U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

NREL Transforming ENERGY

T38 - WETO 1.2.3.401 - Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL)

Technology RD&T and Resource Characterization – Distributed Wind

Jim Reilly
NREL

August 5, 2021

FY21 Peer Review - Project Overview

Project Summary:

- The Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL) project is a collaborative, multi-year research effort to accelerate all size classes of distributed wind (DW) technology development, demonstration, and deployment by advancing and easing DW system integration through:
  - Improved valuation and representation in system modeling and decision support tools
  - Advanced controls development for hybrid systems integration and grid support
  - Increased understanding for resilience support and cybersecurity
- Key Project Partners: Idaho National Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories.

Project Start Year: Fy19
Expected Completion Year: FY 22
Total expected duration: 4 years

FY19 - FY20 Budget: $3,357,292

Key Project Personnel:

- James Reilly (NREL, Lead PI)
- Alice Orrell (PNNL PI)
- Jake Gentle (INL PI)
- Brian Naughton (SNL PI)

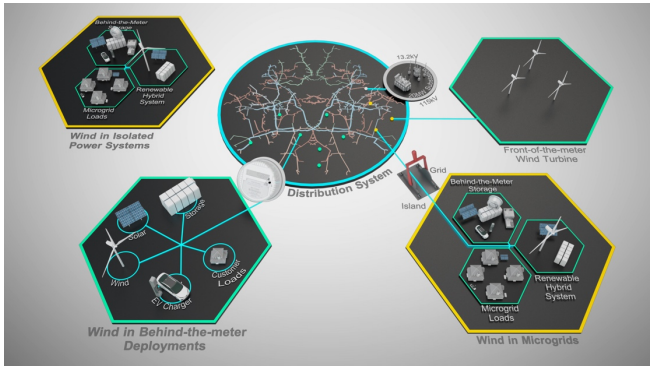
Key DOE Personnel:
Patrick Gilman and Bret Barker

Project Objective(s) 2019-2020:

1. Establish industry advisory board and partnerships to ensure work is impactful and transferable
2. Assess research capabilities across lab facilities fill gaps, and establish high speed Hub;
3. Establish use cases and project definitions to coordinate collaborative work

Overall Project Objectives (life of project):

- Advance wind energy technology as a compatible, secure, and flexible distributed energy resource (DER) to expand market applications



Project Impact

MIRACL research addresses:

- Lack of laboratory test capabilities and access to expertise and research infrastructure.
- Lack of case studies documenting DW deployments with advanced wind turbine controls in microgrid and hybrid system applications.
- Lack of DW representation in microgrid and distribution grid planning, design, and operating tools.

500 kW of Wind on Naval Auxiliary Landing Field San Clemente Island.
Photo courtesy of Ed McKenna/NREL

MIRACL has delivered:

- Access to world class research capabilities
- Published case studies
- Published valuation and resilience frameworks
- Validated models for decision support tools

MIRACL research informs:

- Wind turbine and power electronics manufacturers
- Project designers and system integrators
- Utility and market operators
- Academia

900 kW EWT Wind turbine on St. Mary's Village, Alaska.
Photo courtesy of AVEC

Program Performance – Scope, Schedule, Execution

FY19 (Kickoff)

- Research Roadmap Development
- Engage Industry and Advisory Board
- Standards Entity Identification

FY20 (Baselines)

- Establish Baselines
- Industry Engagement
- Conference Road Show
- Model Development
- Identification of Launchpad Infrastructure Needs

FY21 (R&D)

- Reference System Identification
- Publish and Apply Resilience Framework
- Publish and Apply Valuation Framework
- Desktop Simulation of Advanced Wind Turbine Controls
- Industry Engagement
- Cybersecurity Guide Development
- MIRACL Collaborative Reference System Report
- Outline Launchpad Structure

FY22 (Tech Transfer)

- Hardware-in-the-Loop validation of Advanced Wind Turbine Controls
- Real-world demonstrations
- Results Dissemination
- Launchpad Establishment

Program Performance – Scope, Schedule, Execution

Distributed Wind Use Cases

MIRACL is investigating distributed wind deployments, of all turbine size classes, organized by the following use cases:

1. Isolated systems

Isolated system that is not connected to a larger power system.
Toksook Bay, Alaska, USA

2. Microgrids

Microgrids can operate connected or disconnected from "the grid."
Joint Base Cape Cod – Otis, Buzzards Bay, MA, USA

The US DOE defines the microgrid as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode."

