BLACK START CONSIDERATIONS IN A HIGHLY RENEWABLE SUPPLY FUTURE

NARUC CENTER FOR PARTNERSHIPS & INNOVATION WEBINAR SERIES

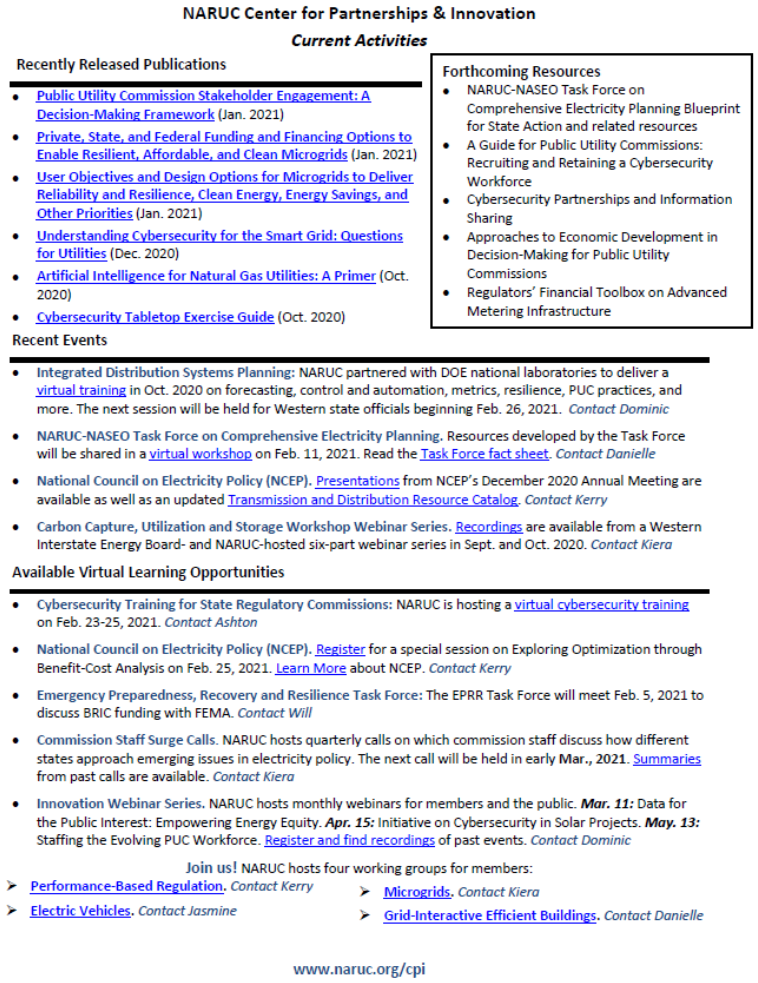
FEBRUARY 24, 2022

ABOUT NARUC

- The National Association of Regulatory Utility Commissioners (NARUC) is a non-profit organization founded in 1889.
- Our Members are the state utility regulatory Commissioners in all 50 states & the territories. FERC & FCC Commissioners are also members. NARUC has Associate Members in over 20 other countries.
- NARUC member agencies regulate electricity, natural gas, telecommunications, and water utilities.

ABOUT NARUC'S CENTER FOR PARTNERSHIPS & INNOVATION

- Grant-funded team dedicated to providing technical assistance to members.
- CPI identifies emerging challenges and connects state commissions with expertise and strategies to inform their decision making.
- CPI builds relationships, develops resources, and delivers trainings.



NARUC Center for Partnerships & Innovation

Current Activities

Recently Released Publications

- Public Utility Commission Stakeholder Engagement: A Decision-Making Framework (Jan. 2021)
- Private, State, and Federal Funding and Financing Options to Enable Resilient, Affordable, and Clean Microgrids (Jan. 2021)
- User Objectives and Design Options for Microgrids to Deliver Reliability and Resilience, Clean Energy, Energy Savings, and Other Priorities (Jan. 2021)
- Understanding Cybersecurity for the Smart Grid: Questions for Utilities (Dec. 2020)
- Artificial Intelligence for Natural Gas Utilities: A Primer (Oct. 2020)
- Cybersecurity Tabletop Exercise Guide (Oct. 2020)

Forthcoming Resources

- NARUC-NASEO Task Force on Comprehensive Electricity Planning Blueprint for State Action and related resources
- A Guide for Public Utility Commissions: Recruiting and Retaining a Cybersecurity Workforce
- Cybersecurity Partnerships and Information Sharing
- Approaches to Economic Development in Decision-Making for Public Utility Commissions
- Regulators' Financial Toolbox on Advanced Metering Infrastructure

Recent Events

- **Integrated Distribution Systems Planning:** NARUC partnered with DOE national laboratories to deliver a virtual training in Oct. 2020 on forecasting, control and automation, metrics, resilience, PUC practices, and more. The next session will be held for Western state officials beginning Feb. 26, 2021. *Contact Dominic*
- **NARUC-NASEO Task Force on Comprehensive Electricity Planning.** Resources developed by the Task Force will be shared in a virtual workshop on Feb. 11, 2021. Read the Task Force fact sheet. *Contact Danielle*
- **National Council on Electricity Policy (NCEP).** Presentations from NCEP's December 2020 Annual Meeting are available as well as an updated Transmission and Distribution Resource Catalog. *Contact Kerry*
- **Carbon Capture, Utilization and Storage Workshop Webinar Series.** Recordings are available from a Western Interstate Energy Board- and NARUC-hosted six-part webinar series in Sept. and Oct. 2020. *Contact Kiera*

Available Virtual Learning Opportunities

- **Cybersecurity Training for State Regulatory Commissions:** NARUC is hosting a virtual cybersecurity training on Feb. 23-25, 2021. *Contact Ashton*
- **National Council on Electricity Policy (NCEP).** Register for a special session on Exploring Optimization through Benefit-Cost Analysis on Feb. 25, 2021. Learn More about NCEP. *Contact Kerry*
- **Emergency Preparedness, Recovery and Resilience Task Force:** The EPRR Task Force will meet Feb. 5, 2021 to discuss BRIC funding with FEMA. *Contact Will*
- **Commission Staff Surge Calls.** NARUC hosts quarterly calls on which commission staff discuss how different states approach emerging issues in electricity policy. The next call will be held in early **Mar., 2021**. Summaries from past calls are available. *Contact Kiera*
- **Innovation Webinar Series.** NARUC hosts monthly webinars for members and the public. ***Mar. 11:*** Data for the Public Interest: Empowering Energy Equity. ***Apr. 15:*** Initiative on Cybersecurity in Solar Projects. ***May. 13:*** Staffing the Evolving PUC Workforce. Register and find recordings of past events. *Contact Dominic*

Join us! NARUC hosts four working groups for members:

