Integrating High Levels of Inverter-based Resources into Power Grids

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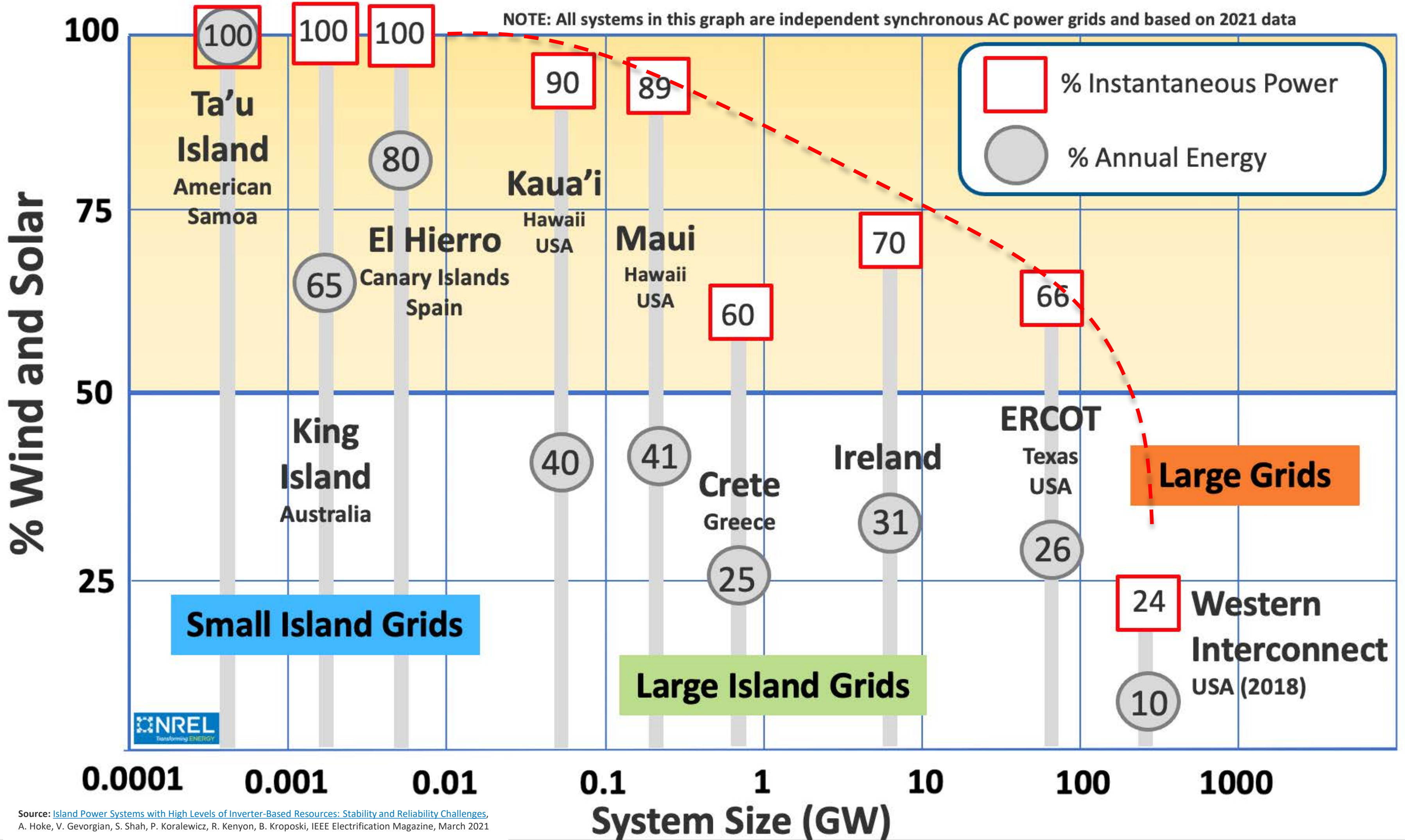
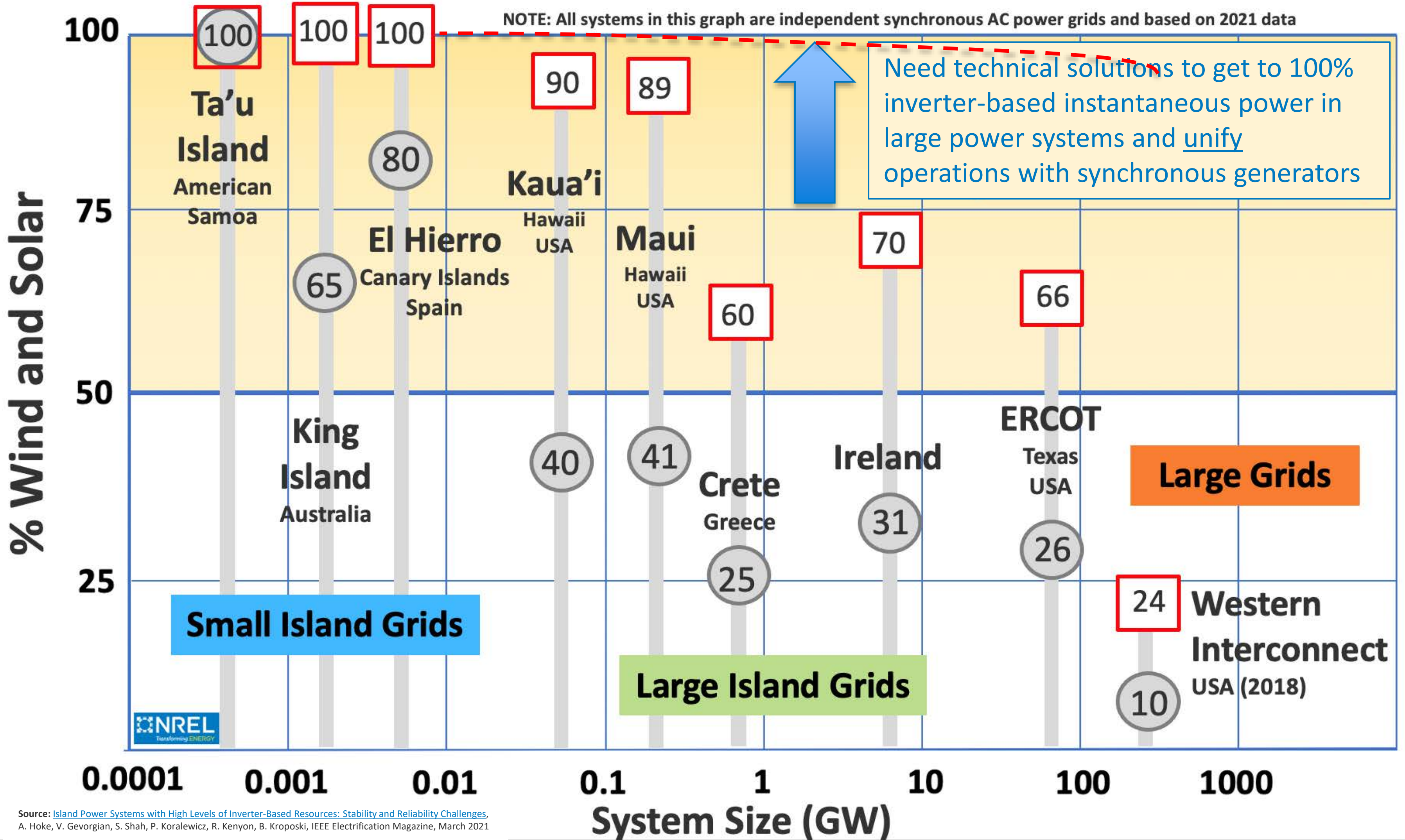
Current Power Systems Operating with Variable Renewable Energy

