Power Electronics for Electrolyzer Applications to Enable Grid Services

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Photo by Dennis Schroeder, NREL 55200

Project Goal

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To develop smart converter for dedicated electrolyzer applications to enable grid services via standardization of control interfaces between hydrogen electrolyzer system low-level controls and power converter controls.

- Development of controls based on same standards that solar and energy storage industry is following
  - IEEE 1547, UL1741, CA Rule-21, HI Rule-14, etc.
- Following SunSpec standardization for Electrolyzer power converter interfacing to grid and Electrolyzer operation (low-level controls).
- Electrolyzer-specific Power Converter for Grid Applications will be developed, like solar PV smart inverters.
- This project directly contributes to DOE HFTO’s ‘Hydrogen Shot’ that seeks to reduce the cost of clean hydrogen to $1 per 1 kilogram in 1 decade ("1 1 1").

Overview

Timeline and Budget

- Project start date: 03/01/2020
- FY23 DOE funding: **$500K**
- FY24 Planned DOE Funding: **$550K**
- Total DOE funds received to date:

FY21: **$550K**, FY22: **$500K**, FY23: **$500K**

Partners

Lead

- National Renewable Energy Laboratory

Industry

- EPC Power Corp, NEL, Typhoon HIL, GE, SunSpec
- In discussion: Semikron Danfoss, Hitachi Energy.

Barriers

- Lack of standardized controls interface for electrolyzer applications in real-world operation as per grid codes and interconnection, inter-operability standards, and scalability analysis.
- Coordinated control of multiple electrolyzers, including interaction with other power electronically-interfaced DER technologies in hybrid energy systems.
- Optimized control for Hydrogen and Electricity Co-Production, including Renewables.

Relevance & Potential Impacts

Relevance

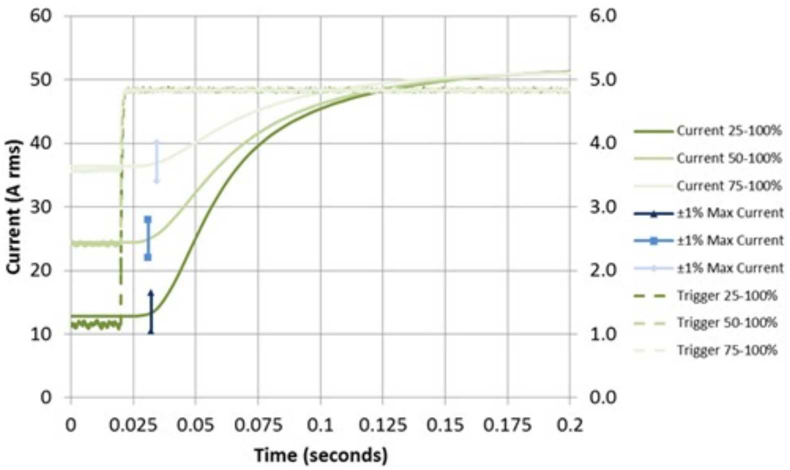
This AOP project will develop a standardized electrolyzer control interface and validation platform for power electronic converter dedicated for low-temperature hydrogen electrolyzer applications to enable grid services.

Potential Impacts

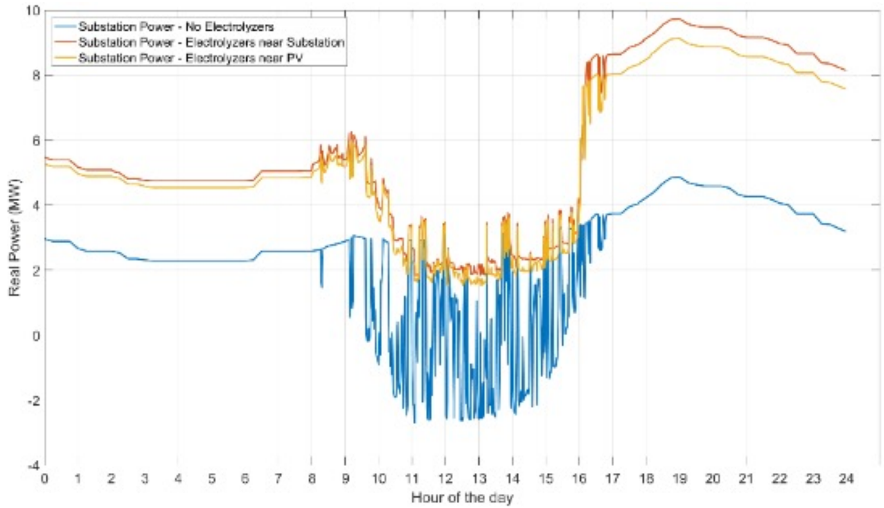
- Provide additional revenue source for electrolyzer through participation in grid services.
- Reduce the cost of deployment and controls integration through standardization. Also reduces risk due to supply-chain issues.
- Enable adoption of green hydrogen via standardizing the integration of energy storage, renewables, and distributed energy resources.
- Provide a controlled validation environment to evaluate scalable integration solution for hydrogen production technologies.
- Improve overall reliability and maintainability of the electrolyzer system for grid applications.
- Directly contributes to DOE HFTO’s ‘Hydrogen Shot’ that seeks to reduce the cost of clean hydrogen to $1 per 1 kilogram in 1 decade ("1 1 1").