- Performance-Based Regulation. *Contact Kerry*
- Electric Vehicles. *Contact Jasmine*
- Microgrids. *Contact Kiera*
- Grid-Interactive Efficient Buildings. *Contact Danielle*

www.naruc.org/cpi

Regularly updated CPI fact sheet with recent publications & upcoming events under Quick Links at:

https://www.naruc.org/cpi-1/

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DR. PAUL STOCKTON, CHAIR OF DOE'S ADVISORY SUBCOMMITTEE ON GRID RESILIENCE FOR NATIONAL SECURITY, AND SENIOR FELLOW, JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY

BLACKSTART IN A HIGHLY RENEWABLE SUPPLY FUTURE: KEY CHALLENGES

PRESENTATION FOR THE NATIONAL ASSOCIATION OF REGULATORY UTILITY COMMISSIONERS

February 24, 2022

Paul N Stockton

BOTTOM LINE UP FRONT

- BLACKSTART POWER RESTORATION CAPABILITIES ARE VITAL FOR NATIONAL SECURITY

- THOSE CAPABILITIES WILL ALSO BE AT INCREASING RISK, UNLESS WE:

  - ASSESS HOW GROWING RELIANCE ON VARIABLE RENEWABLE GENERATION (SOLAR AND WIND) WILL AFFECT BLACKSTART

  - *ACCELERATE* EFFORTS TO DEVELOP AND DEPLOY MITIGATION MEASURES

BLACKSTART BASICS

- THE TYPICAL US POWER RESTORATION PROCESS: OUTSIDE-IN
- BLACKSTART: INSIDE-OUT
- BLACKSTART RESTORATION WILL BE CRUCIAL IF ADVERSARIES CREATE MULTI-REGION OUTAGES
  - OUTSIDE IN: NOT ADEQUATE TO RAPIDLY RESTORE SERVICE TO CRITICAL DEFENSE FACILITIES, URBAN WATER SYSTEMS, ETC.
  - ASSESSING THE POTENTIAL IMPACT OF HIGH VRE PENETRATION ON BLACKSTART IS A NATIONAL SECURITY IMPERATIVE

PHASES OF BLACKSTART

1) THE TRANSMISSION OPERATOR (TOP) STARTS UP THE INITIAL “BLACKSTART RESOURCE”

2) THE TOP THEN ENERGIZES THE “CRANKING PATH”

- THE POWER FROM THE BLACKSTART RESOURCE IS USED TO START THE NEXT GENERATOR ALONG THE ISOLATED TRANSMISSION CORRIDOR
- THAT GENERATOR, IN TURN, STARTS UP THE NEXT ONE, AND SO ON
- AS ADDITIONAL GENERATION COMES ONLINE, OPERATORS PICK UP LOAD TO KEEP THE SYSTEM IN BALANCE
- RESULT: THE TOP CREATES AN INITIAL POWER ISLAND WITHIN THE BLACKED-OUT REGION

BLACKSTART PHASES (CONT)

3) TOPs GROW AND BEGIN TO INTEGRATE/SYNCHRONIZE THEIR POWER ISLANDS (WITH THE HELP OF RELIABILITY COORDINATORS AND OTHER PARTNERS)

- ENABLES THE RESTORATION OF SERVICE TO ADDITIONAL CRITICAL CUSTOMERS
- MAKES THE POWER ISLANDS MORE STABLE
- ULTIMATELY, ENABLES THE RESTORATION OF THE INTERCONNECTION

HIGH VRE PENETRATION: POTENTIAL ISSUES

- PHASE 1 (BLACKSTART RESOURCE): LOTS OF POTENTIAL ZERO-CARBON ALTERNATIVES
- PHASE 2 (ENERGIZE THE CRANKING PATH/ESTABLISH THE INITIAL POWER ISLAND): BIG PROBLEMS
  - MOST TOPs RELY HEAVILY (OR EXCLUSIVELY) ON GAS-FUELED GENERATORS ALONG THEIR CRANKING PATHS
  - ADVANTAGES OF GAS GENERATORS VS VRES
  - NEW ZERO-CARBON TECHNOLOGIES WILL NEED TO REPLICATE THOSE ADVANTAGES

HIGH VRE PENETRATION (CONT)

- PHASE 3 (GROW AND INTEGRATE POWER ISLANDS): ADDITIONAL PROBLEMS
  - AGAIN, MOST TOPs WILL RELY HEAVILY (OR EXCLUSIVELY) ON MULTI MEGAWATT GAS-FUELED GENERATORS TO GROW THEIR POWER ISLANDS
  - SYNCHRONIZING POWER ISLANDS THAT RELY ON VREs --???
  - ADDITIONAL CONSIDERATION: MANY ZERO-CARBON OPTIONS COULD CREATE CYBER VULNERABILITIES BEYOND THOSE THAT CURRENTLY EXIST
    - LET'S PLAN IN ADVANCE TO MITIGATE THOSE CYBER RISKS

THANK YOU!

paul@paulnstockton.com

Paradigm Shift: Black Start from Inverter-Based Resources

-IBR-driven Black Start

Gab-Su Seo, Ph.D.
Senior Engineer, National Renewable Energy Lab.
NARUC Innovation Webinar, Feb. 24, 2022

Motivation – Grid is Transforming!

Why are IBRs being considered for Black Start?

- Level of IBRs skyrocketing. A must?
  - IBRs LCOE getting better
  - Replacing conventional generators (SGs) (foundation of legacy grid)
- Improve *resilience*?
  - Survivability from Distributed gen.
- Increasing Interest in industry
  - IBR black start cost effective?
  - Limited understanding

