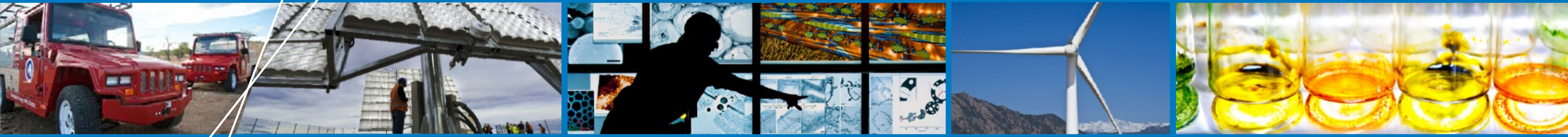
FCTO INTEGRATE Stack Test Bed & Grid Interoperability



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National Renewable Energy Laboratory

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TV030

Overview

Timeline

Project start date: June 2014
Project end date: October 2015
% Complete: 80

Barriers

- G. Hydrogen from renewable sources

Budget

Total DOE Project Value: $1000k
Funding Spent: $600k
Funding Planned FY15: $250k

Partners

- Idaho National Laboratory
- Giner
- Proton Onsite

INTEGRATE Project

Integrated Network Testbed for Energy Grid Research and Technology Experimentation

Relevance – MW-scale electrolyzer systems can provide hydrogen for numerous end uses as well as energy storage and grid ancillary services to improve grid stability and enable higher penetrations of renewable electricity sources.

Impact – NREL designed, built and now operates an electrolyzer test bed to accommodate stacks in the 250 kW range. The open and flexible test platform is fully instrumented to enable balance of plant optimization, efficiency improvements and sub-system replacement to improve overall system performance in steady-state or variable power (wind, solar) modes of operation.

Approach

- Provide an industry accessible and supported platform to test next generation electrolyzer stacks
- Provide meaningful and actionable data to utilities and stakeholders showing the ability of electrolyzers to participate in advanced grid interoperability roles
- Provide a research platform to develop and demonstrate enhanced monitoring & control of electrolyzer stacks and balance of plant to improve system efficiency and grid participation effectiveness.

Demonstrate value of ESIF to industry – flexible, reconfigurable experimental configurations that allows testing of a variety of technology and system configurations, operation parameters, and markets

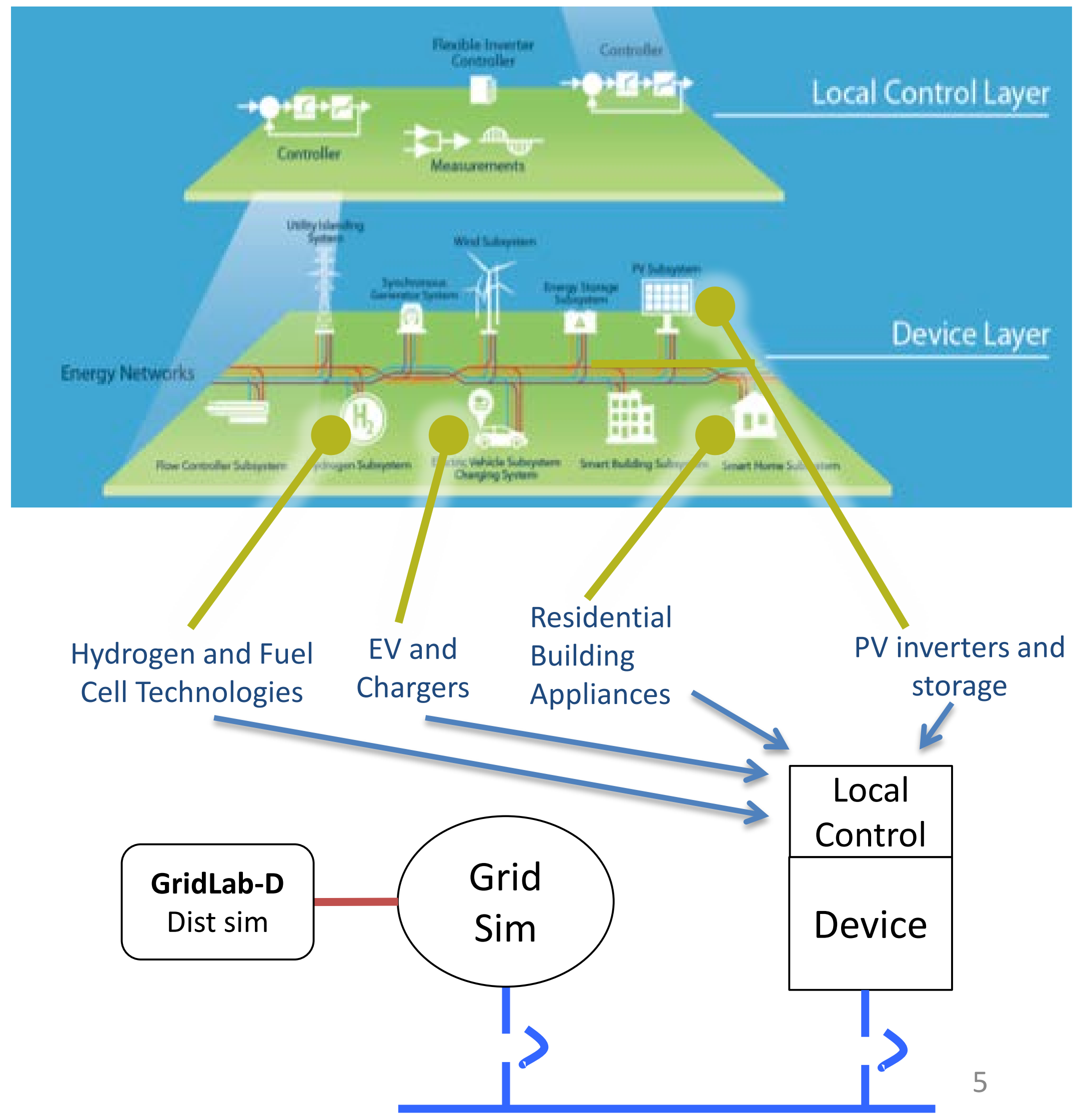
Approach

Task 1 – Characterize ability of individual EE, RE, and DER technologies to provide grid services

1. Identify grid services that EE, RE, and DER could provide
2. Build (in some cases) and characterize individual technologies for grid services under different grid conditions

