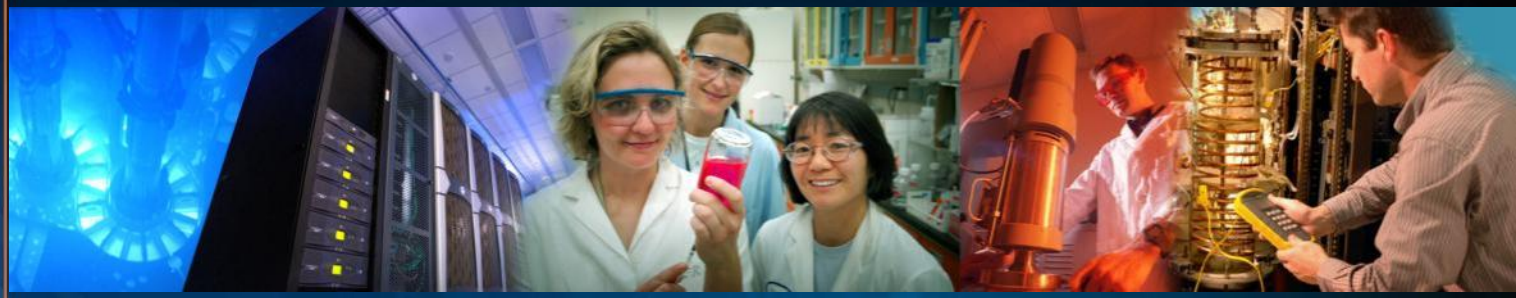
3rd Annual International Workshop on
Grid Simulator Testing of Energy Systems and Wind Turbine Powertrains



