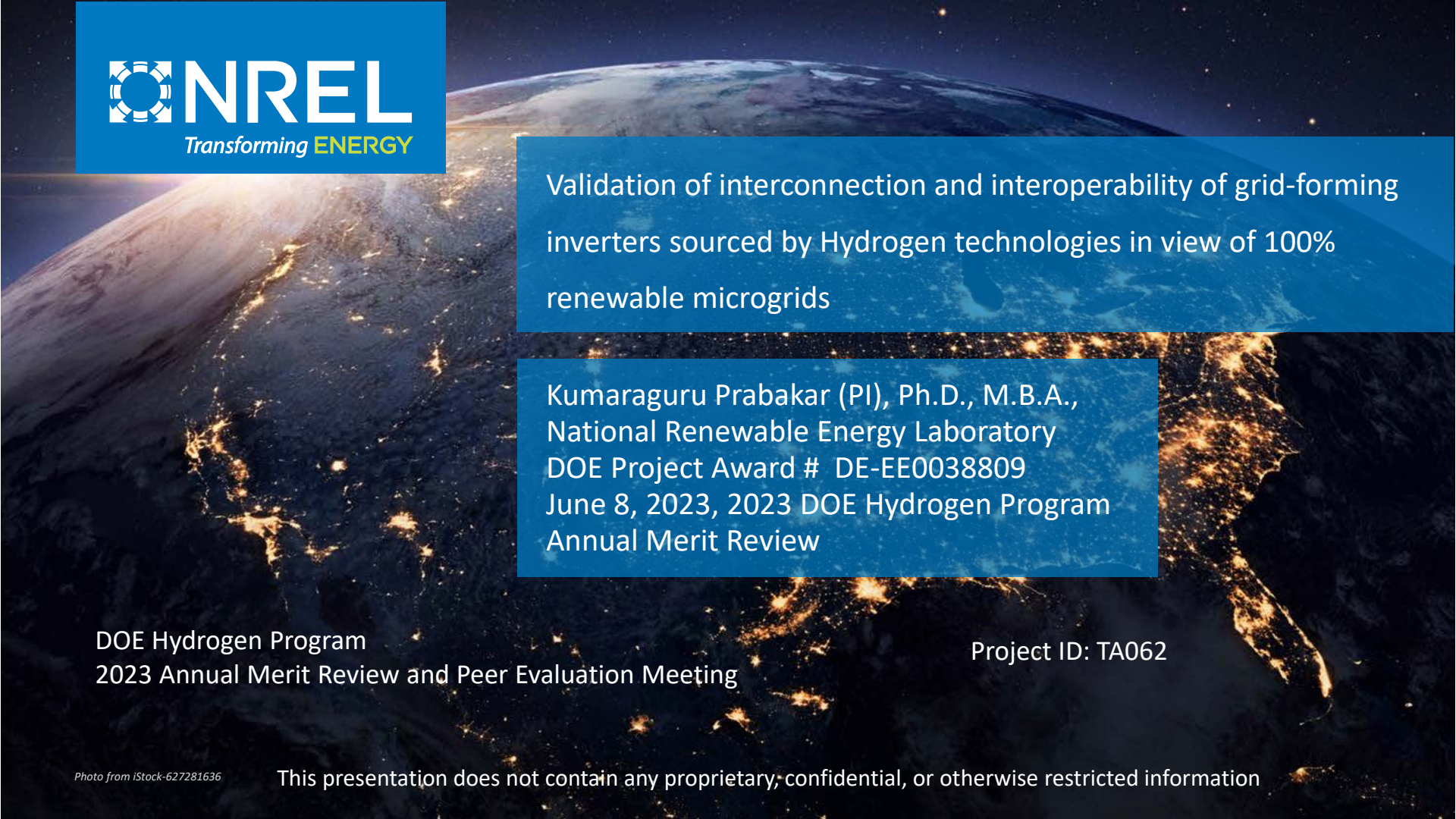

Validation of interconnection and interoperability of grid-forming inverters sourced by Hydrogen technologies in view of 100% renewable microgrids

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DOE Hydrogen Program
2023 Annual Merit Review and Peer Evaluation Meeting

