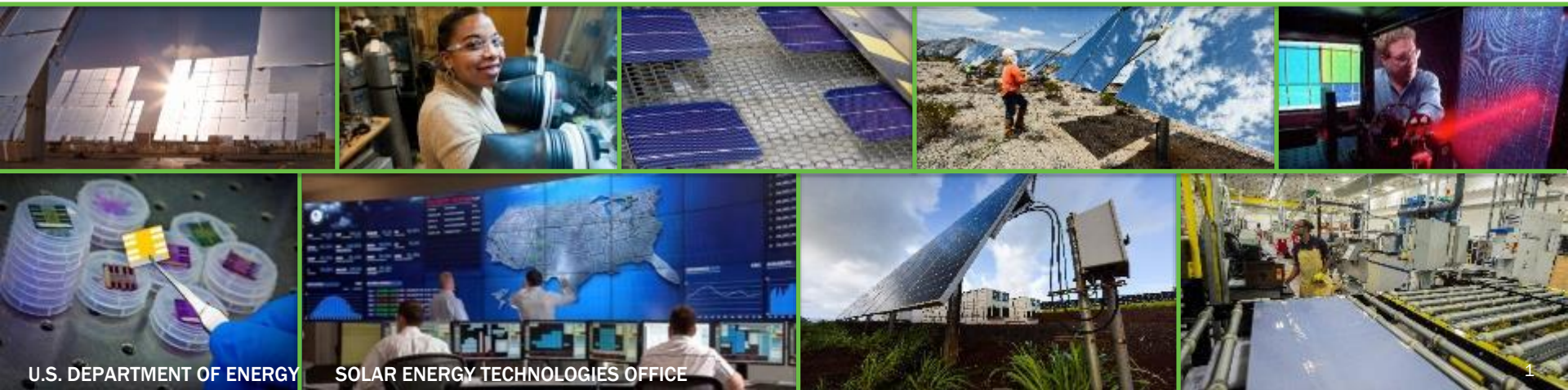
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Power & Control Electronics: Some EERE Perspectives
Including Examples from SETO, WETO, HFTO

Eric L. Miller, HFTO Chief Scientist, Hydrogen & Fuel Cell Technologies Office, EERE

Annual PACE Meeting, August14th, 2024



EERE's Mission

To accelerate the research, development, demonstration, and deployment of technologies and solutions to equitably transition America to net-zero greenhouse gas emissions economy-wide by no later than 2050, and ensure the clean energy economy benefits all Americans, creating good paying jobs for the American people

Why Clean Energy Matters

Transitioning the United States to a clean energy economy enhances economic growth, energy independence, and the health and well-being of the American people.

Buildings & Industry

Learn about EERE's buildings and industry research and development in advanced materials and manufacturing, building technologies, and industrial efficiency and decarbonization.

Renewable Energy

EERE's applied research, development, and demonstration activities aim to make renewable energy cost-competitive with traditional sources of energy. Learn more about EERE's work in geothermal, solar, wind, and water power.