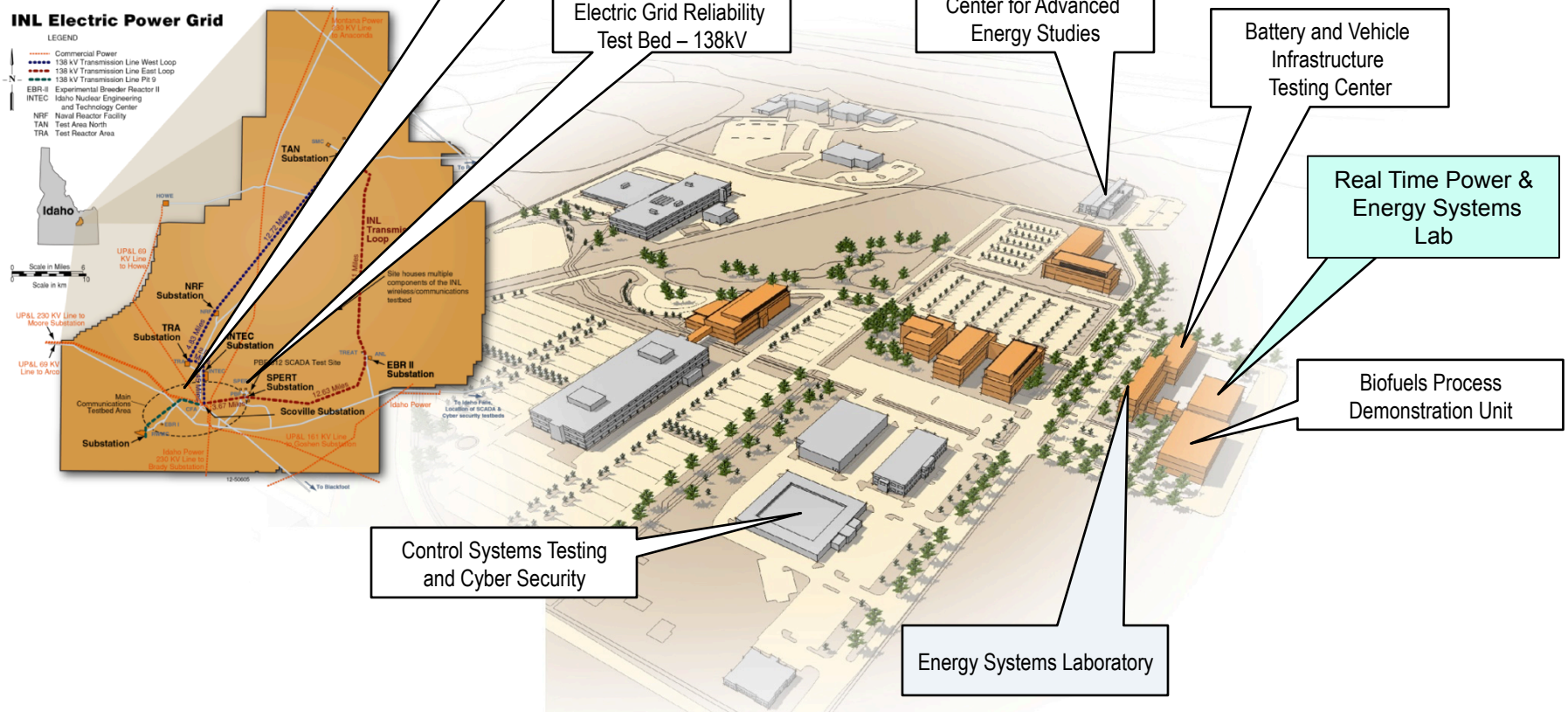
DRTS-DRTS Multi-Lab Connection

Dr. Rob Hovsapian
rob.hovsapian@inl.gov

www.inl.gov

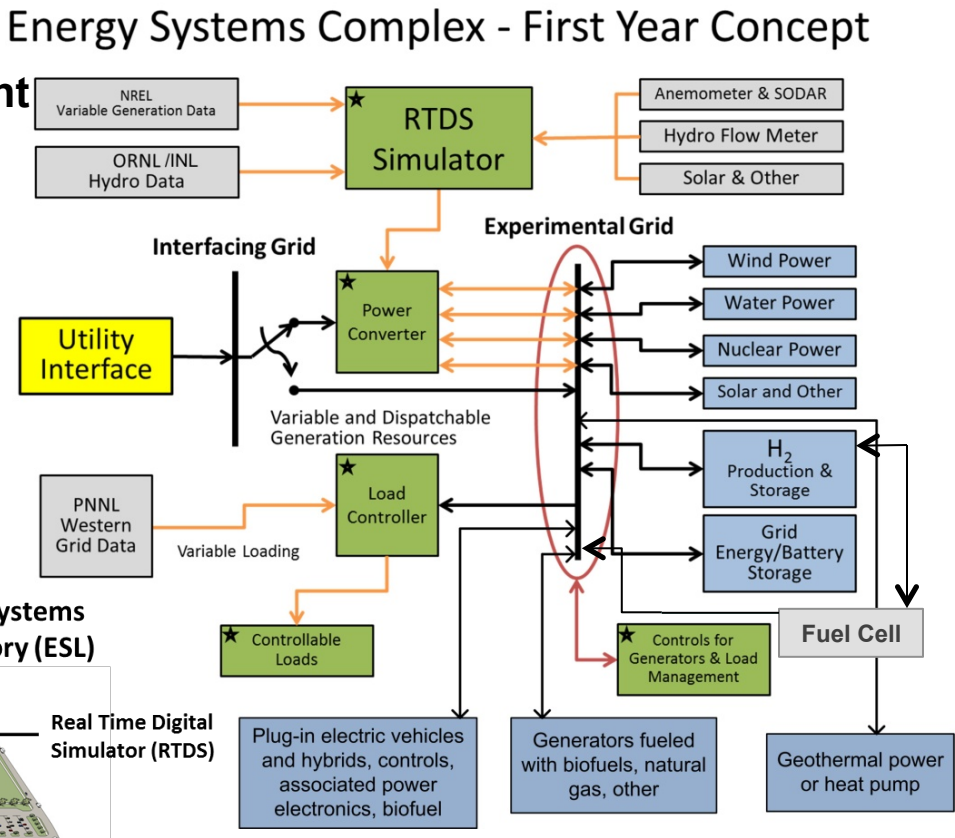
Idaho National Laboratory

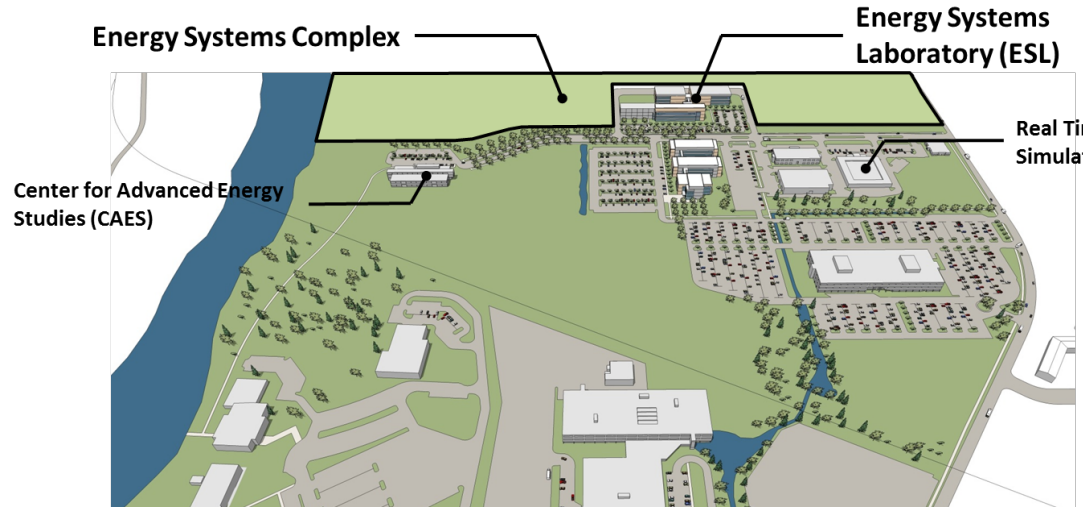
Grid-Related Physical Infrastructure



INL Energy Systems Laboratory's Demonstration Complex and Test Bed

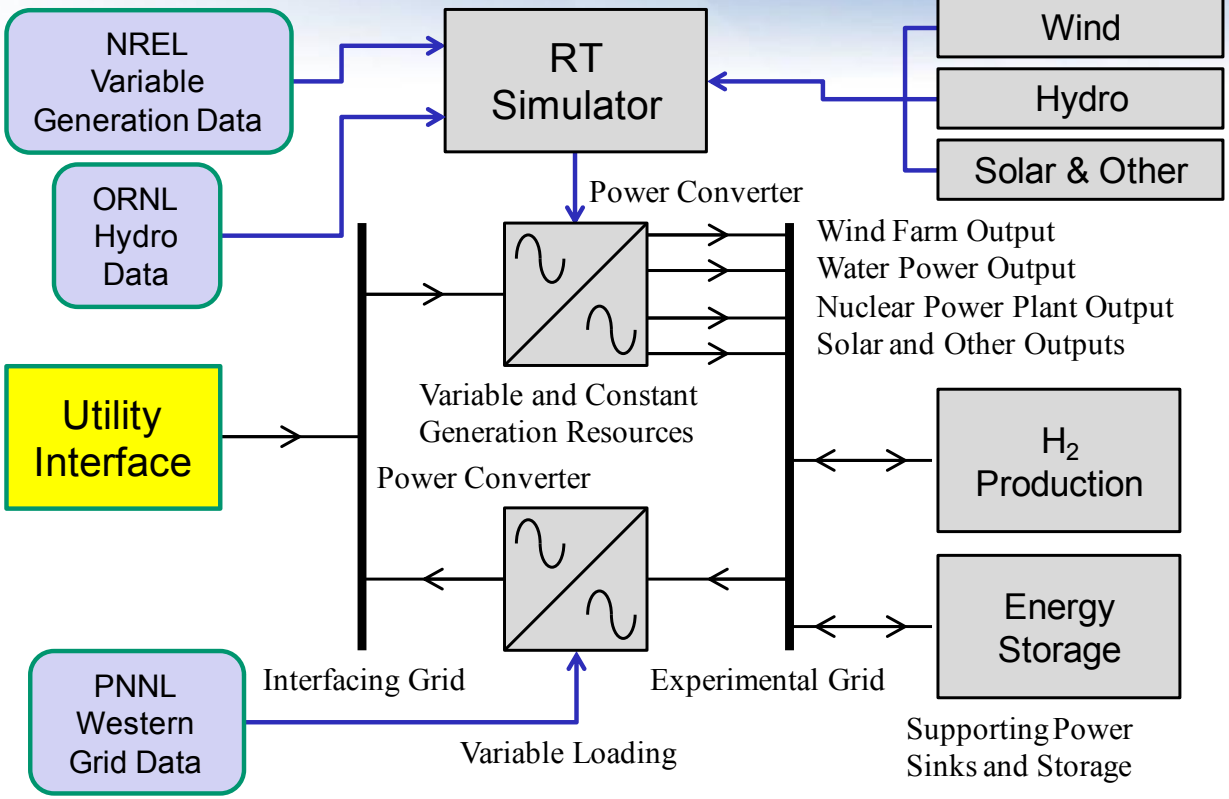
- **Power & Energy Integrated Test Environment**
  - Modeling, simulation, and hardware-in-the-loop capabilities for demonstrations and dynamic analysis
    - Energy farms
    - Integration with HES
    - Control and integration strategies
    - Coupling with energy storage

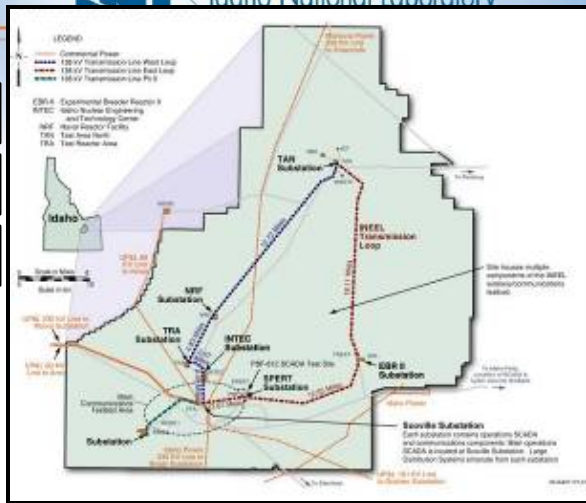


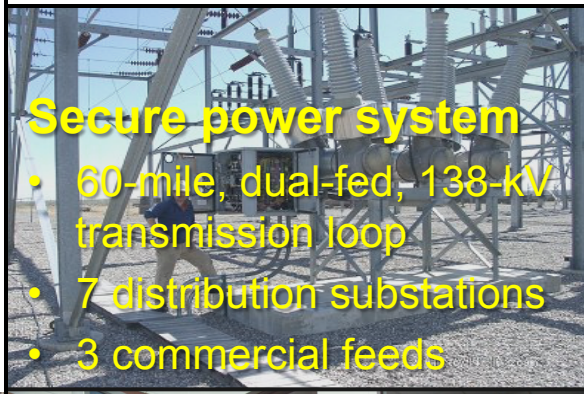


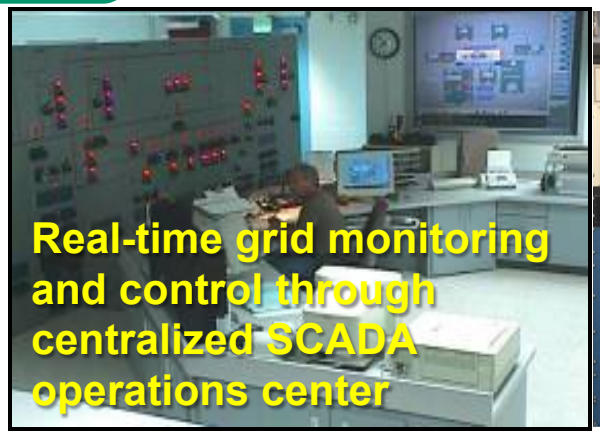
The Energy Demonstration Test Bed

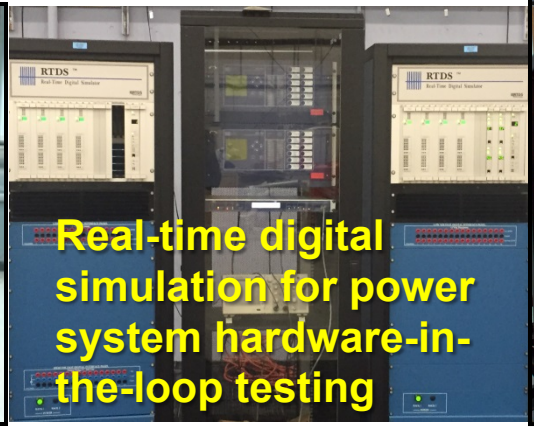
Idaho National Laboratory











DRTS-DRTS Integration - Motivation

- **Leverage the distributed physical assets at multiple Department of Energy (DOE) labs and academic research centers**
- **Idaho National Laboratory (INL)**
  - Energy Systems Lab, INL Wireless Test Bed, CITRIC (Electric Grid Test Bed)
- **National Renewable Energy Laboratory (NREL)**
  - ESIF, NWTC, and so on
- **Integrate these unique facilities based on standard communication protocols**
- **Expand Digital Real Time Simulation (DRTS) capacity to address greater network challenges**
- **Stimulate and sustain inter-organizational research collaborations**

Introduction

- **DRTS using geographically distributed RTDS® such that data links are equivalent to transmission line connecting subsystems**
  - Events take approximately the same time as data transfer
  - Transients and other fast events are localized
- **Research personnel experienced in real time computing**
- **Florida State University and Sandia National Laboratory experience of remote hardware testing (2004-2005)**
  - CAPS-SNL worked on RTDS® to SCADA testing
  - RTDS® simulated power systems and SCADA hardware collected measurements and control commands
- **Mississippi State University and Texas A&M University remote simulations using RTDS® (2009)**
  - Testing different protocols between two power system simulations
  - NI DAS used as protocol interpreter at both ends
- **TCP and UDP based RTS at Aachen University, Germany**

Super Lab Concept - Leveraging Other National Labs and Academic Institutes

Idaho National Laboratory

INL
- Power System Grid Test Bed
- Wireless Test Bed
- SCADA / Cyber Security Test Bed
- Energy Systems Laboratory

NREL
- Energy Systems Integration Facility
- National Wind Technology Center

ANL
- Pump Hydro Energy Storage Systems

SNL
- Energy Storage Test Program
- SCADA Test Bed

PNNL
- NorthWest GridWise Testbed
- Grid Monitoring of the WECC

Aachen University.
Real Time Simulation

Florida State Univ.
- 5 MW Grid simulator
- Real Time Simulation

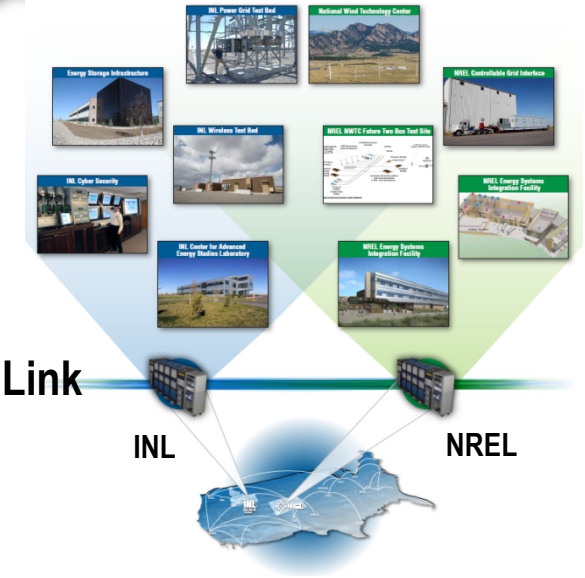
Washington State Univ.
- Real time modeling