3. Behind-the-meter

Behind-the-meter installations to provide local energy services.
Ball Corporation, Findlay, Ohio, USA

4. Front-of-the-Meter

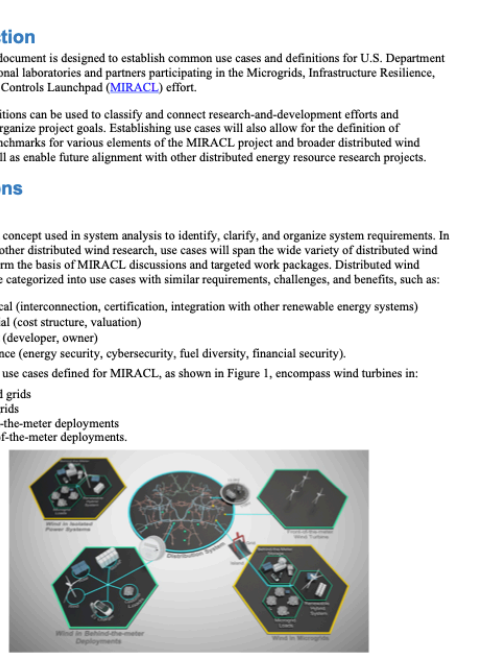
Utility-owned and -operated turbines providing local services.
Kaupuni Village, Hawaii, USA

MIRACL Use Cases and Definitions technical report
https://www.nrel.gov/docs/fy21osti/76918.pdf

Program Performance – Accomplishments & Progress (1 of 2)

MIRACL Team Accomplishments in FY19 and FY20

- All MIRACL milestones were met within the time agreed upon between the national lab and DOE WETO.
- Developed a MIRACL-wide (4 lab) Research Plan for the 4-year arch of the project
- Assessed lab research infrastructure, identified and filled gaps, and virtually connected capabilities
- Developed distributed wind use cases to coordinate work across the three research focus areas
- Produced a MIRACL overview fact sheet for energy.gov and presented at multiple conferences and workshops including Resilience Week, Distributed Wind Energy Association, IEEE ISGT, and Solar Power International
- Developed benchmark power systems models to perform simulations.
- Established a MIRACL Advisory Board and held FY19 & 20 meetings to ensure impactful



Introduction

This resource document is designed to establish common use cases and definitions for U.S. Department of Energy national laboratories and partners participating in the Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL) effort.

Use case definitions can be used to classify and connect research-and-development efforts and ultimately to organize project goals. Establishing use cases will also allow for the definition of operational benchmarks for various elements of the MIRACL project and broader distributed wind program as well as enable future alignment with other distributed energy resource research projects.

Definitions

Use Case

A use case is a concept used in system analysis to identify, clarify, and organize system requirements. In MIRACL and other distributed wind research, use cases will span the wide variety of distributed wind projects and form the basis of MIRACL discussions and targeted work packages. Distributed wind projects will be categorized into use cases with similar requirements, challenges, and benefits, such as:

- Technical (interconnection, certification, integration with other renewable energy systems)
- Financial (cost structure, valuation)
- Market (developer, owner)
- Resilience (energy security, cybersecurity, fuel diversity, financial security).

The high-level use cases defined for MIRACL, as shown in Figure 1, encompass wind turbines in:

1. Isolated grids
2. Microgrids
3. Behind-the-meter deployments
4. Front-of-the-meter deployments.

Excerpt from MIRACL Use Case publication

MIRACL Lab team and DOE presenting at Solar Power International - 2019

For individuals, businesses, and communities building resilient infrastructure, wind energy can provide an affordable, accessible, and compatible distributed energy resource (DER) option that also enhances the capabilities of local grid operations. The Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL) project is designed to make this potential a reality through collaborative research between U.S. Department of Energy (DOE) National Laboratories and industry.