(what do we know)



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



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Technical Challenges with Higher Inverter-based Resources

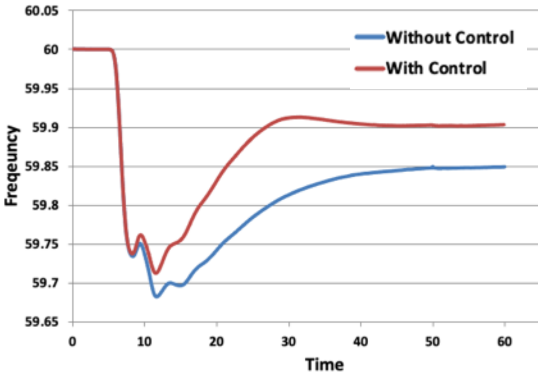
Challenges:

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

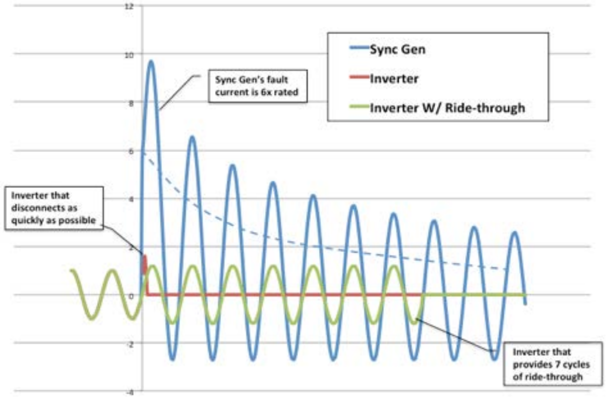
Source: B. Kroposki et al., "Achieving a 100% Renewable Grid – Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," http://ieeexplore.ieee.org/document/7866938/

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

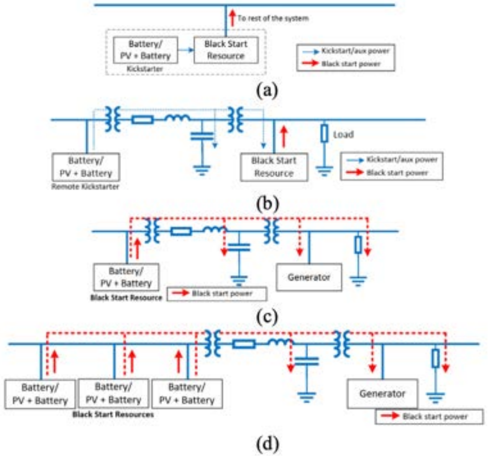
Stability



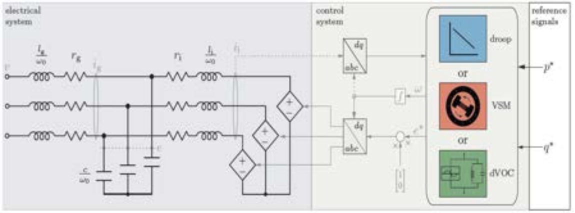
Protection



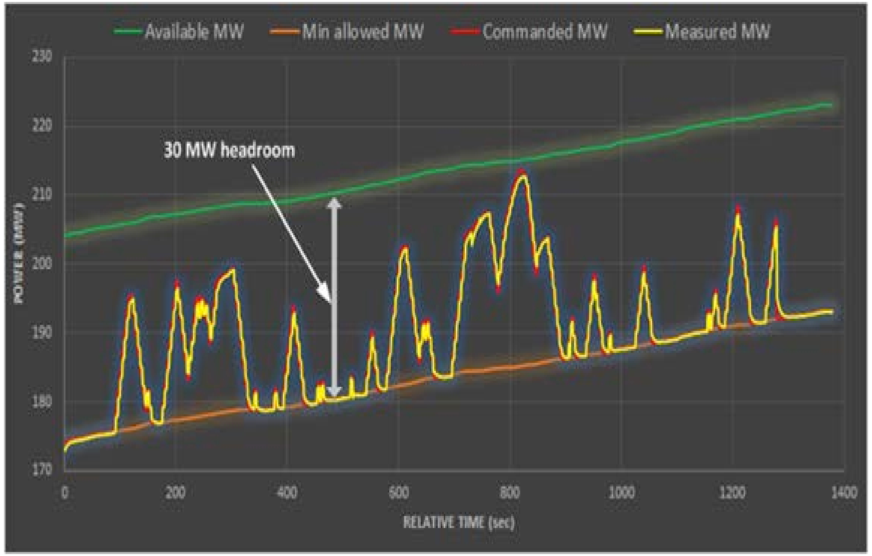
Grid-forming/Blackstart



Control system interactions and resonances



Inverter Based Resources can Provide Grid Services



NREL/FirstSolar/CAISO experiment: 300-MW plant following Automatic Generator Control (AGC) signal