Project ID: TA062

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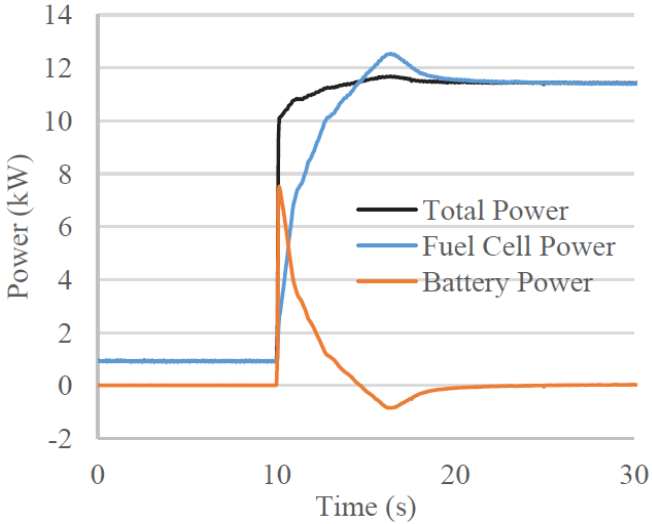
Project Goal

Grid-forming inverters are becoming key assets in distribution systems with microgrids. Fuel cell-coupled grid-forming inverters have the potential to successfully act as grid-forming assets.

Project goals

- Develop a test bed to evaluate and document updates to interconnection and interoperability requirements for grid-forming fuel cell inverters.
- Leverage existing ARIES assets to run hardware-in-the-loop experiments.
- Interconnection and interoperability updates identified through this project will provide cost improvements for the utilities in the US and increase the value of grid-forming fuel cell inverters.
- Accelerate industry adoption of grid-forming fuel cell inverters as a key component in distribution systems/microgrids.



Experimental results from a PEMFC/battery hybrid system responding to a step increase in electrical demand from 0 kW to 9 kW at 10 seconds. [1]

[1] L. Zhao *et al.*, "Dynamic performance of an in-rack proton exchange membrane fuel cell battery system to power servers," *Int. J. Hydrogen Energy*, vol. 42, no. 15, pp. 10158–10174, 2017.

Overview

Timeline and Budget

- Project Start Date: 01/01/22
- Project End Date: 12/31/24
- Total Project Budget: $1,689,000
  - Total DOE Share: $1,189,000
  - Total Cost Share: $500,000
  - Total DOE Funds Spent*: $93,522
  - Total Cost Share Funds Spent*: $43,365

    * As of 04/07/2023

Barriers

- Barriers and Targets
  - Intelligent electronics device capability description (ICD) file development and hosting in public domain.
  - First of its kind power hardware-in-the-loop setup to run grid-forming inverter experiments.
  - Complete power hardware-in-the-loop and controller hardware-in-the-loop integration with microgrid model.
  - Complete test plan execution in hardware setup.

Partners

- NREL
- Sothern California Gas Company,
- University of California, Irvine.