Approach: Roadmap

Electrolyzer can be used as **controllable load** and provide **fast sub-second response**.



Electrolyzer can provide **wide-area frequency** and **voltage regulation.**



- Electrolyzers can enable **higher penetration** of renewable energy with hydrogen production and reduce **transients**.

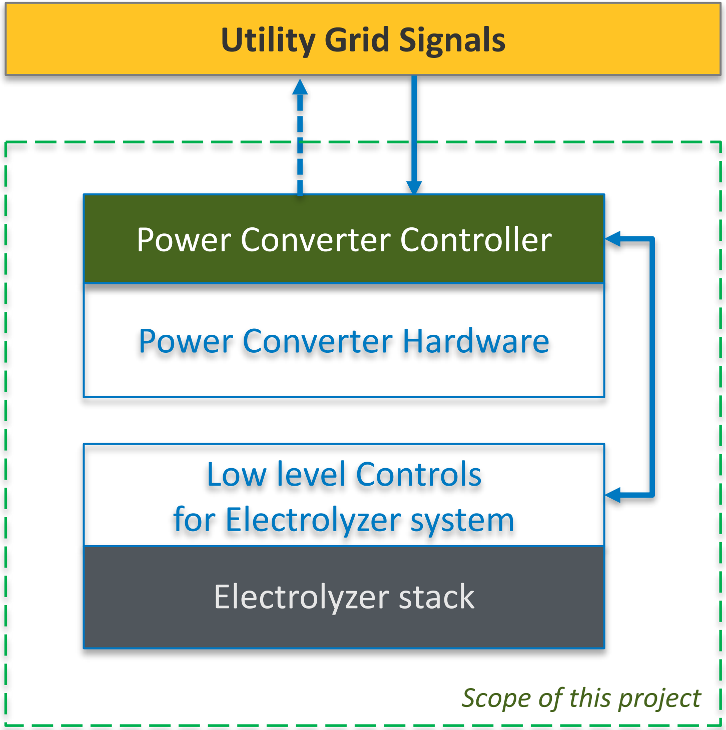
Approach: System-level Architecture

Validate integration of hydrogen electrolyzers

- **Integration of H2 electrolyzer system**: electrolyzer, balance of plant, low-level controls, power electronics, and advanced grid functions.
- Electrolyzers as a fast, controllable, smart load participating in grid services.

Integration of electrolyzer systems for **hybridization** with other generation and storage assets.

- **Grid codes and standards** for participation in grid services.
- Controlled validation environment.



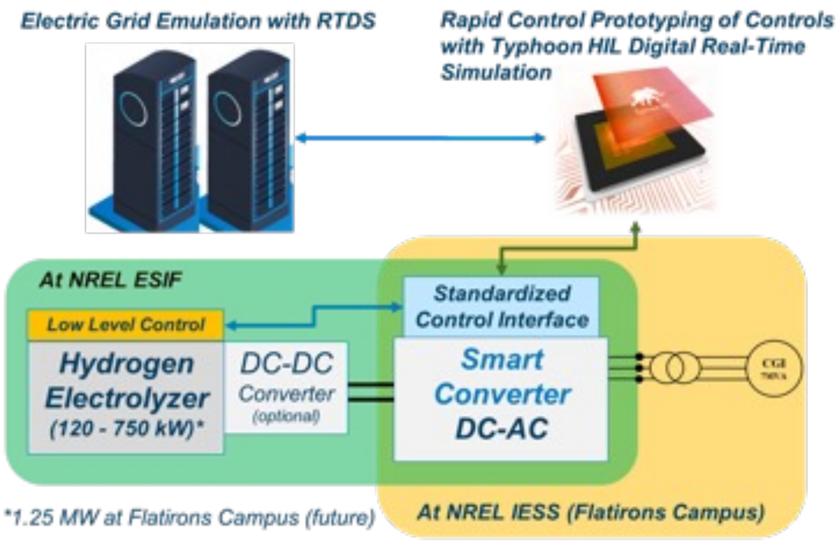
System-level Functional Control Architecture