300-MW PV Plant in California *(Photo from First Solar)*

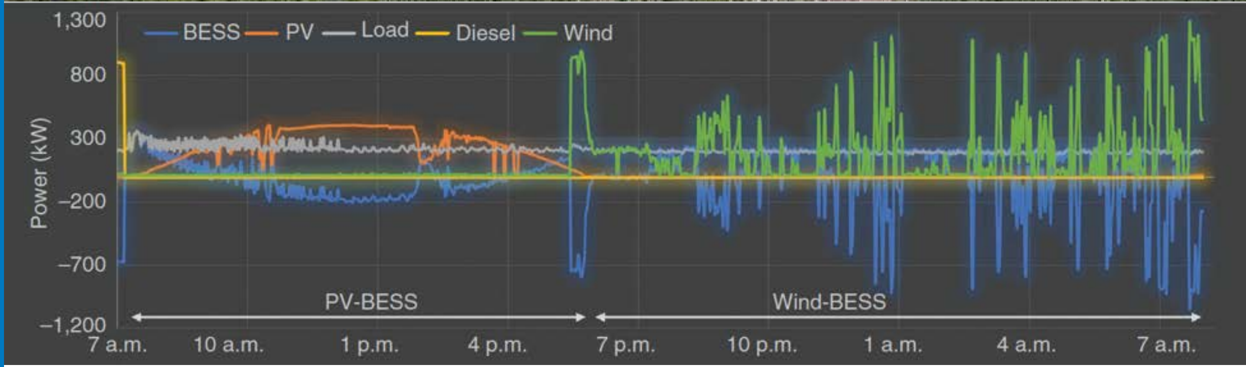
Demonstrated that PV plants (and wind power plants on next slide) can deliver essential grid services.

Source: C. Loutan, P. Klauer, S. Chowdhury, S. Hall, M. Morjaria, V. Chadliev, N. Milam, C. Milan, V. Gevorgian, *Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Power Plant*, http://www.nrel.gov/docs/fy17osti/67799.pdf

Operations 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



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

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

UNIFI Consortium

Unifying the integration and operation of inverters and synchronous machines

Universal Interoperability for Grid-forming Inverters (UNIFI) Consortium

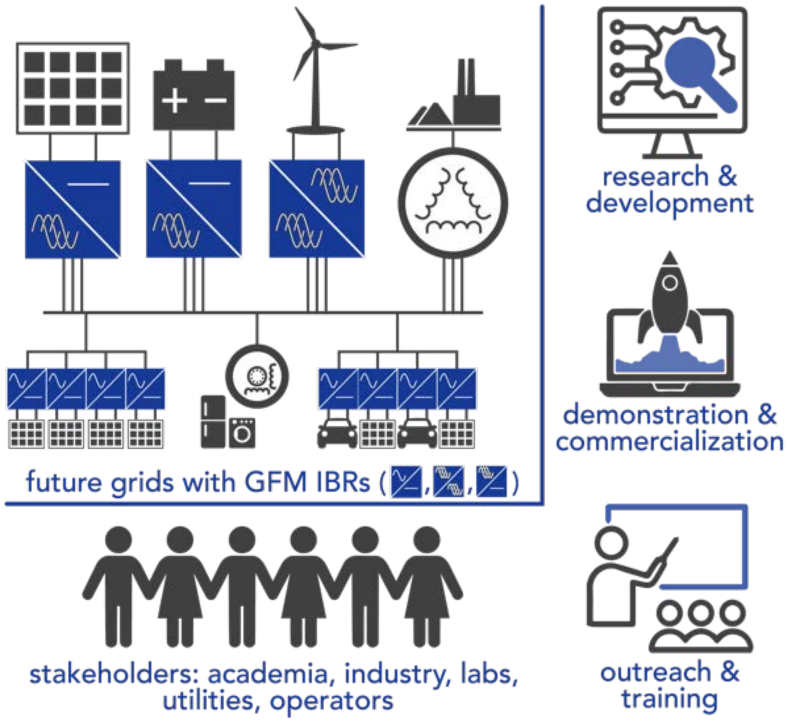
The **UNIFI Consortium** is a forum to address fundamental challenges in seamless integration of grid-forming (GFM) technologies into power systems of the future