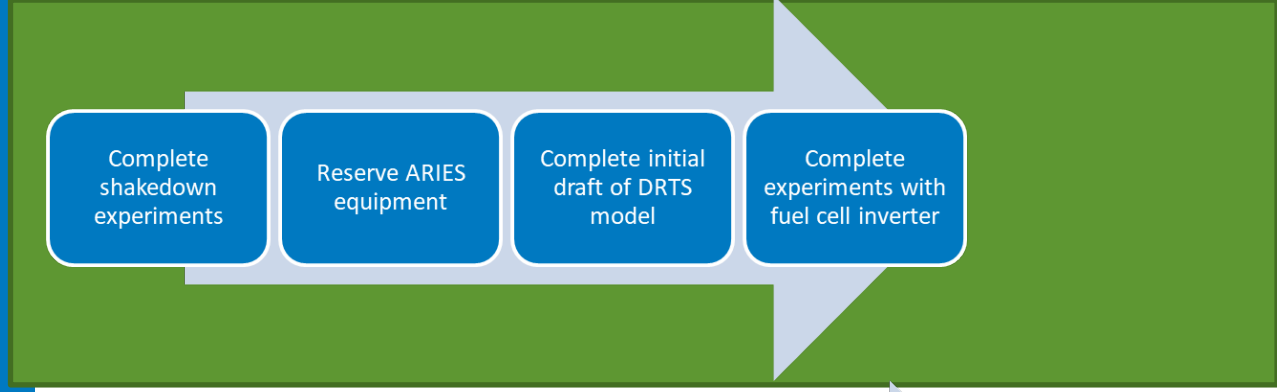
Relevance/Potential Impact

- The efforts taken in this project aim to standardize the sensing (interoperability), operation (interconnection), and control (through microgrid controller) of grid-forming fuel cell inverter.
- Successful updates to the standards *will reduce the cost of installation, operation and control of grid-forming fuel cell inverters* and enabling them to functionally replace traditional generation, resulting in greater market potential and installation at scale.
- The outcomes of this work directly aim at reducing the cost of integration of hydrogen assets into the grid, specifically, interoperability and interconnection costs. The outcomes are available in open source for U.S. manufacturers to utilize and reduce their smart grid integration cost.

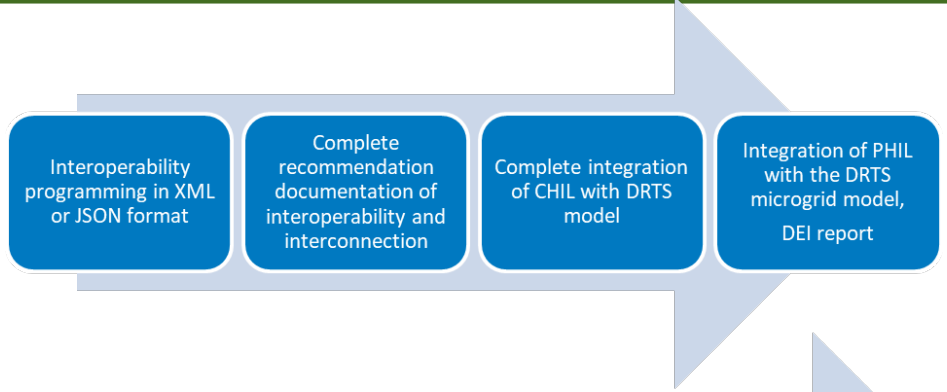
Approach

- The goal of the project is not to create new standards or requirements but to propose updates to existing standards.
- IEEE 1547-2018. 2018. IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.
- UL 1741 Supplement SA: Grid Support Utility Interactive Inverters and Converters, Underwriters Lab, 2016.
- CSA C22.3 No. 9: Interconnection of distributed energy resources and electricity supply systems [Draft]", Canadian Standards Association (CSA) Mississauga, 2019.
- California rule 21,Hawaii 14H.
- Few national grid codes in European Union.
- IEC 61850 Communication networks and systems for power utility automation –Part 7-420: Basic communication structure – Distributed energy resources and distribution automation logical nodes.
- DNP3 Application Note AN2018-001 – DNP3 Profile for Communications with Distributed Energy Resources.
- P2030 Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads.

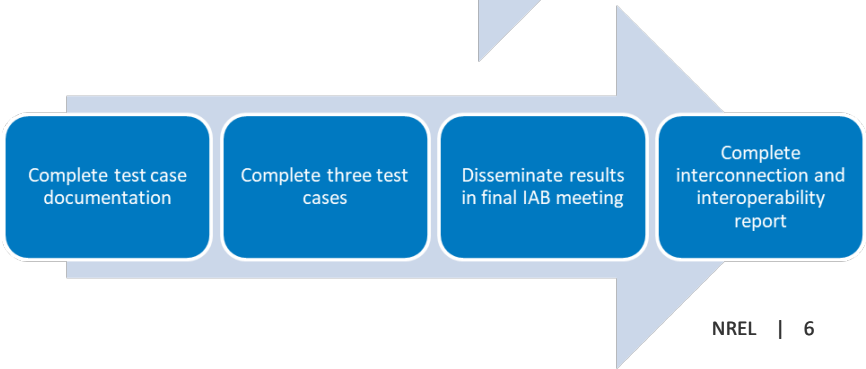
Budget Period 1



Budget Period 2



Budget Period 3



Power hardware

Grid forming inverter power hardware experiments and power hardware-in-the-loop experiments