Approach: Development Environment

- Electrolyzer Smart Power Converter Controls with advanced functionalities.
- Compatibility development and at-scale validation for operational scenarios.
- Integration with renewables, energy storage, controllable loads (buildings, electric vehicles)

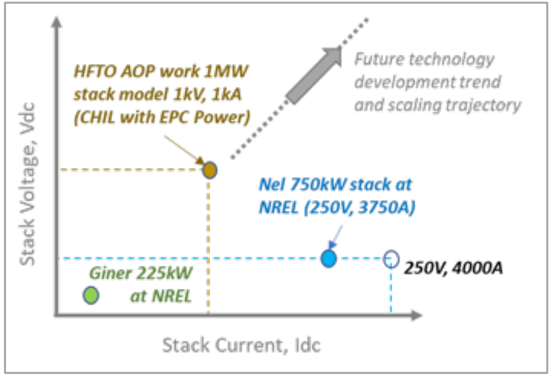
<u>**Functionalities**</u>

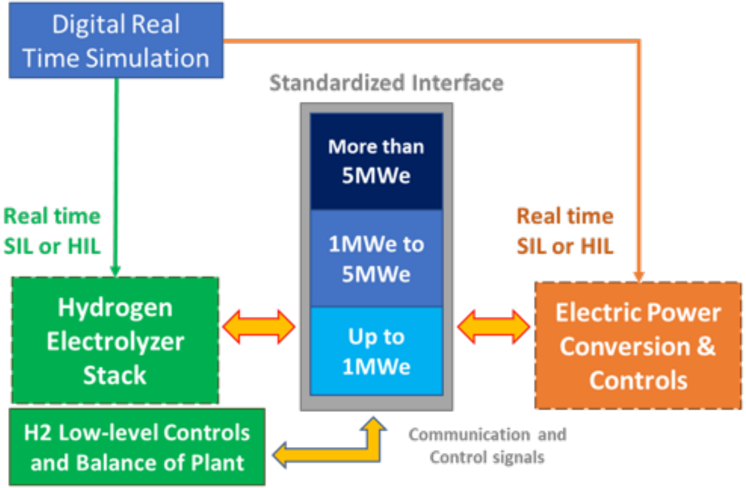
- Integrated controller at lower level of off-the-shelf power electronics for energy conversion and hydrogen generation.
- Optimization-based control to enable optimal participation in hydrogen production/sale and electricity market.
- Support advanced functionalities such as voltage and frequency ride-through controls, virtual inertial response, etc.



Approach: Challenges

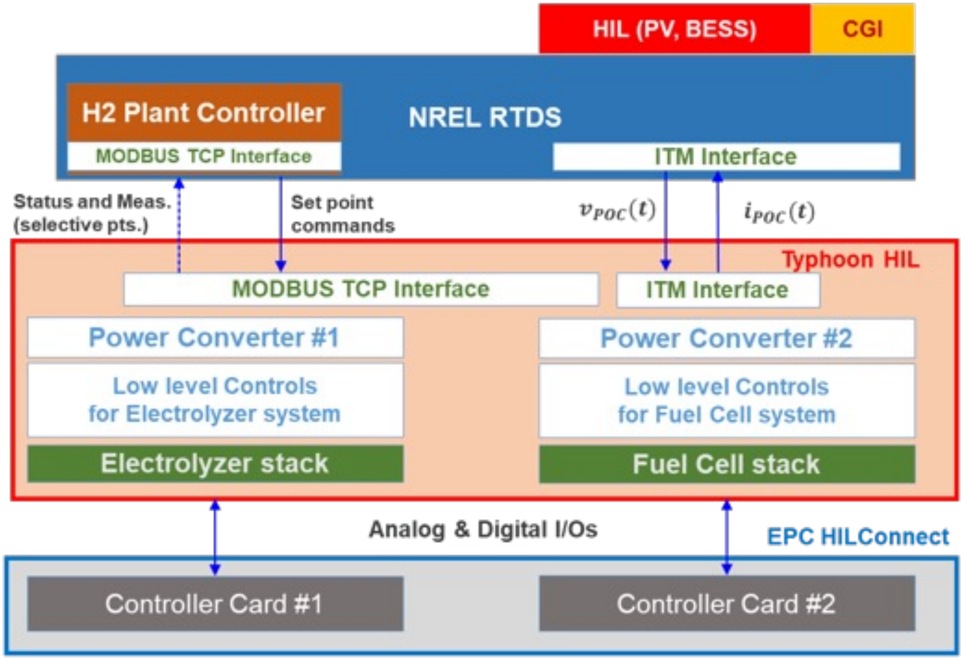
- **Standardization of Electrolyzer Controls**: To support hydrogen electrolyzer testing and evaluation, a validation platform for various functional standardization of electrolyzer controls (and interfaces) with next generation of control systems.
- **Modularity of Power Converter & Electrolyzer Stacks**: At-scale integrated testing of commercial electrolyzer and power conversion and controls as real-time controller-in-the-loop (CIL) and hardware-in-the-loop (HIL) at ARIES.
- **Interoperability**: The testbed will be capable of supporting automated interface testing for electrolyzers of different power capacities, ranging from sub-MWe, to 20MWe at-scale as HIL and hundreds of MW as CIL.