Sustainable Transportation & Fuels

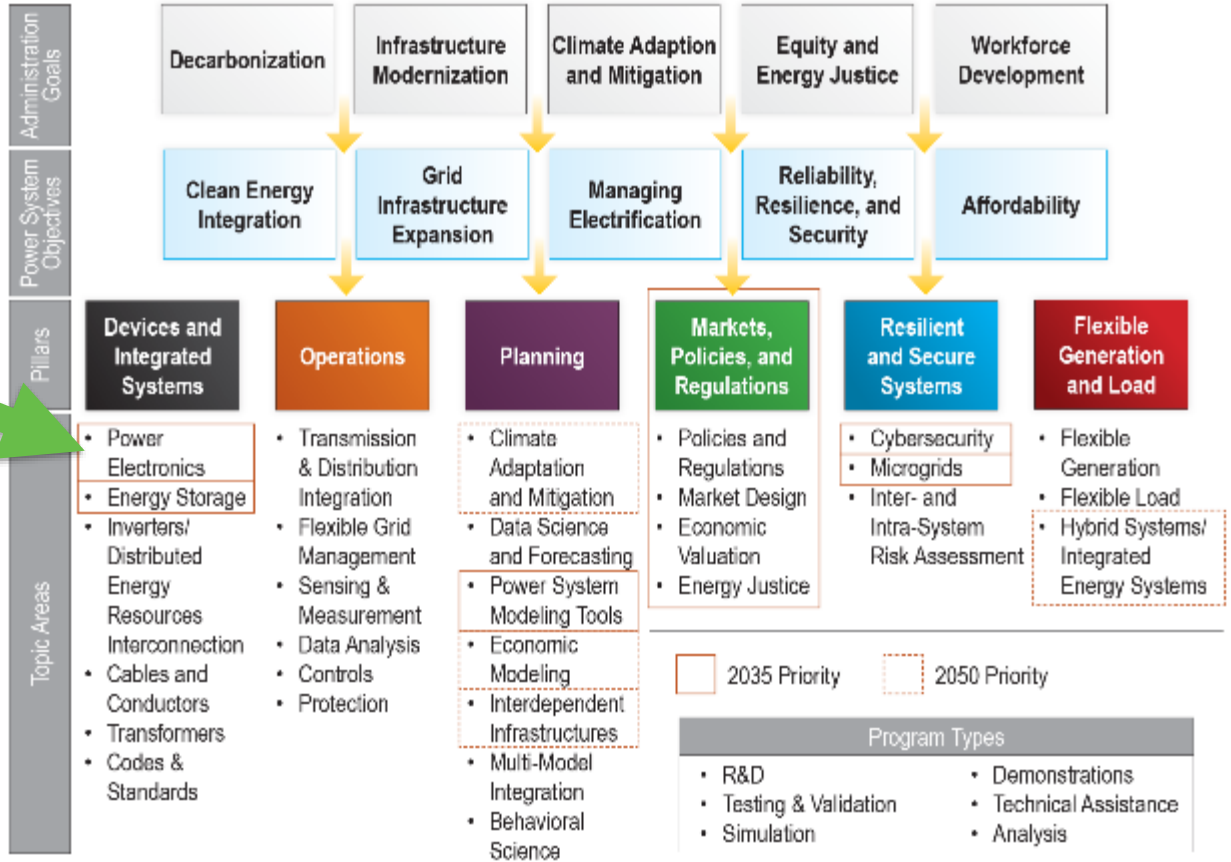
Learn about EERE's work in bioenergy, hydrogen and fuel cells, and vehicles to increase access to domestic, clean transportation fuels and improve the energy efficiency, convenience, and affordability of transporting people and goods.

Supporting DOE's Grid Modernization Initiative

- ***The Grid Modernization Initiative (GMI)*** works across the U.S. Department of Energy (DOE) to address the research and development (R&D) challenges facing the 21st century grid.
- Modernizing the grid is essential for achieving the administration's goals of ***100% clean electricity by 2035 and a decarbonized economy by 2050***.
- The GMI focuses on developing new architectural concepts, tools, and technologies that will ***better measure, analyze, predict, protect, and control the grid,*** as well as enable the institutional conditions that allow for ***rapid development and widespread adoption*** of these tools and technologies.