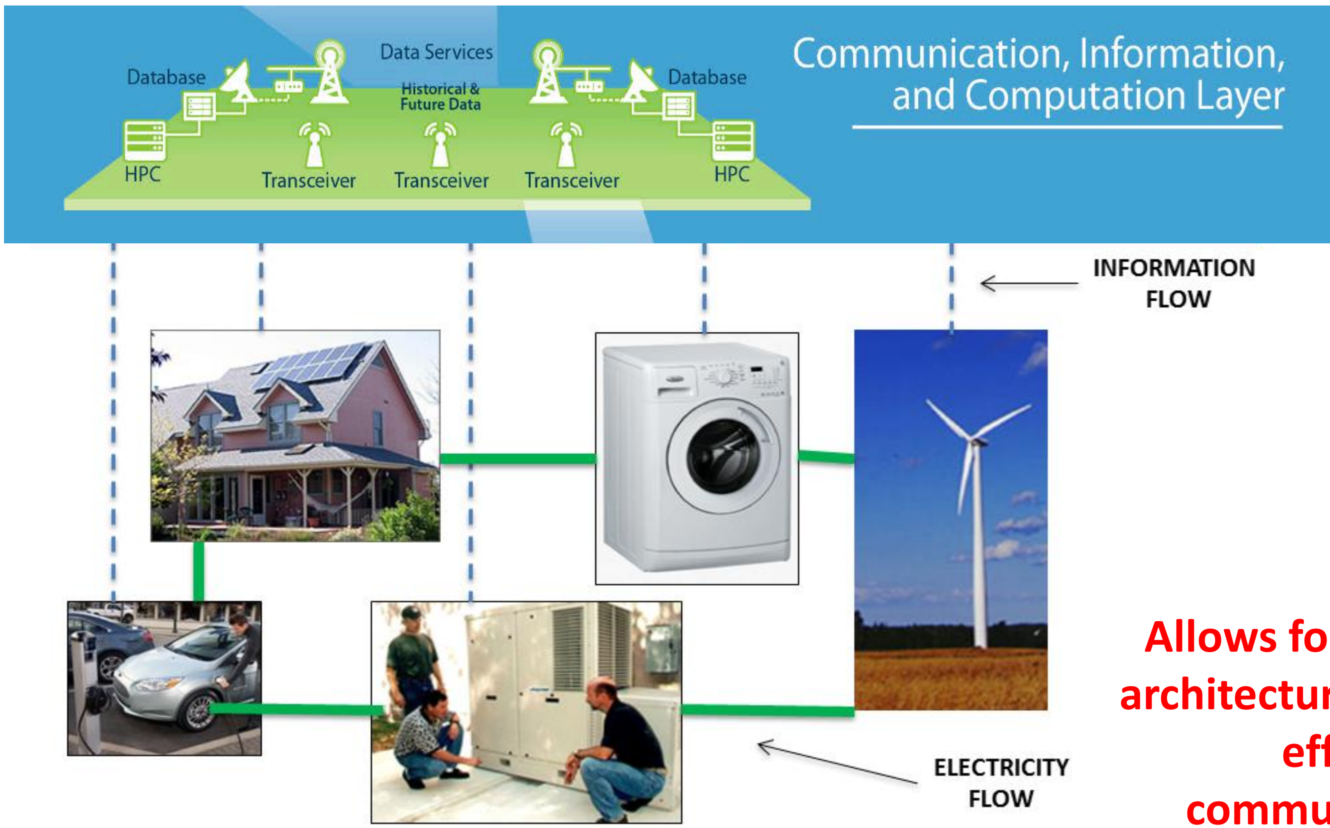
Technologies:

- Hydrogen Systems
  - Electrolyzer
  - Fuel cell
- PV Inverters: big, small, basic advanced
- Residential appliances
- EV: Smart Charge + V2G
- Large scale wind



Approach

Task 2 – Develop Communications, Information, and Computation (CIC) for integration of multiple devices



- Open source platform for interoperability and communications between devices
- Based on open standards and protocols and controls
- Contains computational algorithms
- Connections to External Sites

Allows for evaluations of control architectures and understanding of effect of imperfect communications on controls

Approach

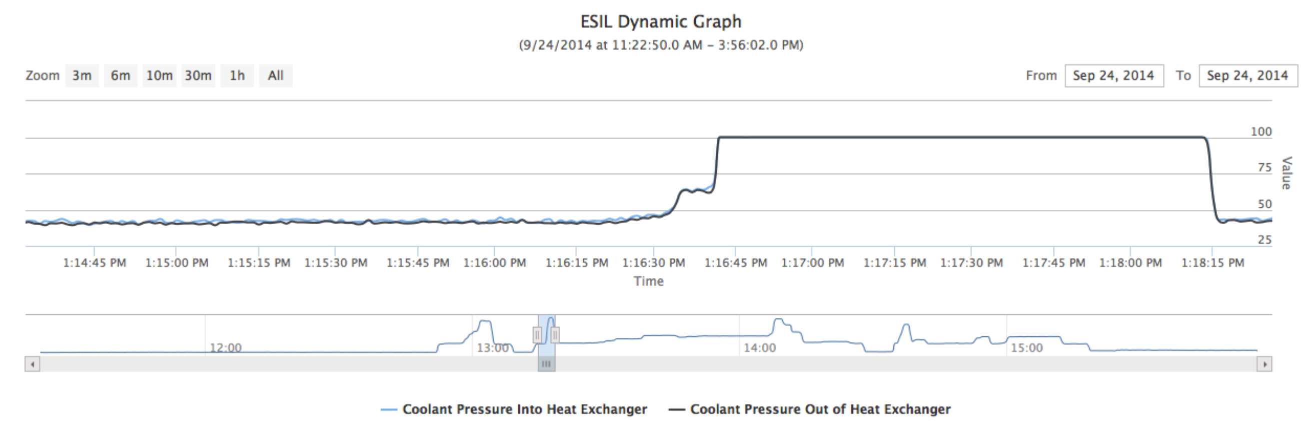
Task 2 – ESIL Laboratory Data Capabilities

Data services

- Research datasets are collected into secured projects, with permissions managed by the Principal Investigator
- Research data can be curated, by assigning metadata through the use of tags and classifying the data structure and permissions
- Search and filter capabilities to easily find data across projects and datasets.

Data visualization & sharing capabilities

- Visualize extracted time series data **graphically** and **interactively**, without the need to predefine graphs
- Download data as an aggregated, refined output dataset for data sharing and further analysis