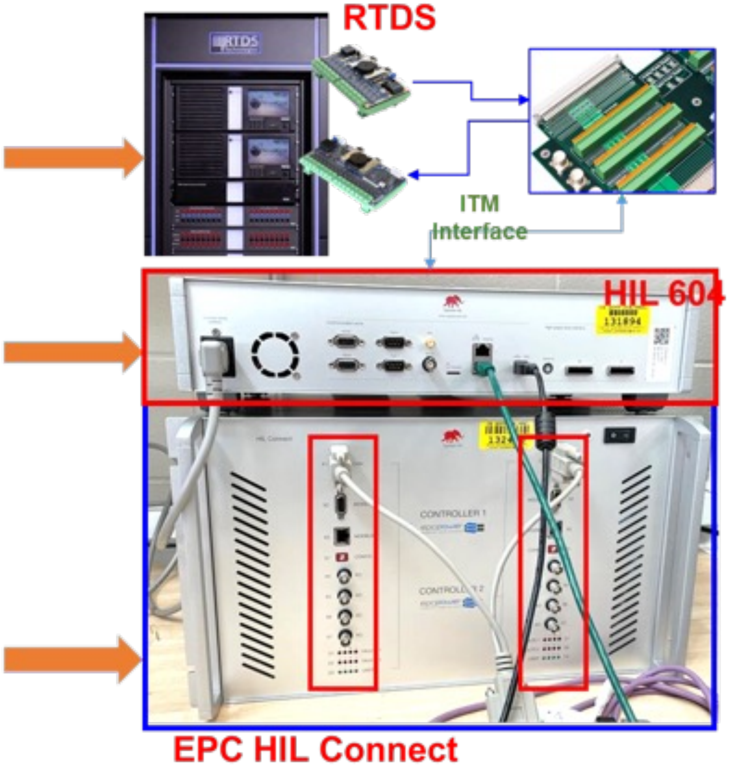




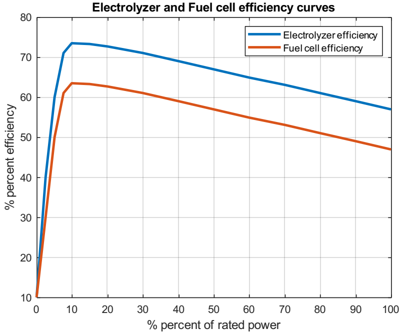
Successfully achieving the above three will help achieve scalability through at-scale evaluation and non-linear scaling using physics-informed machine learning at ARIES.