GMI Priorities & Six Key Pillars

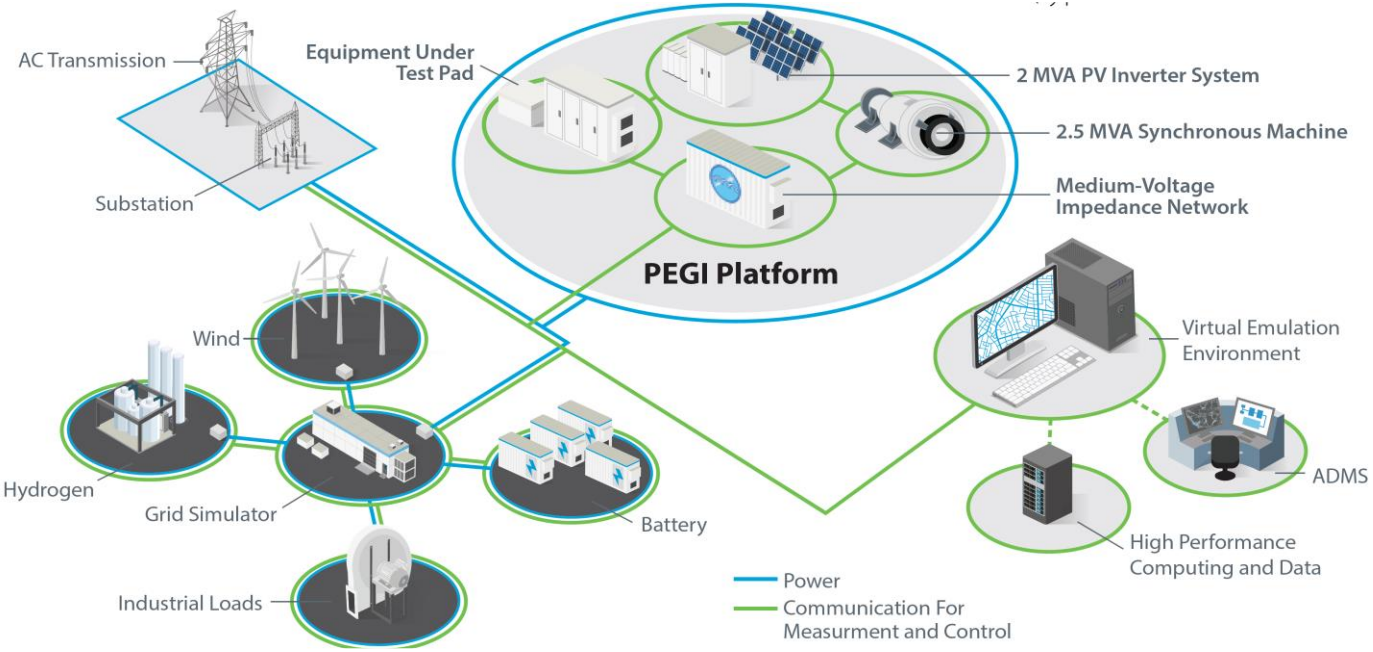
Power & Control Electronics Identified as a Priority for GMI, & Across the DOE Energy Earthshots



Power Electronics Grid Interface (PEGI) at NREL

A research platform to validate inverter-based resources and power electronic-dominant energy systems

- Industry Workshop, May 24-25, 2023, https://www.nrel.gov/grid/power-electronics-grid-interface-workshop.html
- Prior call for proposals, DOE provides 50% cost share for partner research



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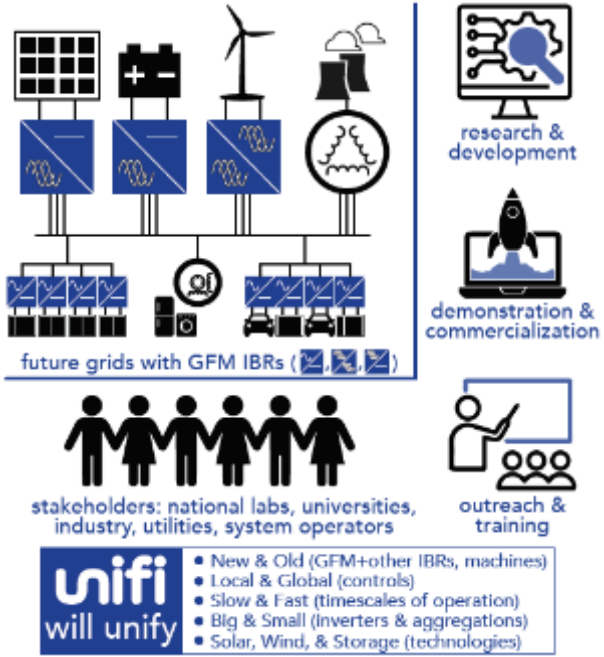
Grid-Forming Technologies Consortium (NREL)

UNIFI consortium - $25M over 5 years to establish a framework for continued industry collaboration on grid forming technologies.

PI: Ben Kroposki, NREL

Modeling and Simulation Area:

- WECC-approved GFM models: REGFM_A1 and REGFM_B1
- Study applicability/limits of EMT vs. phasor
- Accelerate simulation time of EMT-phasor co-simulation platforms
- Validate black box EMT GFM models and developed reduced-order generic models
- Develop and maintain software testbed system and GFM model library



Project link:

1. https://sites.google.com/view/unifi-consortium/home
2. https://www.energy.gov/eere/solar/unifi-consortium