(a) Fuel cell inverter

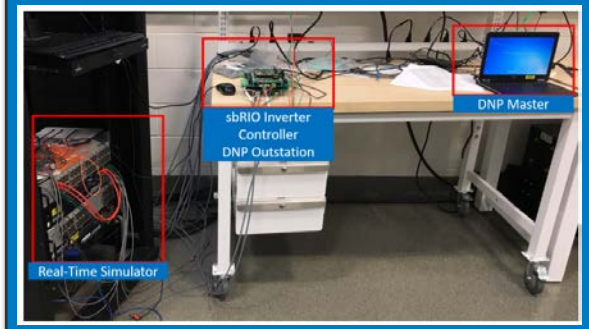
(b) Fuel cell stack setup

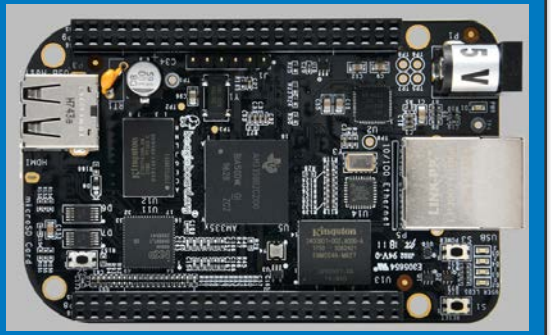
Fuel cell inverter and fuel cell stack setup leveraged from ARIES lab setup

- Run power hardware-in-the-loop experiment with grid-forming fuel cell (100kW) inverter and enable transition between grid-following and grid-forming modes of operation.
- Identify necessary updates to interconnection standards.

Controller hardware setup

DRTS to support both PHIL and CHIL experiments





(a) Opal-rt FPGA | (b) Beaglebone board

Controller hardware equipment

- Inverter modeled in opal-rt FPGA.
- Inverter controller in sbRIO board.
- Interoperability codes developed in Beaglebone board.
- Evaluation before integrating the interoperability with power hardware.
- Push interoperability codes to open-source.

Controller hardware setup

DRTS to support both PHIL and CHIL experiments

(a) RTDS Novacor rack

(b) Microgrid controller

Controller hardware equipment

- Microgrid modeled in RTDS.
- Microgrid controller with grid-following/grid-forming inverter mode change capability.
- Identify updates to interconnection standards for microgrid operation and gid-forming capability.

Accomplishments and Progress

- Executed CRADA with Southern California Gas Company, and subcontract with University of California, Irvine.
- Completed alpha version of interoperability codes. Submitted open-source software record and will be available in public domain after review.
- Completed power hardware-in-the-loop experiments with grid-forming inverter. Submitted digest in IEEE conference to disseminate the methodology to run power hardware-in-the-loop experiments with grid-forming inverters.
- Procured microgrid controller to work with Banshee microgrid model.

Response to Previous Year Reviewers'

- No reviewer comments from previous year.

Collaboration and Coordination

Partner	Role
Southern California Gas Company	Cost share partner, DEI contributor.
University of California, Irvine	DEI task lead. Analysis lead.
Etap	Microgrid controller vendor.
Triangle microworks	Interoperability code commercialization partner.

Industry advisory board	Topic of interest
NIST	Interoperability/interconnection.
Bosch	Fuel cells supporting grid-forming operation
Washington State University	Fuel cell inverter operation in distribution system
Schatz Energy Research Center	Interoperability/interconnection

Industry advisory board meetings held at least twice a year to update on progress and receive feedback.

Remaining Challenges and Barriers

- Integrate etap microgrid controller with Banshee microgrid model in digital real time simulator.
- Integrate power hardware with the Banshee microgrid model and the microgrid controller.

Proposed Future Work

- Interoperability
  - Submit final version of ICD file for electrolyzer and fuel cell for release in public domain.
  - Complete standards recommendations documentation and submit the document for review and dissemination in open source.
- Interconnection
  - Complete integration of controller hardware and power hardware equipment with Banshee microgrid model (2023).
  - Execute test plan using the integrated experimental setup (2024).

Summary

- Develop ICD files to enable interoperability to electrolyzers and fuel cells. Demonstrate the developed codes in beaglebone board. This reduces the cost of enabling communications to hydrogen assets and integrating them in the distribution system.
- Integrate microgrid controller and grid-forming fuel cell inverter with digital real time simulation model of Banshee microgrid model to showcase islanding, resynchronization, islanded operation and grid-connected operation of the system with the support of grid-forming fuel cell inverter.

Thank You

www.nrel.gov

NREL/PR-5D00-85598

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Technical Backup and Additional Information

Technology Transfer Activities

- Open-source software record submitted - SWR-23-42.

Special Recognitions and Awards

- No special recognitions and awards.

Publications and Presentations

- No publications.