Univ. of Texas at Austin.
- Physics Based Modeling

CAES –
UI, ISU, BSU

Colorado State Univ.
- Power System Dynamic Modeling

Univ. of New Mexico
- Wind Dynamic Modeling



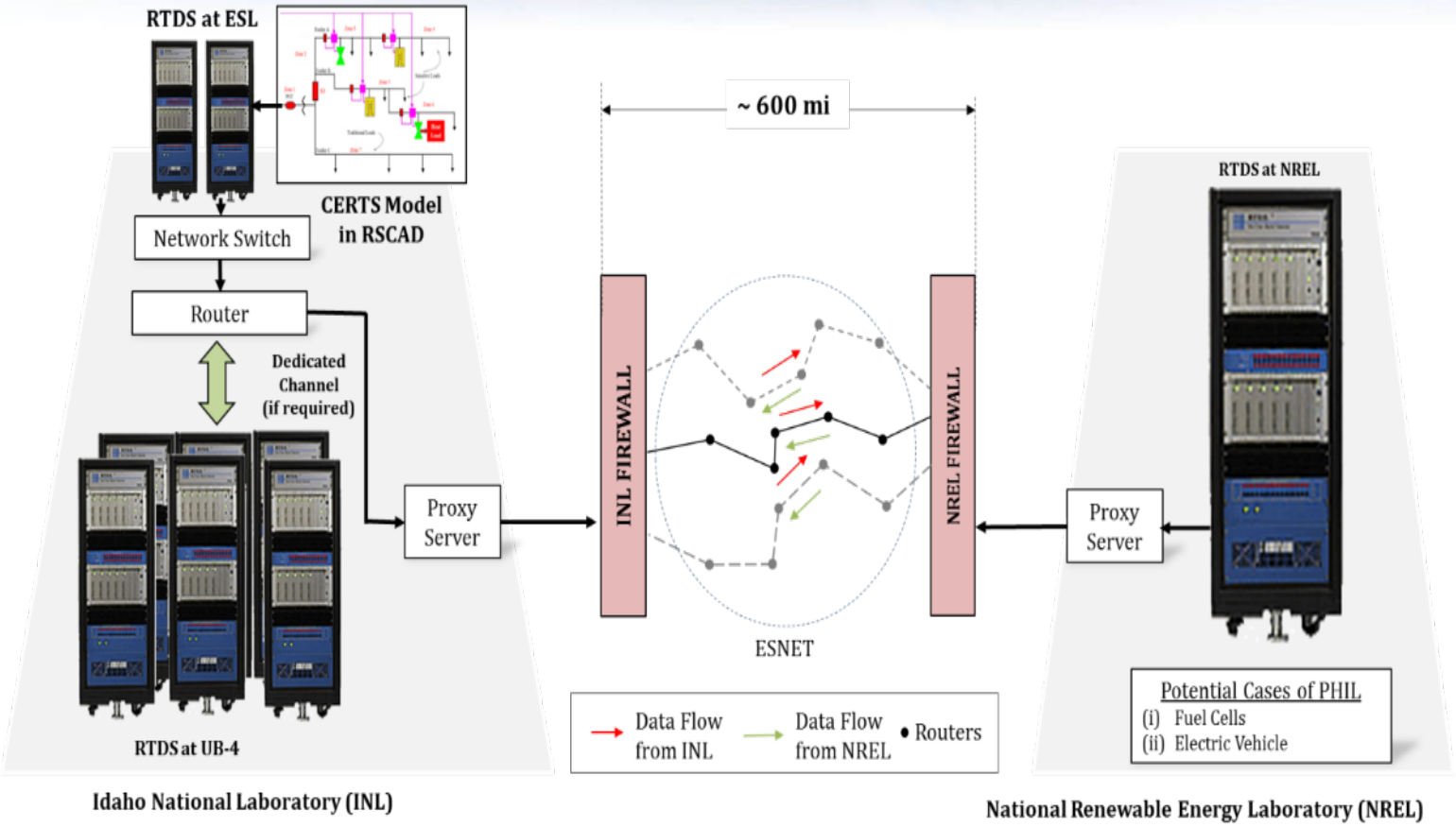
SIEMENS

TESLA

California ISO
Shaping a Renewed Future

PG&E

INL – NREL DRTS Current Architecture



INL Assets

- **Power and control systems modeling**
- **PHIL – vehicles, batteries, wind, super-capacitors, microgrid, etc.**
- **CHIL – front end controllers**

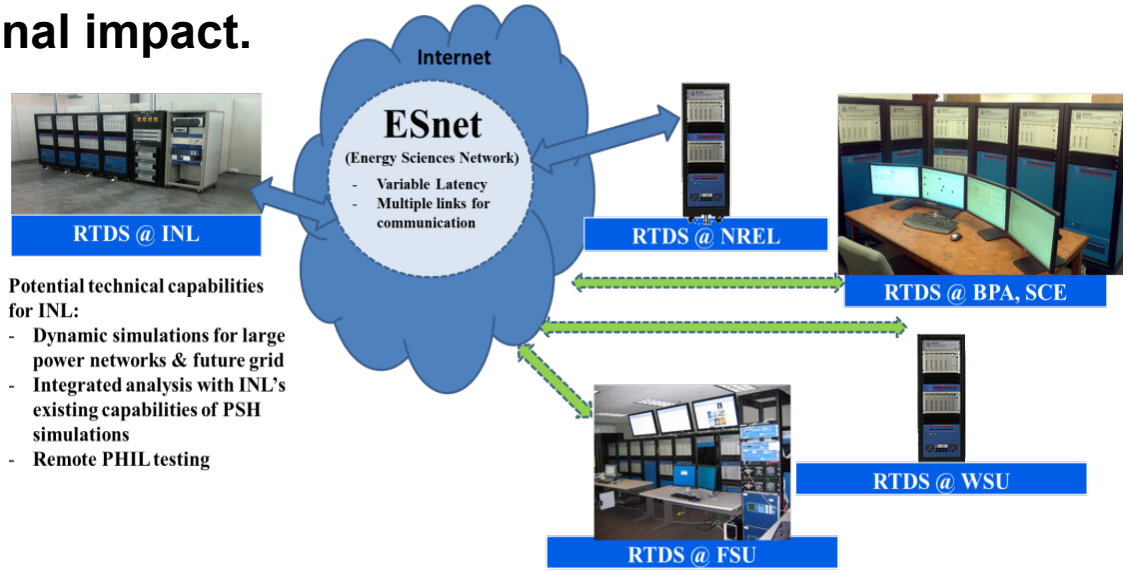
NREL Assets

- Power systems modeling
- Wind turbines and CGI at NWTC
- ESIF assets – electric vehicles, electrolyzer, etc.

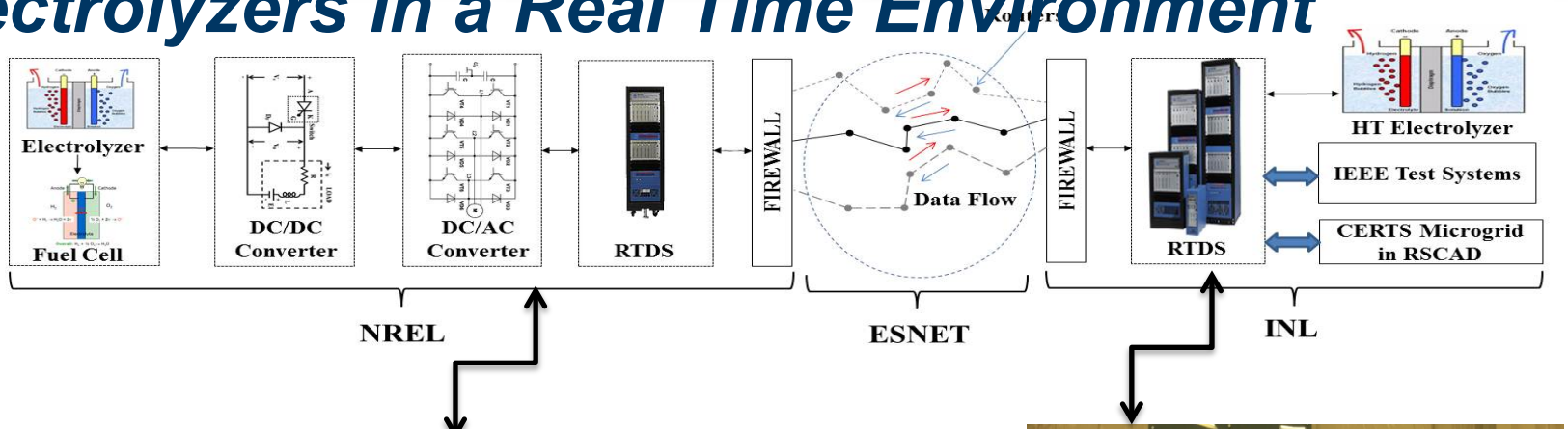
Objectives

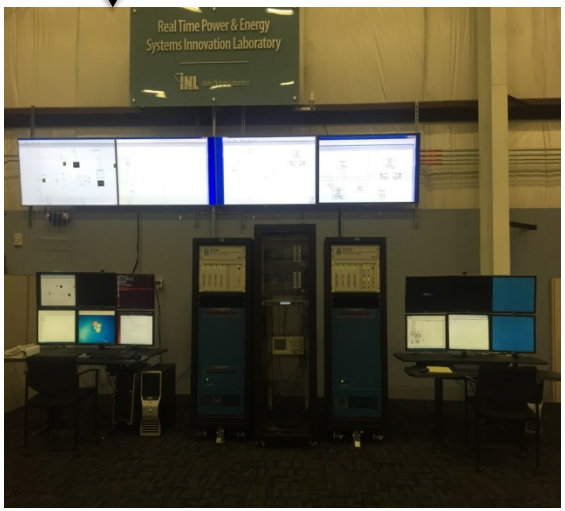
- ***Significance & Impact***

The proposed development of these capabilities will foster stronger ties and collaboration with researchers and scientist from other National labs, academic researchers, and utilities for future dynamics and transient simulation research for large power and energy systems. Once successful, this research will have regional and national impact.



Dynamic Modeling and Validation of Fuel Cell/ Electrolyzers in a Real Time Environment





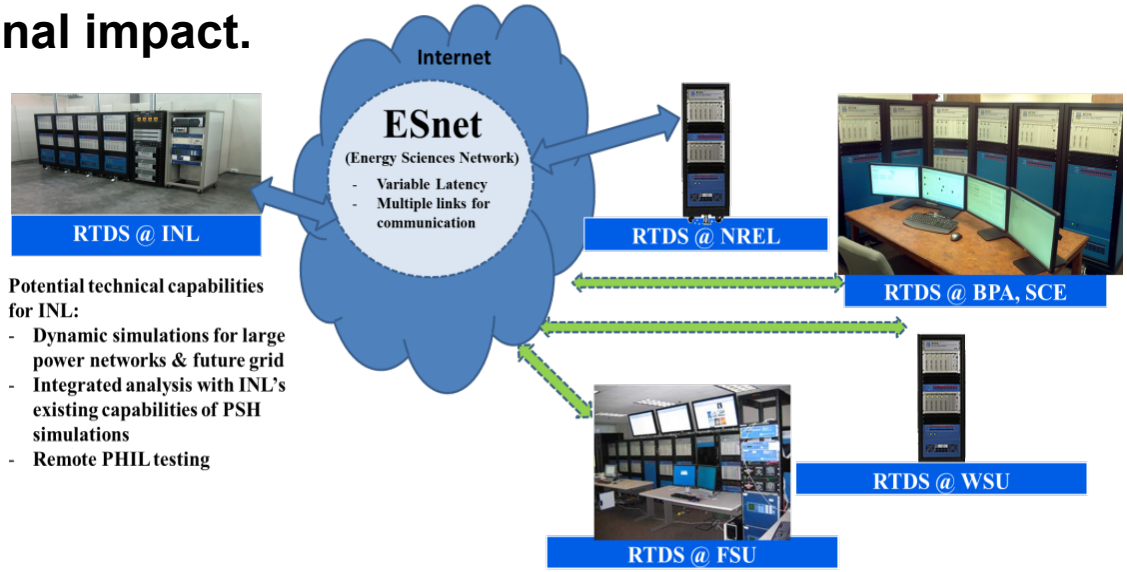
Current Distributed RTS Test Environment