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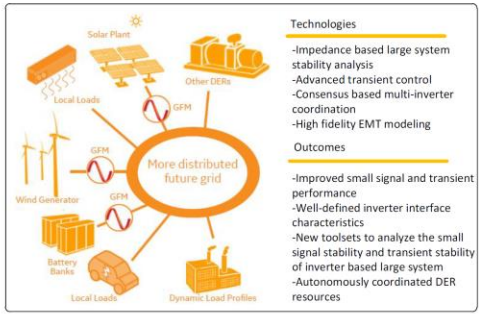
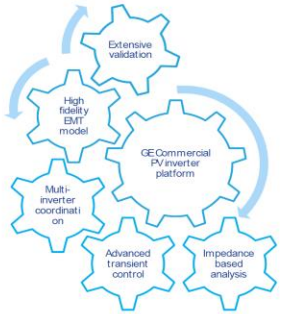
Grid-Forming (GFM) Inverter Control - SETO

Advanced grid-forming (GFM) inverter controls, modeling and system impact study for inverter dominated grids

Project Objectives:
Develop a new impedance based large system stability analysis method.
Develop, implement and validate advanced controls for GFM PV inverter(s) to improve the stability of inverter dominated grid.
Develop high fidelity models to study GFM inverters' system impact.
Demonstrate the proposed technology in a 100% renewable test facility and a real PV plant.



Project overview



Technical approach

2x1MW GE LV5 Solar inverters

NREL terabase First Solar. ercot

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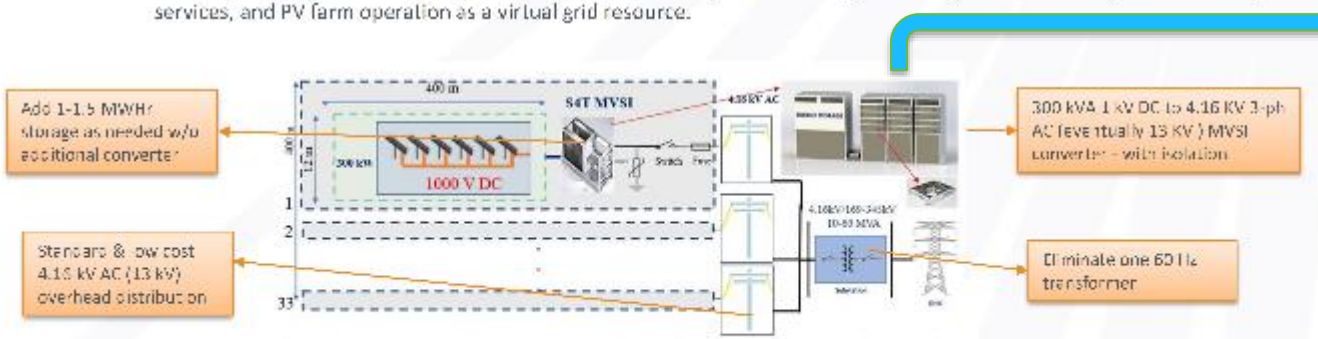
(Source: Maozhong Gong, GE Research, project funded by SETO)

Developing Multiport PV-BESS Converters - SETO

Project Objective

Georgia Tech Center for Distributed Energy

- Develop and demonstrate a new approach for larger commercial and utility scale PV farms which reduces the 'balance of systems' (BOS) cost by
  - Employing a novel Medium Voltage String Inverter (MVSI) topology (soft switching solid state transformer – S4T) to convert 1000 Vdc to 4.16 kVac.
  - Plant collection using standard, low-cost overhead MV distribution network.
  - Enabling energy storage integration without additional converter cost to achieve dispatchability of the PV resource.
  - Providing advanced functionality: autonomous operation, track ISO signals for dynamic balancing and ancillary services, and PV farm operation as a virtual grid resource.



GRID BLOCK

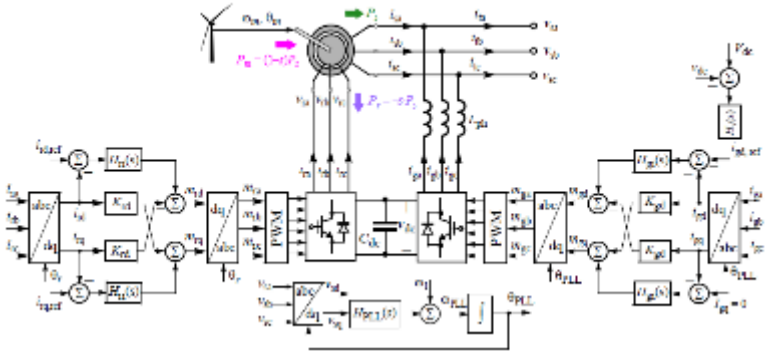
One 500kW Grid Block supports up to 16 charging stations plus solar and storage. Grid Block forms a microgrid with transformer, multi-channel inverter, protection, isolation, and control functions included.