Enabling Wind-Centered DER Systems

Four DOE National Laboratories—the National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, and Idaho National Laboratory—are joining forces to develop and improve the planning, design, and operation of wind-centered microgrids to complement solar, energy storage, and other DERs for grid-tied and isolated operation.

Funded by the DOE Office of Energy Efficiency and Renewable Energy's Wind Energy Technologies Office, the MIRACL project seeks to equip and validate wind technology as a plug-and-play resource with solar, storage, and other DERs in hybrid systems. Collaborative research under MIRACL is enhanced by a new high-speed data platform that connects the data, models, and physical assets across the four laboratories needed to address research and development priorities.

Three Primary Research and Development Priorities

1. **Accurately Value Grid System Contributions from Wind as a DER:** Research and develop grid modeling tools to more accurately represent wind's techno-economic performance in, and value to, microgrids, hybrid DER installations, distribution grid systems, and energy markets.
2. **Advance Controls for Wind-Hybrid DER Systems:** Develop and demonstrate the grid support functions of wind turbines in grid-connected and isolated microgrids and increase the control and communications compatibility of wind turbines with other DERs.
3. **Understand and Guard against Cyber Threats in Distributed Wind Applications:** Research and develop methodologies to understand cyber vulnerabilities, develop threat-resilient supervisory control, and achieve greater, measurable resilience in microgrids and distribution systems through wind integration.

MIRACL's R&D efforts will also provide a platform enabling validation of hybrid DER system technologies to maximize grid support, resiliency, and value for utilities and their customers.

Page 1 of MIRACL Fact Sheet at energy.gov

Program Performance – Accomplishments & Progress (2 of 2)

Valuation and Modeling (PNNL)

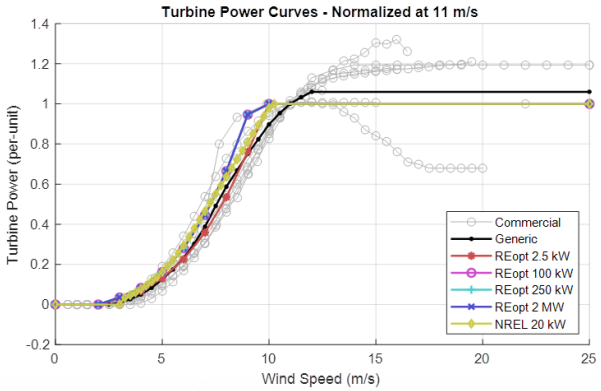
- Developed a technical report on "Distributed Wind Representation in Modeling and Simulation Tools: An Assessment of Existing Tools".
- Developed a generic turbine recommendation for inclusion in common modeling software such as NREL's REopt, HOMER, and GridLab-D.
- Developed an internal memo and spreadsheet around value streams and markets for distributed wind.

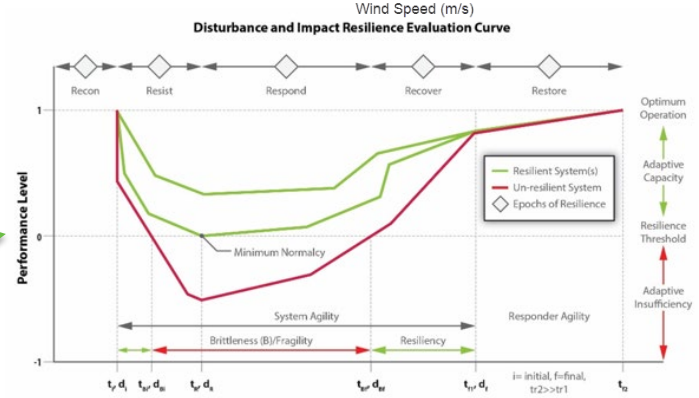
Resilience and Cybersecurity (INL)