Approach: H2 Electrolyzer Power Converter Development Environment



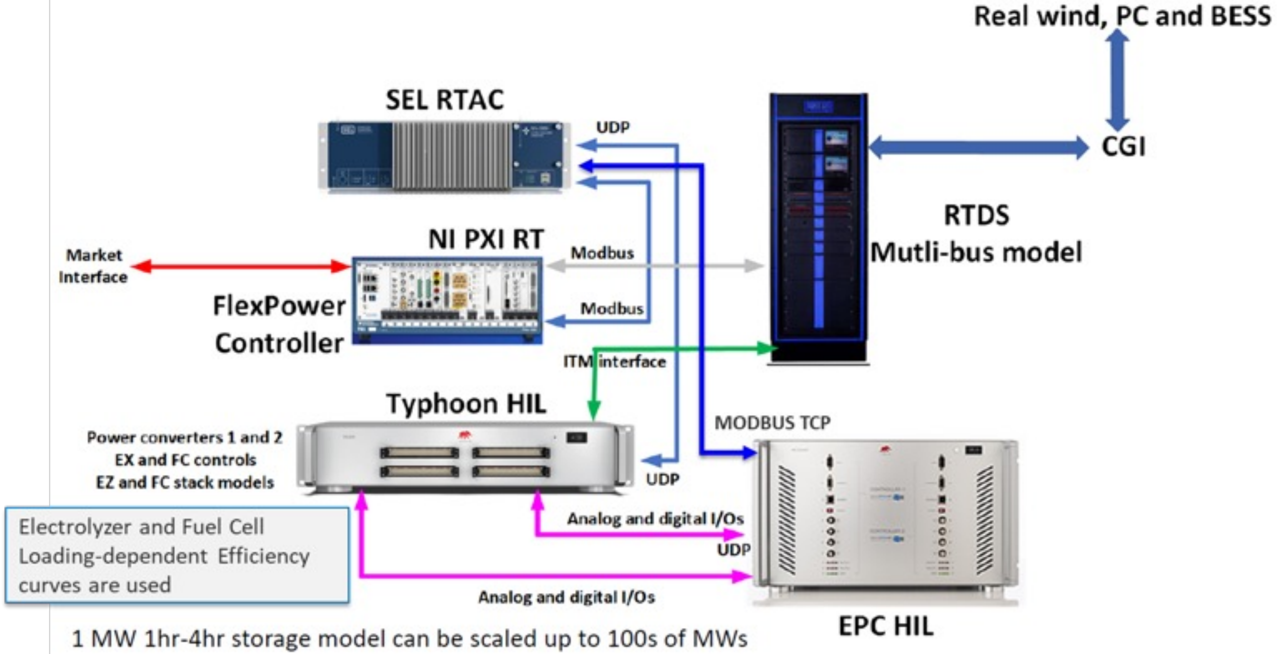


GMLC FlexPower Hybrid Energy System Integration CHIL with H2 Energy Storage System



Power (%)	EL η (%)	FC η (%)
2.5	40	30
5	60	50
7.5	71	61
10	73.5	63.5
15	73.25	63.25
20	72.75	62.75
30	71	61
40	69	59
50	67	57
60	65	55
70	63	53
80	61	51
90	59	49
100	57	47

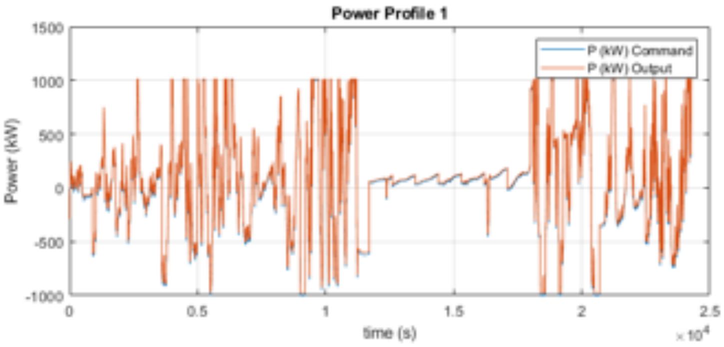
Hybrid energy integration leverages CHIL platform in Typhoon for validation of H2 applications.

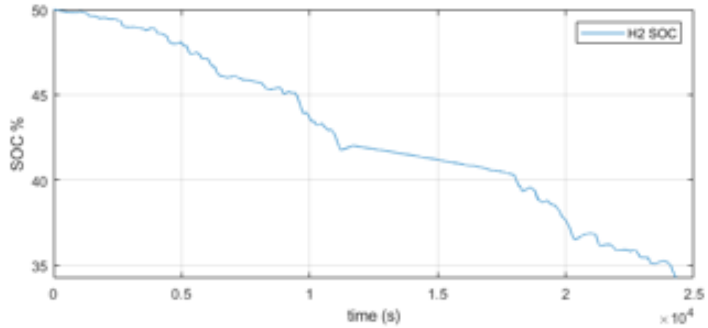


CHIL for H2 System as Long-term Energy Storage
(1 MW Electrolyzer + 1 MW Fuel Cell)

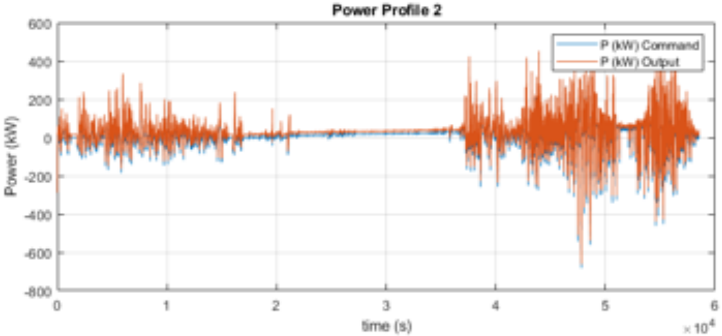
For Hybrid Plant Demo: Actual CHIL capacity = 1 MW with digital scaling to 100 MW

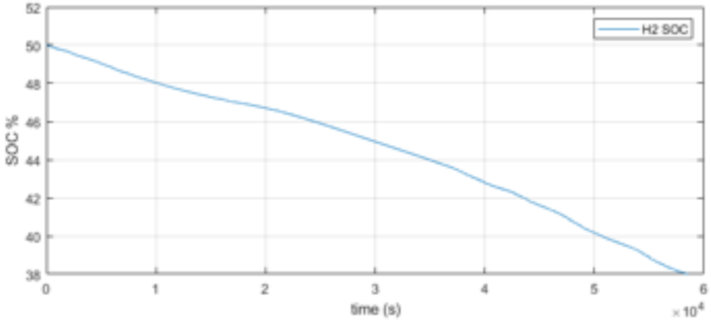
Profile 1: **6.75 hours**, SOC_initial = 50%