- **2 RTDS models developed:**
  - 4 bus 2 area test system (Developed by Dr. Kundur)
  - IEEE 13 node feeder test system
- **Transmission network (source) at INL and the distribution network (sink) at NREL**
- **Transmission network comprises of a current source that approximates the load**
- **Distribution network comprises of a voltage source that approximates the source**
- **PEM FC/electrolyzer connected at the distribution network and operated as an electrolyzer**
- **Socket (SKT) firmware used to exchange TCP/IP data**

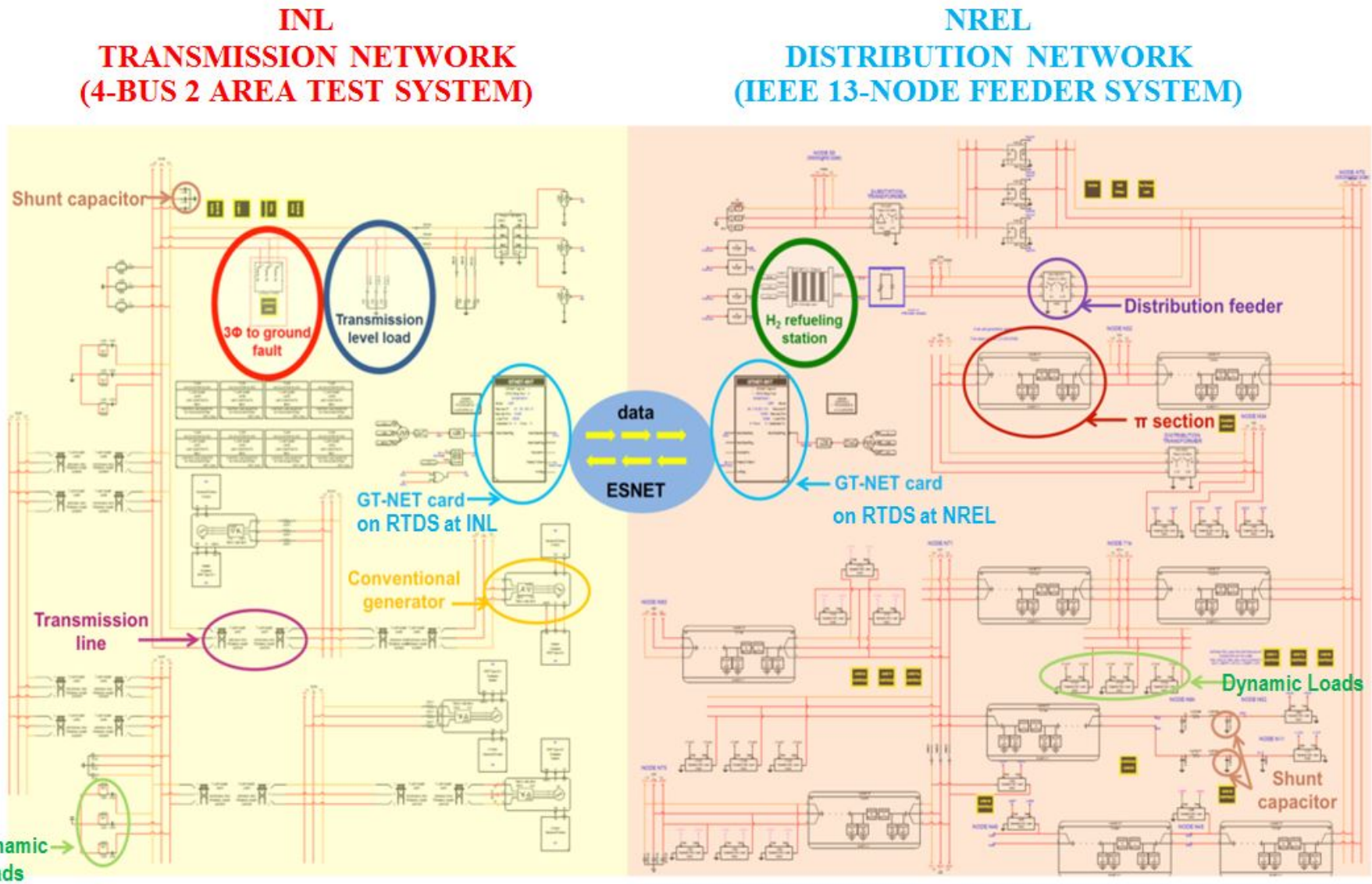
Objectives

- ***Significance & Impact***

The proposed development of these capabilities will foster stronger ties and collaboration with researchers and scientist from other National labs, academic researchers, and utilities for future dynamics and transient simulation research for large power and energy systems. Once successful, this research will have regional and national impact.



INL-NREL Test Setup



Technical Approach

Technical Approach To Achieve Objectives

- Network experiments between INL and NREL qualify the data latency challenges
- Establish a programmable and reconfigurable network communication layer between two RTDS systems to emulate real world communication events.
- Integrated Phasor Measurement Units (PMU) units with RTDS and communication layers.
- Synthesize power system events using real world events and actual PMU data from other national labs.
- Develop latency mitigation techniques
- Conduct dynamic simulation of large utility system and monitor transient events to demonstrate the value of RT simulation with higher details and better accuracy.

Benefit and Harvest Strategy

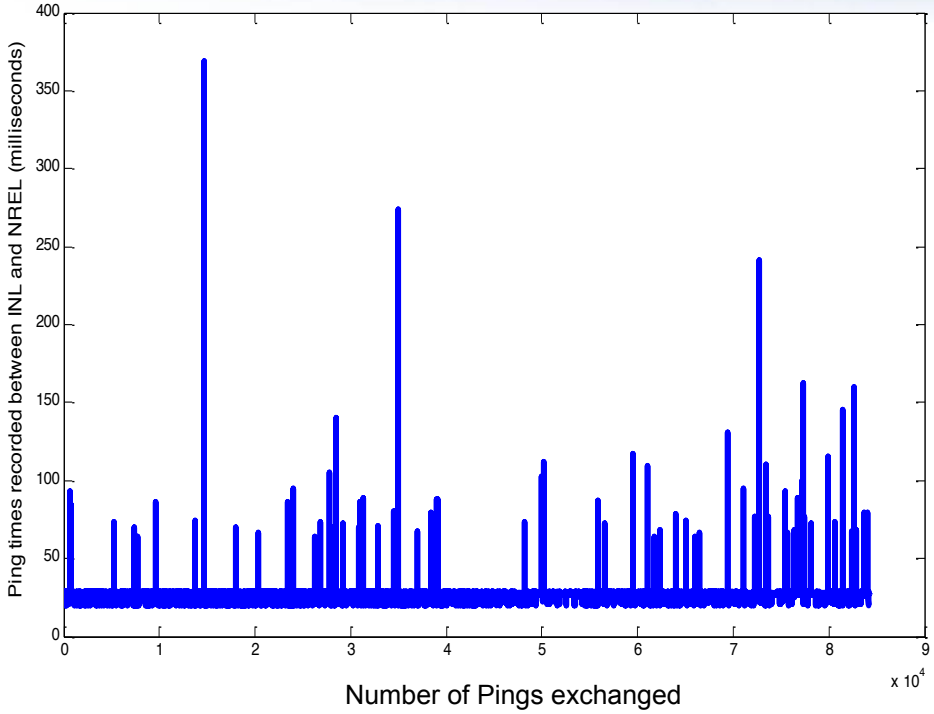
- ***New Collaborations***
  - Academic Colorado State Univ., Washington State Univ., & Florida State Univ.
  - Industrial – RTDS, Typhoon HIL
- ***Publications***
  - We currently have two Journal publications in works based on our early work in this area.

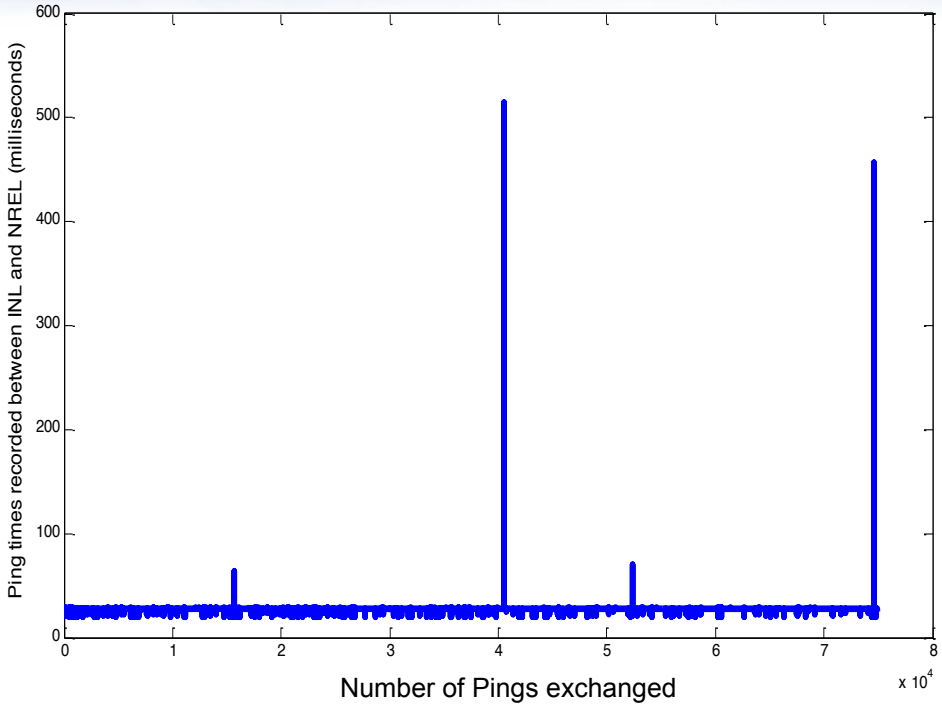
    > "**Role of Linear Prediction in Geographically Distributed Real Time Simulations" Journal (Submitted)**

Intellectual Property

- In order to maximize the impact and benefits to DOE, most of the models and technics developed as part of this project will be open to the power and energy community and the information will be disseminated via journal publications.
- The only technology that could be patented is the data latency mitigation techniques, and we will know more as we start the development.