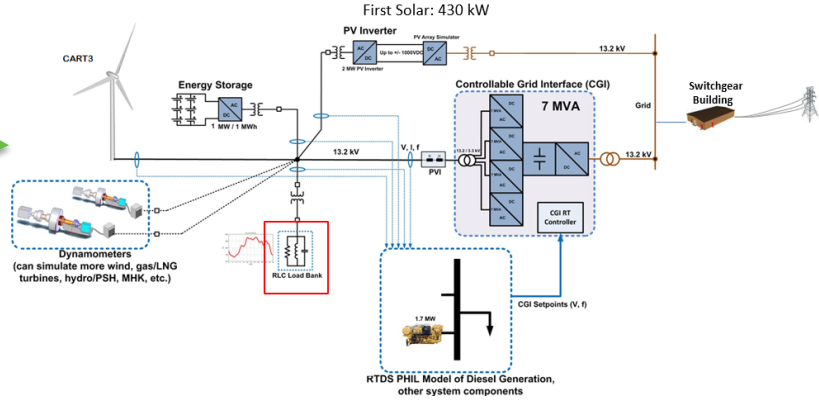
- Developed a virtualized testbed that allows for modeled or real wind generation, physical or cyber plant information, and was used as a basis for a research paper on Anomaly Detection in Network Emulated Wind-Powered Microgrids.
- Submitted a report to IEEE Power and Energy Conference on "Adaptive Capacity Determination for Critical Load in Power Systems".
- Published a report on "Resilience in an Evolving Electrical Grid"

Advanced Controls (NREL and SNL)

- Published "A Research Roadmap for Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad" to establish a baseline for MIRACL controls research.
- Development of power system models in MATLab Simulink and OpenDSS to simulate the four use cases
- Developed MATLab Simulink component models of configurable distributed wind turbines, battery storage, solar PV, and dynamic loads; including microgrid controller and component control modules.
- Document distributed wind focused benefits of IEEE 1547-2018 and potential certification challenges https://www.nrel.gov/docs/fy21osti/78948.pdf



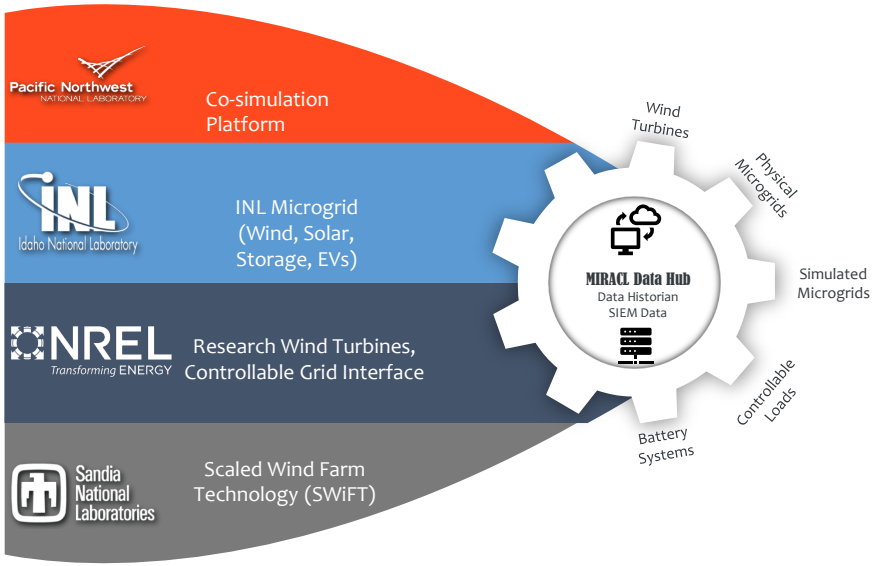




Project Performance - Upcoming Activities (Page 1 of 2)

MIRACL Team Activities for FY 2021 and Beyond

- FY21 and FY22 MIRACL Advisory Board meetings to obtain industry and academic feedback on results and research plans.
- Coordinate work on a joint technical report applying MIRACL research towards real-world turbine deployments, or reference systems, in:
  - Isolated Grid – St. Mary's 900 kW turbine operated by the Alaskan Village Electric Cooperative
  - Grid-connected – two 10.5 MW turbine deployments, share a substation with an ethanol plant, owned by Iowa Lakes Electric Cooperative
- Identify opportunities to expand industry partnerships for lab-based validation and field demonstration efforts.
- Expand on distributed wind centric hybrid integration challenges and research opportunities.
- Complete integration of infrastructure across the MIRACL laboratories into the MIRACL Data Hub, to enable laboratories and industry to share data, models, and physical assets for research, demonstration, and validation.
- Initiate the MIRACL "Launchpad" and begin coordinating with industry on pilot research collaboration.



