The Need for Grid-forming (GFM) Inverters in Future Power Systems

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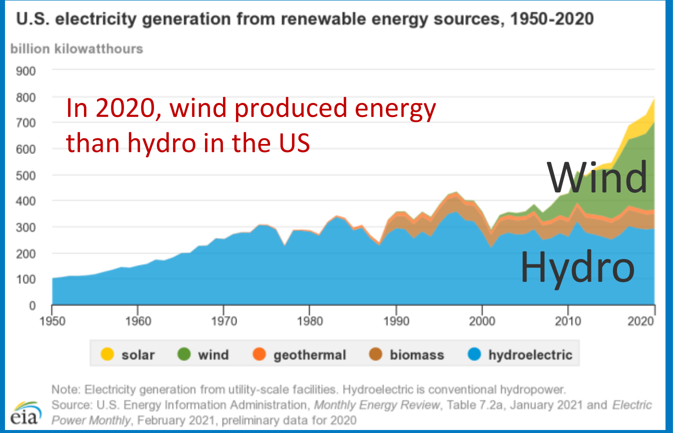
Photo: NREL

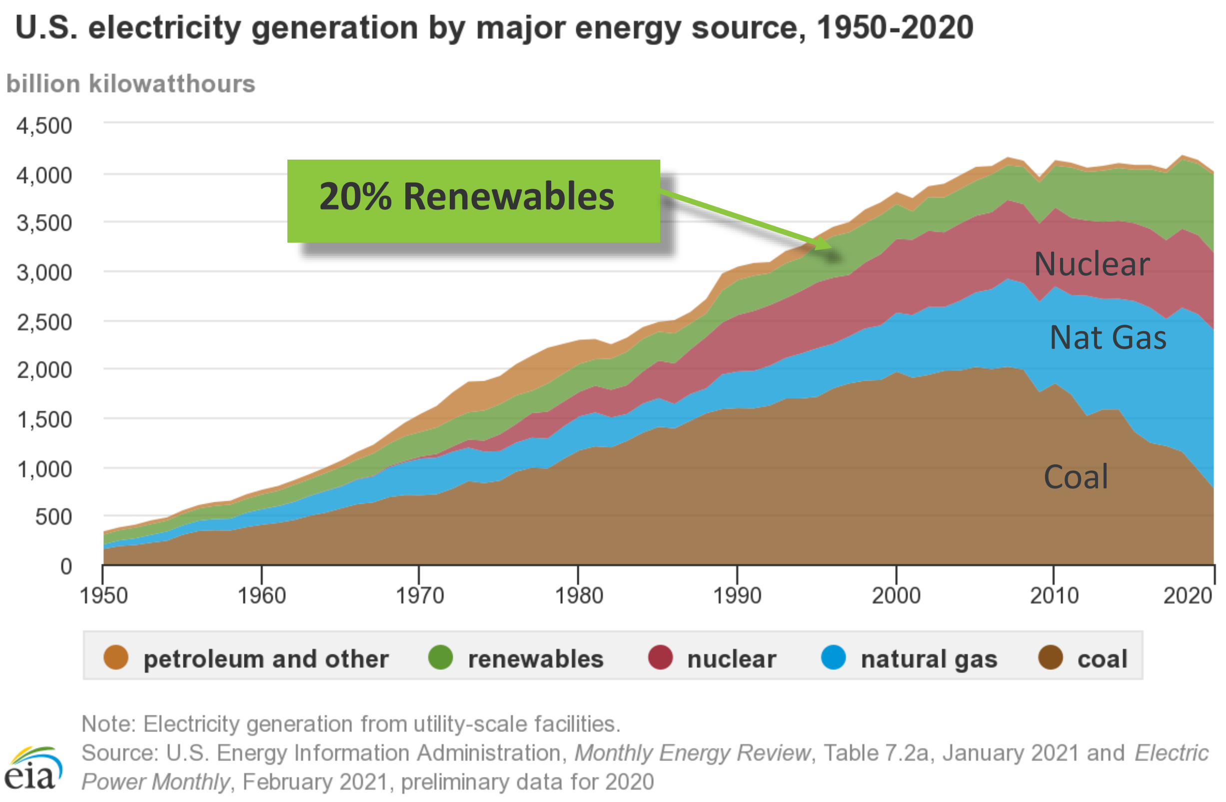
The US Energy Supply is Shifting

Since 2010:

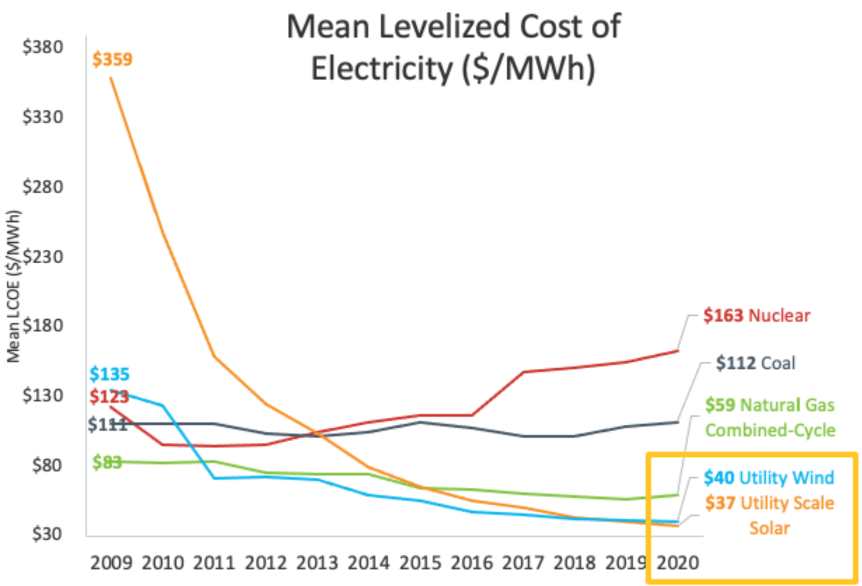
- Coal has declined
- Gas and Renewables have increased
- Nuclear and Hydro have remained steady



2020 was the first year that Renewables surpassed either Nuclear or Coal in energy generation in the US.

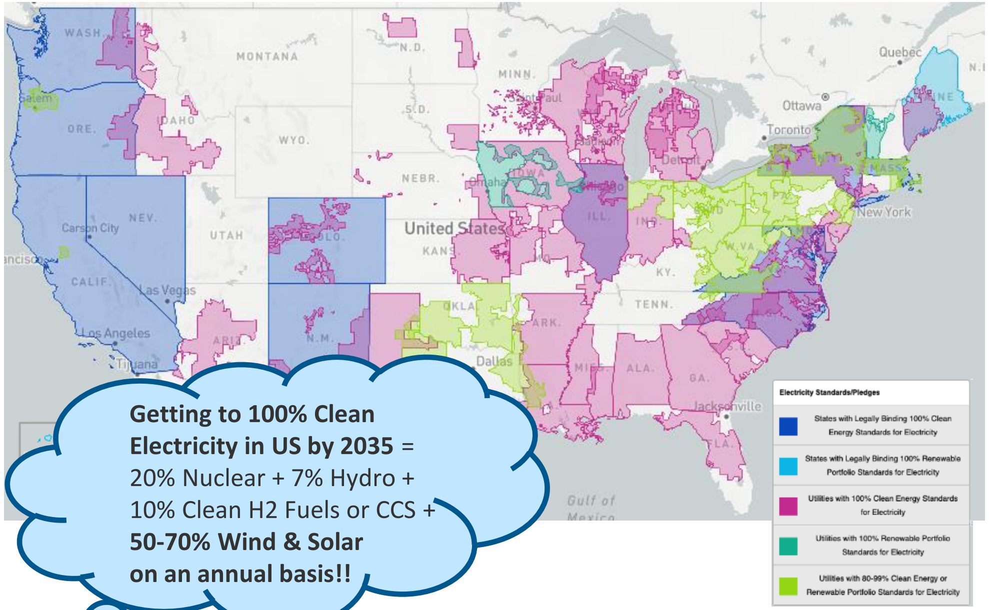


Economics of Wind and Solar as well as Clean Energy Goals are driving Renewable Energy Deployments



State and Utility Decarbonization Commitments

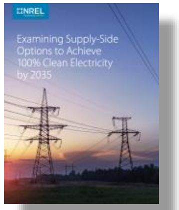
https://www.catf.us/2020/10/state-and-regional-decarbonization-commitments/



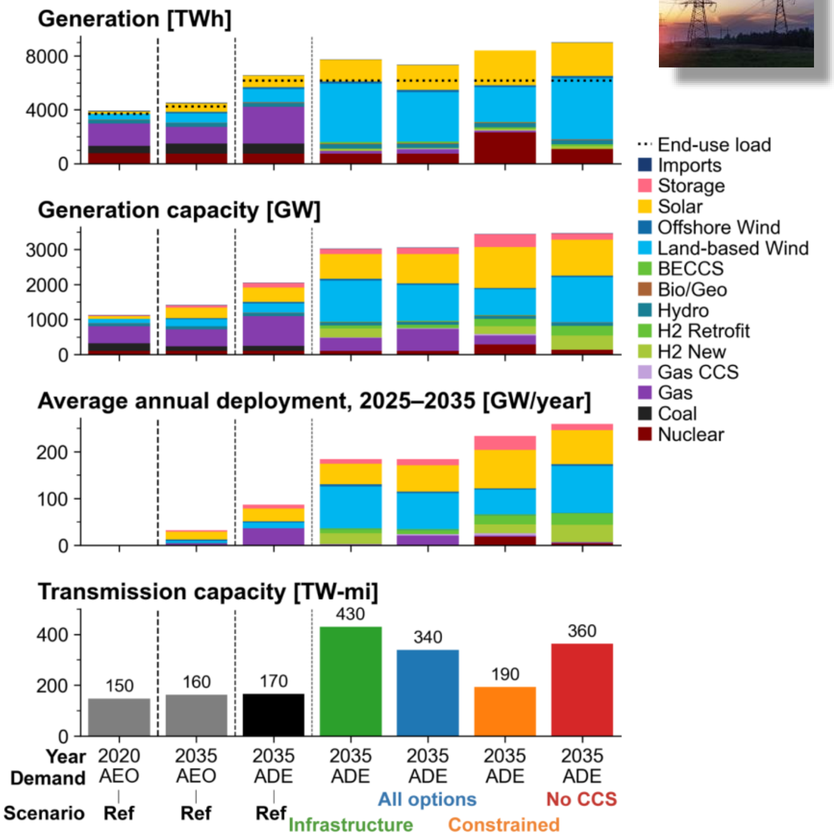
Getting to 100% Clean Electricity in US by 2035 =
20% Nuclear + 7% Hydro +
10% Clean H2 Fuels or CCS +
50-70% Wind & Solar on an annual basis!!