WAN Performance



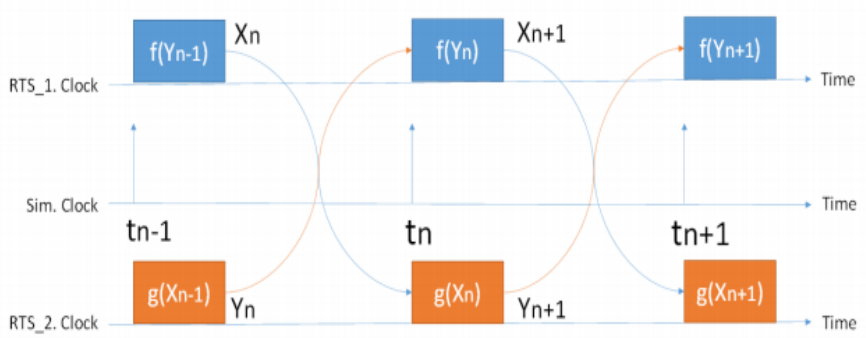


- **Demonstration shows that most data packets took less than 30 milliseconds to travel between INL and NREL**

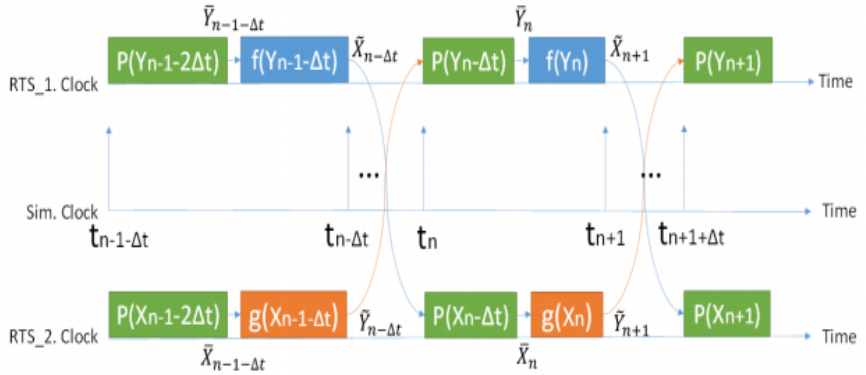
- Maximum = 369 milliseconds
- Minimum =20 milliseconds
- Average = 27.1557 milliseconds
- Data drops =24

- Maximum = 515 milliseconds
- Minimum =20 milliseconds
- Average = 27.0409 milliseconds
- Data drops =17

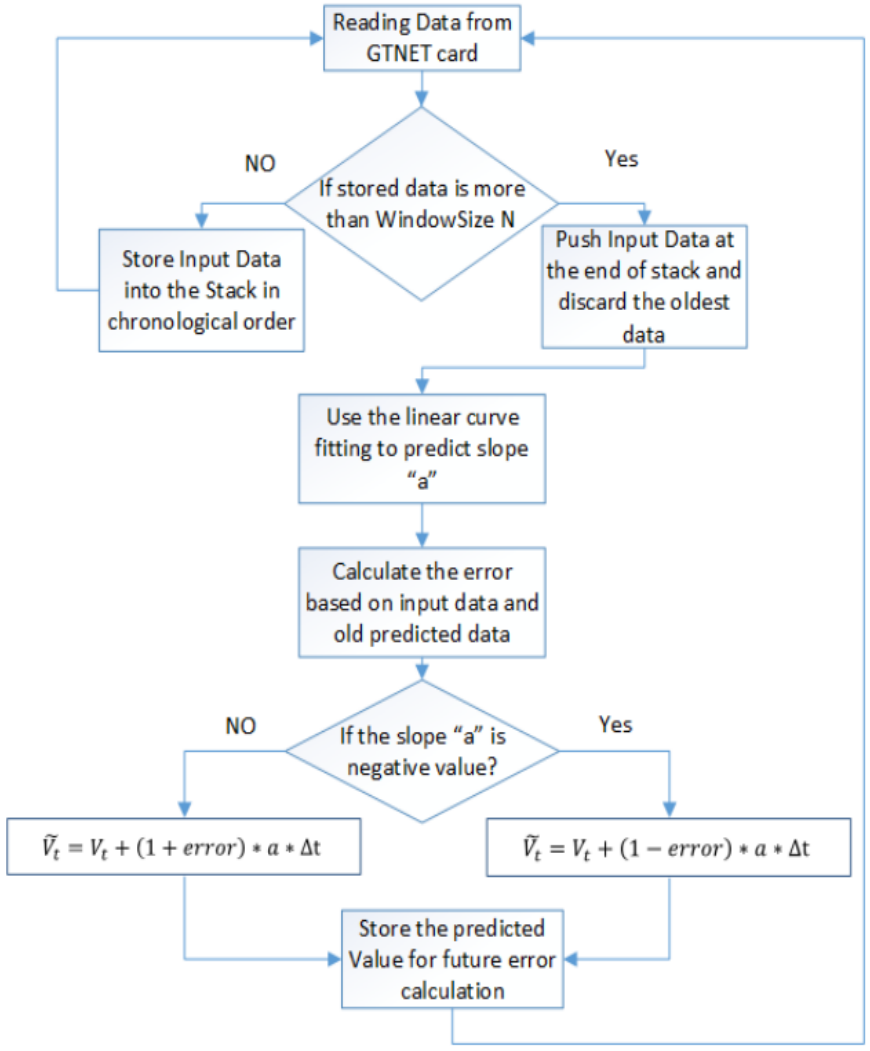
Mitigation using Predictor Approach



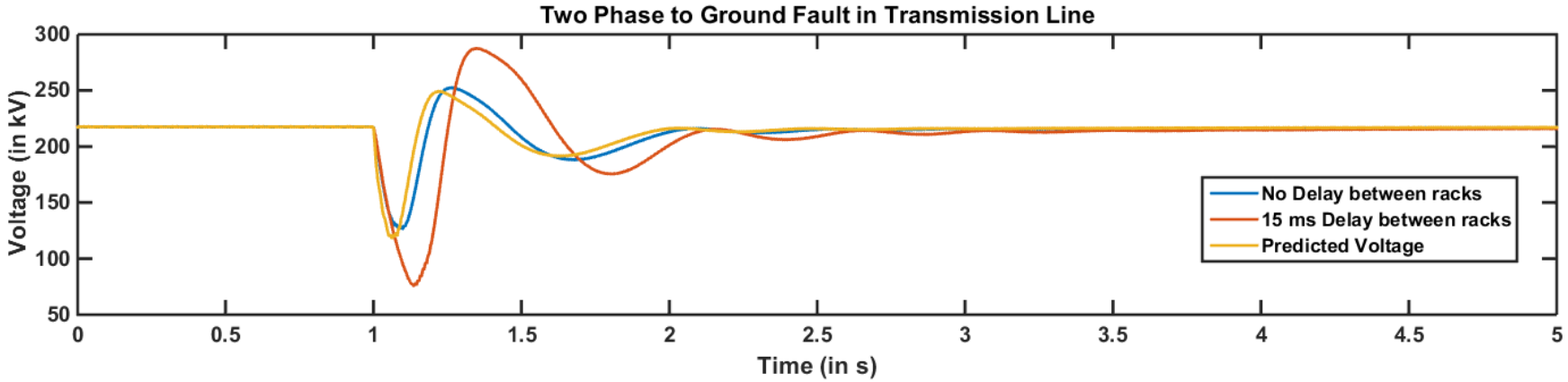
4.1 Ideal Condition: There is no communication latency between two simulator