MIRACL Data Hub POC: Jake Gentle Jake.Gentle@inl.gov

10.5 MW Distributed Wind Plant - Superior Site. Image courtesy of ILEC.

Project Performance - Upcoming Activities (Page 2 of 2)

Valuation and Modeling (PNNL)

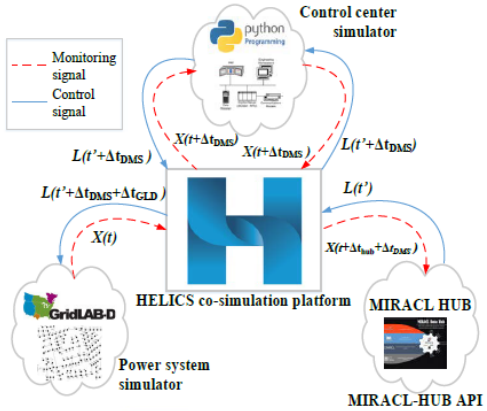
- Published "Distributed Wind Representation in Modeling and Simulation Tools: An Assessment of Existing Tools" in February 2020.
- Developed a co-simulation platform between power system models, the MIRACL Data Hub, and common techno-economic analysis tools.
- Publishing a "Valuation Framework for Distributed Wind and Distribution Hybrids".

Resilience and Cyber Security (INL)

- Publish a "Cybersecurity Guide for Distributed Wind"
- Publish a "Distributed Wind Connectivity Vulnerability Assessment"
- Publish reports on "Distributed Wind Resilience Metrics for Electric Energy Delivery Systems"
- Publish a report on "Resilience Framework for Electric Delivery Systems for Distributed Wind".
- Advance the Integrated cybersecurity assessment advisor technology (ICAAT) for industry

Advanced Controls (NREL and SNL)

- Developed a MIRACL Controls-specific fact sheet. https://www.energy.gov/sites/prod/files/2021/02/f82/miracl.controls.2021.pdf
- Submitted a paper to IEEE Power and Energy Society General meeting that was accepted on "Integration of Storage in the DC Link of a Full Converter-Based Distributed Wind Turbine". Preprint version can be found at https://www.nrel.gov/docs/fy21osti/78347.pdf
- Developed reports currently in the publishing process on "Wind and Solar Hybrids Complementarity for Energy Resilience", and a technical report on "Load Control for Frequency Response to Support High-Contributions of Wind in Isolated Grids",
- Publishing a technical report and publication of dynamic models used to perform controls analysis under MIRACL, including wind turbine models, and a model of a portion the Flatirons Campus that includes other generation to benefit the broader industry.
- Completing three technical reports on advanced distributed wind controls and grid integration to be structured by Isolated Grids, Microgrids, and Grid-Connected deployments.
- Developed Power-Hardware-in-the-Loop facility at SNL's Distributed Energy Technology Lab: https://share ng.sandia.gov/news/resources/news_releases/turbine_emulator/
- R. Darbali-Zamora, F. Wilches-Bernal and B. Naughton, "Configurable Microgrid Modelling with Multiple Distributed Energy Resources for Dynamic System Analysis", 2021 IEEE Power and Energy Society General Meeting (PESGM), July 25-29 2020, Washington, DC, USA.