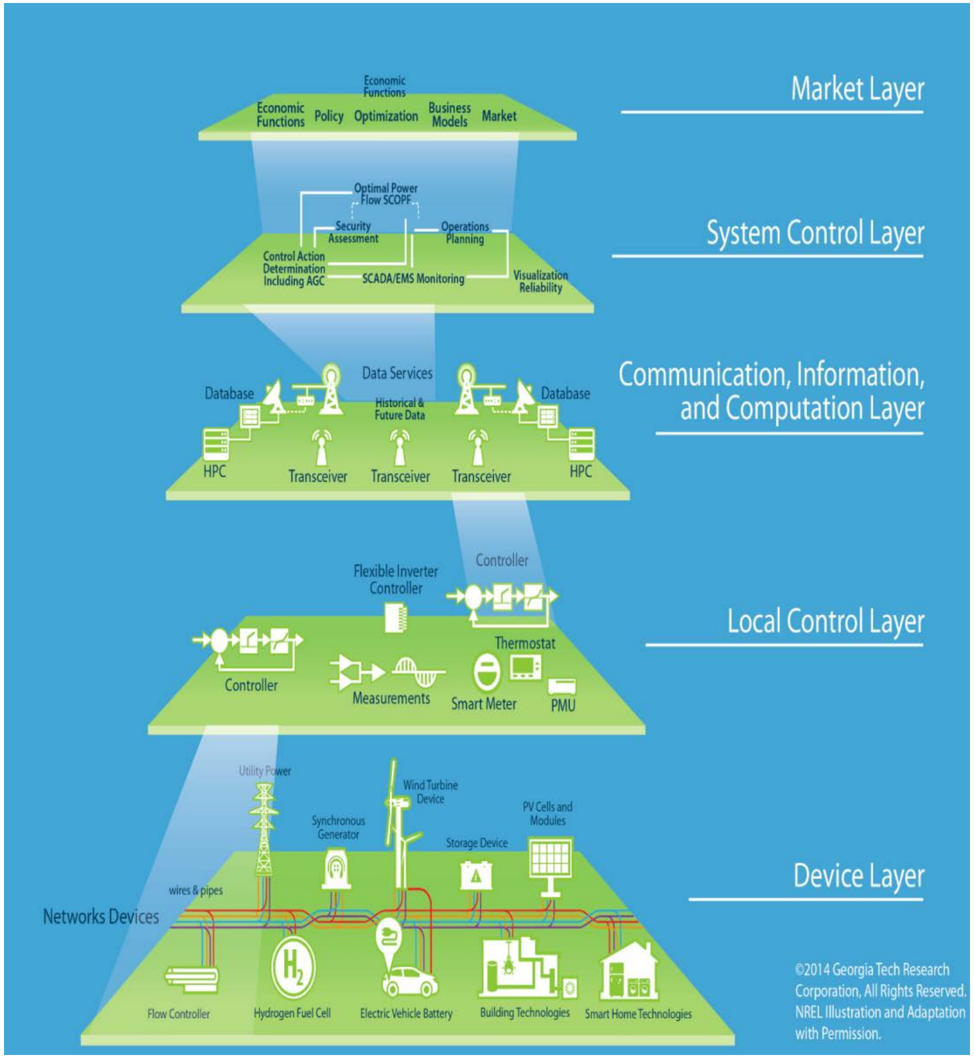


Dynamic Graphing for ESIL

#	TSID	VARNAME (September 24, 2014 at 1:14:31:14 PM - 1:18:25:18 PM)	VARAVG	TAGNUMBER	UNITS	VARTYPE
☐	739	Coolant Flow Out of Heat Exchanger	1.204	FT-296	gpm	Flow
☑	727	Coolant Pressure Into Heat Exchanger	66.033	PT-292	psig	Pressure
☑	743	Coolant Pressure Out of Heat Exchanger	65.324	PT-293	psig	Pressure

Approach

Task 3 – Demonstrate integrated systems with EE and RE technologies deliver grid services



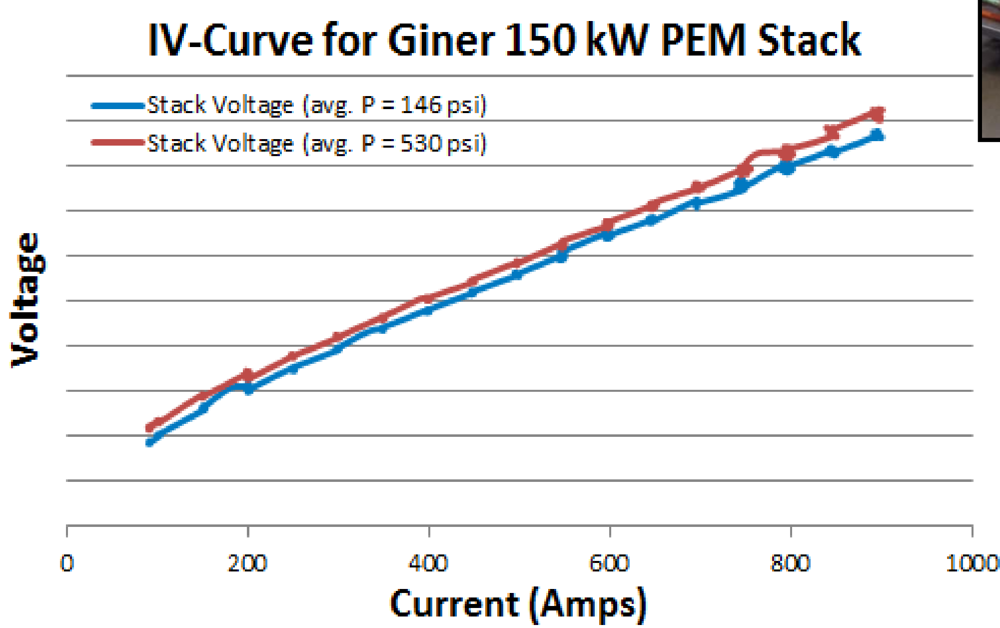
- *Device*, *Local Control*, and *Cyber Layer* built in Tasks 1 and 2
- Basic *Market Layer* to pass financial information
  - Optimize energy system control based on financial information
- Basic *System Control* layer
  - Basic energy management for integrated systems
  - Controllers for ancillary services
- Conduct analysis of integrated systems to provide grid benefits at several scales (Home, Campus, Distribution, Regional)

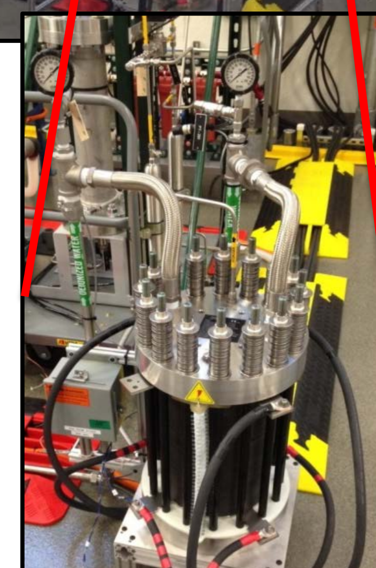
Progress & Accomplishments

Task 1 – Large Active Area Stack Test Bed

First testing completed with Giner Inc.

- Three (3) 150 kW PEM stacks
- IV-Curves were collected at stack temperature of 70 °C
- Individual cell voltages were collected at different current and stack pressure levels