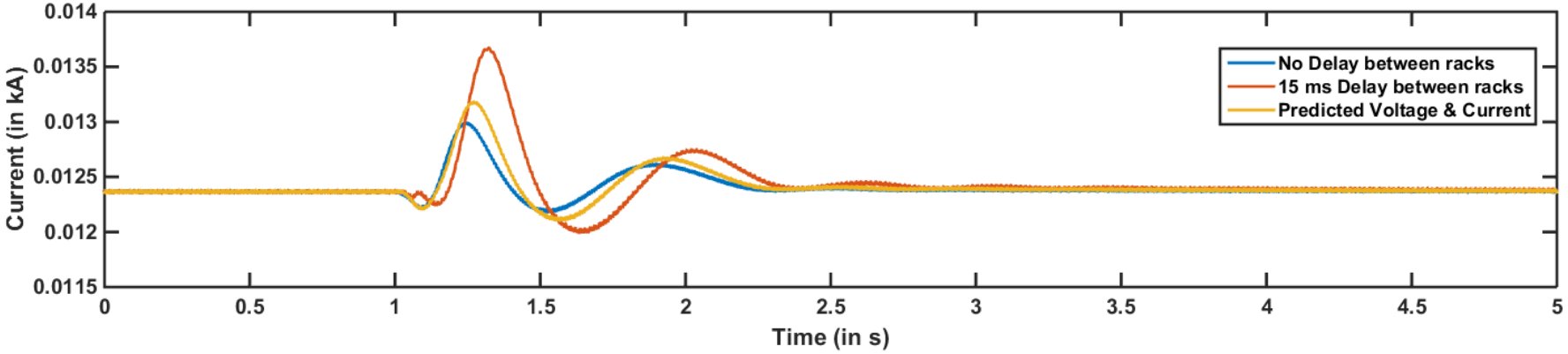


4.2 Prediction Condition: There is Δt communication latency between two simulator

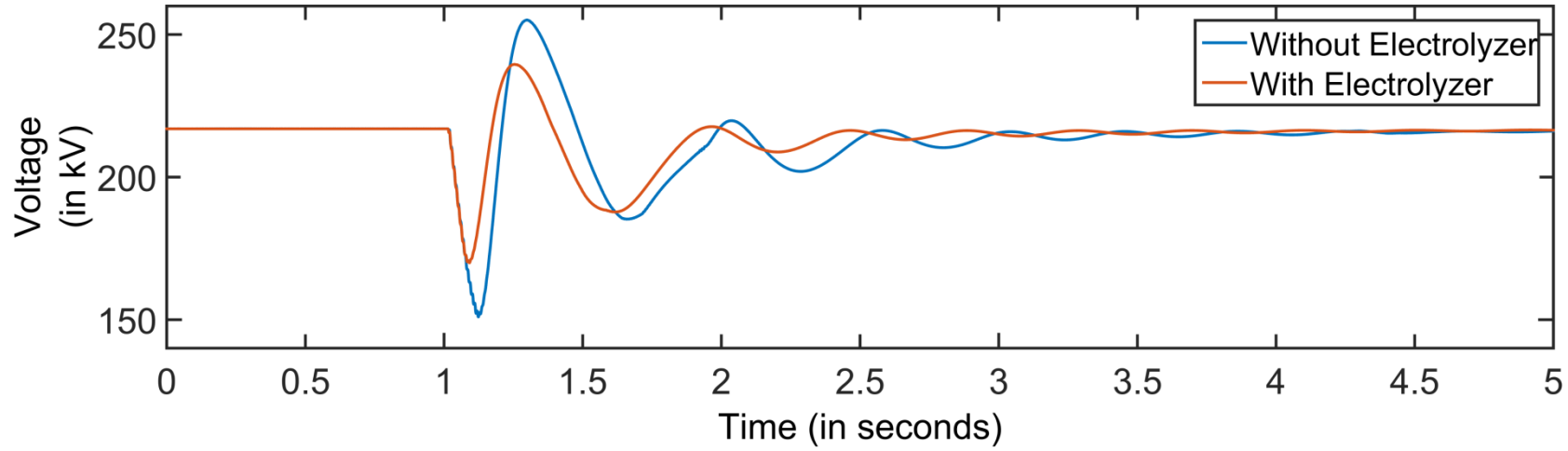


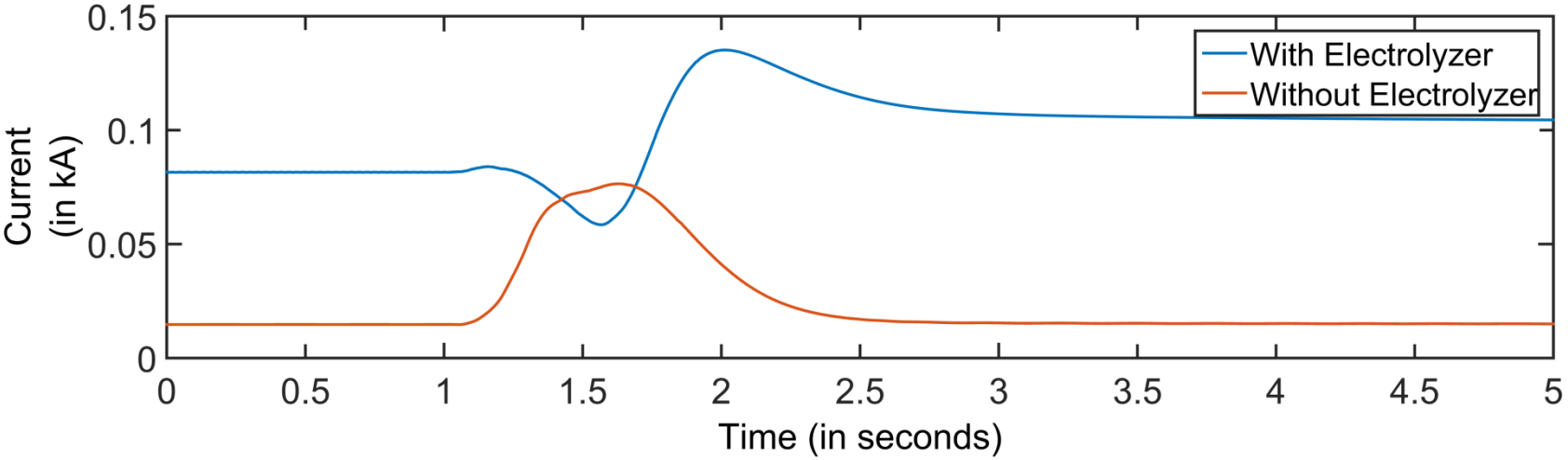
Improvements With Data Predictor Approach



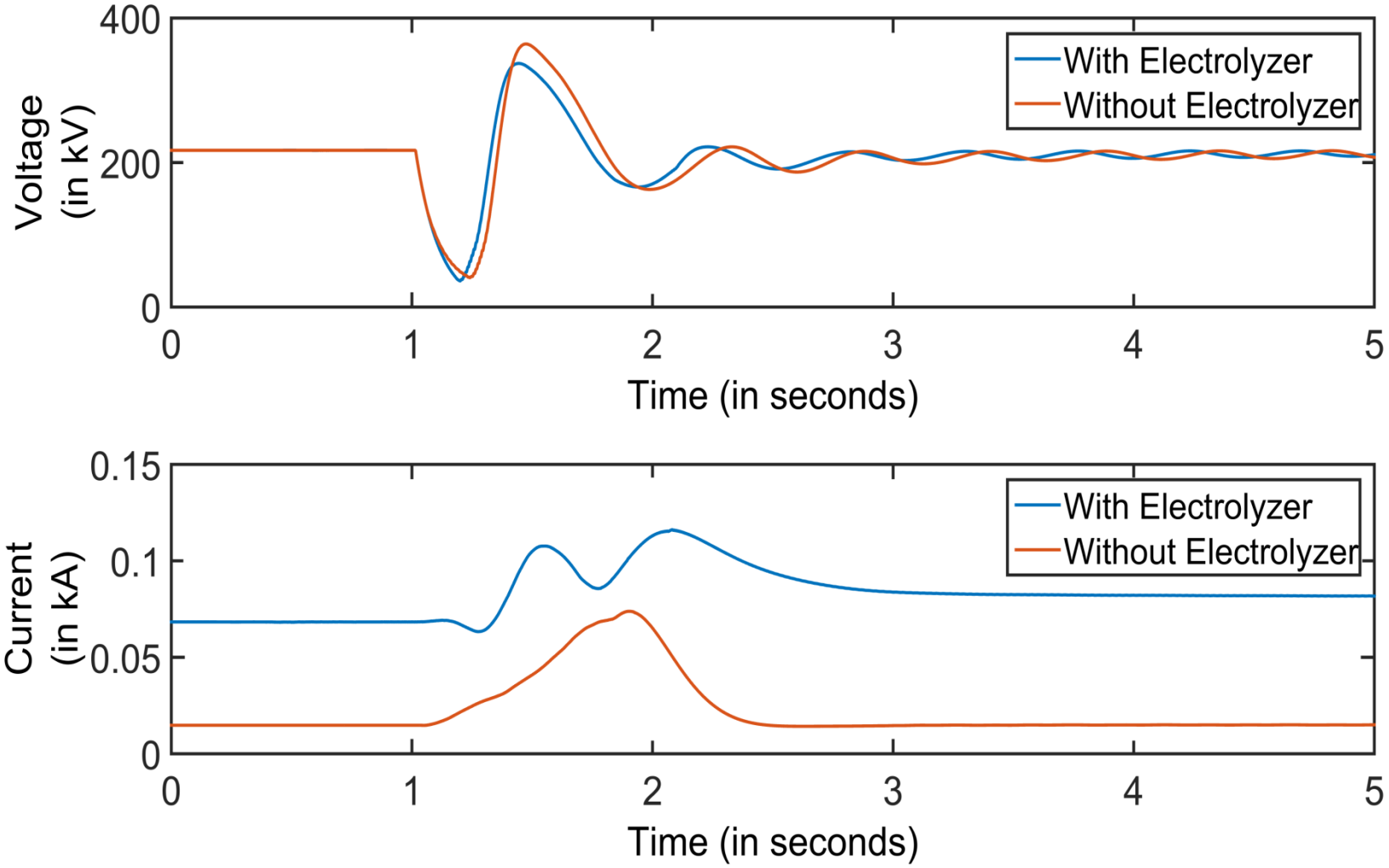


Single Line to Ground Fault (LG)





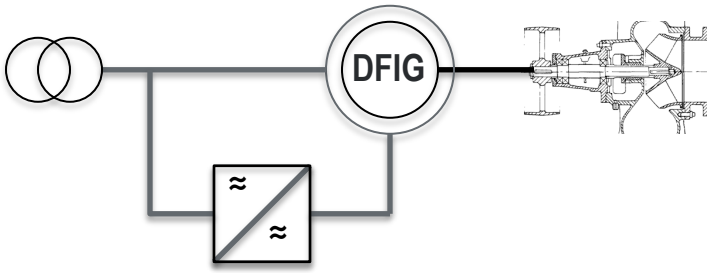
Triple Line to Ground Fault (LLL-G Fault)



Pumped Storage Hydropower (PSH) Transient Simulation Modeling

Idaho National Laboratory

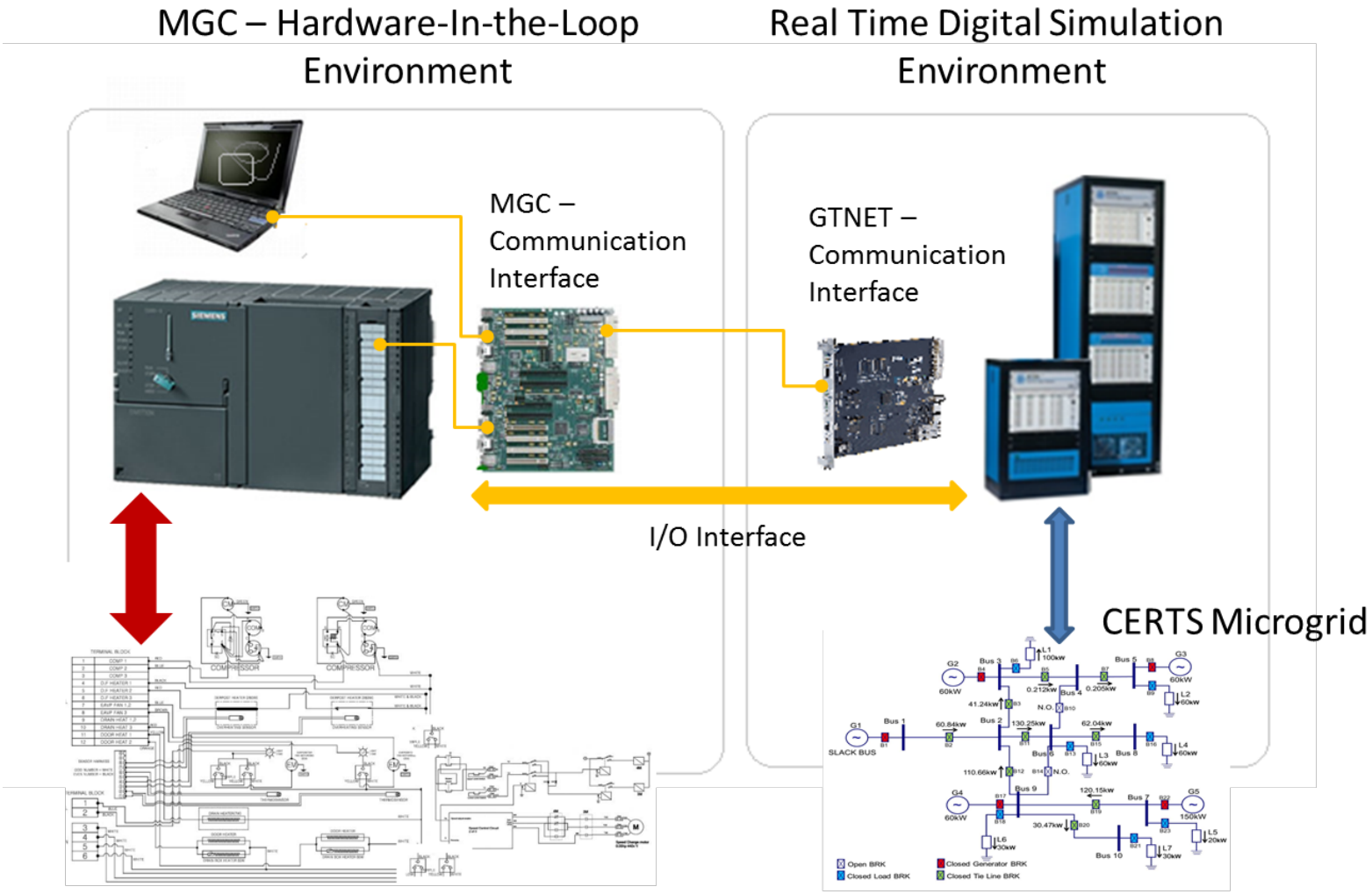
- Develop transient models in small time steps (2 -50 μs) to better understand the dynamic interactions between electromagnetics and hydrodynamics. (Electrical / Mechanical Co-simulation)
- Study the hydrodynamic behaviors such as water hammering and flywheel effects due to sudden load and fault conditions.
- Conduct System level testing and analysis on the Real Time Digital Simulator
- Provide a greater understanding of variable renewable interactions and the value of PSH energy storage.