(Source: Deepak Divan, Georgia Tech, project funded by SETO)

Grid Forming Control for Wind - WETO

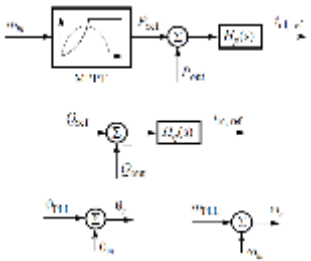
- **Main impact**: This project provides industry with answers on how wind power can provide grid forming services to the grid to increase grid stability and resiliency.
- We demonstrated operation of multi-MW wind turbine in grid forming mode for Type 3 wind turbine topology.
- For Type 4 wind turbine topology we conducted modeling studies to demonstrate benefits of GFM operation
- The results of this project will inform all segments of stakeholder community about control methods, challenges and benefits, and future standardization of grid forming operation of wind power.
- Validated GFM wind models produced by this project can be used in future integration studies.

Validated full model of GFM Type 3 WTG

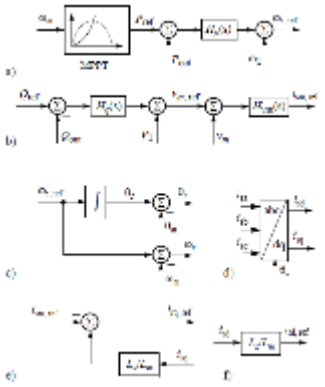


DFIG-based Type III wind turbine with vector current control of RSC and GSC.

RSC outer control loop for GFL operation



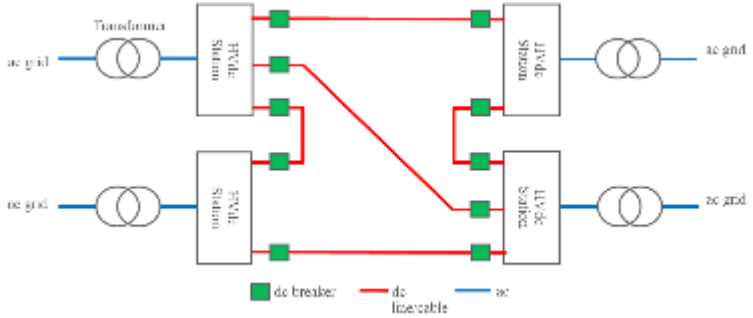
RSC outer control loop for GFM operation



HVDC R&Ds for Wind Integration - WETO

HVDC Standards FOA

- Objective: Develop HVDC standards to support multi-vendor multi-terminal HVDC for offshore wind
- 3 Topic Areas
  - TA1: HVDC Standards and Benchmark System
  - TA2: MTDC Controls and Functional Requirements
  - TA3: HVDC Curriculum Development

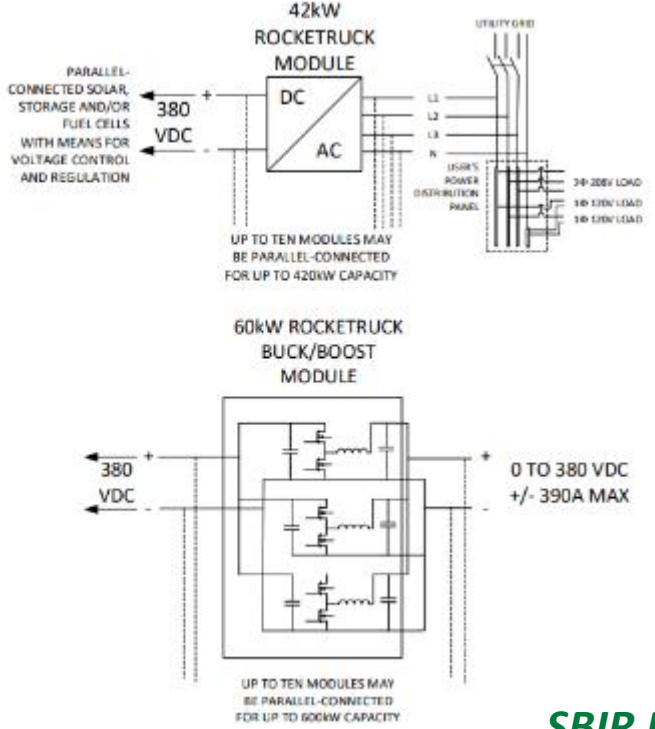


IDEAL-HVDC FOA: in collaboration with OE

- Objective: innovative HVDC converter designs that can lead to the cost reduction goal established by CORE initiative
- Open topics with targeted areas of innovation

