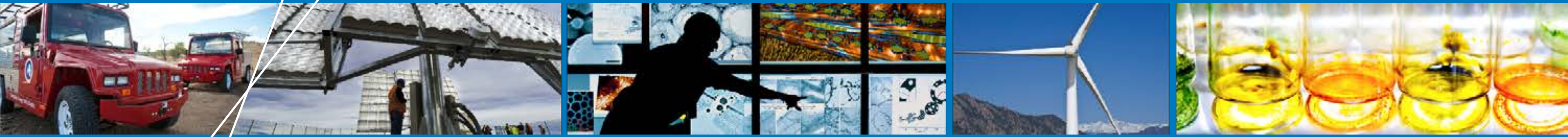
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Idaho National Laboratory
Operated by Battelle Energy Alliance

Dynamic Modeling and Validation of Electrolyzers in Real Time Grid Simulation



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Idaho National Laboratory and National Renewable Energy Laboratory
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Project ID TV031

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline

- **Project start date: 06/01/15**
- **Project end date: 09/30/17**

Budget

Total project budget: $3660K

Total recipient share: $2100K(INL), $1560K(NREL)

Total federal share: $3660k

Total DOE funds spent*: $0

* As of 3/31/15

Barriers

- **Barriers addressed**
  - Accurate utility network modeling in Real Time Simulation
  - Front End Controller design for participation in Demand Response
  - Inter lab communication to synchronize simulator and assets

Partners

- **Funded partners**
  - Idaho National Laboratory and National Renewable Energy Laboratory
- **Collaborators**
  - Utilities: PG&E, CAISO, 1 utility (TBD)
  - Academic: Humboldt State University, Florida State University

Relevance

- **<u>Objectives</u>: Validate the benefits of hydrogen electrolyzers through grid services and hydrogen sale to fuel cell vehicles for full-scale deployment through the:**
  - Characterization of the potential and highest economic value (near and midterm < 7 years) based on the needs of multiple stakeholders (utility, aggregator, and hydrogen station operator) for specific grid regions and identification of at least three scenarios for demonstration
  - Demonstration of the reliable, fast-reacting performance of hydrogen-producing electrolyzers (response time, settle time, duration, operation limits, start/stop time, and durability) for at-scale energy storage devices that support the grid through ancillary services and Demand Response (DR), as well as producing hydrogen for fuel cell vehicle fueling for at least three scenarios.
  - Verification of the communications and controls needed for successful participation in electricity markets and DR programs.

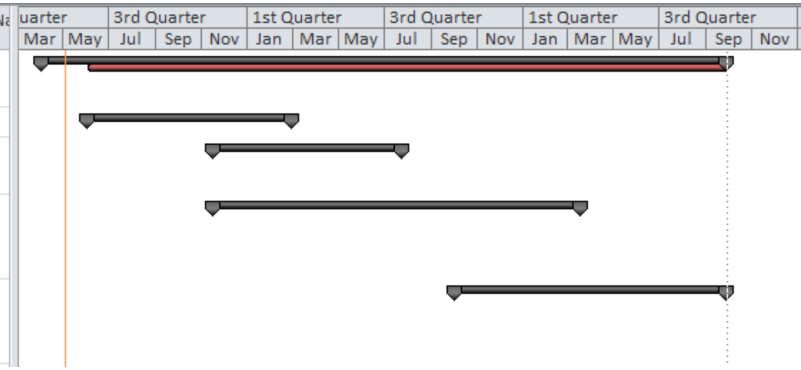
Approach: Electrolyzer based H_2 for grid services

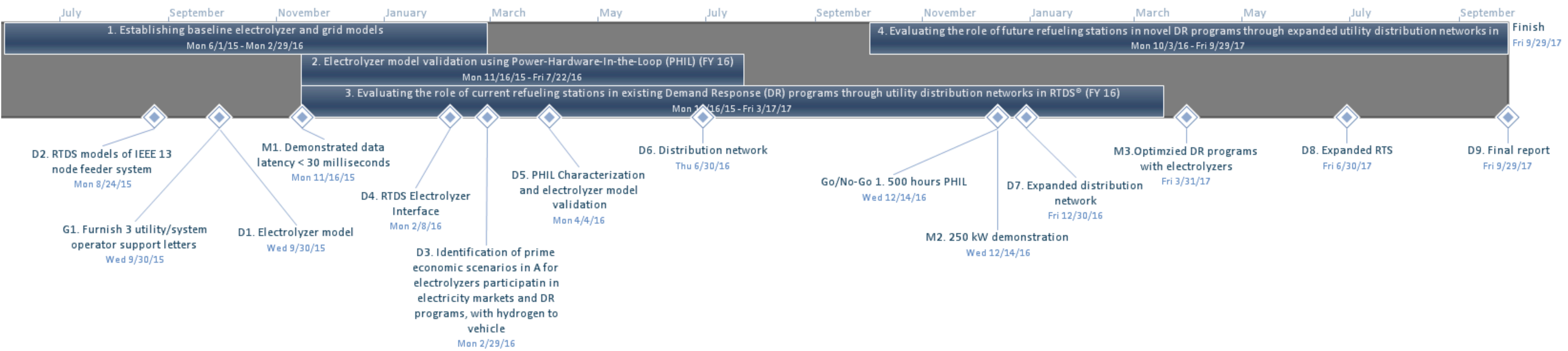
- **This is a new project, starting in June 2015**
- **Technical approach includes**
    - Electrolyzer model validation and simulation in a distributed real time environment that can be used for electrolyzer based fueling station business case analysis (California focus)
    - Utility distribution network identification and modeling in Real Time Simulator for present case
    - Interface development between electrolyzer and Real Time Simulator to perform Power-Hardware-In-the-Loop (PHIL) model validation
    - Synchronizing the Real Time Simulators at INL and NREL to conduct distributed Real Time Simulations with HIL
    - Location identification of hydrogen refueling station within the utility territory

