Power Converter for Electrolyzer Applications

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AMR Project ID # TA035

Project Goal

Project Goal

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-4, 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.

Overview

Timeline and Budget

- Project start date: 03/01/2020
- FY21 planned DOE funding (if applicable): **$500K**
- Total DOE funds received to date:
  - FY20: $**550**K
  - FY21: $**500**K

Partners

Lead

- National Renewable Energy Laboratory

Industry

- EPC Power Corp, NEL, Typhoon HIL, Dynapower (planning stage)

Barriers

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

Relevance & Potential Impacts

- **Relevance**

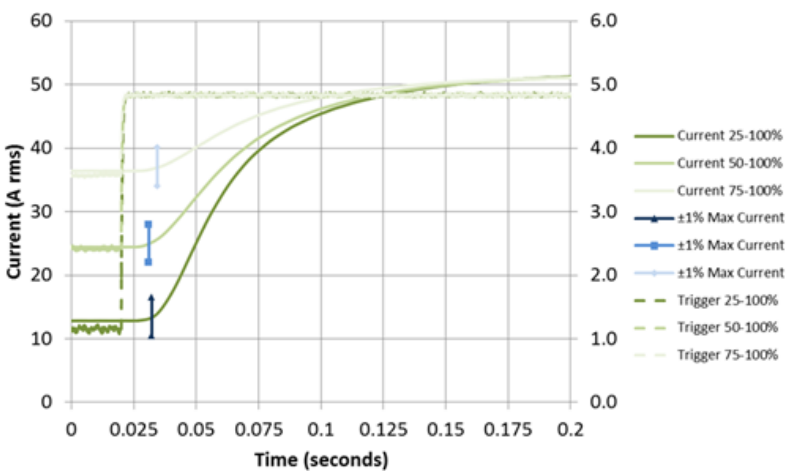
This AOP project will develop a standardized electrolyzer control interface for power electronic converter dedicated for low-temperature hydrogen electrolyzer applications to enable grid services.

- **Potential Impacts**

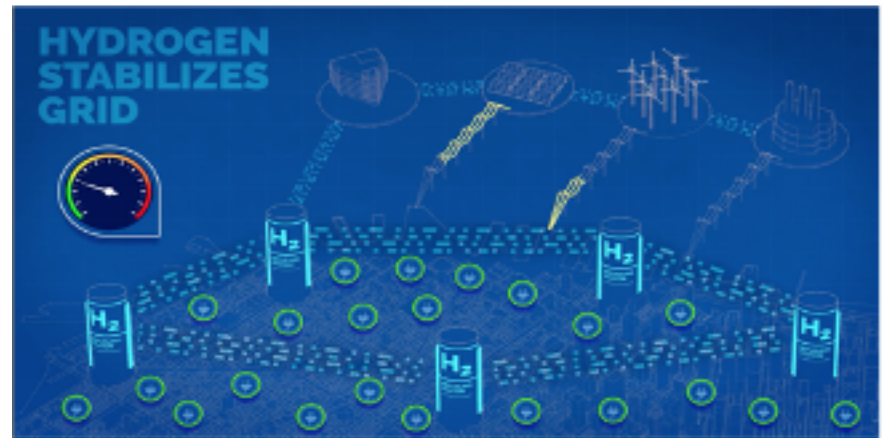
- Provide additional revenue source for electrolyzer through participation in grid services.
- Reduce the deployment cost and controls integration through standardization.
- Enable adoption of green hydrogen via standardizing the integration of energy storage, renewables, and distributed energy resources.
- Improve overall reliability and maintainability of the electrolyzer system for grid applications.