Fuel Cell Integrated Power Electronics Module - HFTO

Developing an advanced power electronics module to eliminate the common drawbacks of relying on commercial off-the-shelf (COTS) inverters for fuel cell generator applications, with the specific objectives of improving fuel cell data communications, achieving power characteristics more compatible with end user requirements, and reducing integration cost and complexity



- **Developed designed for more compact fuel cell power converter ("FCIPEM" SBIR Ph I)**
  - Gallium nitride (GaN) semiconductors
  - Smaller filter components and heat sink
  - Multiple DC input ports (fuel cell + battery)
- **Preliminary design funded by a separate DOE SBIR Phase I project ("FCIPEM")**
- **Future plans**
  - Develop bench prototype with combination of company funds expected from Southern California Gas
  - Develop operational prototype and demonstrate on MFCG Mini if FCIPEM project continues to Phase II

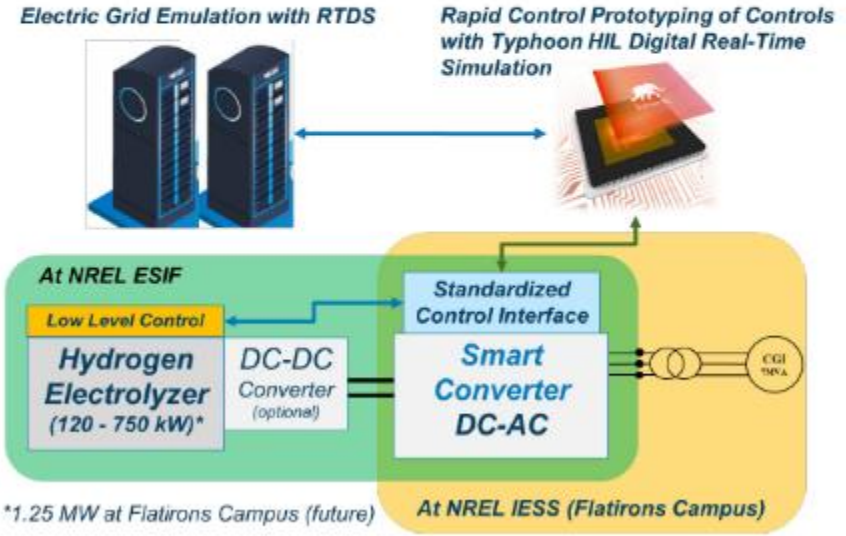
SBIR PI Project Led by RockeTruck, Inc.