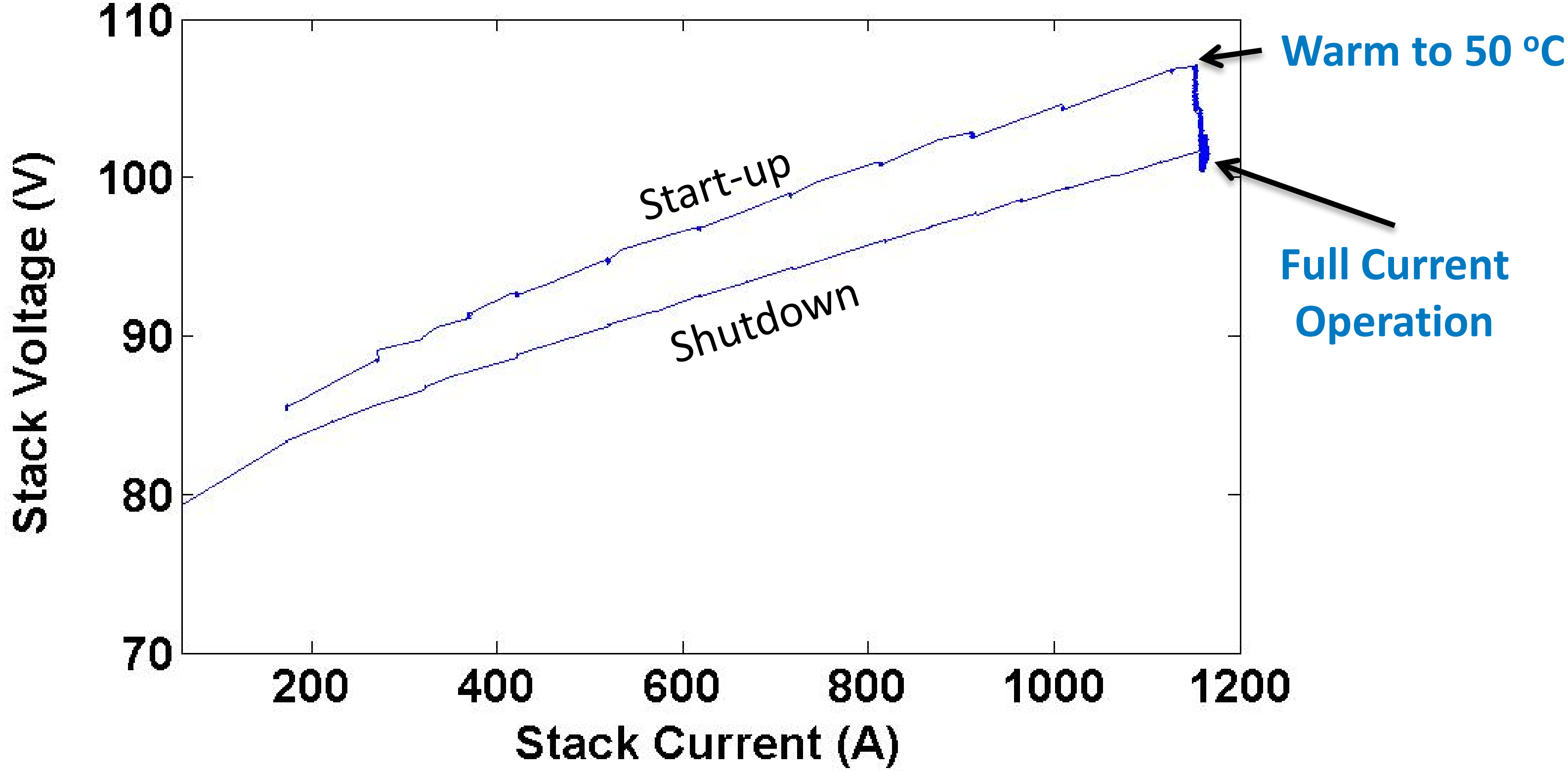


Giner and NREL team demonstrate (3) 150 kW of PEM electrolysis, at the highest current densities yet. November 2014

Progress & Accomplishments

Task 1 – VI Polarization Curve

- 50-cell, 120 kW, 2.5 kg/hr PEM stack (Proton Onsite) installed in the large active area stack test bed
- Onsite production for FC labs, vehicle refueling, component testing (e.g., Hoses, PRD, compressors), grid interoperability and stack decay and BoP optimization under variable power

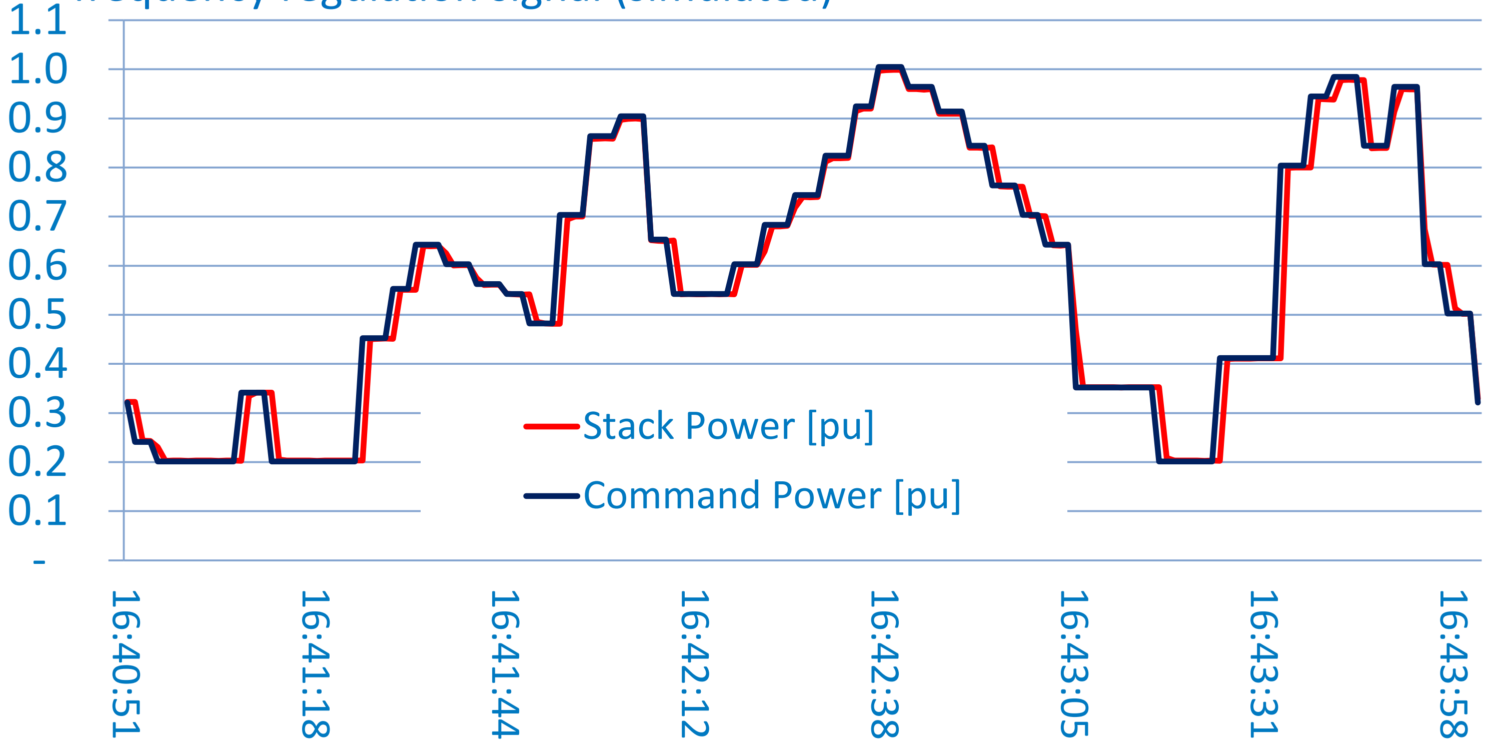


Progress & Accomplishments

Task 1 – PEM Electrolyzer Renewable System Integration

Demonstrating grid support – Frequency Regulation

- Renewable energy sources are variable and electrolyzers can be used to balance the grid
- NREL testing on the large active area stack test bed using a 120 kW stack
  - Demonstrated grid ancillary services following a traditional 4 second frequency regulation signal (simulated)