Approach: Roadmap

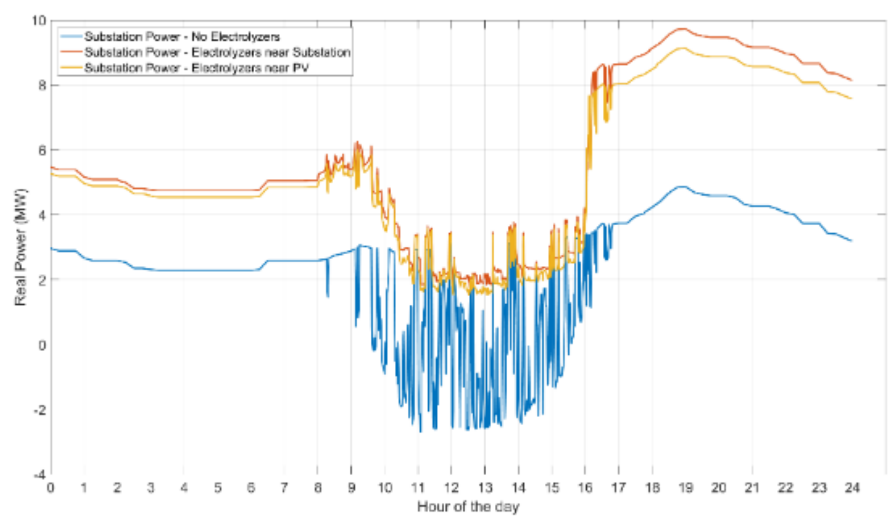
- Electrolyzer can be used as **controllable load** and provide **fast sub-second response**.



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



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



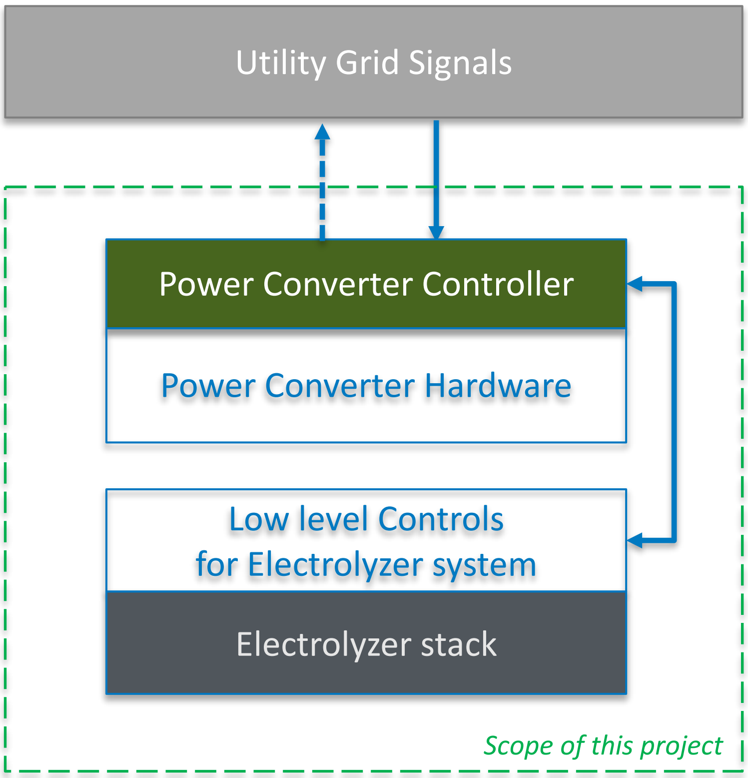
Approach: Roadmap

Electrolyzer Unit Characterization Results: Fast response time & quick slew rate

Performance Metric	Ramp-up & Ramp-down	Load Steps	Demand Response	Random Variation in Load
Response Time	< 1second	< 1second	< 1second	< 1second
Settling Time	< 1second	< 1second	< 1second	< 1second
Slew Rate	+1 kW/second -1 kW/second (Other rates were 0.5 and 2 kW/second)	Predetermined load values at variable times	10 kW, 20 kW, 30 kW, 40 kW, 50 kW, 118 kW, & E-20 DR (PG&E) at 2, 5, and 10 minutes interval	Random set-points between 13 & 118 kW per second
Operational Limits	13 kW to 118 kW	13 kW to 118 kW	13 kW to 118 kW	13 kW to 118 kW
Startup and Shutdown Time	30 seconds and < 1 second	30 seconds and < 1 second	30 seconds and< 1 second	30 seconds and < 1 second

Approach: System-level Architecture

- Project focus is on developing a **standardized control interf**ace on **Smart Power Converter** with the low-level controller (electrolyzer embedded), including BOP.
- As part of the project, the optimization and control will reside on the power converter and will be programmed on converter control cards (typically DSP-based) for real-time communication.
- Develop **automated testing platform** for HIL-based validation of the standard **SunSpec MODBUS** interface for electrolyzer application.
- Power converter development includes consideration of **modular design approach** that can be used for varying electrolyzer sizes – from **kW to multi-MW** levels.