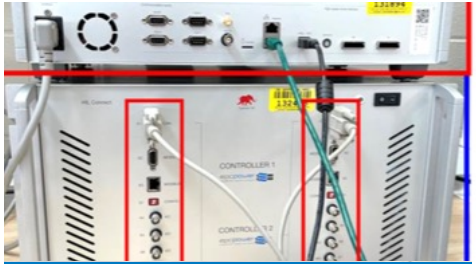
Profile 2: **16.2 hours**, SOC_initial = 50%





NREL-INL-ESnet Live Demonstration of H2 Energy Storage as CHIL for Hybrid Energy System

NREL ASSETS



PEM Electrolyzer Controller HIL

Solar PV with Inverter Controls

Battery 1MW / 1MWh

Controllable Grid Interface

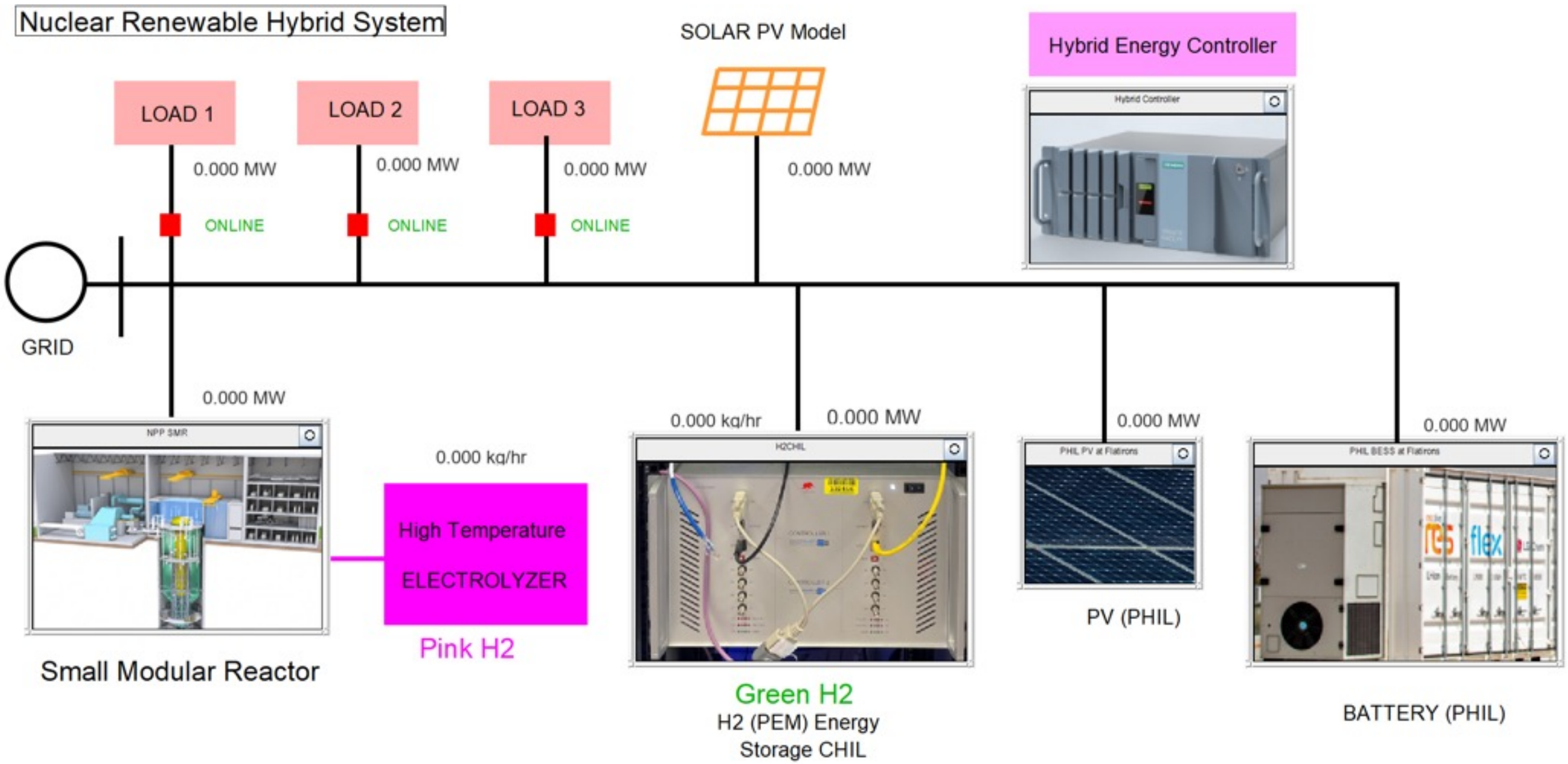
INL ASSETS

HSSL Nuclear Facility

High Temp Electrolyzer

- https://www.nrel.gov/news/features/2023/combined-superlab-demonstrates-unique-hybrid-power-plant.html
- https://www.es.net/news-and-publications/esnet-news/2023/combined-superlab-demonstrates-unique-hybrid-power-plant/

H2 CHIL in Hybrid Energy Evaluation over ESnet



https://www.nrel.gov/news/features/2023/combined-superlab-demonstrates-unique-hybrid-power-plant.html

Approach: Standardization using SunSpec

Real-time Simulation

SunSpec MODBUS Interface in Typhoon for Hydrogen Electrolyzer, includes low-level control integration with H2SCADA.

Model Validation

SunSpec MODBUS Standard and Vendor Model in Typhoon HIL with EPC Power's power converter controller.

CHIL Validation

Typhoon HIL

epcpower excellence in power conversion

Proposed FY23 Activities and Progress

