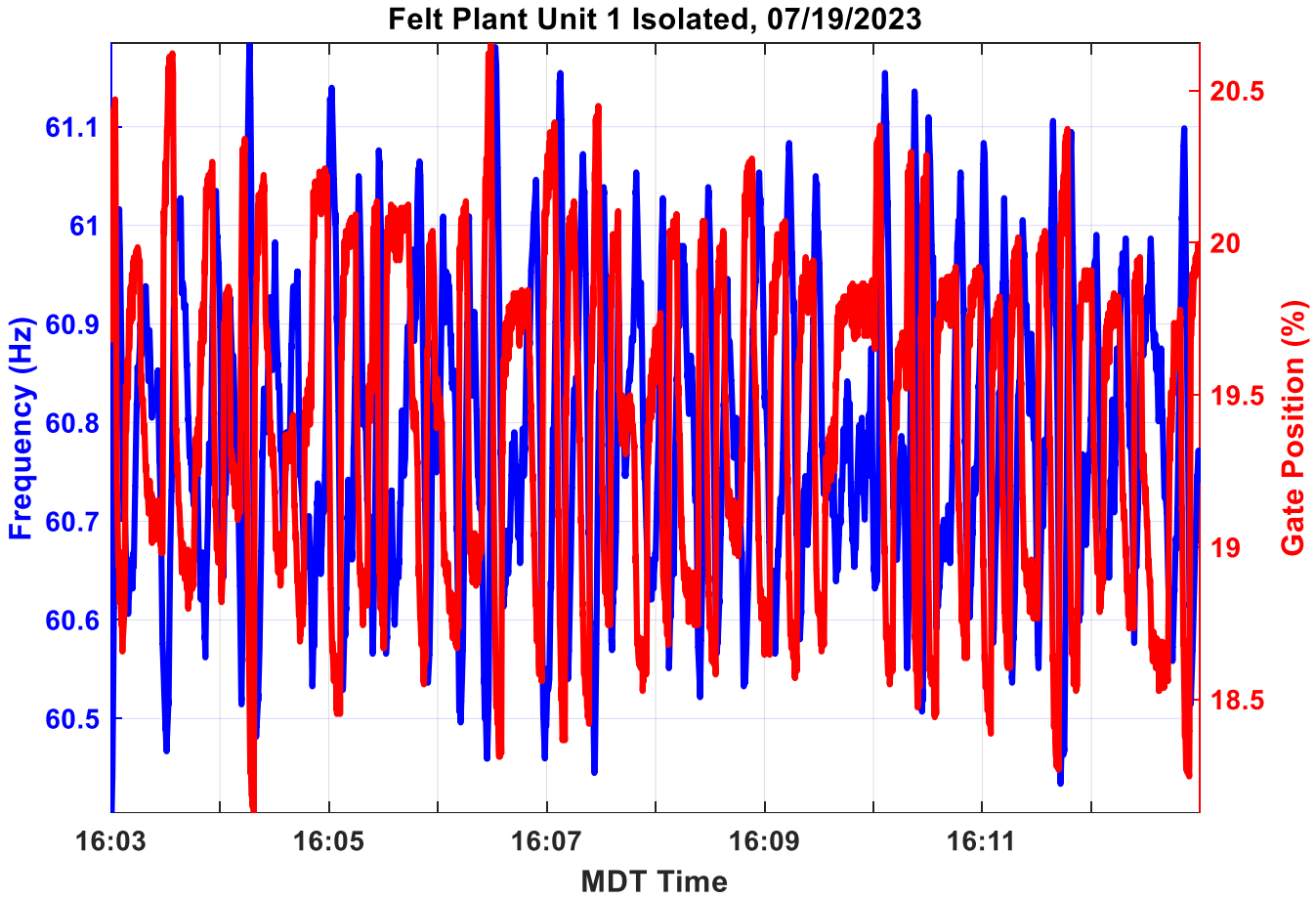
Startup to Breaker Closer



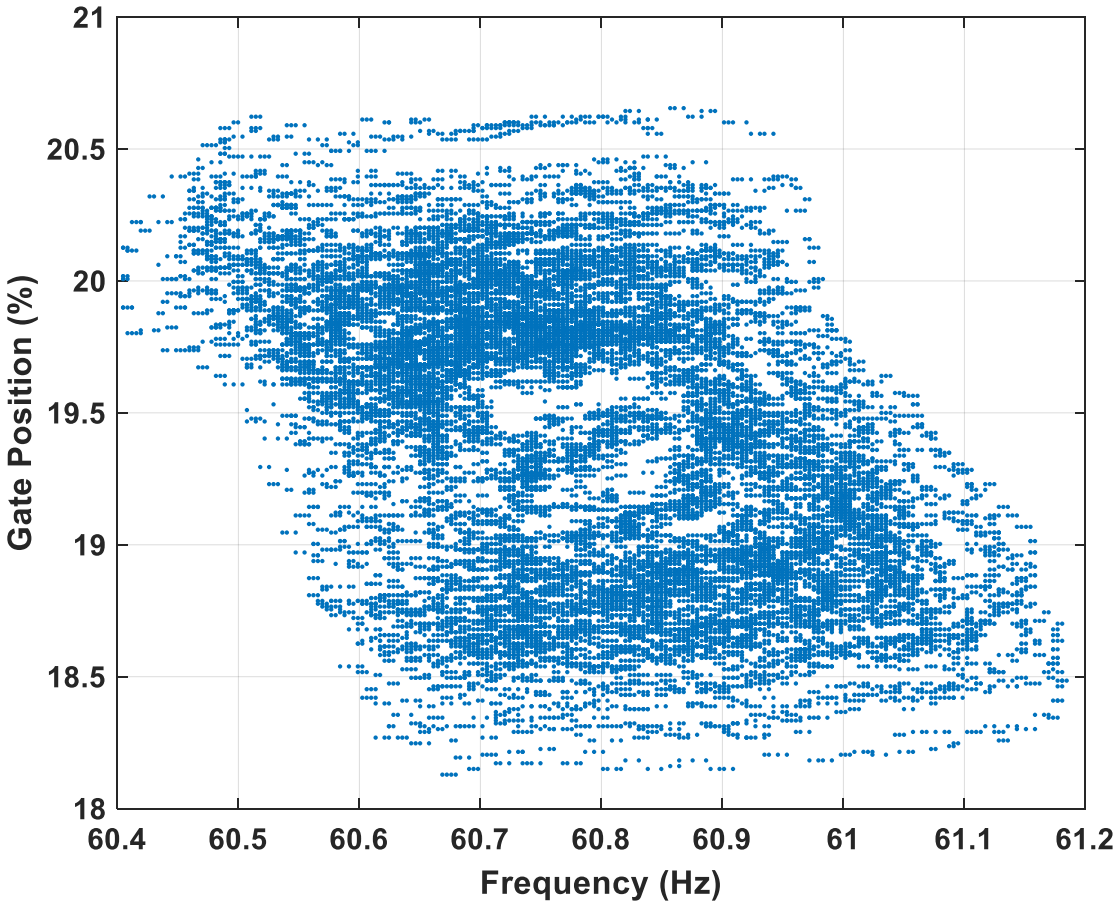


Oscillation goes away as soon as grid connected

Unit 1 Operation on 19th July 2023



Isolated mode carries station load (10% of unit capacity). Oscillation (of range: 0.6 Hz) is present in Isolated Mode – Direct consequence of low loading and vacuum pressure valve reaction.



Gate position responses in hysteresis fashion.

Lessons from FRE Demonstration

- Guide vane control
  - Minimal retrofit can enable smoother and high-resolution control.
- Connecting a “traditionally grid following” small hydropower plant to “dead” grid,
  - Need to assess auxiliary power system.
  - Need to audit contact switches.
  - Need to have “islanded” mode protection settings.
- Inverter operating mode will vary based on energy storage siting,
  - Grid following would be better near the hydropower plant.
  - Grid-forming would be better near the critical loads.

Ongoing Effort

- Black start Implementation Guidance is under development
  - How to enable black start of a traditionally Non-black start Hydropower Plant or grid dependent hydro (GDH) ?

- INL is working with some case study partners for the validation of this Guidance
  - No cost share
  - Not a field demonstration
  - INL Announcement Link: https://inl.gov/news-release/idaho-national-laboratory-seeks-small-hydropower-utility-for-case-study/

References

Black Start Field Demonstration with FRE

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2. Gilbert et al. 2024 “High-Penetration Microgrids Providing Grid Stability Using Frequency-Watt Control”, DOI: https://doi.org/10.1109/GreenTech58819.2024.10520610
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4. INL Article on RAPID MIB, 2023: https://inl.gov/integrated-energy/microgrid-in-a-box-opening-new-possibilities-in-defense-utilities-disaster-relief/
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Black Start Field Demonstration with IFP

1. Alam et al. 2022 “PHIL Validation of Ultracapacitor Storage for Black Start Application”, Link: https://www.osti.gov/servlets/purl/1906486
2. Alam et al. 2022 “Power Hardware-In-the-Loop Hydropower and Ultracapacitor Hybrid Testbed”, DOI: https://doi.org/10.1109/PESGM48719.2022.9917167
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4. Banerjee et al. 2022 “Modeling a Bulb-Style Kaplan Unit Hydrogovernor and Turbine in Mathworks-Simulink and RTDS-RSCAD”, DOI: https://doi.org/10.1109/TD43745.2022.9816952
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Thank You!

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