In 2021, wind and solar provided 13% of US electricity

NREL 100% by 2035 Study



- In all modeled scenarios, new clean energy technologies are deployed at an unprecedented scale and rate to achieve 100% clean electricity by 2035.
- As modeled, **wind and solar energy provide 60%–80% of generation** in the least-cost electricity mix in 2035, and the overall generation capacity grows to roughly three times the 2020 level by 2035—including a combined 2 terawatts of wind and solar.

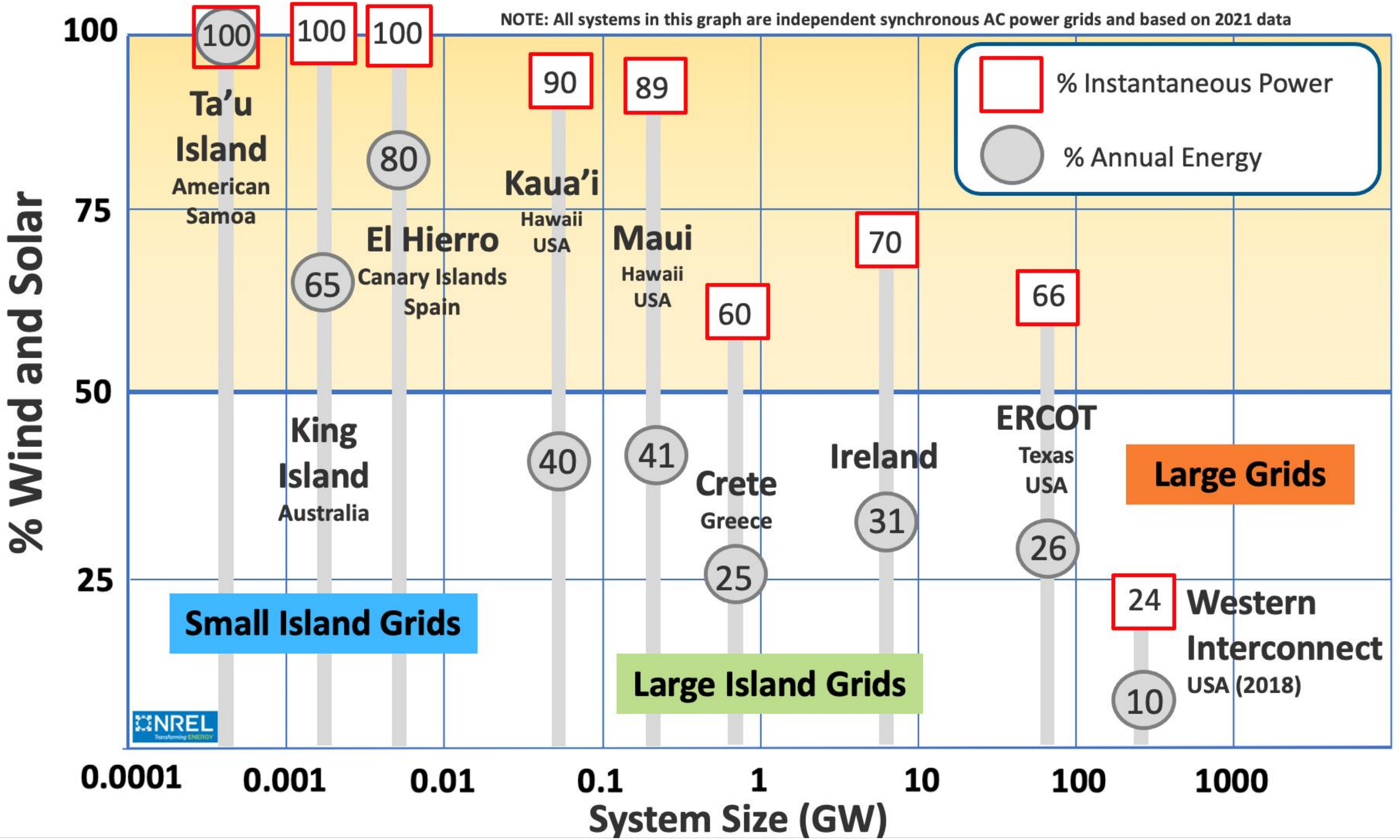


Denholm, Paul, Patrick Brown, Wesley Cole, et al. 2022. *Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035*. Golden, CO: National Renewable Energy Laboratory. NREL/TP- 6A40-81644. https://www.nrel.gov/docs/fy22osti/81644.pdf