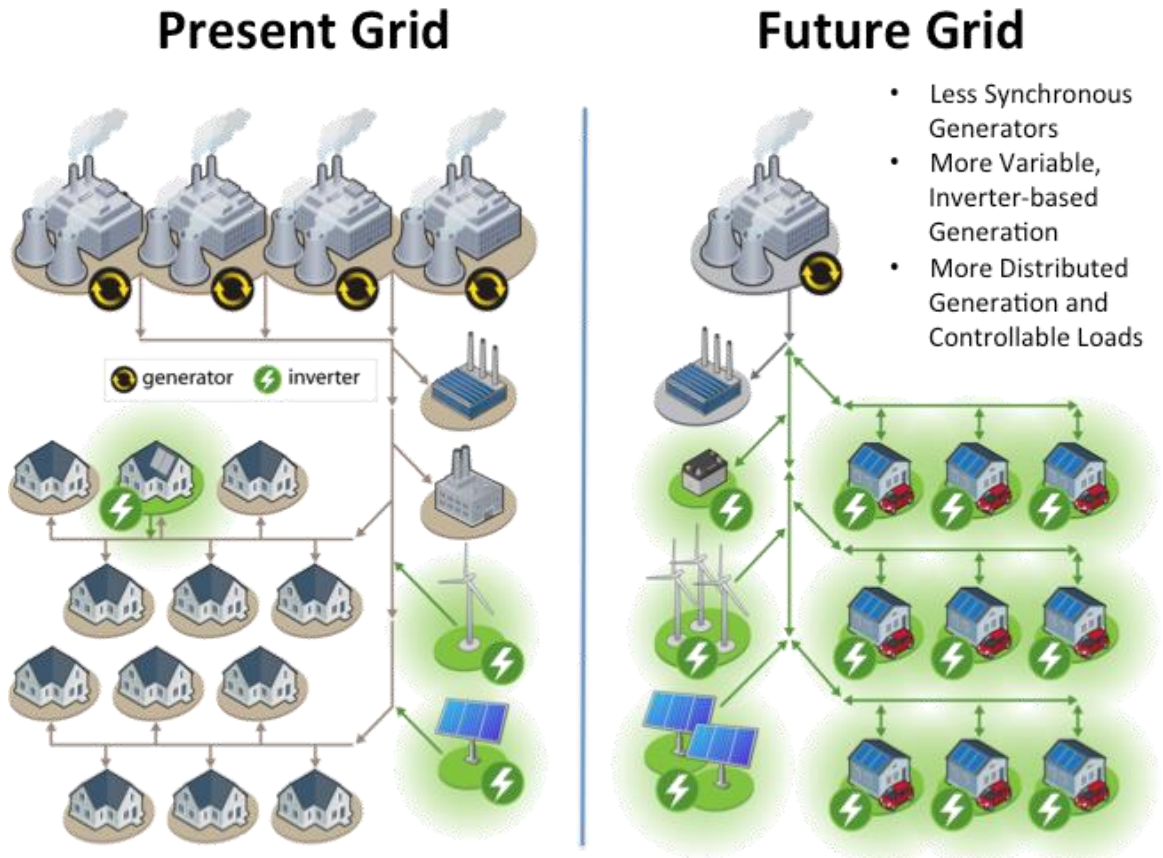


Image source: NREL

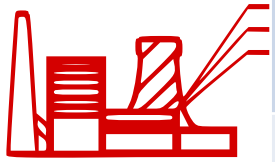
Fig.1. Future grid with high level of renewables.

*SG: Synchronous Generator
*IBR: Inverter-Based Resources
*LCOE: Levelized Cost of Energy

Ref: Addressing 100 VRE system.

Machine vs. Inverter—Fundamentally Different

What are the Fundamental Differences between SG and Inverter?



	Machine (SG)	Inverter
Source	Controllable	Uncontrollable (storage needed)
Dynamics	Slow, large inertia	Fast, inertia-less
Short Circuit	6-10 pu covered	Limited to 1-1.2 pu
Scale	Large (GW)	Small (ensemble of many at W-kW)
Control	Well understood	Have been GFL (—load) Grid-forming just emerging

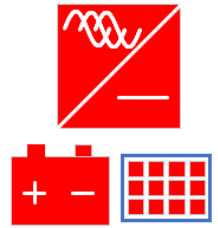


Image source: NREL

*SG: Synchronous Generator (conventional generator, e.g., thermal generator)
*pu: per unit

With these in mind, let us see what are the challenges in black start with IBRs

Ref: GFM inverter roadmap.

Technical Challenges

- May have **no one large IBR black start resource reserved**
  - Multiple IBRs, combined with storages, should be involved in black start process → increase complexity, not well understood
- Challenge & Opportunity come together
  - Effect of inrush/transient current more critical due to less SCR
  - Delicate control available. Inverter can soft-start the backbone

No industry practice/protocol in place yet.

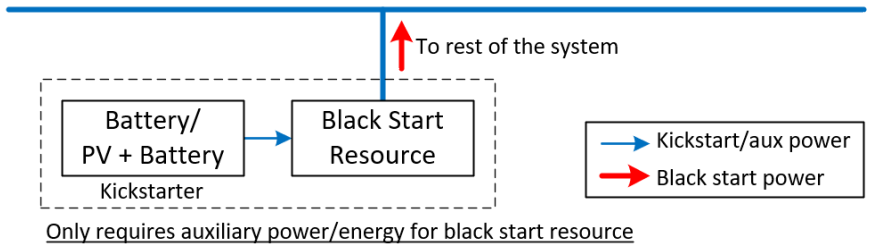
→ Research, Development, and Demonstration in *high demand*.

*IBR: Inverter-Based Resources
*SCR: Short Circuit Ratio

Ref: Hodge et al., Addressing Technical Challenges in 100% Variable Inverter-Based Renewable Energy Power Systems100% VRE system.

Renewable + Storage: 4 Potential Use Cases

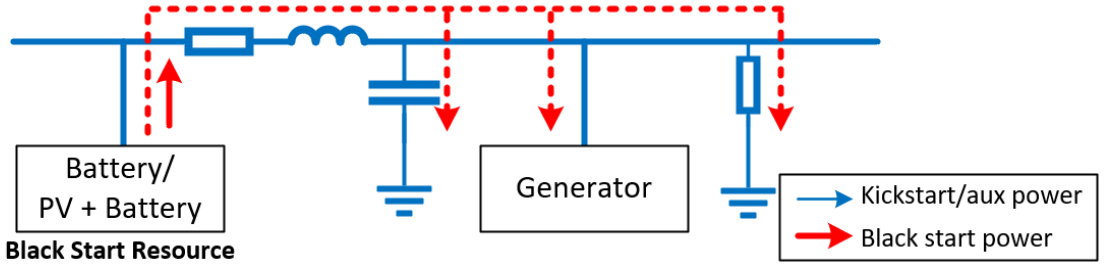
#1: BSR Kickstarter: Co-located



Only requires auxiliary power/energy for black start resource

Well defined & contained. Use cases already seen. Near-future solution. Limited use, 1:1 match.

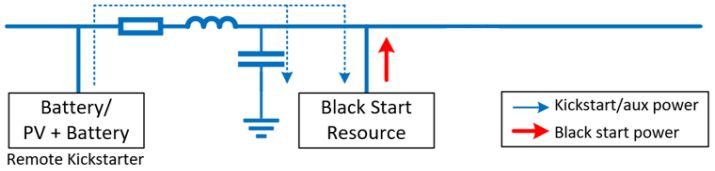
#3: Full BSR w/ single GFM unit



A Storage Unit (or PV+Storage) as a fully functional black start resource

Replaces current BSRs. May require more sectionalized systems to reduce the baseline load and/or demand in the cranking path.