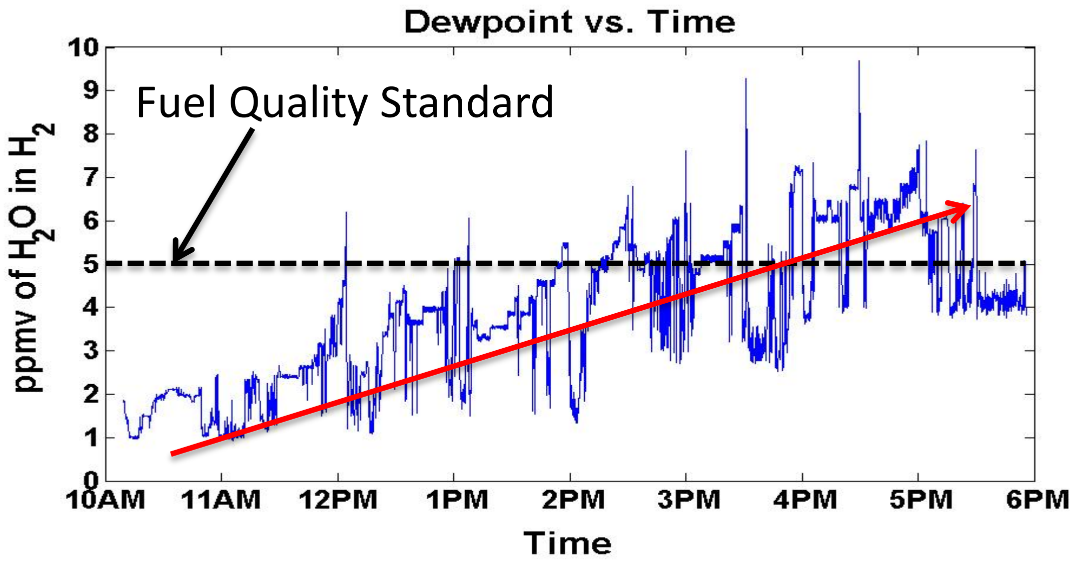


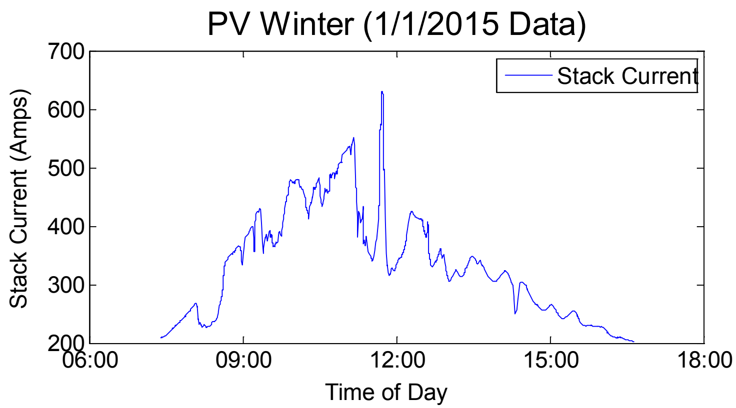
Progress & Accomplishments

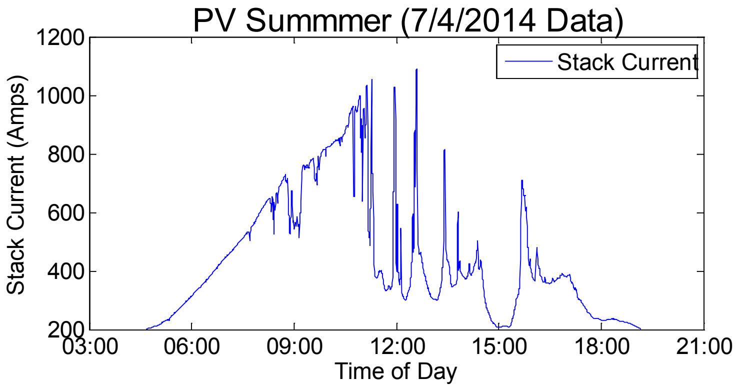
Task 1 – Optimize Balance of Plant

System efficiency improvements under variable power

- Drying losses in variable operation with NREL's variable flow drying technique
  - Dew point sensor saturating or drifting
  - Result of independent fuel quality showed water vapor < 1 ppm

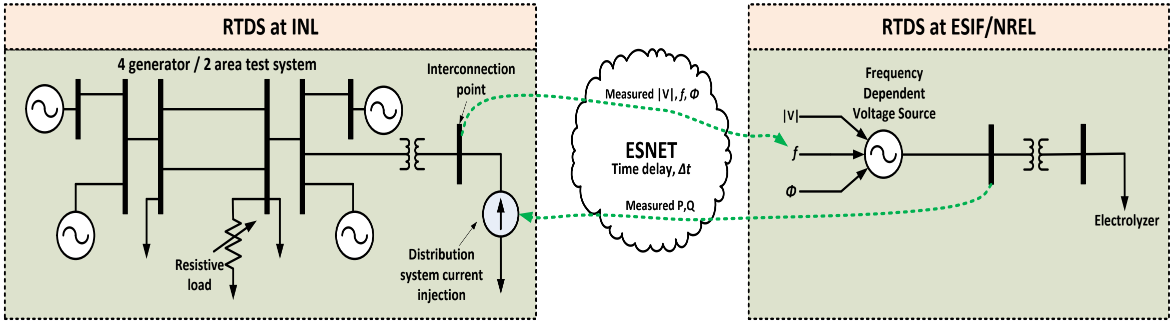


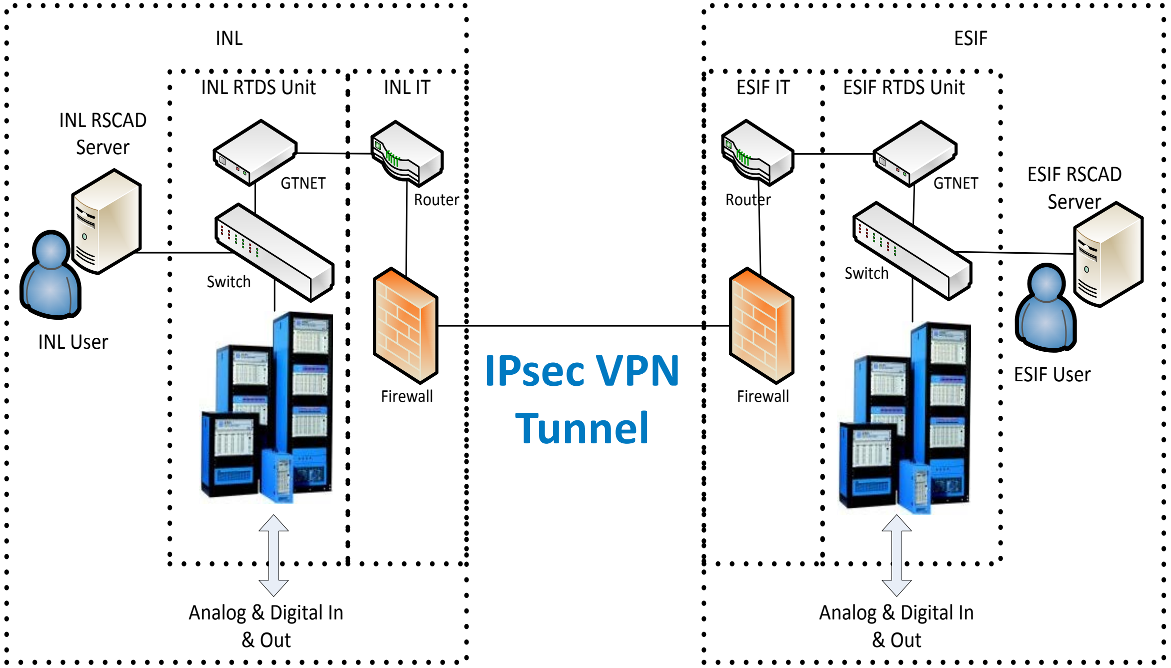




Progress & Accomplishments

Task 2 – ESIF/INL RTDS Link Experiment





- **Experiment consists of a two-part RTDS simulation**
  - Transmission system model runs at INL RTDS
  - Distribution system model and electrolyzer model run at ESIF/NREL RTDS
  - The two parts exchange data across the internet in real-time
- **The top diagram indicates experiment's design**
- **Bottom diagram indicates the IT infrastructure diagram**
- **Experiment was successful in exchanging data at 1200 samples/sec**
- **Experiment results on next slide**