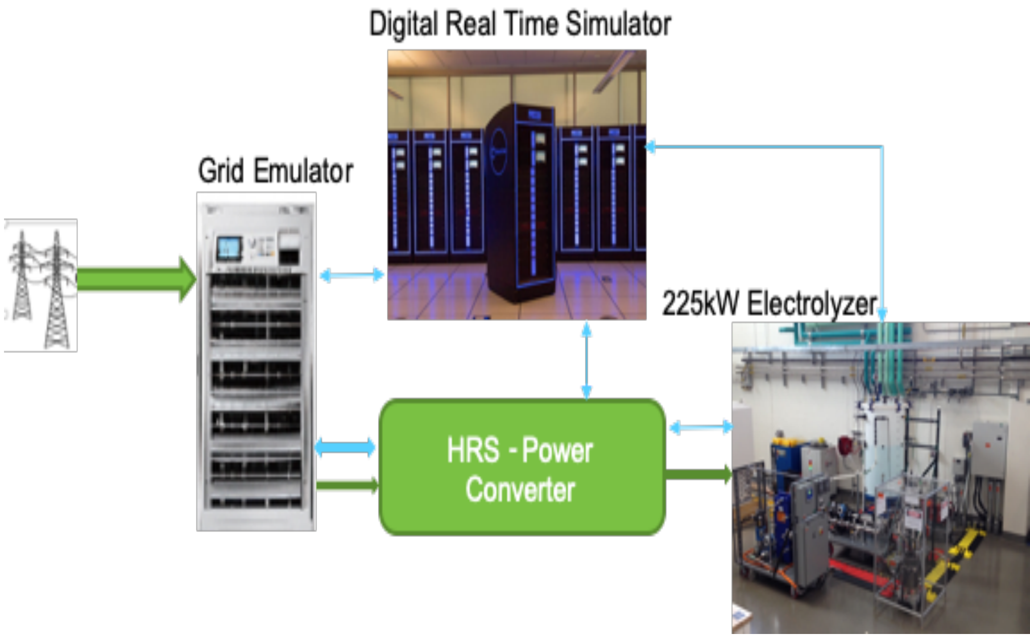


System-level Functional Control Architecture

H2 Electrolyzer Power Converter development environment

For actual grid implementations and adoption by utilities, it is essential to develop controls based on

- Grid codes/interconnection standards (IEEE 1547-2018), inter-operability standards.
- Standards that solar and energy storage industry is following.
  - E.g. SunSpec standardization for Electrolyzer power converter interfacing to grid and Electrolyzer operation (low-level controls).



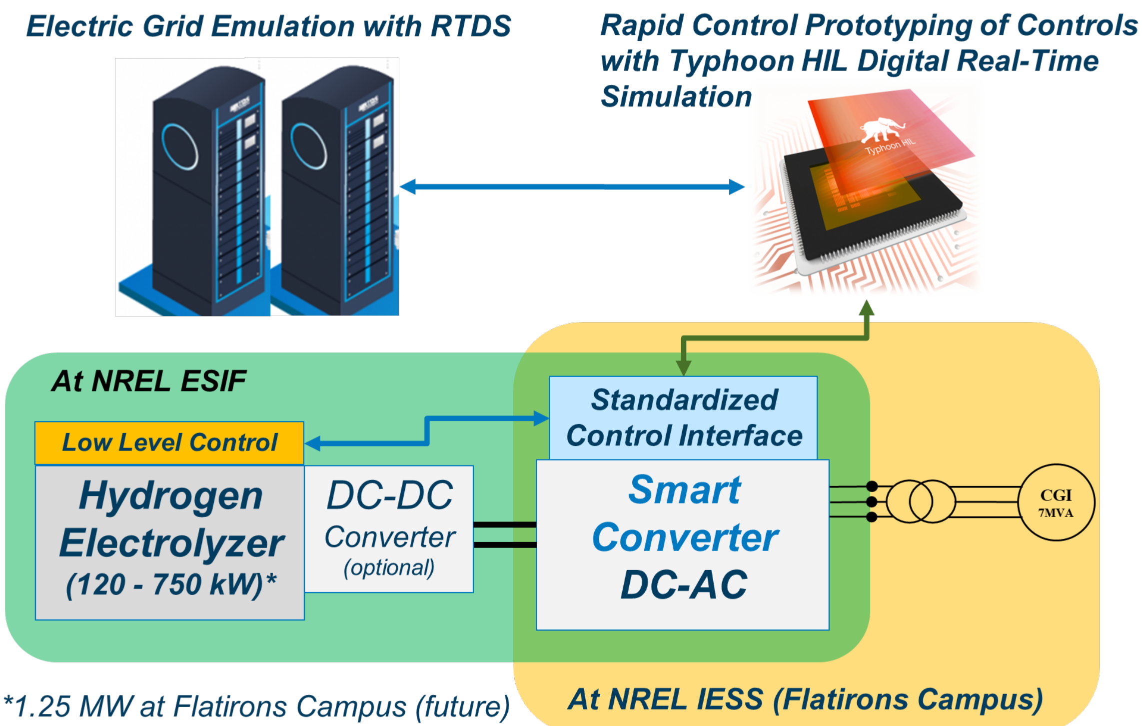
- Future coordinated control of multiple electrolyzers, including interaction with other power electronically-interfaced DER technologies including solar, wind, electric vehicles, electrical energy storage, and conventional power plants in the electric grid.