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

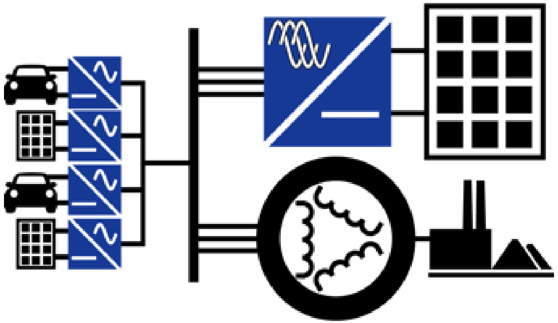
Team includes: 4 National Labs, EPRI,
12 Universities, and 20+ Industry partners



UNIFI – Standardizing Inverter-Machine Integration

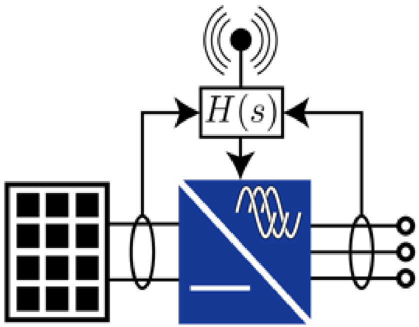
System-level Interoperability Guidelines

- Promote the coordinated and seamless operation of a plurality of GFM technologies from multiple vendors while ensuring stability and reliability
- Scalable Secondary Control; System-level Stability; Frequency and Voltage Regulation Metrics; Black-start Capabilities; Cyber-secure



Unit-level Functional Requirements

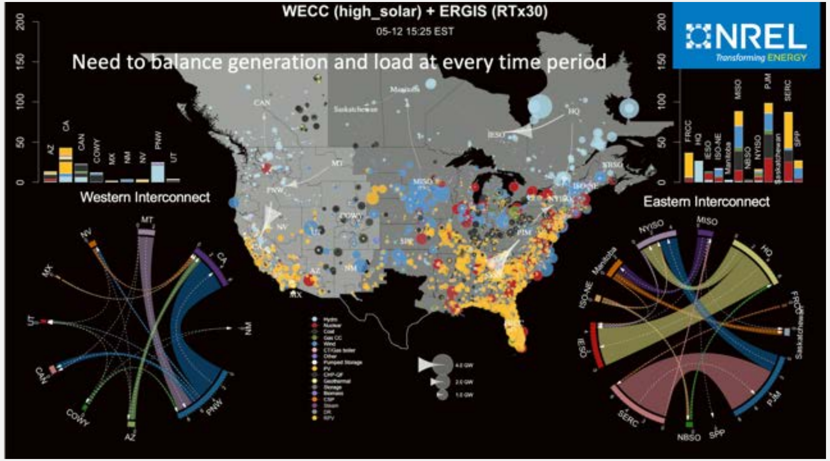
- Establish baseline GFM-IBR/plant/aggregation-level capabilities to comply with Interoperability Guidelines
- Real-time Control with Integrated Dynamic Protection; Autonomous Primary Control; Signal I/O Interface; GFM-IBR/Plant/Aggregation-level Stability; Power-quality and Protection Requirements