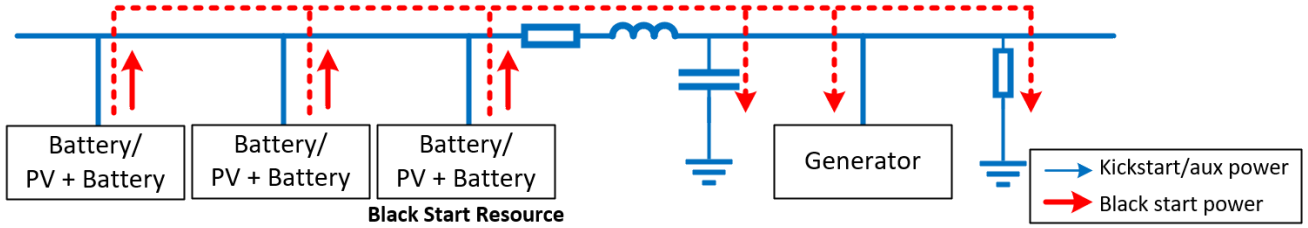
#2: BSR Kickstarter: Not co-located



Needs to supply the auxiliary power of the Black Start Resource, and the real and reactive powers required by the transmission line to the Black Start Resource

A step forward from #1. More flexible (1:n match); can cover multiple generators. GFM inverter should overcome "unknown" loading/fault or fail.

#4: Full BSR w/ multiple GFM units



Multiple Inverters capable of collective black start

Futuristic, but maybe ultimate solution. Can cover wide area with aggregated capacity. Most resilient; not relying on specific resources; autonomy and adaptive operation can be obtained.
Involves complexity. More understanding and standardization needed.

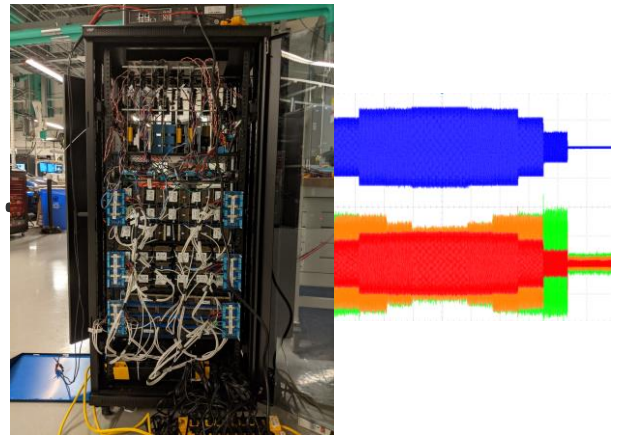
*BSR: Black Start Resource; GFM: Grid-Forming.

Ref: PESGM 2020.

Laboratory Activities at NREL for Black Start

Black start-related R&D works at NREL

- Closely working with DOE, Labs, Industry, Academia.
- From near-future concept to forth seeing concepts
  - COM-free & COM-assisted
  - Centralized & decentralized coordination
  - Distribution (bottom-up) & Transmission
  - Cyber security. Use of blockchain…
- From 30W prototype to MW scale



Full HW GFM IBR testbed w/ programmable inverters.
Image source: NREL

NREL Flatirons Campus is capable more than 20MVA
Image by Josh Bauer, NREL

*BSR: Black Start Resource; GFM: Grid-Forming.

U.S. DEPARTMENT OF ENERGY

unifi consortium
universal interoperability for grid-forming inverters

A consortium to pave the way for future power grid

Future power systems with any mix of machines and IBRs at any scale that are affordable, secure, reliable, clean, and resilient

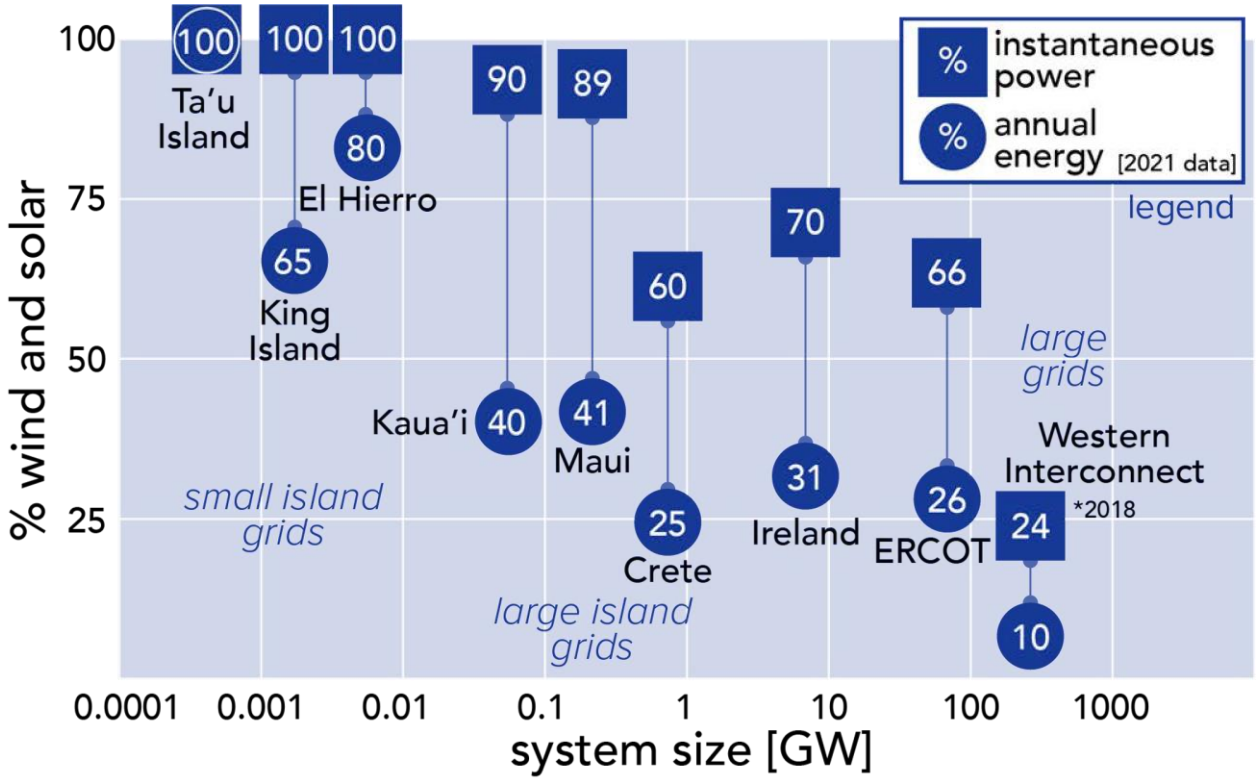
Vision

Forum to address fundamental challenges in seamless integration of GFM technologies into power systems of the future

Purpose

Conduct research and development, demo concepts at scale, author best practices and standards, train next-generation workforce

Goal



Ref: Official DOE announcement and NREL press release

What is UNIFI?