Identify 3 power conversion & control vendors for different capacities of electrolyzer systems.

- Discussed with Opal-RT to include one power converter vendor for developing standardized Controller Hardware-in-the-Loop for H2 electrolyzer on Opal-RT platforms.

Establish high-level test plan for integrated testing of electrolyzer and power conversion & control and develop SunSpec validation and automated testing for identified vendors

- Established standardization checklist and automated test interface scripts based on SunSpec protocols. Integrated CHIL with H2 energy storage system was validated in multiple NREL projects (FlexPower, ESnet NREL-INL connectivity).

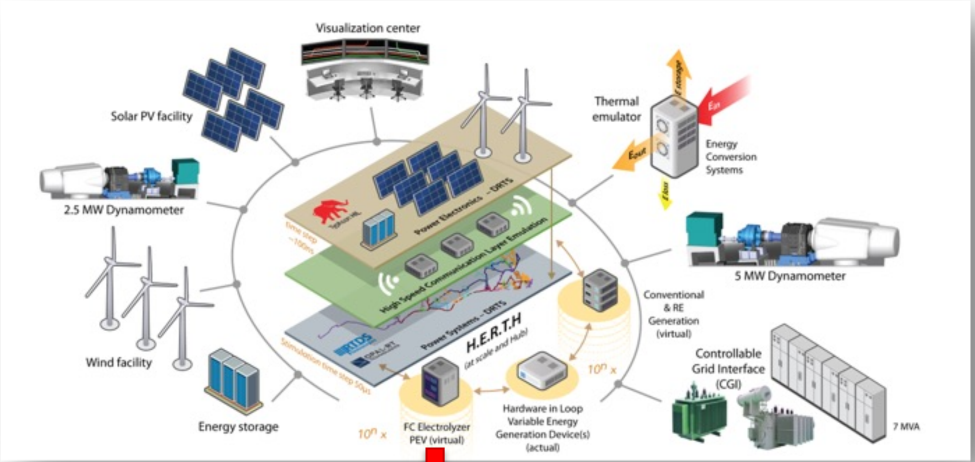
Experimental validation using Controller Hardware-in-the-Loop

i. Scalability approaches for electrolyzer and power converter, for at-scale Controller and Power HIL.
ii. Integrate any electrolyzer with any power conversion and controls – standardization for different capacities and DC-coupled integration of H2 Electrolyzer.
iii. Expand our approach to DC-DC coupling of H2 Electrolyzer as CHIL in Typhoon HIL platform system, Opal-RT, and RTDS platforms at ARIES (e.g., solar PV, Electric Vehicles, Fuel Cells, Wind, Battery Storage, etc.)