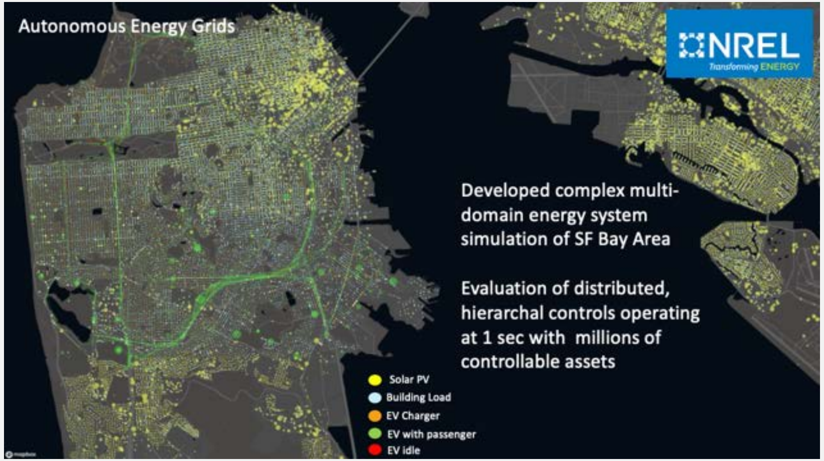
The Need for Better Measurements

As more inverter-based resources (PV, wind, batteries, EV, smart loads) are integrated into the grid, better, faster measurements of grid conditions will be useful to ensure proper grid operation.

Transmission System



Distribution System



Summary

- The power industry is seeing a shift towards 100% clean energy goals and each region has a variety of resources to tap into to meet these goals
- Inverter-based resources (IBR) are being integrated into power gids at increasing levels
- Several technical challenges exist for integration of IBR at high levels
- Better sensing, measurement, and data analytics can help solve some of these challenges
- All these challenges are solvable and we need to work together to address them

For More Information

- *Lazards's Levelized Cost of Energy Analysis-Version 14.0 – 2020* https://www.lazard.com/perspective/lcoe2020
- "Achieving a 100% Renewable Grid – Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," B. Kroposki et al., IEEE Power & Energy Magazine, Nov/Dec 2017 http://ieeexplore.ieee.org/document/7866938/
- *"Addressing technical challenges in 100% variable inverter-based renewable energy power systems",* B. Hodge et al., WIREs Energy and Environment, April 2020, https://onlinelibrary.wiley.com/doi/full/10.1002/wene.376
- *"WWSIS: Phase 3A",* N.W. Miller et al., http://www.nrel.gov/docs/fy16osti/64822.pdf
- *"Autonomous Energy Grids: Controlling the Future Grid with Large Amounts of Distributed Energy Resources",* B. Kroposki, A. Bernstein, J. King, D. Vaidhynathan, X. Zhou, C. Chang, and E. Dall'Anese IEEE Power and Energy Magazine, November/December 2020, https://ieeexplore.ieee.org/document/9229208
- *"Impact of Flexibility Options on Grid Economic Carrying Capacity of Solar and Wind: Three Case Studies",* P. Denholm, J. Novacheck, J. Jorgenson, and M. O'Connell, National Renewable Energy Laboratory, NREL/TP-6A20-66854, December 2016, https://www.nrel.gov/docs/fy17osti/66854.pdf
- *"The challenges of achieving a 100% renewable electricity system in the United States",* P. Denholm, D. Arent, S. Baldwin, D. Bilello, G. Brinkman, J. Cochran, W. Cole, B. Frew, V. Gevorgian, J. Heeter, B. Hodge, B. Kroposki, T. Mai, M. O'Malley, B.Palmintier, D. Steinberg, and Y. Zhang, Joule, May 2021, https://www.sciencedirect.com/science/article/pii/S2542435121001513
- *"Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States",* Mai, Trieu, Paige Jadun, Jeffrey Logan, Colin McMillan, Matteo Muratori, Daniel Steinberg, Laura Vimmerstedt, Ryan Jones, Benjamin Haley, and Brent Nelson, 2018, NREL/TP-6A20-71500. https://www.nrel.gov/docs/fy18osti/71500.pdf
- *"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 https://ieeexplore.ieee.org/document/9371251

Thank you

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