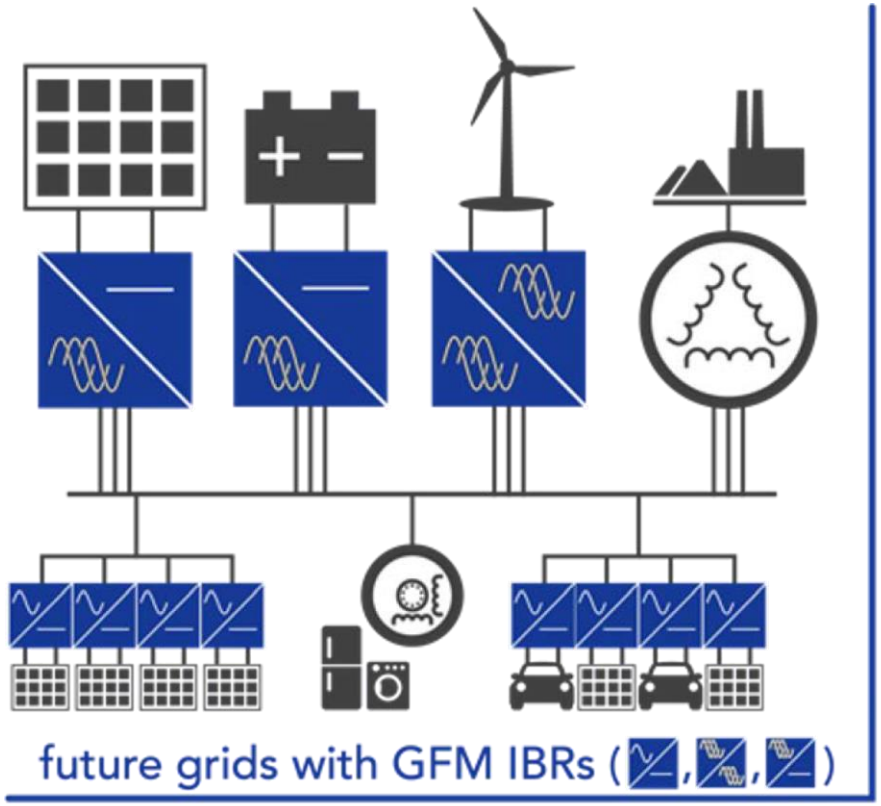
The **UNIFI Consortium** is a forum to address fundamental challenges in the seamless integration of grid-forming (GFM) technologies into power systems of the future

Bringing the industry together to unify the integration and operation of inverter-based resources and synchronous machines

Three major focuses:

- Research & Development
- Demonstration & Commercialization
- Outreach & Training

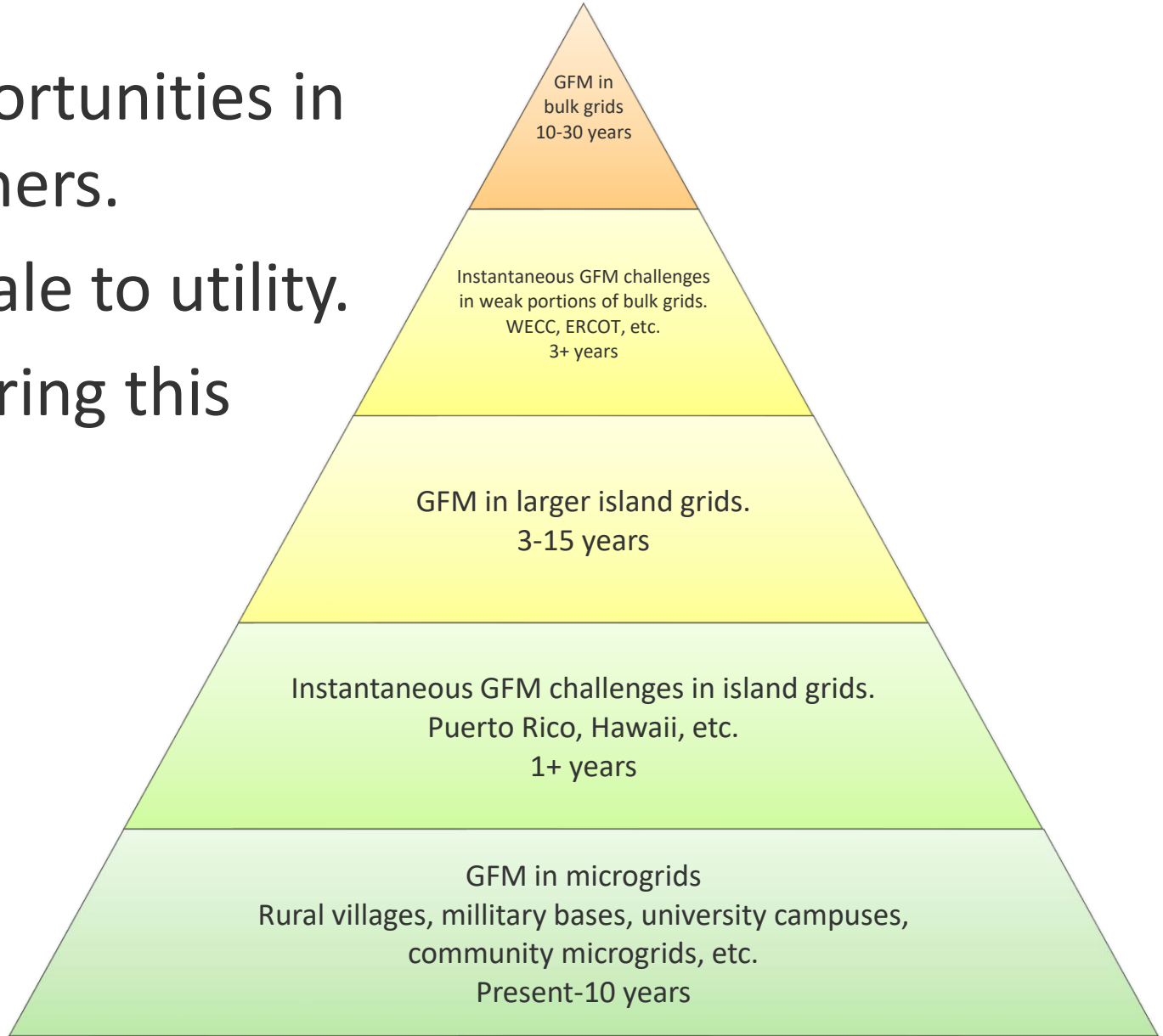
DOE Funding for 5 years – Organization will be sustainably funded with Memberships during and after the initial 5 years



Conclusion

- IBRs bring challenges and opportunities in black start as well as in the others.
- Lots of miles to go from lab scale to utility.
- R&D will be a key enabler to bring this reality.

Ref: GFM inverter roadmap.



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Senior Engineer, National Renewable Energy Lab.
Email: Gabsu.Seo@nrel.gov
Profiles: NREL, Google, LinkedIn

Thank you

Want to learn more about research and development works at NREL for this space?