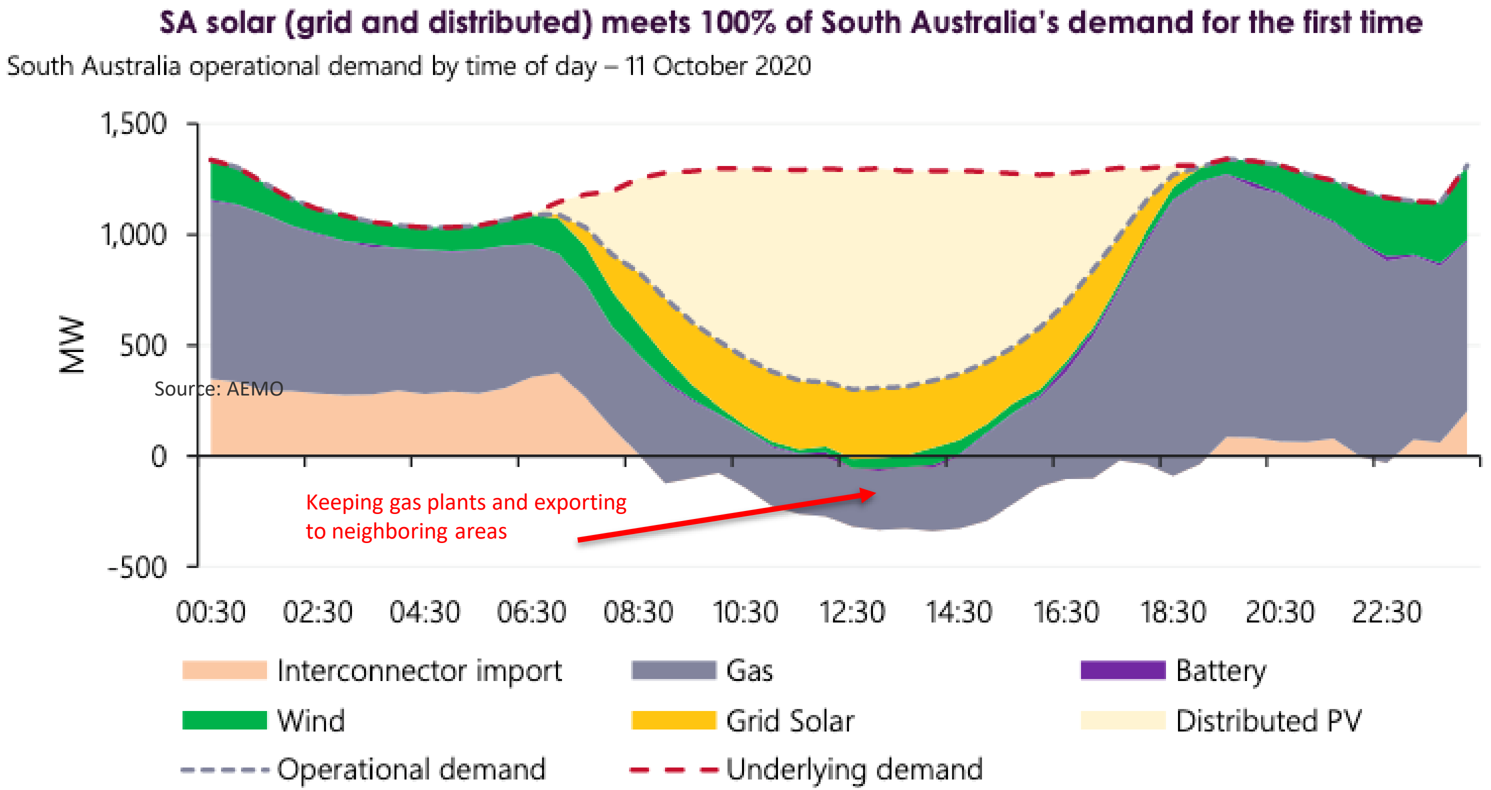
Current Power Systems Operating with Variable Renewable Energy

(what do we know)