Approach: Development Environment

- Electrolyzer Smart Power Converter Controls with multiple functionalities will be developed.
- Compatibility development and validation for various modes of operation.

Functionalities

- 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.



Project Status YTD

FY21 Activities (continuation of 'Smart Converter for Dedicated Electrolyzer Applications')

- Selected a power converter vendor to develop and tightly integrate the hydrogen Electrolyzer functionalities with power converter using CHIL-based testing and prototyping to demonstrate IEEE 1547-2018.
  - EPC Power Co. selected for providing power converter and controller for Electrolyzer.
  - In discussions with Dynapower as a 2nd vendor – obtaining teaming agreements.
  - Working with Typhoon HIL & EPC Power to develop converter controller as HIL for DRTS.
- High-level design meetings to identify key and unique characteristics of Electrolyzer with EPC Power, and Nel.
- CHIL interface EPC controller hardware configured; integration with electrolyzer expected to be completed by June 2021.
- Power converter hardware in final design phase (kW rating, topology, configuration).
- SunSpec MODBUS will be used for standardized control interface between power converter, low-level controller of the Electrolyzer, and grid controls.

Typhoon HIL

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SunSpec MODBUS Interface Development

SunSpec MODBUS Interface Development using DER Information Model Specification

Document #: X99999

Status: Draft
Version: 1.0-02-01-2021

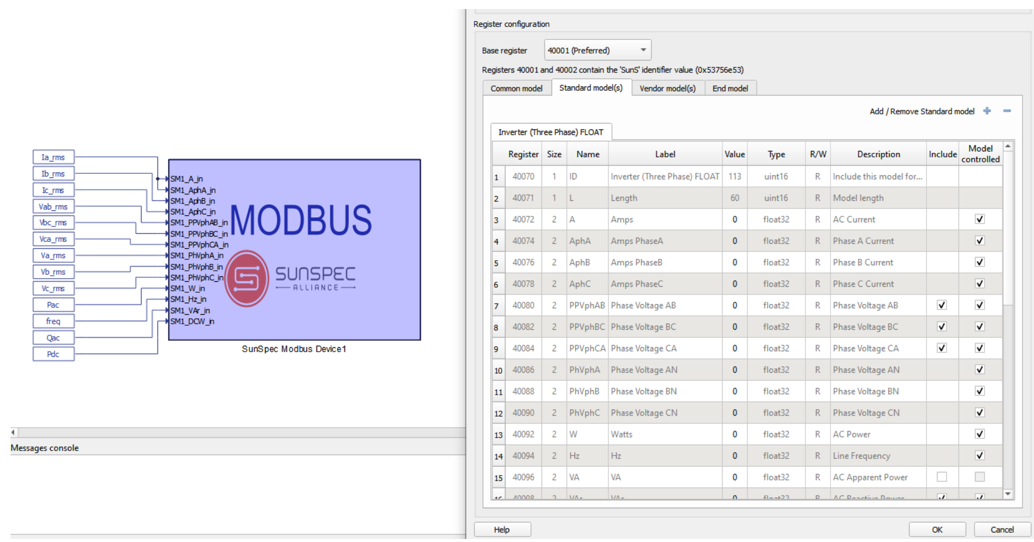
SunSpec DER Information Model Specification

SunSpec Specification

SUNSPEC ALLIANCE

Abstract

This document describes the SunSpec Distributed Energy Resource (DER) information models that provide support for the Institute of Electrical and Electronics Engineers (IEEE) 1547-2018 functionality using SunSpec information modeling.