- Black start of power grids with inverter-based resources
- Grid-forming inverter controls
- Cybersecurity for future electric grid
- Autonomous energy systems
- Grid modernization

www.nrel.gov

NREL/PR-5D00-82258

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Black Start in a Highly Renewable Environment

Mike Bryson
Sr. VP – Operations
PJM Interconnection

NARUC
February 24, 2022

Groundwork

Backup Generation

- Requirement for immediate power for prolonged periods

Storm Restoration

- Priority of restoration

System Restoration

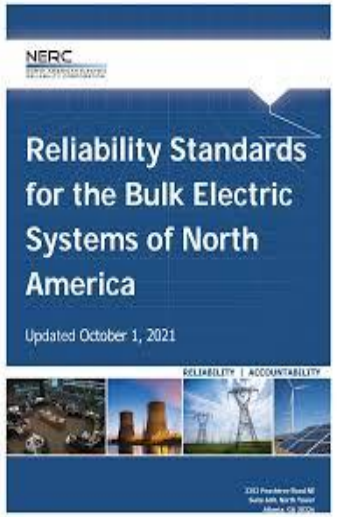
- Black start
- Large areas of the system
- Tie lines preferred over black start resources

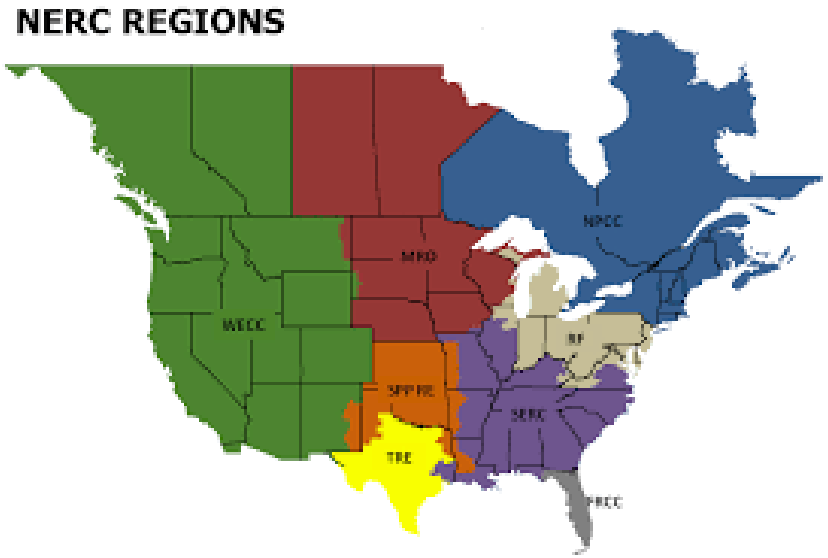
Black Sky Scenario

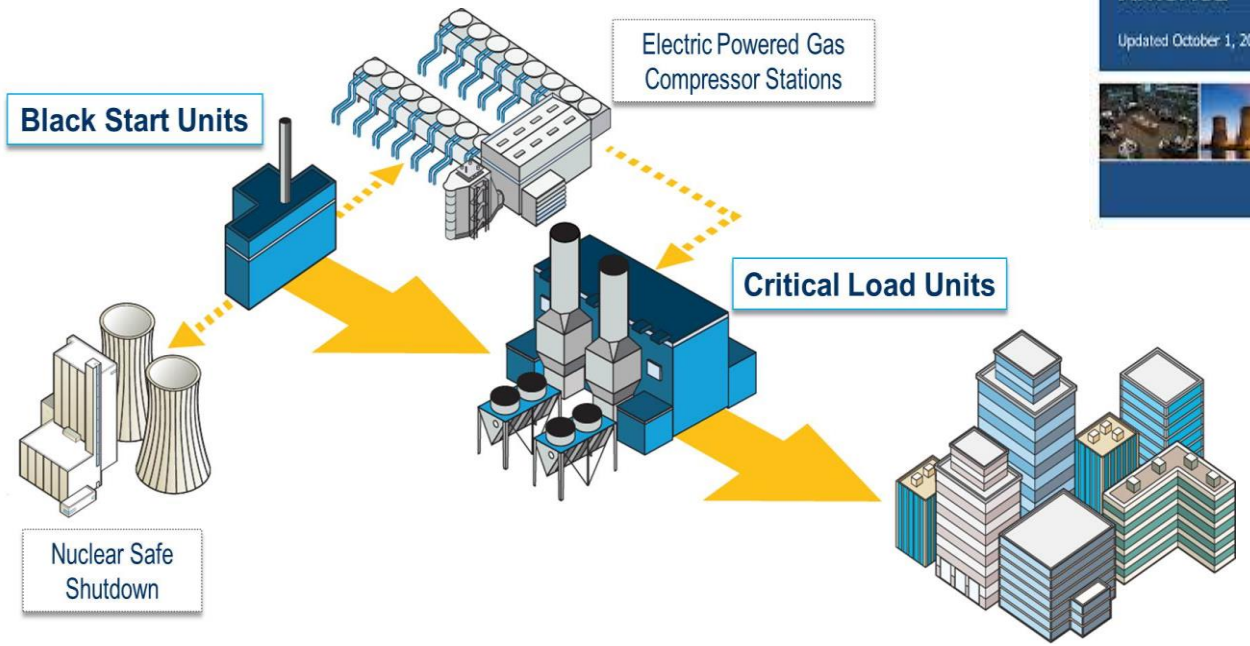
- Prolonged periods of outages based on major infrastructure damage
- Independent islands
- Distributed resources
- Renewables
- Potential for black start resources

Black Start / System Restoration

- Standard core competency across all utilities in the U.S.
- Approach governed by NERC Standards – EOP-005 & EOP-006
- Generally a bottom-up approach







System Restoration: PJM Approach

PJM Critical Load Definition

- Power to start critical load generating units (units with a hot start time of 4 hours or less)
- Nuclear safe shutdown power
- Power for critical gas infrastructure (electric-powered gas compressor stations)

Black Start Units

- Ability to self-start / close to a dead bus within 3 hours
- Provide power to serve “critical loads”

Restoration Process

Black Start

- Black start units are brought online without outside power from the system

Critical Load

- Cranking paths from BSRs to CL are developed based on TO restoration plans
- Additional steps, such as picking up load blocks or bringing on other generation, are taken as needed to stabilize the cranking path and island

System Control

- System voltages and frequency need to be controlled to avoid tripping or damaging equipment
- Tripping the restoration island results in having to start the restoration over

Black Start Resources – Renewables vs. Thermal

Black Start Unit Selection Criteria

Technical Feasibility

- Reliability analysis / EOP-005 studies
- Unit location / characteristics
- Operational / environmental restrictions

