



Paradigm Shift: Black Start from Inverter-Based Resources -IBR-driven power system black start

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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

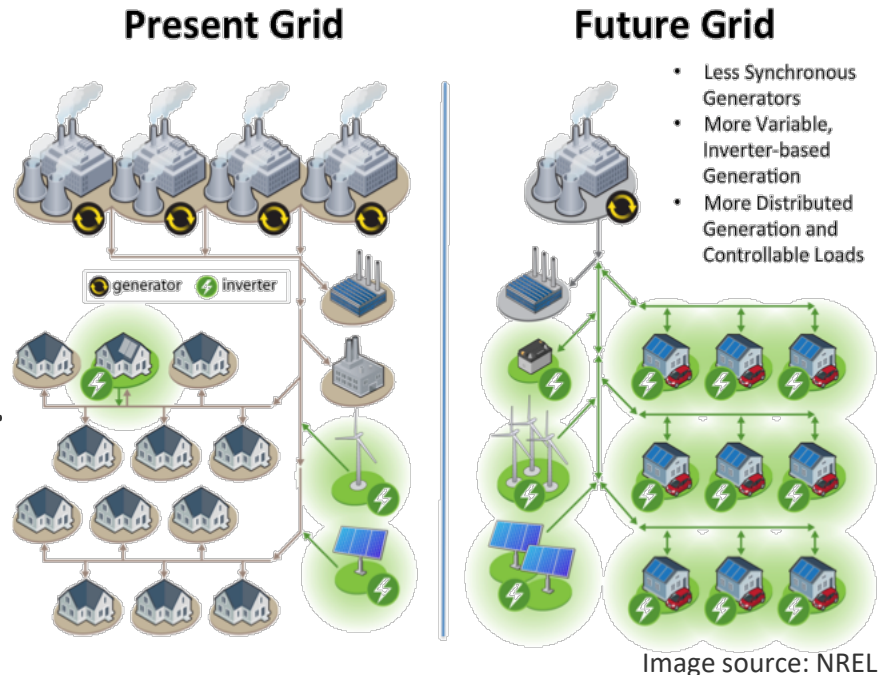


Fig.1. Future grid with high level of renewables.

*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

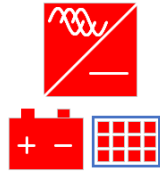
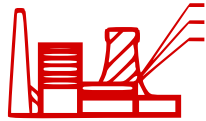


Image source: NREL



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

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

*pu: per unit

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*.

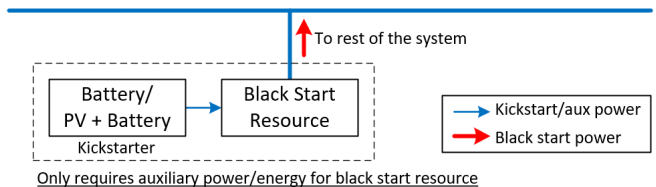
*IBR: Inverter-Based Resources

*SCR: Short Circuit Ratio

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

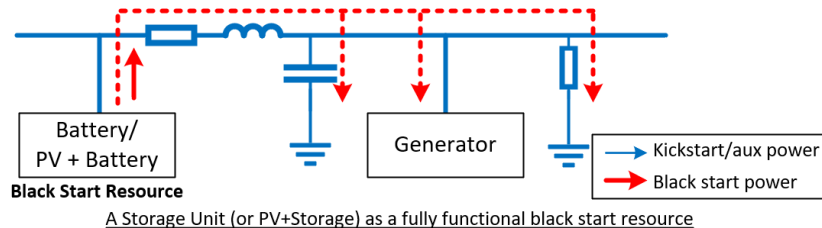
Renewable + Storage: 4 Potential Use Cases

#1: BSR Kickstarter: Co-located



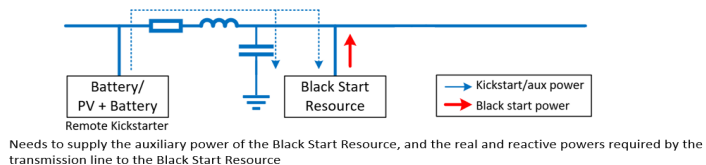
*Well defined & contained. Use cases already seen.
Near-future solution. Limited use, 1:1 match.*

#3: Full BSR w/ single GFM unit



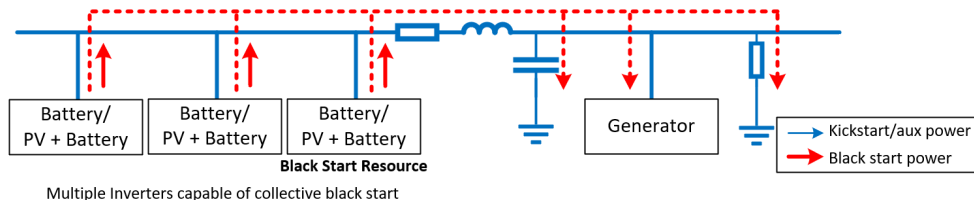
Replaces current BSRs. May require more sectionalized systems to reduce the baseline load and/or demand in the cranking path.