Typhoon HIL implementation for CHIL

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- The project was not previously reviewed.

Collaboration and Coordination

- Project collaborators
  - Typhoon HIL (Rapid Control Prototyping, Power Electronics Interfacing, and Standardization as per IEEE 1547-2018)
  - EPC Power Corp. (Power Converter hardware, Modular Hardware Implementation for Electrolyzer Control Interface).
  - Coordination with GMLC FlexPower (DER integration and validation).
- Working directly with the power converter manufacturer for advanced grid applications at multi-MW levels through modular implementation.
- Technology transfer to industry and standards community for electrolyzers as DERs.

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Remaining Challenges and Barriers

- Current work will develop and test electrolyzer interface for a modular approach from kW to sub-MW level. To prove MW-level scalability of modular approach, the future work will include 1.25 MW electrolyzer using the same control configuration.
- Engage more electrolyzer and power converter vendors in standardization discussion.

Proposed Future Work

- Design specifications for control integration and CHIL.
- Demonstrate vendor-neutrality and industry adoption: the team will identify one or two more power converter vendors to adopt the solution/implementation developed in collaboration with EPC Power Corp. for an electrolyzer smart converter; Dynapower – in discussion.
- At-scale demonstration using PHIL at NREL ESIF (750 kW) and/or NREL Flatirons (1.25 MW) using a modular building block approach (250 kW modules). This approach will support larger MW-scale deployment at NREL Flatirons under ARIES using 250 kW steps.
- Conduct an industry webinar for obtain feedback from industry on our development and implementation approach.
- Integration with FlexPower: This task will apply the electrolyzer power converter controller through integration with the FlexPower project This task will focus on the communications and control of the power converter used with the electrolyzer to produce hydrogen and grid services.

Proposed Future Work: Future Milestones

Design documentation of Electrolyzer power converter standardized interface.	Documentation of signal and data interface design for power converter on Electrolyzer low-level controls (stack, BOP, hydrogen storage) and grid side.	6/30/2021	Quarterly Progress Measure (stretch)
Perform HIL testing of power converter controller at NREL with Electrolyzer stack under various dynamic conditions.	Perform power hardware-in-the-loop of standardized power converter controller with electrolyzer at NREL ESIF.	9/30/2021	Annual Milestone
Identification and selection of two other power converter vendors to adopt the standardization for electrolyzers.	Conduct an industry survey to obtain feedback from industry on our development and implementation approach. Work with power converter vendors to identify two more vendors that will adopt the standardization approach for electrolyzers.	9/30/2021	Annual Milestone (SMART)

Summary

- Project Summary
  - **Electrolyzer dedicated Smart Power Converter** hardware prototype for demonstrating advanced control functionalities for **grid services** from electrolyzers such as voltage and frequency support, ride-through controls, virtual inertial response, etc.
  - **Rapid control prototyping**-based approach for actual power converter and electrolyzer hardware (up to **750 kW in FY21-22**, and **1.25 MVA in future**).
  - **Standardization of control** functionalities and at-scale testing protocols (SunSpec MODBUS) for electrolyzer dedicated applications as per grid codes and standards such as IEEE 1547-2018, CA Rule 21, HI Rule 4, etc.
  - Controller Hardware-In-the-Loop (CHIL) validation using digital twin in a **real-world at-scale** environment to **reduce risk of field deployment**.
  - **Coordination** with ongoing HFTO funded project for DER integration and validation (GMLC FlexPower)
  - **Technology transfer** to industry and standards community for electrolyzers as DERs.

Thank You

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Publication Number

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Technical Back-Up Slides

(Include this “divider” slide if you are including back-up technical slides [maximum of five]. These back-up technical slides will be available for your presentation and will be included in Web PDF files released to the public.)

Technology Transfer Activities

- Working directly with the power converter manufacturer for modular implementation of advanced grid applications at multi-MW levels.
- The development of controls and interface will be in open-source as per grid codes and standards such as IEEE 1547-2018.
- Technology transfer to industry and standards community for electrolyzers as DERs.