Power Converter for Electrolyzer Applications - HFTO

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

Functionalities

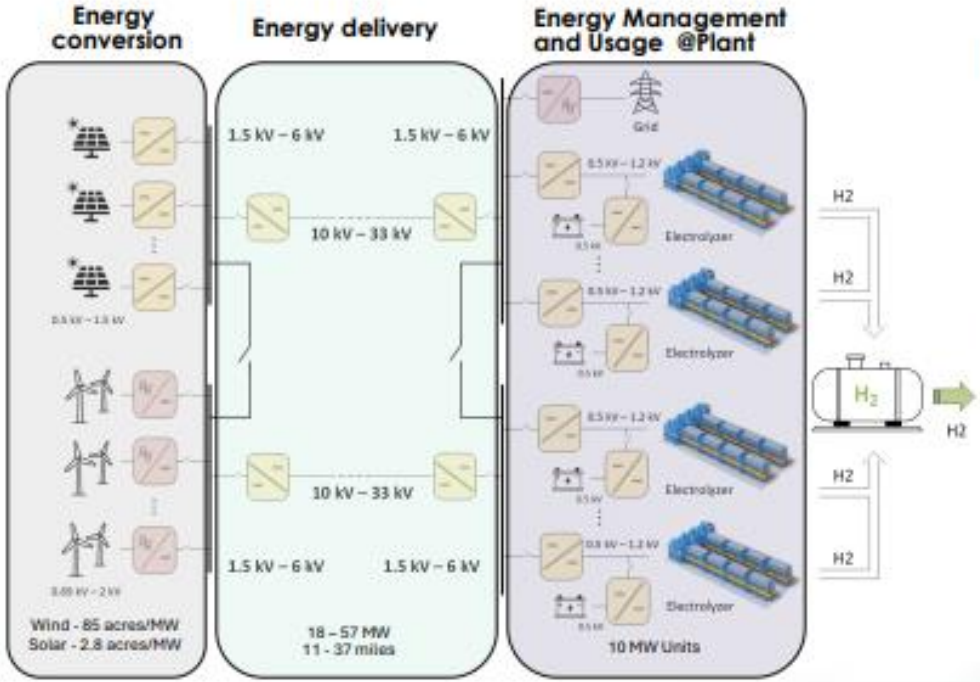
- Integrated controller at lower level of off-the-shelf power electronics for energy conversion and hydrogen generation.
- Optimized-based control to enable optimal participation in hydrogen production/sale and electricity market.
- Support advanced functionalities such as voltage and frequency ride-through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



Prior-Year Project Led by NREL

A More Holistic Approach is Needed

DC **Green** Hydrogen production Ecosystem Medium Voltage



Benefits:

- **Off-grid MVDC for MW-Scale** Wind+Solar green H2 production : **accelerated deployment** in comparison to grid connected solution (long permitting time)
- MVDC Distribution -> **Increased efficiency** with DER Integration
- MVDC Links -> Capacity expansion in congested areas while **deferring infrastructure investments**
- Higher stability provided by DC system

PACE MERIT Project Use Case Example

2023 GMI Lab Call Topics

Topic Area 1:

Power and Controls Electronics (PACE),

in the Power Electronics area of the *Devices and Integrated Systems* Pillar

Topic Area 2:

Cybersecurity for Architectures, Standards and Practices (CASP),

in the Cybersecurity area of the *Resilient and Secure Systems* pillar

Topic Area 3:

Quantum Facilities for Computing, Sensing, and Security (qFACSS),

in the Power System Modeling Tools area of the *Planning* pillar

Topic Area 4:

Equitable System Operation and Planning (ESOP),

in the Energy Justice area of the *Markets, Policies, and Regulations* pillar

Topic Area 5:

Climate Impact on Energy Resources (CIER),

in the Climate Adaptation & Mitigation area of the *Planning* pillar

Topic Area 1: Power and Control Electronics (PACE) *Supporting Offices: EERE, OE*

Addresses gaps in 'smart' medium-voltage (MV, 4.16kV-34.5kV) electrical interfaces critical to a modernized grid through development of a medium-voltage power and control electronics sub-system approach that is modular, scalable, and cost effective.

Performance targets and success metrics would be developed to focus on achieving low-cost, along with high-efficiency, security, and reliability, while providing interoperability across a broad array of realistic use cases employing diverse technology options for generation and loads.*

Specific Tasks to Include:

- Stakeholder Engagement
- Facilitating Harmonized Standards
- Hardware/Software Design
- Hardware/Software Implementation
- Impact Analysis
- Gap Analysis