Progress & Accomplishments

Task 2 – Established a first of its kind RTDS to RTDS communications network between NREL's ESIF and INL

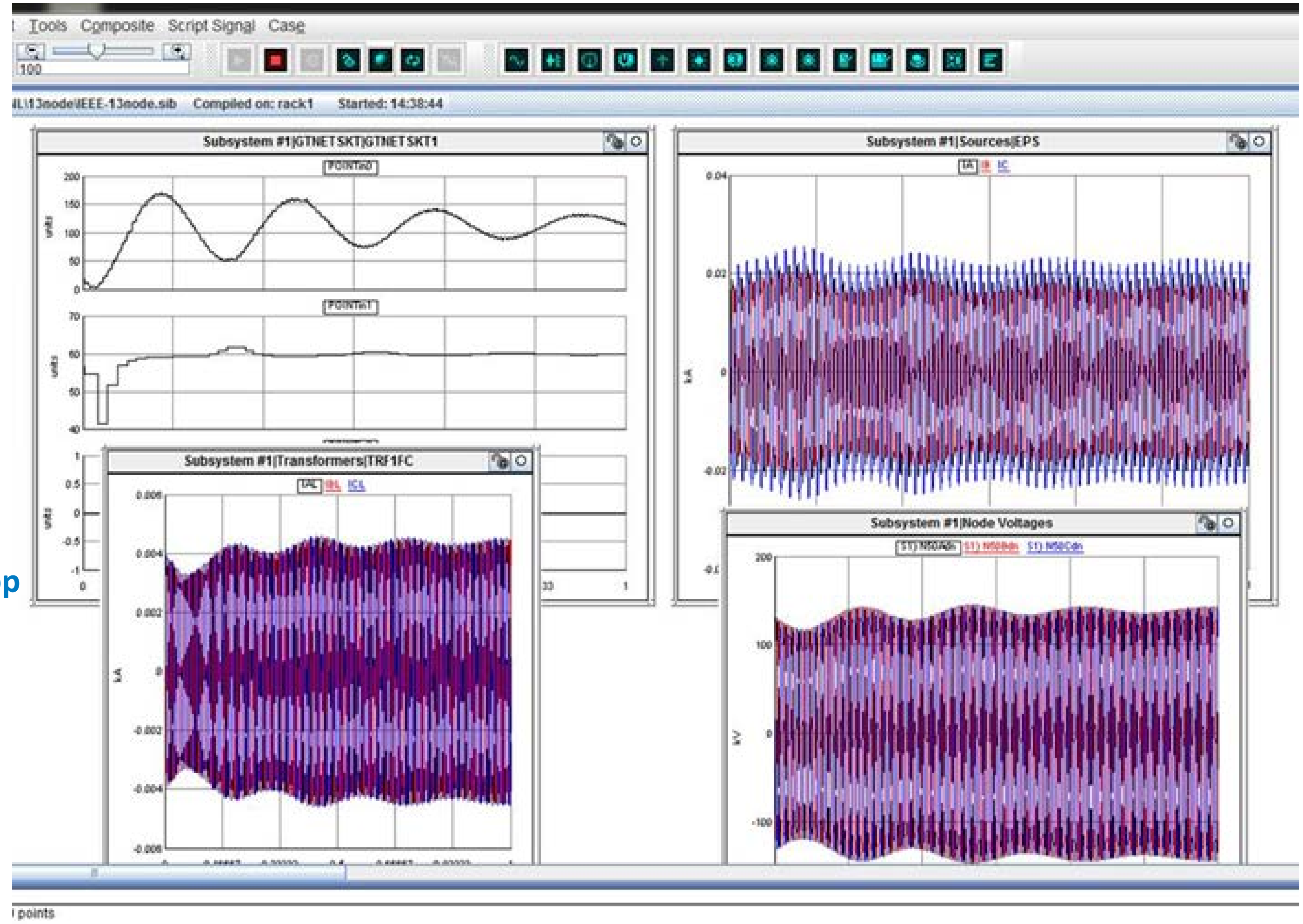
- **Successful bi-directional communication test between ESIF RTDS and INL RTDS - December 2014**
  - It was the first time, as we understand, that 2 RTDS machines communicated over a WAN (wide area network); observed latency was ~27ms.
- **Successful bi-directional communication between ESIF RTDS and NWTC CGI RTDS allowing real-time exchange of data - February 2015**
  - Maximum practical data rate allowing lossless transfer of data was 1200 samples per second (or 20 point per cycle for 60 Hz signal)
  - Time delay observed was 1ms