Accomplishments and Progress: Contributions from Industry Partners

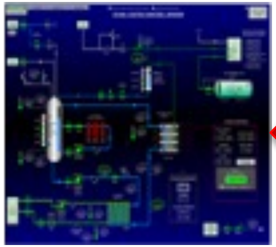
- **Opal-RT** is a digital real-time simulation vendor and has approached one power electronics vendor for standardized CHIL platform co-development with NREL for evaluation of H2 electrolyzer technologies.
- **EPC Power Co**. continued collaboration with NREL team for development of controller interfaces using SunSpec Modbus and hardware-in-the-loop with EPC off-the-shelf power converters for hydrogen electrolyzer applications, which could also be integrated with solar PV, Electric Vehicles, Fuel Cells, Wind, Battery Storage applications.
- **GE Power Conversion** has provided details on the modular approach for power converter and controller evaluation as CHIL with SunSpec Modbus interface. Finalizing HIL setup at NREL.
- **SunSpec** has provided System Validation Platform tool and provided inputs on the script development for automated testing of electrolyzer-power converter interfaces using SunSpec standardization.
- **Typhoon HIL** has provided inputs on setup for real-time CHIL of EPC Controller cards, and SunSpec Modbus configuration in real-time simulation environment.
- **Nel** provided inputs on electrolyzer stack size, configuration, operating voltages and currents for MW-level stacks.
- Initiated discussions on IEEE 1547.9 Standard (IEEE Standards Coordinating Committee 21) for consideration of H2 electrolyzer technologies.

Accomplishments and Progress: MW-scale Integration of H2 Electrolyzer with ARIES

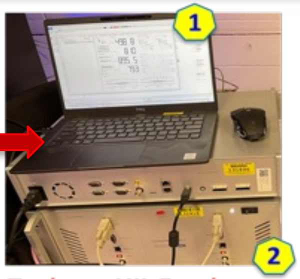


MW-scale Integration of H2 Electrolyzer in a 20MW Hybrid Energy Environment at ARIES

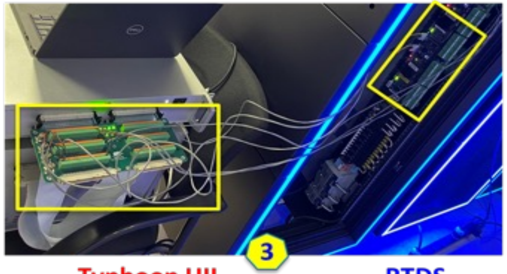
- Electrolyzer to renewable hybridization.
- Multi-technology energy storage evaluation.
- A controlled environment to evaluate scalability of MW-level systems.
- Real world platform for grid integration design and control evaluation.



H2SCADA
(low-level controls for Electrolyzer system)

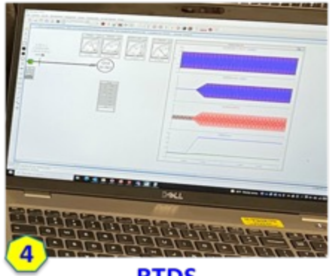


Typhoon HIL Emulator + EPC HILConnect



Typhoon HIL Interface Board

RTDS GTAO & GTAI



RTDS RSCAD

Collaboration and Coordination

- Project collaborators
  - Typhoon HIL (Rapid Control Prototyping, Power Electronics Interfacing, and Standardization as per IEEE 1547-2018).
  - Opal-RT Technologies for CHIL platform specific to H2 technology validation.
  - EPC Power Corp. (Power Converter hardware, Modular Hardware Implementation for Electrolyzer Control Interface).
  - Coordination with GMLC FlexPower (DER integration and validation).
  - Additional industry: to expand standardization and solution for electrolyzers, a discussion with industrial motor drive companies such as Danfoss Semikron initiated.
- Working directly with the power converter manufacturer for advanced grid applications at multi-MW levels and direct DC-coupled applications (GE and EPC Power).
- Technology transfer to industry and standards community for electrolyzers as DERs. Discussions on IEEE 1547.9 Standard (IEEE Standards Coordinating Committee 21) for consideration of H2 electrolyzer technologies.

Proposed Future Work

Remaining Challenges and Barriers

- Scalability of modular approach (from MW to multi-MW levels), and validation with 1.25 MW electrolyzer at NREL ARIES.
- Engage more electrolyzer and power converter vendors in standardization discussion.

Next Steps

- Scalability validation based on performance with 1.25 MW electrolyzer at NREL ARIES.
- Validation of multi-vendor engagement assessment for standardization and modularity has not been fully evaluated, both electrolyzer and power converter industrial partners.
- Demonstrate hybridization of electrolyzer with other DC technologies.

Summary

- Established standardization checklist and automated test interface scripts for 1MW Electrolyzer based on SunSpec protocols.
- Additional digital real-time platforms added for development and validation of integration specific to H2 electrolysis technologies.
- Demonstrated integrated CHIL of H2 energy storage system for hybrid application at NREL with digital scaling up to 100 MW.
- Demonstrated remote connectivity using ESnet for real-time operation hybrid nuclear-renewable-hydrogen using 1 MW H2 Electrolyzer CHIL and MW-scale assets at NREL ARIES. (https://www.power-grid.com/renewable-energy/doe-labs-built-a-vpp-with-solar-a-nuke-electrolyzers-and-storage-it-worked/)
- Expanded industry collaboration for standardization and solution for electrolyzers with industrial motor drive companies.