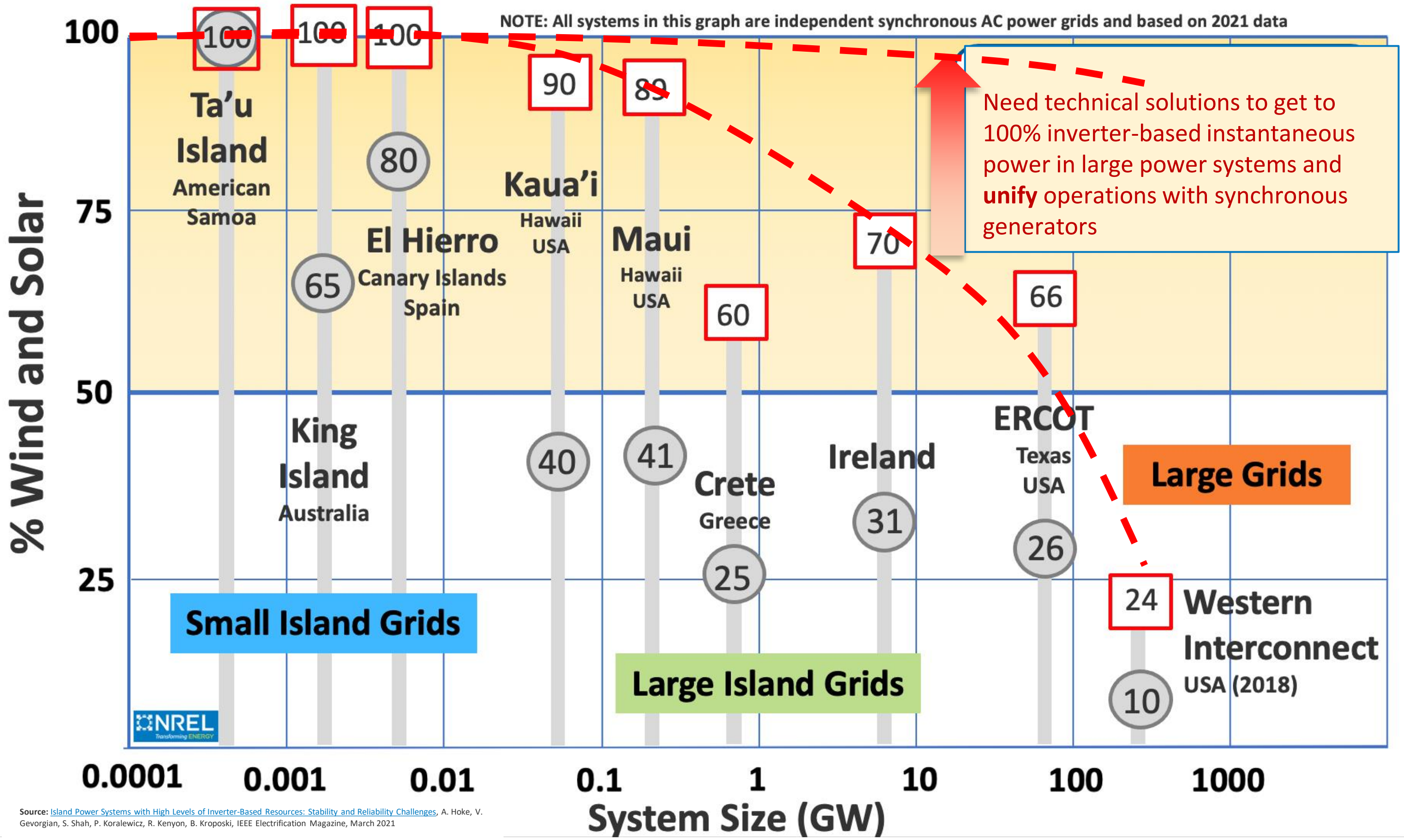
Current Power Systems Operating with Inverter-based Resources (IBR)



South Australia – Already at 100% IBR (but…)



To get closer to 100% IBR, you need grid-forming (GFM)



Source: Island Power Systems with High Levels of Inverter-Based Resources: Stability and Reliability Challenges, A. Hoke, V. Gevorgian, S. Shah, P. Koralewicz, R. Kenyon, B. Kroposki, IEEE Electrification Magazine, March 2021

Technical Challenges with Higher Inverter-based Resources

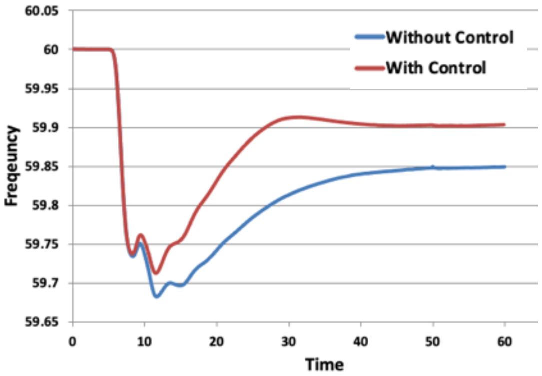
Challenges:

- Frequency Stability (Lower System Inertia)
- Voltage Stability and Regulation
- System Protection
- Grid Forming capability
- Black Start capability
- Control system interactions and resonances
- Cybersecurity

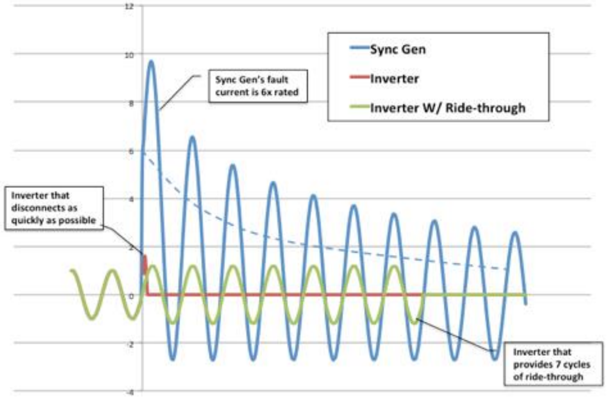
Source: B. Kroposki et al., "Achieving a 100% Renewable Grid – Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," http://ieeexplore.ieee.org/document/7866938/

Source: Blackstart of Power Grids with Inverter- Based Resources, H. Jain, G. Seo, E. Lockhart, V. Gevorgian, B. Kroposki, 2020 IEEE Power and Energy General Meeting: https://www.nrel.gov/docs/fy20osti/75327.pdf