Progress & Accomplishments

Task 2 INL/NREL RTDS Results – NREL End

Frequency drop and voltage data incoming from INL

Frequency drop causes oscillations which affect electrolyzer current



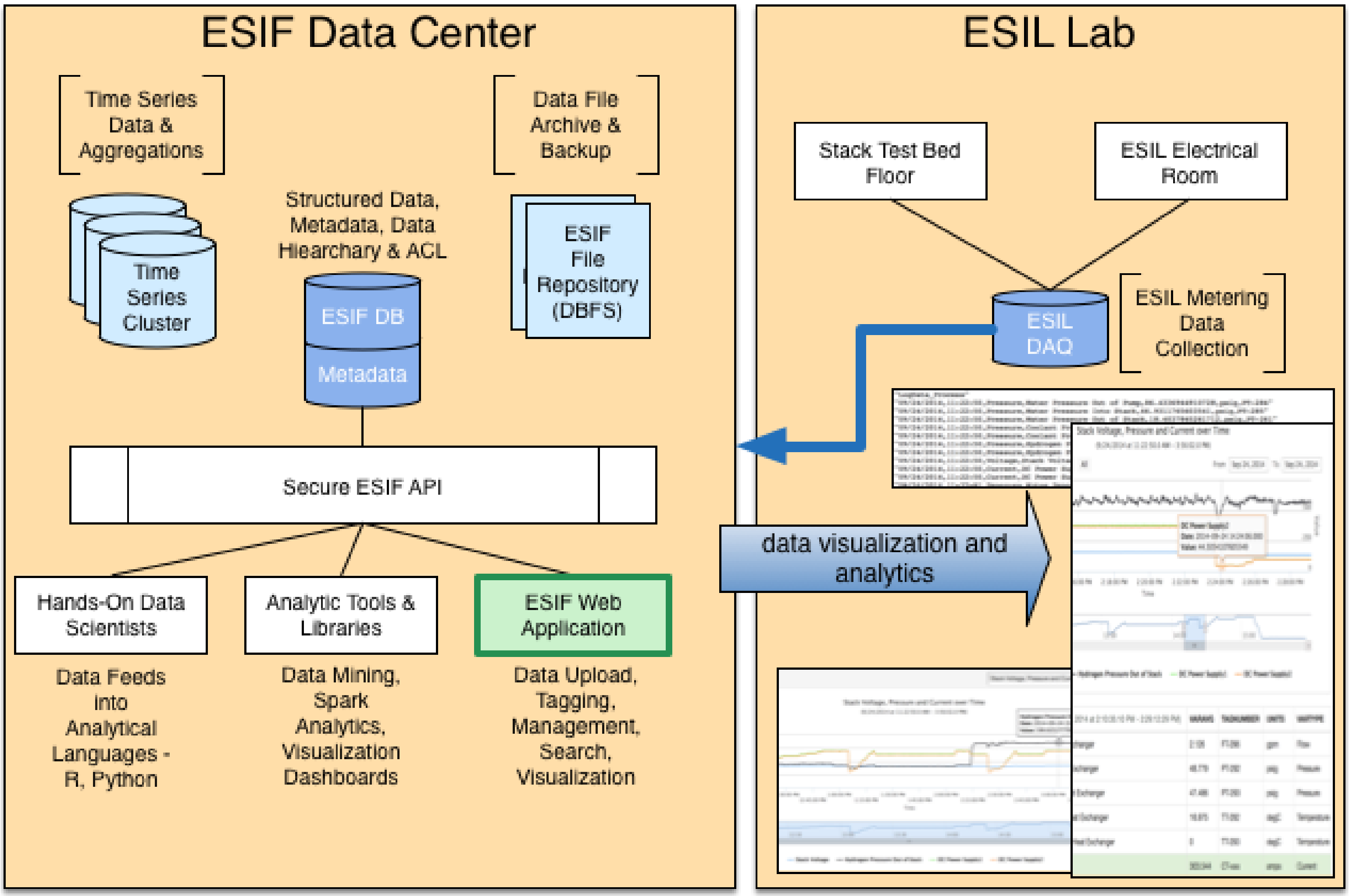
Current data sent to INL

Variations in node voltages affect current at feeder substation

Oscillations affect node voltages on distribution circuit

Progress & Accomplishments

Task 2 – ESIL Laboratory Data Architecture



= data connectivity (collection and visualization) established through this task

Progress & Accomplishments

Task 3 – Services Analyzed

Operating Reserves

Spinning, Regulation, Non-Spinning, Flexibility

Capacity

Ability to avoid capacity charges by reducing demand during periods of high demand

Energy

Ability to avoid high prices (typically when value of products are lower than marginal energy prices)

	Regulation Requirement (MW)	Spinning Contingency Reserve (MW)	2013 Energy Demand (MW)
CAISO	Varies. Avg: 338 up, 325 down	Avg ~850	45,097 peak, 26,461 avg, 231,800 GWH total
ERCOT	Varies: Avg:~ 300 down, ~500 up Range 400-900	2800 (max 50% from load)	67,245 peak, 332,000 GWH total
MISO	Range of 300-500	1000 (2000 total, 1000 spin)	98,576 peak 52,809 avg,
PJM	753 average in 2013	Tier 2 1375 (max 33% from DR)	157,508 peak, 784,515 GWH total
ISO-NE	Range 30-150, average 60	1750 (10-Minute Reserve) 2430 (30-Minute Reserve	27,400 peak, average 14,900
NYISO	150-250	10 min spin 330 east, 655 10 min total 1310	Peak 33,956, average 18,700
SPP	Avg ~300 up, ~320 down	545	Peak 45.256, Total 230,879 GWh

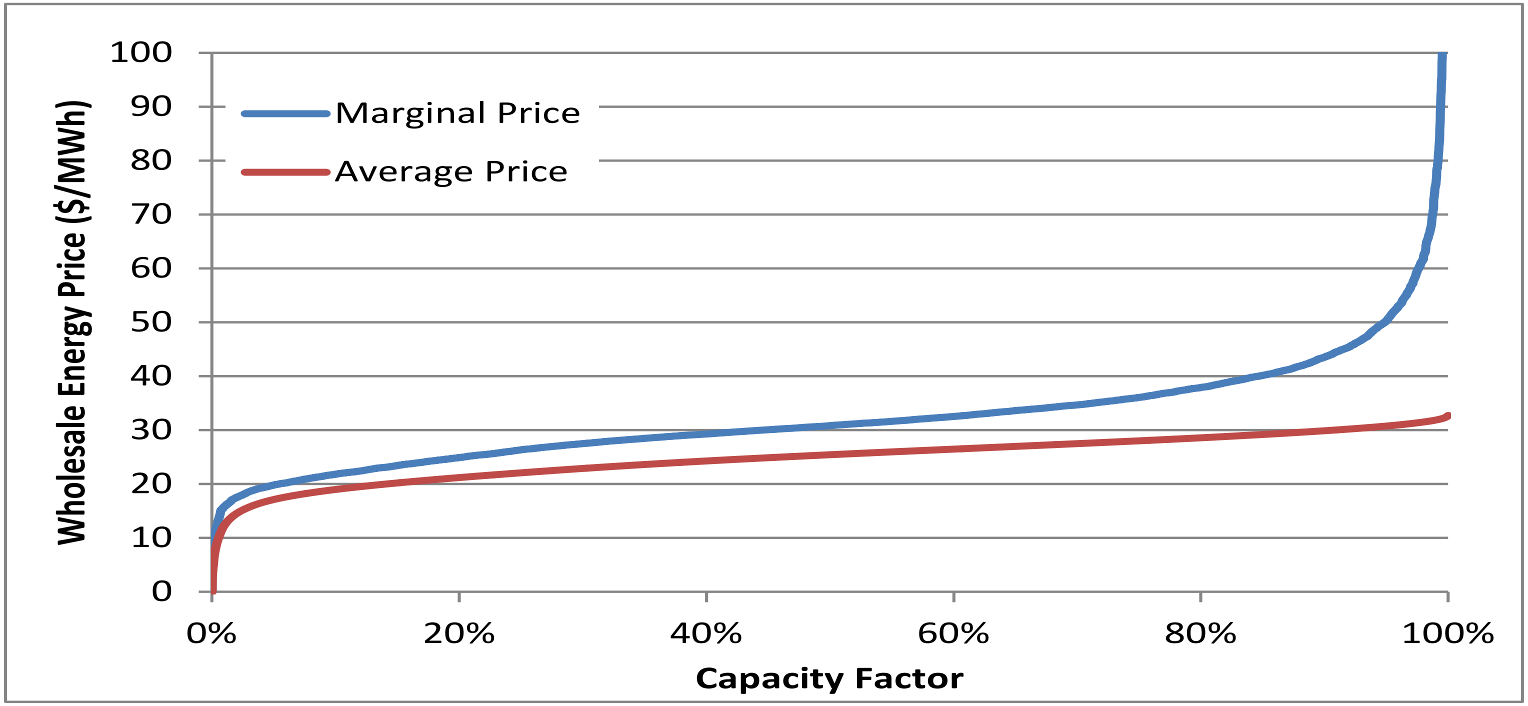
Example: Regulation and Spinning contingency reserve requirements in wholesale markets in the U.S.