Approach

Timeline – Gantt chart

Task Name	Duration	Start	Finish	Predecessors	Resource Na
Dynamic Modeling and Validation fo Electrolyzers in Real-Time Grid Simulation	652 days	Wed 4/1/15	Thu 9/28/17		
1. Establishing baseline electrolyzer and grid models	195 days	Mon 6/1/15	Mon 2/29/16		
2. Electrolyzer model validation using Power-Hardware-In-the-Loop (PHIL) (FY 16)	180 days	Mon 11/16/15	Fri 7/22/16		
3. Evaluating the role of current refueling stations in existing Demand Response (DR) programs through utility distribution networks in RTDS® (FY 16)	350 days	Mon 11/16/15	Fri 3/17/17		
4. Evaluating the role of future refueling stations in novel DR programs through expanded utility distribution networks in RTDS® (FY 17)	259 days	Mon 10/3/16	Fri 9/29/17		





Approach: Milestone

- **Milestone is listed as follow:**
  - Demonstrate distributed Real Time Simulation (RTS) between INL and NREL with high data rate exchange (< 30 milliseconds/exchange)
  - Demonstrate a 250-kW electrolyzer operating in both the energy market and the ancillary service market simultaneously for 500-hours producing 2,000 kg of hydrogen
    - Computation and analysis of cost versus revenue comparison, stack durability, and system feasibility
  - Develop 3 novel Demand Response (DR) programs for optimizing hydrogen refueling station operation to generate a minimum of 10% additional revenue
    - Partner utilities will provide guidelines and consulting to develop the novel DR programs
    - Performance assessment of the hydrogen refueling stations under existing DR programs for comparison is planned

Approach: Go/No-Go

- **FY 2015:**
  - Collaborate with 3 partners and clarify their role in the collaboration
    - PG&E: Provide consultation on cost share to ensure fully implementation of DR program. Provide PG&E infrastructure and network data to simulate real world distribution network.
    - CAISO: Perform design review of the experiment especially electrolyzer participation in DR programs. Assess application of proposed DR programs in practical system operation.
    - Aggregator: Review DR portfolios. Identify an existing DR portfolios for this system
  - Investigate at least 3 distribution networks of PG&E to allow hydrogen refueling station interconnection
  - Collaboration with external affiliation may be required to enable RTS of large scale system

Approach: Go/No-Go

- **FY 2016:**
  - Demonstrate distributed RT PHIL for a minimum of 200 hours between INL and NREL based on dynamic conditions adopted from discussions with PG&E
  - Validated electrolyzer model via characterized data must operate at a minimum of 60% (LHV) stack efficiency

Accomplishments and Progress

- **New project start**
- **Leveraging existing work between INL and NREL**

News Release

INL and NREL Demonstrate Power Grid Simulation at a Distance

Capability makes national laboratory assets accessible to grid researchers worldwide

Monday, May 04, 2015

The Energy Department's National Renewable Energy Laboratory (NREL) and Idaho National Laboratory (INL) have successfully demonstrated the capability to connect grid simulations at their two labs for real time interaction via the Internet. This new inter-lab capability enables the modeling of power grids in greater detail by allowing software and equipment anywhere in the world to establish a real-time connection to the unique facilities and capabilities available within the DOE national laboratory complex.

The two national laboratories were able to connect their "Real-Time Digital Simulators" (RTDS) and achieve grid simulation so hardware or software in one lab can directly interact with the hardware or software at the other lab. While connected, the local power grids handle any actual power flows into and out of the hardware. INL has multiple RTDS racks that can be interfaced to NREL's grid simulator, allowing the simultaneous simulation of complex power systems with many electrical buses and multiple distribution feeders.

"This successful collaboration between INL and NREL demonstrates how today we are creating the laboratory of the future by connecting key capabilities across the country to address pressing energy challenges," said Steven Aumeier, INL's Associate Laboratory Director for Energy and Environment.

"This new capability allows NREL and INL to interconnect a wide variety of equipment and software simulations to support grid modernization objectives," NREL's Associate Director for Energy Systems Integration Bryan Hannegan said. "Such interconnections combine and leverage the strengths of the national laboratories to greatly broaden the impact of our work in the nation's interest."