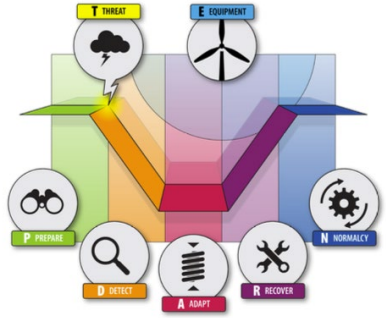
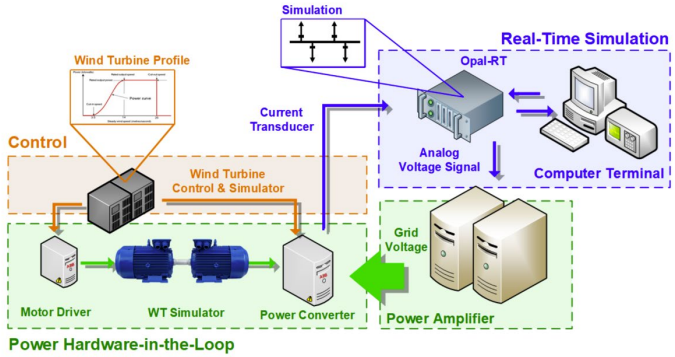
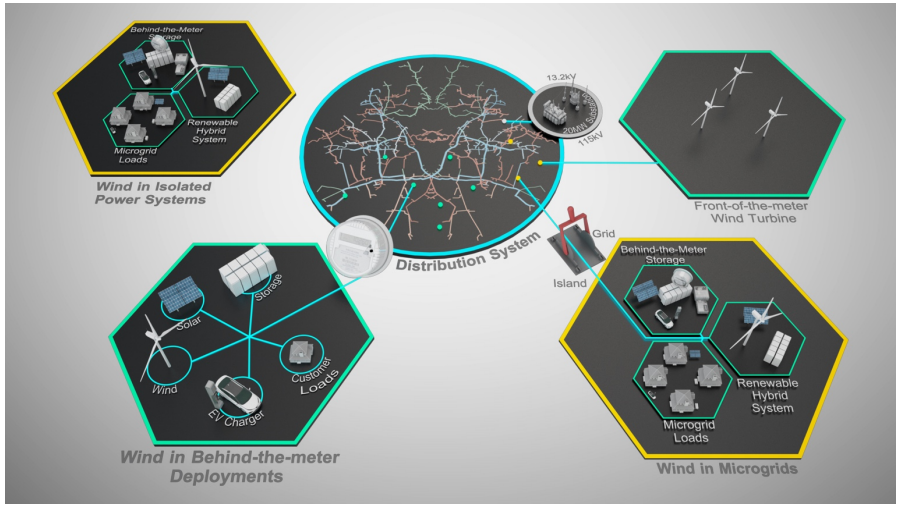


Figure 5: Key elements in resiliency definitions



Stakeholder Engagement & Information Sharing

- Advisory Board
  - Nine members from electric co-operatives, universities, regional energy markets, electric utilities, wind turbine manufacturers, controls integrators, and more.
- Conference “road show” in FY19 and FY20 to broadcast work and solicit collaboration opportunities
  - Solar Power International, IEEE Innovative Smart Grid Technologies, INL Resilience Week, Distributed Wind Energy Association, International Energy Agency (Task 41 and others)
- Journal Publications
  - Submitted 5 technical reports to IEEE Power and Energy Society General Meetings.
- FY22 – Conference Panels and Journal Publications
- Engagement and Collaboration
  - Multiple subcontracts with industry and academia.
  - Collaboration with DOE-sponsored Wind Innovations for Rural Economic Development (WIRED) and Competitiveness Improvement Project (CIP) awardees
  - Pursuing additional collaboration platform for laboratory supported industry research



MIRACL Advisory Board members and collaborators

Key Takeaways and Closing Remarks

Success of the MIRACL project is demonstrated through an increase in the quantifiable benefits of wind in distribution systems, isolated grids, and microgrids.

- **Impact:** Increased amount of resources available to the DW community including advanced distributed wind case studies and technology validation platforms.
- **Performance:** Successful multi-laboratory collaboration over 4+ years leading to a rapid expansion in distributed wind focused R&D and opportunities for continued industry engagement with DOE and national laboratories.
- **Engagement:** Direct engagement across the industry in the form of input, validation, and collaborative R&D.