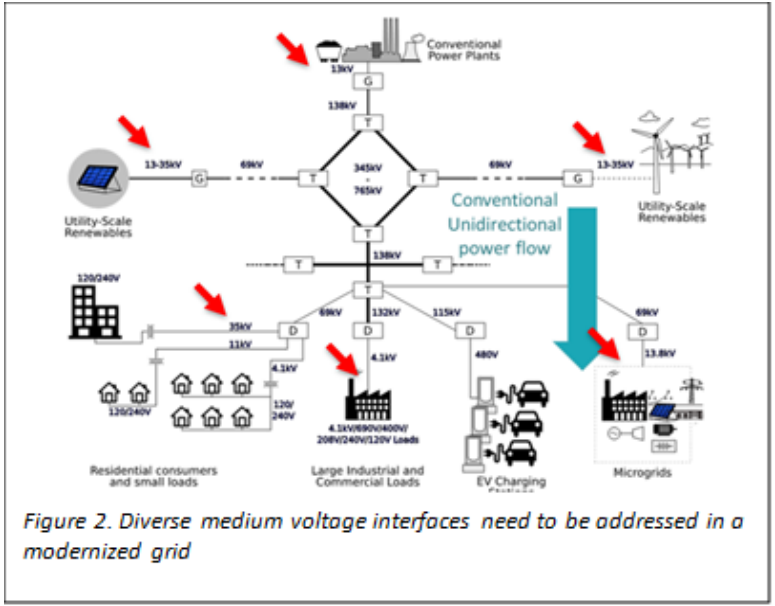
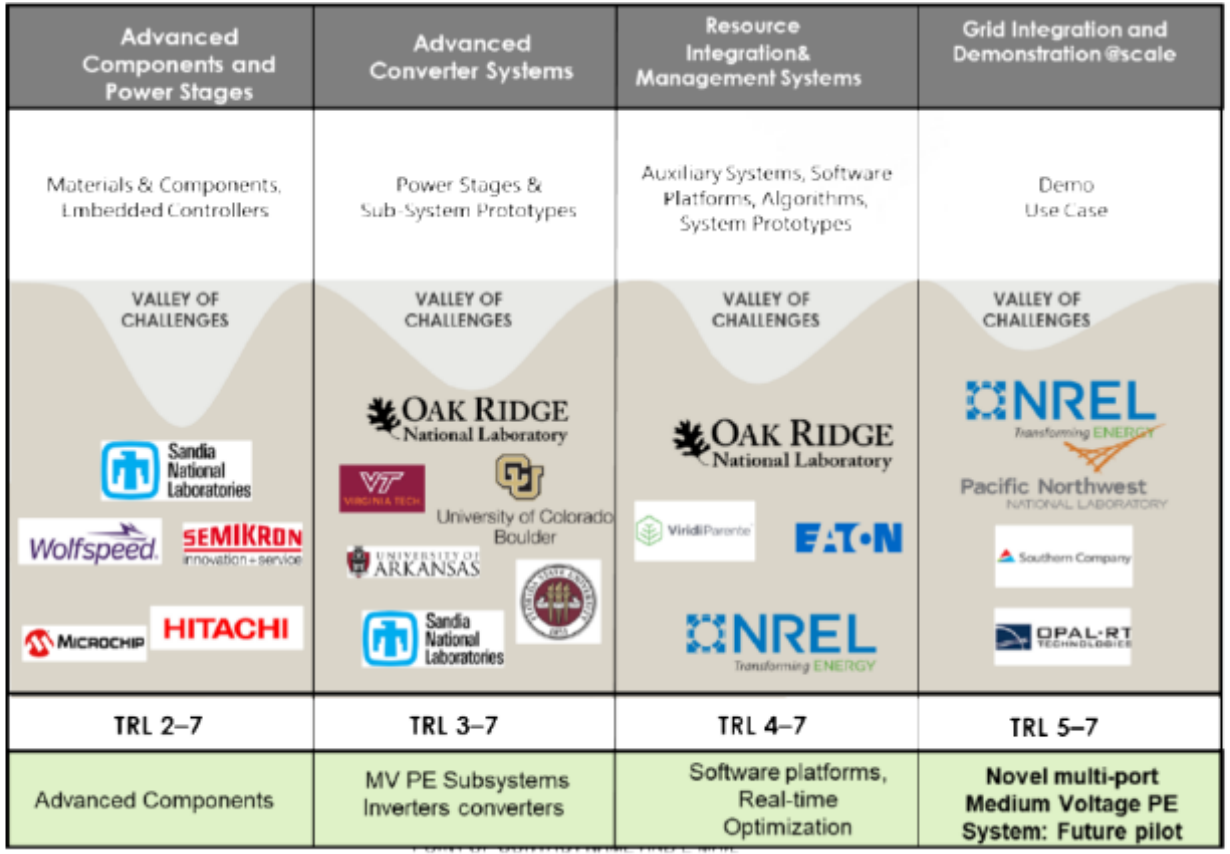


Figure 2. Diverse medium voltage interfaces need to be addressed in a modernized grid

*Examples include: connecting wind, solar, energy storage, and fuel-cells/electrolyzers to the grid; controlling power flow; and providing grid support/conditioning services.

PACE-MERIT: Research Consortium Framework

Resources



Deferring Further Details to Madhu!

Thank you

EERE Career Homepage

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