Connecting two grid simulation models at a distance requires rapid, reliable communication with little delay time. For this demonstration, the connection successfully exchanged data that was sampled 1,200 times each second, with an average delay time of only 28 milliseconds. Grid simulations are particularly useful for testing a grid's transient responses - the immediate response to a sudden change, such as the loss of a power generator or a sudden increase or decrease in demand.

Future experiments will match the utility-scale transmission system at INL to a simulated distribution line at NREL, which will be connected to an electrolyzer that produces hydrogen from electricity. If the electrolyzer is turned down to consume less electricity, that change in operation will be reflected in the distribution line simulation, which will relay its response to the INL system. Then, the INL transmission line also will respond appropriately to that change. To make the power flows work out, the local Colorado grid will provide power for the electrolyzer, while the local Idaho grid will absorb the power produced by INL's transmission system.

This successful RTDS test shows that facilities in many locations can interconnect with this system for advanced demonstrations. This network of RTDSs can form a virtual laboratory that allows multiple laboratories to cooperate on energy integration, particularly for grid simulations.

NREL's Energy Systems Integration Facility (ESIF) has the capability to merge computer-based simulations of the power grid with actual energy systems hardware such as wind turbines, solar panels, batteries, and electric vehicles - a capability called "power hardware in the loop." Meanwhile, INL operates the National Electric Grid Reliability Test Bed, which features a utility-scale transmission system and distribution systems that can be customized for multiple power grid configurations. Transmission systems are the tall, high-voltage towers that carry large amounts of power across the countryside, and distribution systems are the relatively low-voltage systems that deliver the power to our homes and businesses.

The NREL-INL virtual connection was funded by the Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE) project, which is sponsored by the Energy Department's Office of Energy Efficiency and Renewable Energy and managed by NREL. INTEGRATE is a cost-shared project with industry, universities, and other stakeholders that will award up to $6.5 million in federal funds to technical teams throughout the country that are working to address the challenge of high penetrations of renewable energy on the nation's power grid.

INL is one of the U.S. Department of Energy's (DOE's) national laboratories. The laboratory performs work in each of the strategic goal areas of DOE: energy, national security, science and environment. INL is the nation's leading center for nuclear energy research and development. Day-to-day management and operation of the laboratory is the responsibility of Battelle Energy Alliance.

NREL is the U.S. Department of Energy's primary national laboratory for renewable energy and energy efficiency research and development. NREL is operated for the Energy Department by The Alliance for Sustainable Energy, LLC.

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Collaborations

- Idaho National Laboratory and National Renewable Energy Laboratory
  - Prime and jointly funded project partner
  - Laboratory resources will be leveraged for research and development
- Utilities: PG&E, CAISO, and one other CA utility (TBD)
  - Real world and market information for direction in research
  - Actual data and system models for case studies, technology evaluation, and demonstrations
- Universities: Humboldt State University, Florida State University
  - Research partners for modeling, simulation, and information dissemination

Challenges

- Establishing the baseline models for electrolyzer and distribution test systems
- Interfacing the electrolyzer hardware with the RTS based HIL simulations
- Maintaining a constant low latency for data exchange between the RTS at INL and NREL to perform synchronized simulations

Proposed Future Work

- **Project plan for FY 2015 (Under progress)**
  - Establishing baseline representation of electrolyzer and distribution test networks in Real Time Environment
  - Establishing communication between the Real Time Environments at INL and NREL
  - Business case analysis of electrolyzer based Hydrogen refueling stations with a focus on California
- **Key Milestone FY 2015**
  - Demonstration of a stable distributed RTS with electrolyzer model at NREL and distribution network at INL within a time latency less than 30 milliseconds
    - This milestone is critical because the time latency of RTS will determine the future design of experiment
- **Proposed Future Work**
  - Experimental set up from FY 2015 will assist in validating a dynamic electrolyzer model
  - Validation is based on characterized data obtained from RTS PHIL testing
  - Determination of location of Hydrogen refueling stations for the Bay area (California)
  - Assessment and implementation of suitable DR programs with the utilities
  - Performance and economic assessment of Hydrogen refueling stations under the DR programs

Summary

- **Validated dynamic electrolyzer models and suitable distribution networks for testing to be created in Real Time Environment**
- **Identification of suitable locations of Hydrogen refueling station in California based on maximizing revenue based on participation in the energy markets**
- **Performing distributed Real Time and Power-Hardware-In-the-Loop Simulations to assess the technical and economic participation of Hydrogen refueling stations in existing Demand Response programs**
  - Minimum operation of 500 hours of hardware operation
- **Design of novel DR programs based on utility experiences to maximize the revenue for Hydrogen refueling stations**
- **Leveraging assets across the DOE lab complex, utilities, and academia**
  - INL (RTDS assets and personnel); NREL (Electrolyzer hardware, RTDS, personnel)
  - Utilities (consultation, data, and Demand Response program design)
  - Academia (personnel and computing resources)