Smart Converter for Dedicated Electrolyzer Applications to Enable Grid Services

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H2 Electrolyzer Power Converter development environment

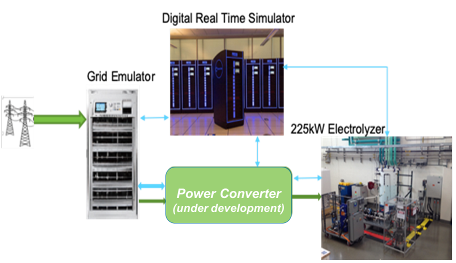

Figure 1: Hydrogen Refueling Station Power Converter Development Environment

PHIL testing

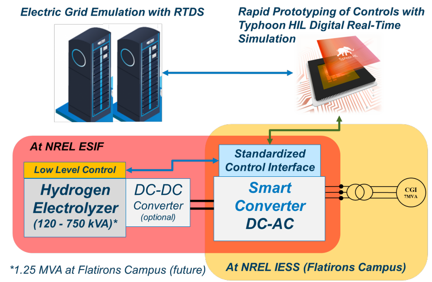

Figure 2: PHIL testing of Smart Converter with DRTS, Electrolyzer for rapid prototyping of advanced control functionalities.

System-level Functional Control Architecture

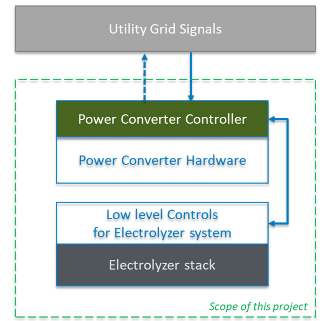

Figure 3: System-level Functional Control Architecture

Development and testing environment at NREL ESIF and NREL IESS at Flatirons Campus

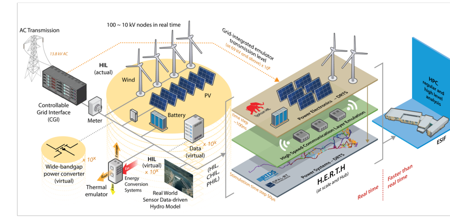

Figure 4: Development and testing environment at NREL ESIF and NREL Flatirons Campus

Provision of Grid Support Services from Hydrogen Electrolyzers

- Electrolyzers have emerged as a promising technology for supporting grid frequency and voltage support for bulk grid.
- The provision of flexibility in electric grid from electrolyzers has been proven in a real-time grid simulation environment.
- Fast-autonomous response of electrolyzers/hydrogen refueling stations (HRS) through load curtailment and planned operation for hydrogen production has been tested in a laboratory environment using actual utility data, including the PG&E grid.

However, for actual grid implementations and adoption by utilities, there exist research gaps:

1. Controls development as per grid codes/interconnection standards (IEEE 1547-2018), inter-operability standards.
2. Coordinated control of multiple HRS, including interaction with other power electronically-interfaced DER technologies including solar, wind, electric vehicles, electrical energy storage, and conventional power plants in the electric grid.

Functionalities of Standardized Interface

This AOP project proposes **standardized control interface** with the following functionalities:

Functionalities

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

Partners and Vendors

nel· Typhoon HIL epcpower excellence in power conversion DYNAPOWER

Development and Hardware Implementation

- As part of the project, the optimization and control will reside on the EGI, and will be programmed on converter control hardware for real-time communication.
- Coordinated control of cluster of DERs with electrolyzers, as well as communication capabilities with power system operator.

Project Tasks (FY 2021)

1. Survey off-the-shelf power electronic converters suitable for electrolyzer operation and control.
2. Identify the high-level design for smart power electronics converter.
3. Develop control architecture for bulk (transmission) and distribution grid interconnection codes and standards.
4. Identify a power electronics vendor and jointly develop power converter controllers.
5. Implement and test power converter at NREL with electrolyzer stack (up to 750 kW at ESIF, 1.25 MW at Flatirons in future) under various dynamic conditions.

Project Outcomes

1. Power converter hardware prototype for demonstrating advanced control functionalities for grid services.
2. Standardization of control functionalities as per grid codes and standards such as IEEE 1547.
3. At-scale testing protocols for electrolyzer specific applications.
4. CHIL validation with ongoing projects (*e.g. GMLC FlexPower*)
5. Technology transfer to industry and standards community for electrolyzers as DERs.

Future functionalities

1. Sparse communication-based approach for coordinated control between various distributed nodes with various controllable DERs to provide a cohesive autonomous or guided response.
2. Establish and maintain a real-time communication and control mechanism at individual DER converters that will appear as a single controllable entity to the bulk electric grid for hybrid applications.
3. Enable and serve as a platform for cybersecurity implementation based on typical and upcoming grid communication protocols.