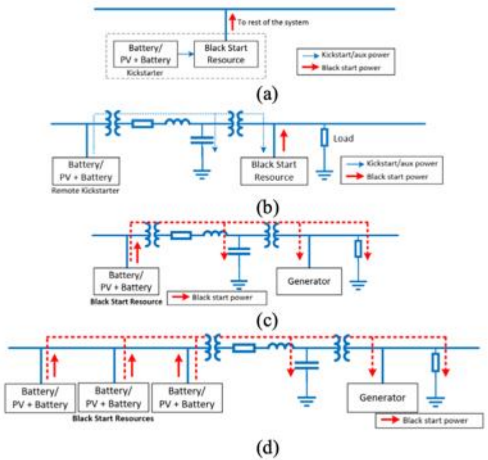
Stability



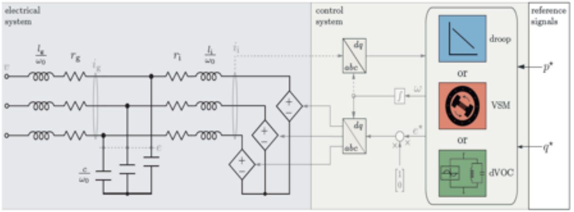
Protection



Grid-forming/Blackstart

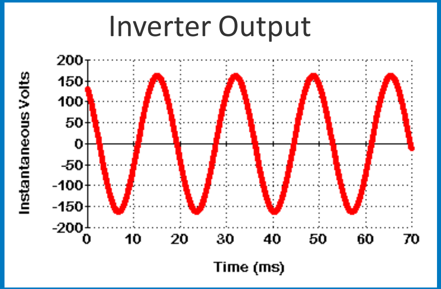


Control system interactions and resonances



Power System Oscillations

Grid Following (GFL) vs. Grid Forming (GFM)



- Assumes grid is already formed - Needs a grid to synchronize to
- Cannot make its own voltage sinewave
- Acts as a current source

- Can make its own voltage sinewave and acts as a voltage source
- Can synchronize to other sources
- Can blackstart the grid

Follower

Leader

Source: Lin, Yashen, Joseph H. Eto, Brian B. Johnson, Jack D. Flicker, Robert H. Lasseter, Hugo N. Villegas Pico, Gab-Su Seo, Brian J. Pierre, and Abraham Ellis. 2020. **Research Roadmap on Grid-Forming Inverters**. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-73476. https://www.nrel.gov/docs/fy21osti/73476.pdf.

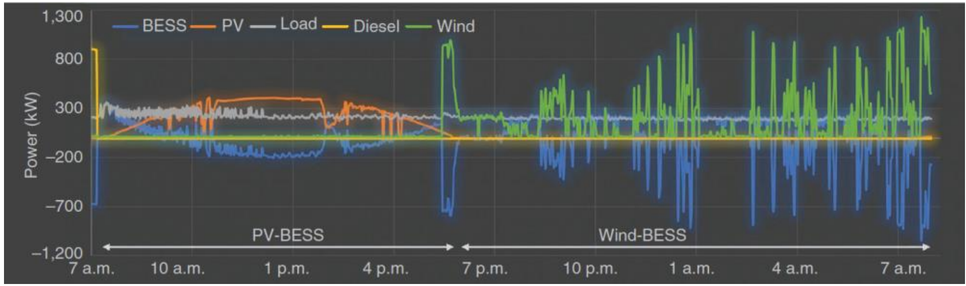
Operation of a 100% Wind-Solar-Battery Power Grid

(including Blackstart)

- 1.5MW Wind turbine, 450kW PV system, and 1MW/1MWh Battery
- NREL operated a 100% Wind-PV-Battery Grid for 72 Hours during a site outage
- Demonstrating new control techniques for these types of systems

Source: Island Power Systems with High Levels of Inverter-Based Resources: Stability and Reliability Challenges, A. Hoke, V. Gevorgian, S. Shah, P. Koralewicz, R. Kenyon, B. Kroposki, IEEE Electrification Magazine, March 2021

24-hour operation of Wind-PV-Battery System at NREL's Flatiron Campus



Benefits to Using Grid-forming (GFM) IBR

- Can maintain system voltage
- Very fast response to disturbances
- Blackstart capability
- Enable higher levels of wind and solar to be integrated in grids
- Improved system reliability and resilience
- Added economic value from providing essential grid reliability services

Global Landscape

Grid codes and roadmaps around the world recognize the role of grid-forming (GFM) inverter-based resources (IBRs)

Challenges

- Poor definitions of capability and functionality across technologies; lack of standardization
- Limited-to-no consensus on expected performance from unit and system levels
- Vendors/Manufacturers and Utilities/Operators appear to be locked in circular death spirals