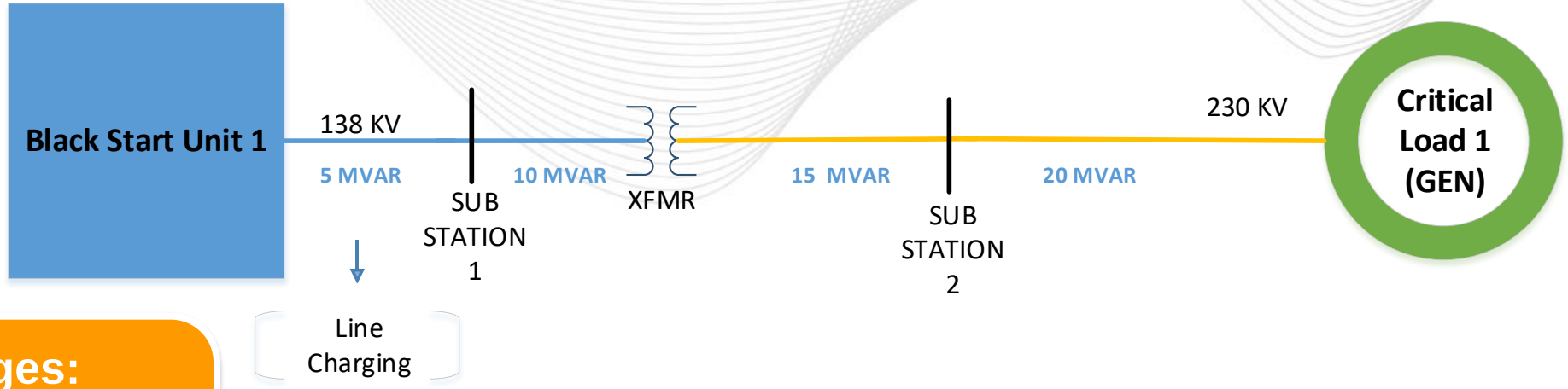
Fuel Assurance

- Dual fuel with on-site preferred
- Multiple pipelines with Firm gas

Operational / Environmental Restrictions

- Ramping, load following, minimum operating level, voltage control
- Permitting restrictions

Primary Cranking Path

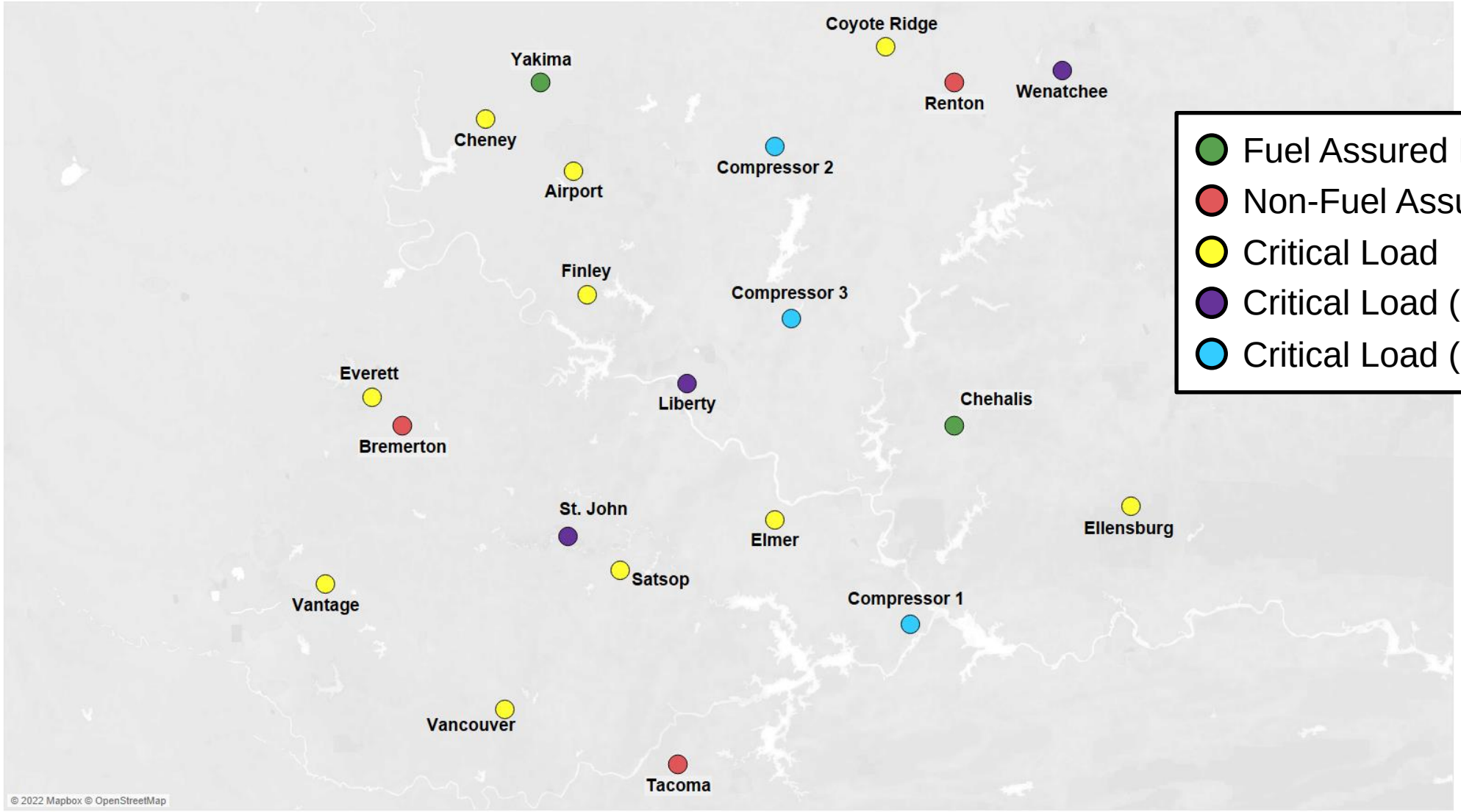


Challenges:

- Multiple steps
- Failures along the way necessitate a restart

Cranking Path	Substations	Lines	Generators	Load
Primary Path BS 1 to CL 1	2	4	0	0