Progress & Accomplishments

Task 3 – Summary of Market Opportunities

- Discussion of current prices for services, technical requirements
- Draft under review, expected publication June 2015*

Example: Energy costs as a function of electrolyzer capacity factor



***Draft** report, “Summary of Market Opportunities for Electric Vehicles and Dispatchable Load in Electrolyzers.”

Collaborations

Giner

- Technical service agreement and testing of three (3) 150 kW PEM electrolyzer stacks
- Test results sharing

Proton Onsite

- Hydrogen drying system and stack procurement
- Testing and results sharing

Idaho National Laboratory

- Modeling, simulation and control using Real Time Digital Simulation systems at each laboratory

Proposed Future Work

- Demonstrate control of 120 kW electrolyzer stack test bed using RTDS to RTDS link between INL and NREL
- Assist Giner with the testing of their next generation PEM electrolyzer stacks
- Work with Proton Onsite on power supply optimization and cost reduction, reducing drying losses and balance of plant performance in variable power mode

Summary

Relevance

MW-scale electrolyzer systems can provide hydrogen for numerous end uses as well as energy storage and grid ancillary services to improve grid stability and enable higher penetrations of renewable electricity sources.

Approach

Demonstrate value of integrated approach to systems by providing;

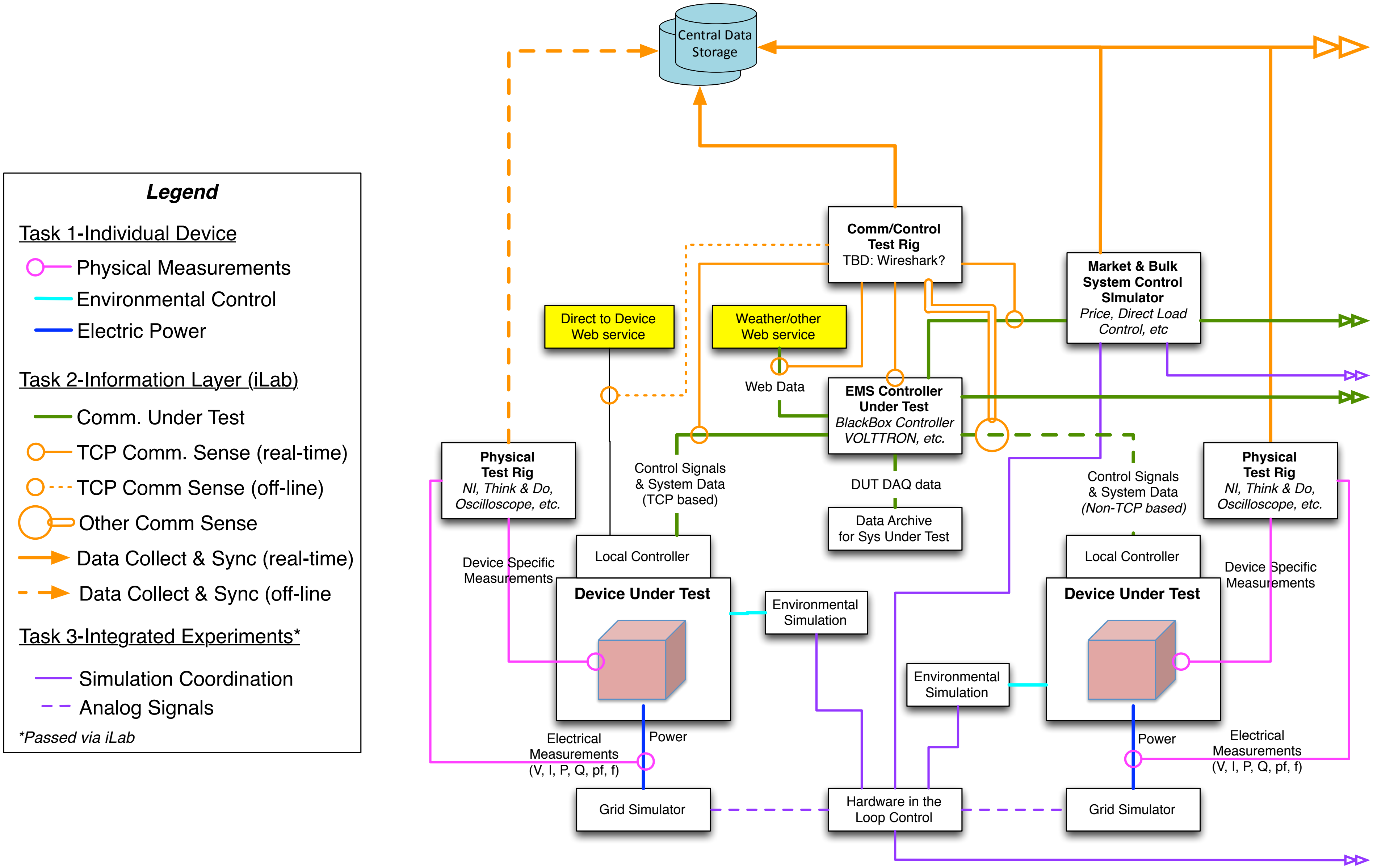
- An industry accessible open platform to test next generation electrolyzer stacks and balance of plant optimization and cost improvements
- Meaningful and actionable data to utilities and stakeholders showing the ability of electrolyzers to participate in advanced grid interoperability roles
- A research platform to develop and demonstrate enhanced monitoring & control of balance of plant systems to improve system efficiency and grid participation

Progress & Accomplishments

- Designed, built, commissioned and operating electrolyzer stack test bed with 120 kW stack
- Electrolyzers can minimize the cost of energy services by providing multiple services
- Established a first of its kind RTDS to RTDS communications network between NREL's ESIF and INL
- Developed data services to capture, analyze, visualize and share data from test bed

Technical Back-Up Slides

Integrate: Multiple Labs/Sites (Task 3B)



	Product Types	General Description	How Fast to Respond?	Ramp up (MW/Min)	Length of Response (Duration):	Fully Respond by:	Frequency, How Often Called ?
ANCILLARY SERVICES	Contingency Reserve	Rapid response to loss of supply	1 minute	1st 5 minutes	≤ 30 minutes usually only needed for 10-15 min	≤ 10 minutes	Called once per 1-2 days
	Regulation Reserve	Rapid response to unscheduled deviations from scheduled net load	30 seconds	1st 5 minutes	Determined by load (hourly blocks, energy neutral within 15 minutes), calculated every 5 minutes	By 5 minutes	Every available hour Continuous load within the specified period bid into *net zero over a large time scale
	Flexibility Reserve	Regulation response on a longer (5+ min) time scale	5 minutes	1st 5 minutes	1 hour	60	Every available hour. continuous every hour of the year,
ENERGY	Energy Shifting	Move energy over time	5 minutes	1st 5 minutes	1 hour + depends on need	10 minutes ≥ 1 hour by time specified	Every available hour Called 1-2 times/day Notification – 4hr ahead (8 hr window)
	Firm Capacity	Ability to contribute to planning reserve	Top 20 hours by BA (coincident with system peak)				