Solutions

- Standardize Requirements
- Validate through models, controls, testing, demonstrations at scale
- Educate the industry

unifi consortium

universal interoperability for grid-forming inverters

unifi consortium

universal interoperability for grid-forming inverters

Co-led by NREL, University of Texas-Austin, and EPRI

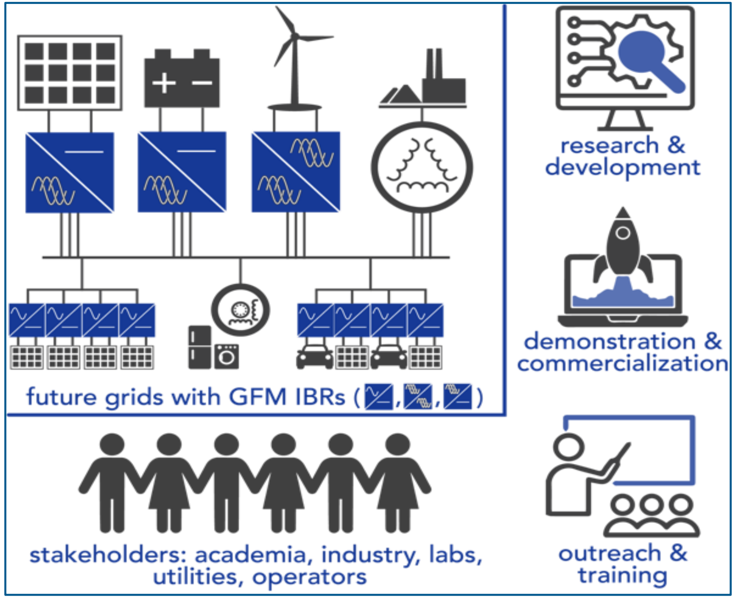
U.S. DEPARTMENT OF ENERGY

The **UNIFI Consortium** is a forum to address fundamental challenges to 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** (Modeling, Controls, Hardware, Integration & Validation)
- **Demonstration & Commercialization** (Large Demonstrations, IP Management, Products, Standards)
- **Outreach & Training** (Education, Workforce Development, Communications, Events)



For More Information: https://sites.google.com/view/unifi-consortium/home

UNIFI Organizational Structure

unifi consortium

Research & Development	Commercialization & Demonstration	Outreach and Training
• Modeling and Simulation • Controls • Hardware • Integration and Validation	• 20MW demonstration • IP Management • Domestic Products • Standards	• Education • Workforce Development • Communications • Events

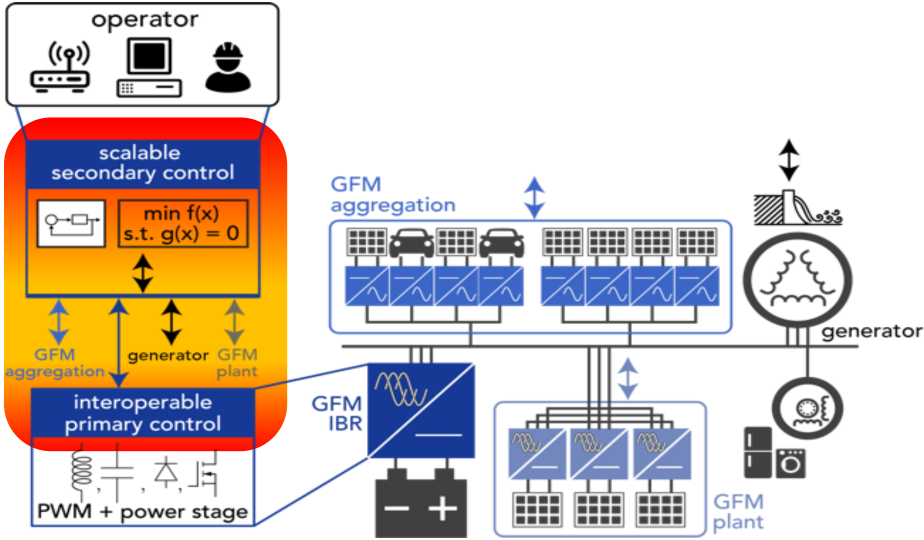
UNIFI Goals

Curate vendor- and technology-agnostic ***"UNIFI Specifications for GFM"*** that standardize performance and benchmark capabilities of GFM technologies across scales

- ***System Level - Guidelines*** *- that promote the coordinated and seamless operation of GFM technologies from multiple vendors while ensuring stable and reliable power grids*
- ***Inverter Level - Requirements*** *– that define GFM-IBR capabilities which are specified in a vendor-agnostic fashion to satisfy all system-level interoperability guidelines*

Convene continuous collaboration between inverter manufacturers (on one end) and system operators and utilities (on the other) to bridge gaps between power-systems and power-electronics industries