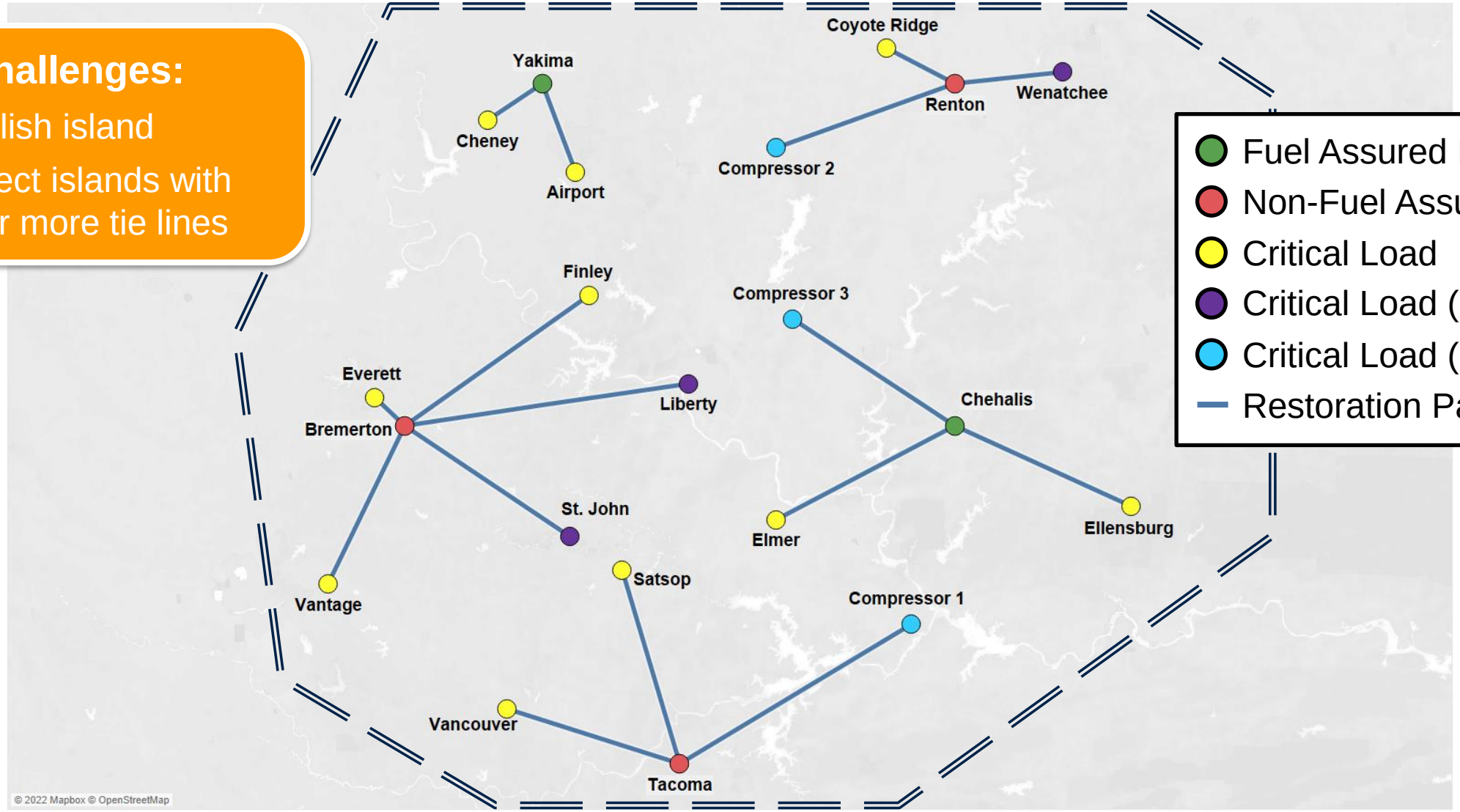
Hypothetical Case: Blacked Out Zonal Layout



Hypothetical Case: Standard Restoration

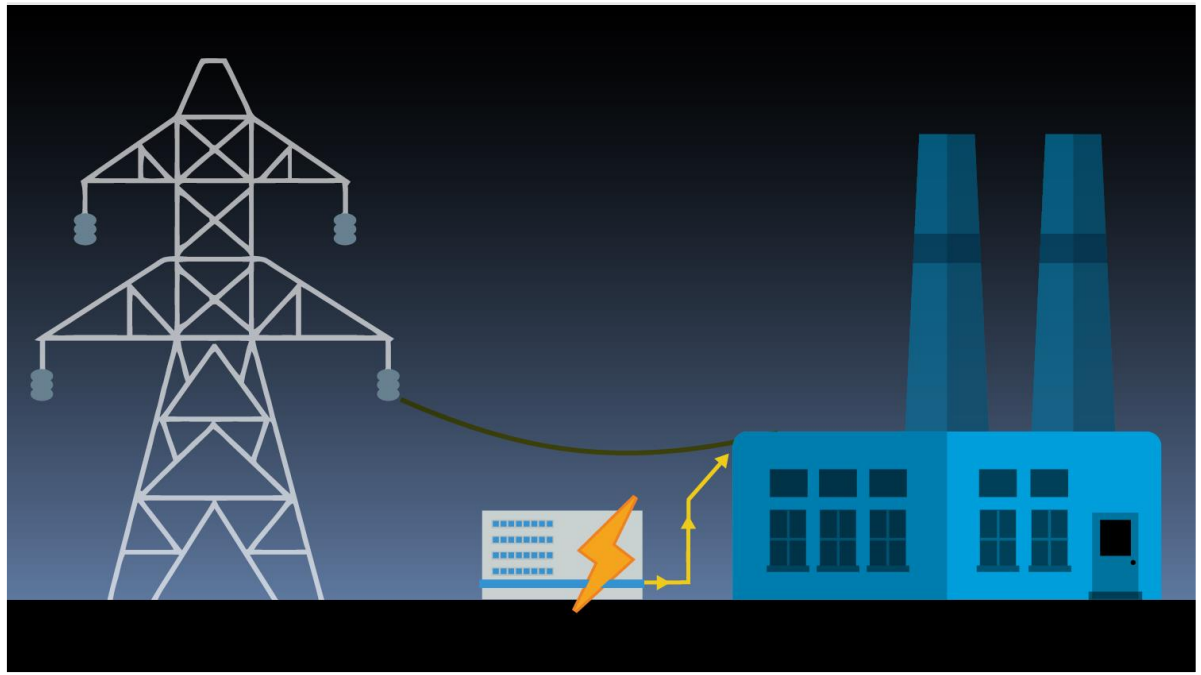
Challenges:

- Establish island
- Connect islands with one or more tie lines



Industry Research

- Intermittent resources have competitive hurdles to become fully functional black start but are advancing
- Progressive look toward hybrid generation using multiple resource types along with storage
- Research and developers have demonstrated the use of storage as a cranking unit for a black start resource as well as “grid-forming” inverter technology



System Restoration and the Changing Resource Mix

1. Current black start resources are typically oil or natural gas units. How can renewable resources, storage technology, distributed energy resources (DER) or alternative technologies be utilized for black start?
2. How and when, during a restoration event, are renewable generators reliably allowed to resume normal operations? Output restrictions will be required for system control (stability, thermal, voltage, power balance).
3. Adequate standards and enforcement in place to ensure DER can meet performance expectations during restoration (and normal) operations – multi-jurisdictional challenges.
4. State renewable policies should allow for transition of reliability services such as black start.
5. PJM has evaluated valid storage-based resources as black start resources.
6. Renewable resources have the potential to provide black start in a hybrid configuration.

NARUC Innovation Webinar series

One Thursday each month, 3-4pm ET

All NARUC members and stakeholders are invited

March 17, 2022: Aligning EV Customer Charging with Grid Needs

April 21, 2022: Leveraging Distributed Energy Resource Capabilities through Transactive Energy

May 19, 2022: Collaborating with University-Sponsored Energy Innovation Centers

June 16, 2022: Alleviating the Energy Burden: Regulatory Tools to Increase Energy Affordability

Learn more and register at: https://www.naruc.org/cpi-1/innovation-webinars/

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