Co-simulation of the Electromagnetic & hydrodynamic Transients

Idaho National Laboratory · NREL NATIONAL RENEWABLE ENERGY LABORATORY · THE UNIVERSITY OF TEXAS AT AUSTIN · Argonne NATIONAL LABORATORY

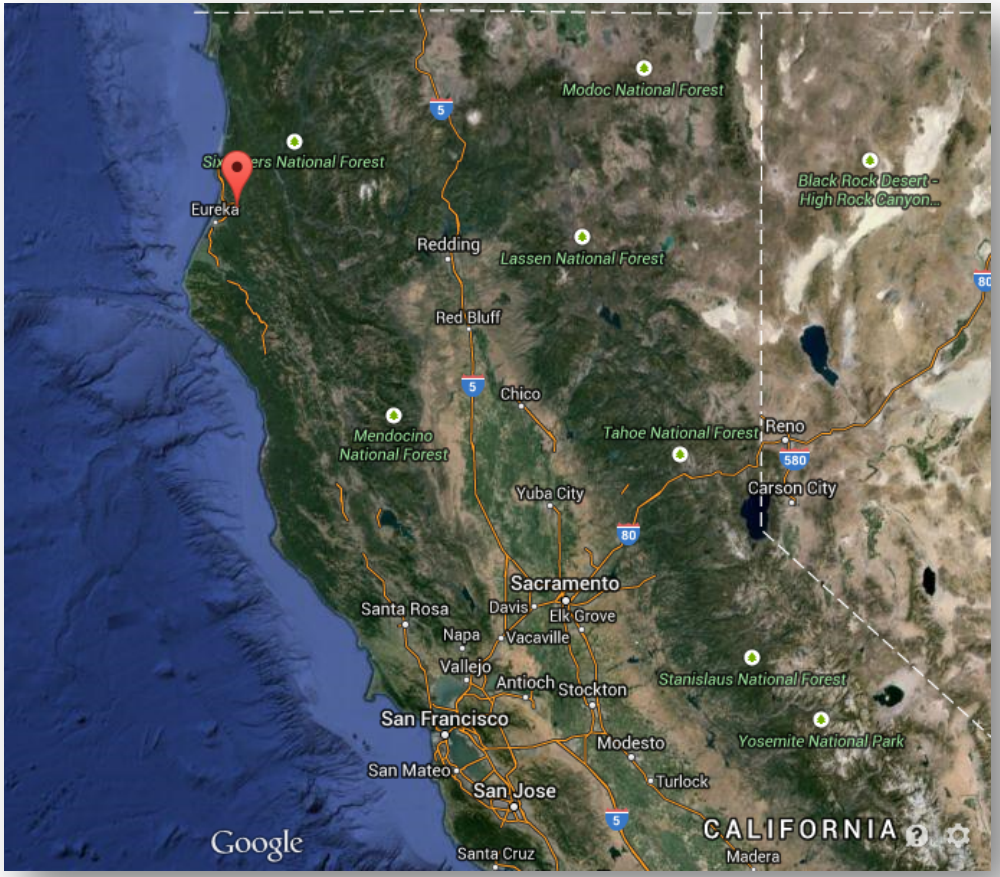
Other RTS Research at INL - Microgrid R&D



Idaho National Laboratory

Real World Project

Next Generation Microgrid Controller for a Red-Cross Evacuations Route



- Funded by California Energy Commission's Electric Program Investment Charge
- **Program Goal:** Demonstration of Low Carbon-Based Microgrids for Critical Facilities

- Our Partners:

SIEMENS

Idaho National Laboratory

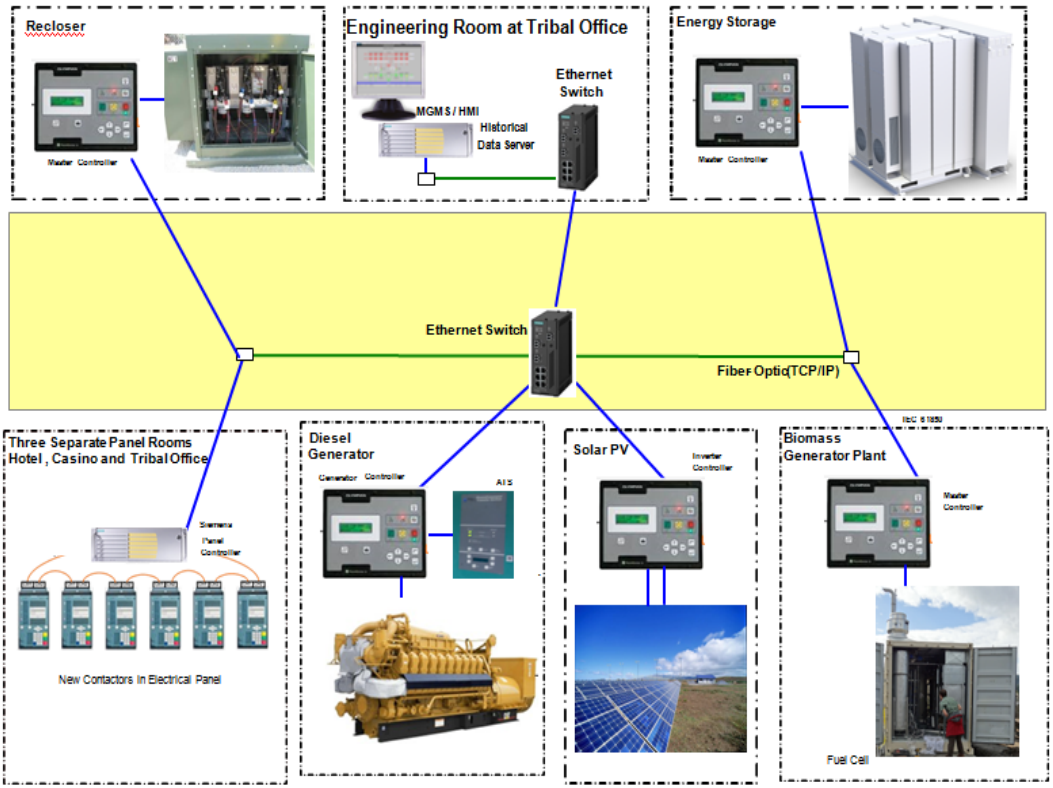
HUMBOLDT STATE UNIVERSITY 1913

TESLA

PG&E

CEC- Project Architecture

Blue Lake Rancheria

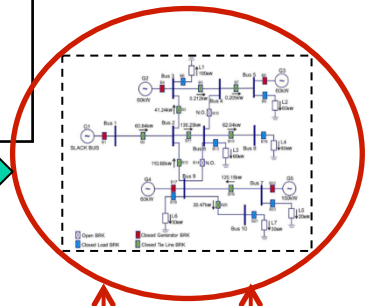


Blue Lake Rancheria , CA

Microgrid Modes of Operation:

1. Grid connected
2. Black start transition
3. Off-grid operation
4. Resynchronization to PG&E network

PG&E Power System Network



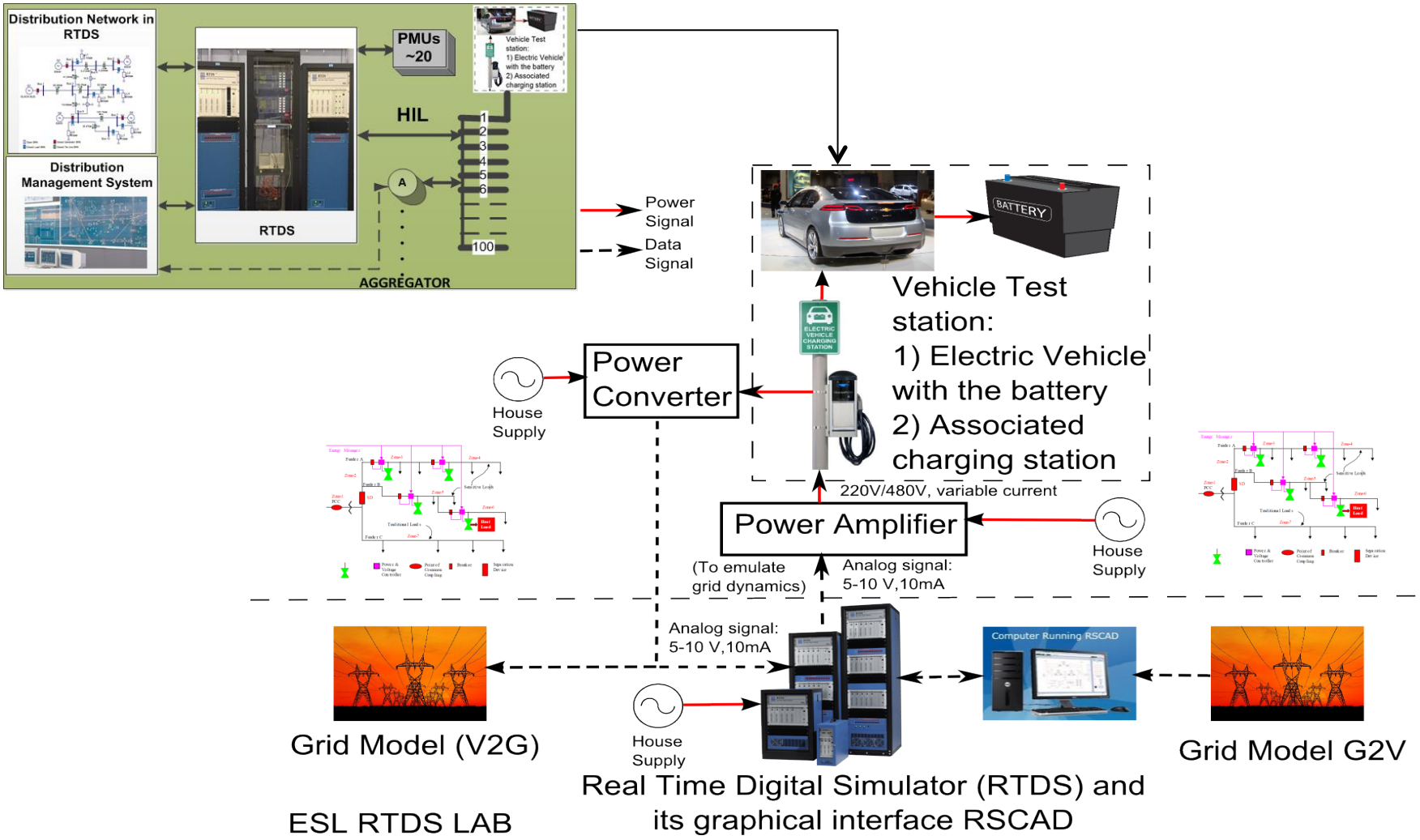
Controller in the Loop (CHIL)