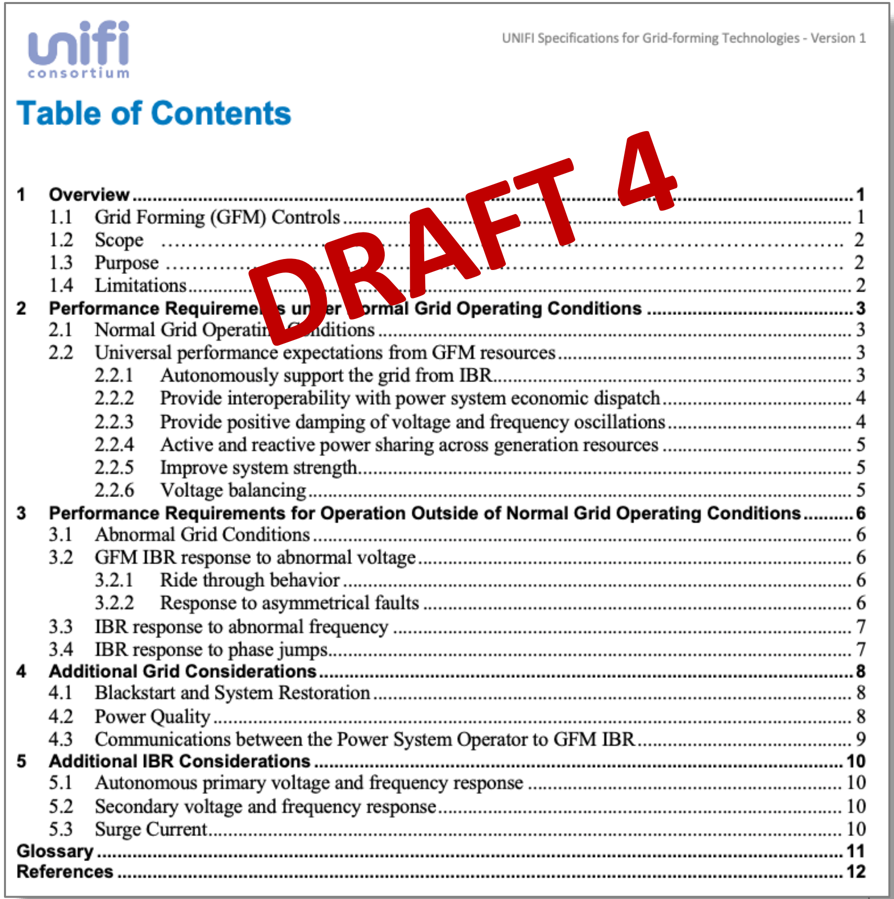
Cultivate inclusive culture and leverage member cooperation for sustained innovation



UNIFI Specifications for GFM Technologies

- The UNIFI Specifications for Grid-forming Technologies establish functional requirements and performance criteria for integrating GFM IBRs in electric power systems at any scale.

- Provide uniform technical requirements for the interconnection, integration, and interoperability of GFM IBR units and plants



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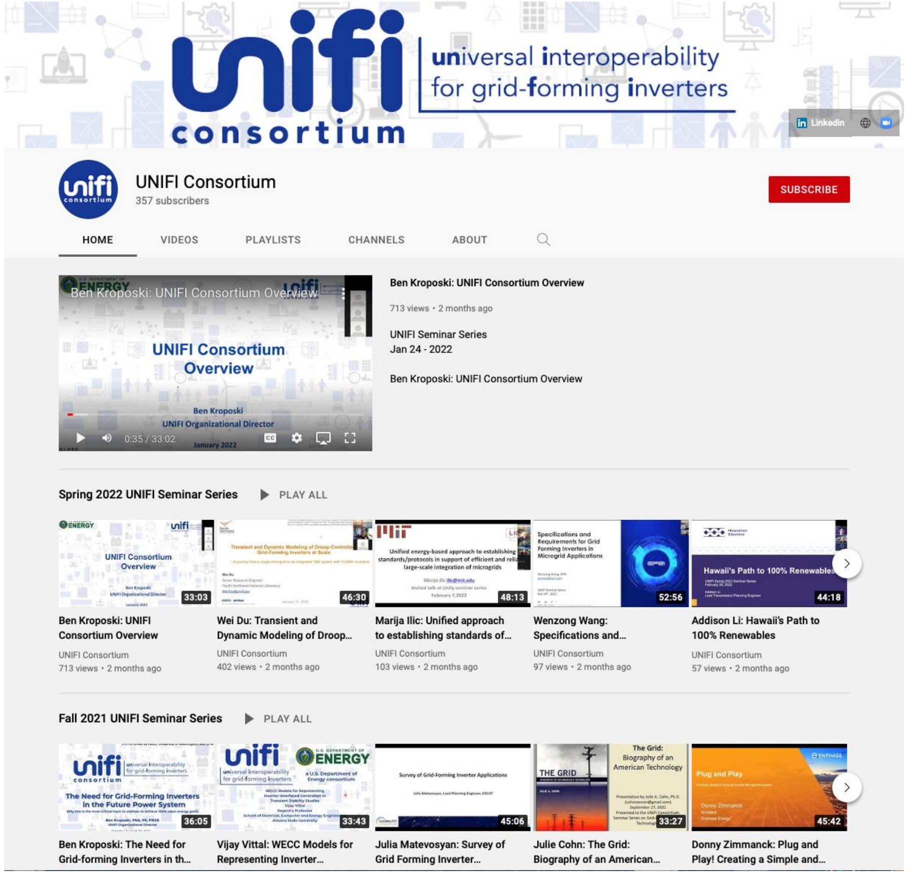
- join the UNIFI Group

YouTube

- visit the UNIFI Channel that hosts the Weekly Seminar Series every Fall and Spring



Thank you

NREL
Transforming ENERGY