#2: BSR Kickstarter: Not co-located



*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

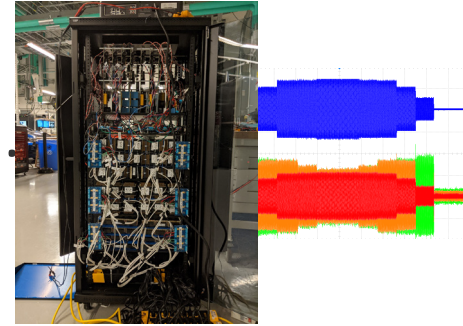


*Futuristic, but maybe ultimate solution. Can cover wide area with
aggregated capacity. Most resilient; not relying on specific resources;
autonomy and adaptive operation can be obtained.
Involves complexity. More understanding and standardization needed.*

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

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

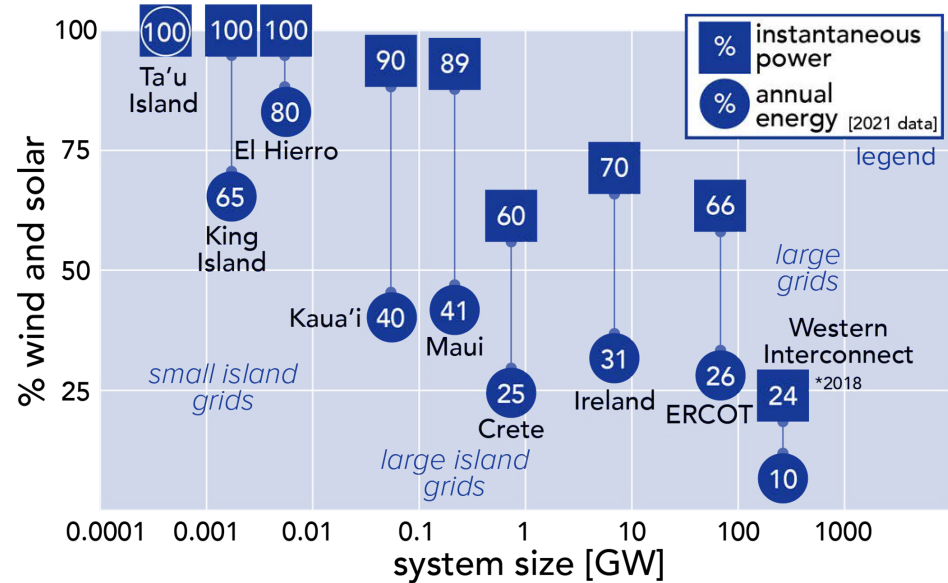
Vision

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



What is UNIFI?

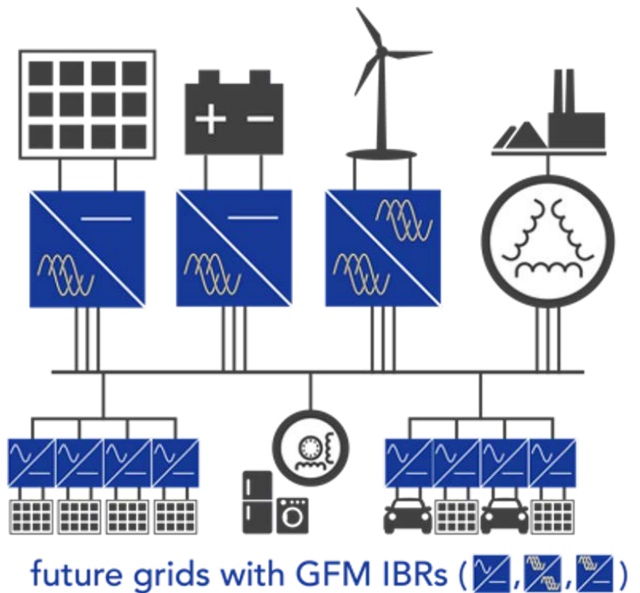
The **UNIFI Consortium** is a forum to address fundamental challenges in the seamless integration of grid-forming (GFM) technologies into power systems of the future

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



future grids with GFM IBRs



stakeholders: academia, industry, labs, utilities, operators



research & development



demonstration & commercialization



outreach & training

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.



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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](#)

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