Power Hardware in the Loop (PHIL)

INL

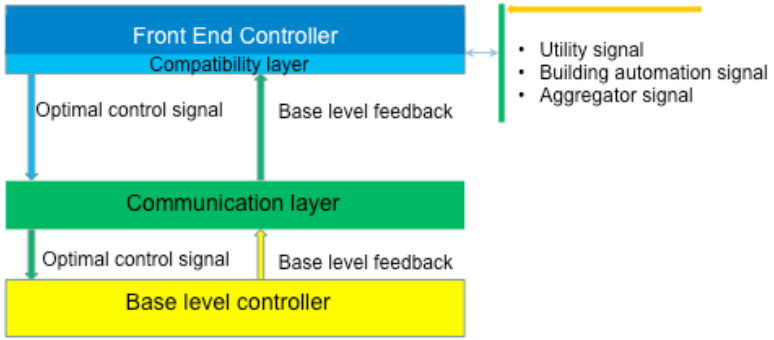
Value Addition: Simulation of multiple *what-if* scenarios before field deployment

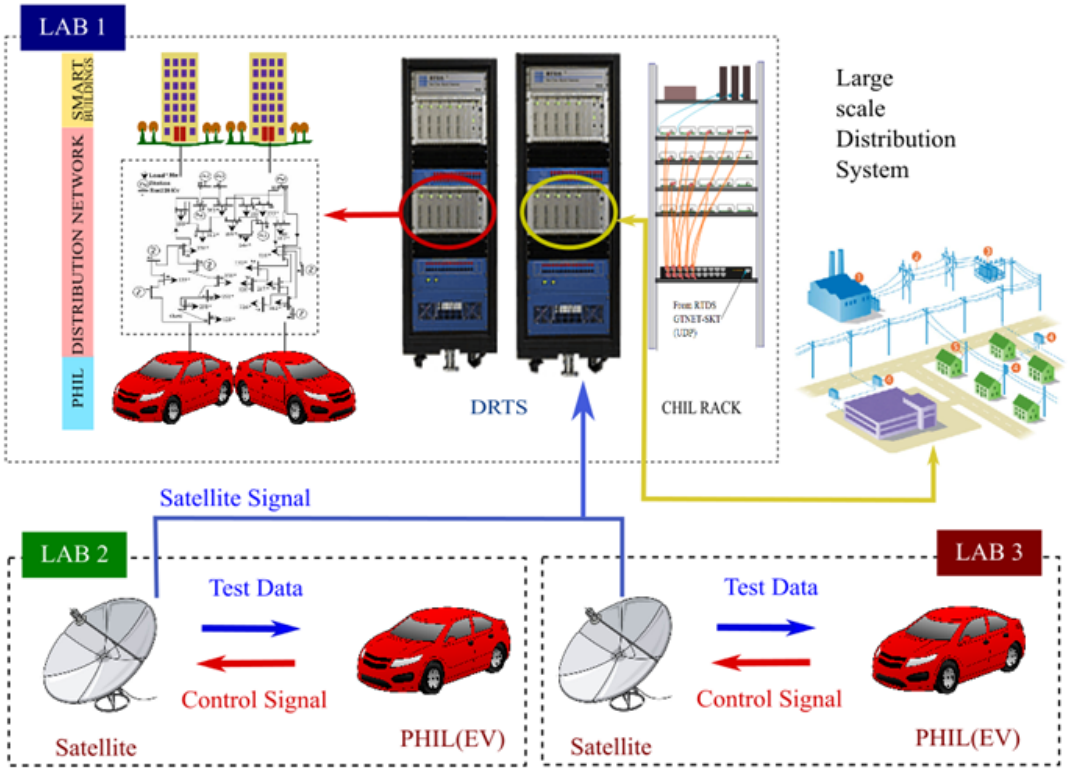
Vehicle Charging Station Integration with DRTS



EV integration with DRTS

FEC rapid prototyping using CHIL





Long term objective

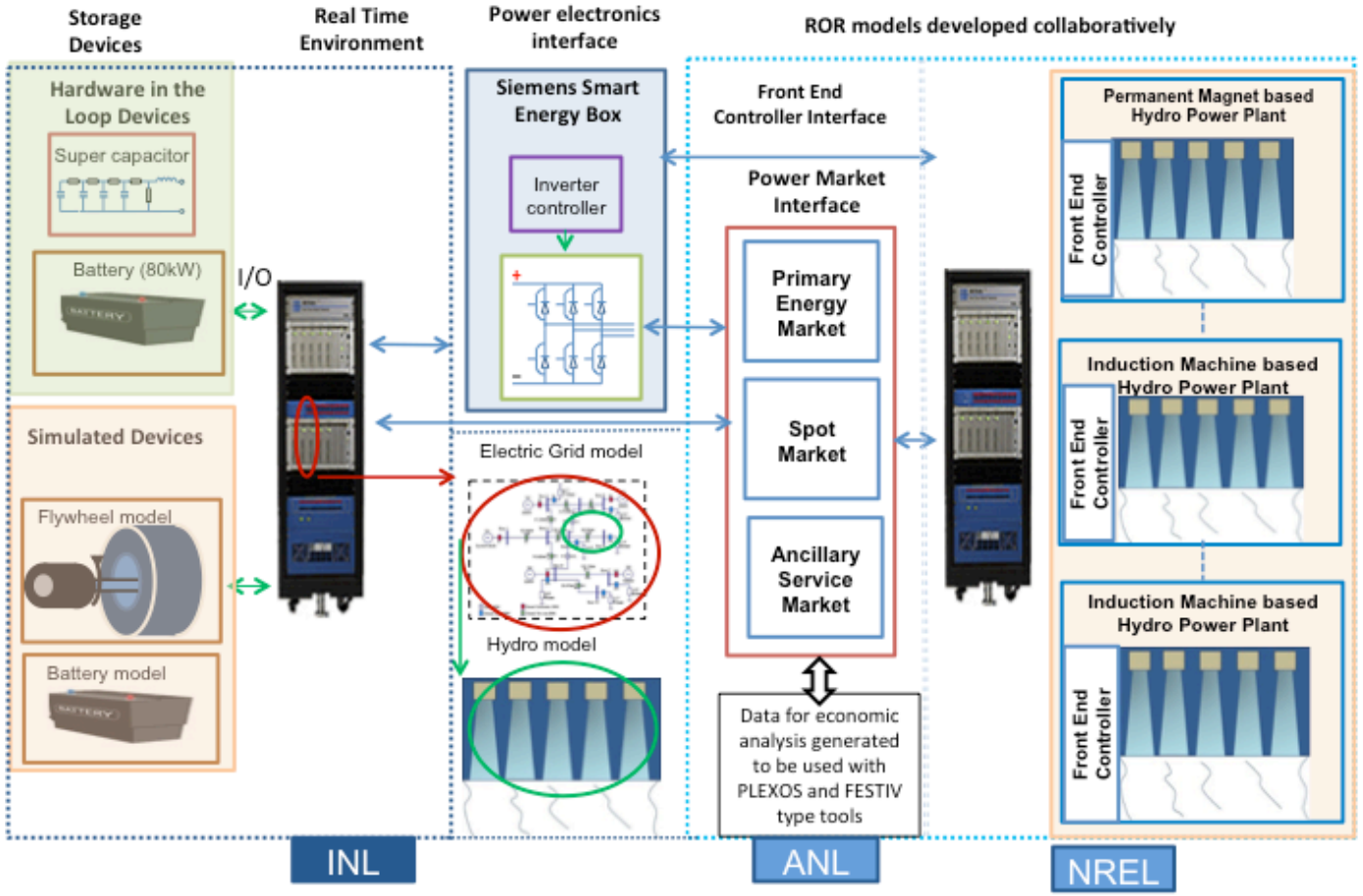
- Enable flexible G2V and V2G for achieving balance between power supply and demand

Short term objective

- Enable charging load cohesively curtail or increase the overall charging load for achieving balance between power supply and demand

Integrated Hydropower and Storage Systems Operation for Enhanced Grid Services

- **Supercapacitor will be connected as PHIL at INL**
- **Battery Bank / Power Converter integration at NREL**
- **Assess the economic and financial value streams of ROR HPPs at ANL**



Summary

- **Real time simulation conducted on geographically distributed RTDS systems between INL and NREL**
  - Transmission network at INL, and distribution network with electrolyzer at NREL.
- **Communication Latency problems identified and mitigation strategy formulated.**
- **Data Predictor approach helps to reduce errors due communication latency in distributed real-time simulation.**
- **Better frequency damping during LG, LLG, LLLG faults after electrolyzer integration.**
- **Two major projects utilizing DOE Lab DRTS infrastructure**
  - California Energy Commission's Red Cross evacuation route microgrid
  - Dynamic Modeling and Validation of Electrolyzers to Demonstrate its Value in a Real Time Environment
- **Recent press articles:**
  - Smart Grid News - ***NREL and INL connect power grid technology over the Internet***
  - World of Renewables / Environmental XPRT ***- INL and NREL Demonstrate Power Grid Simulation at a Distance***
  - PHYS-ORG ***- INL and NREL demonstrate power grid simulation at a distance***

Thank you