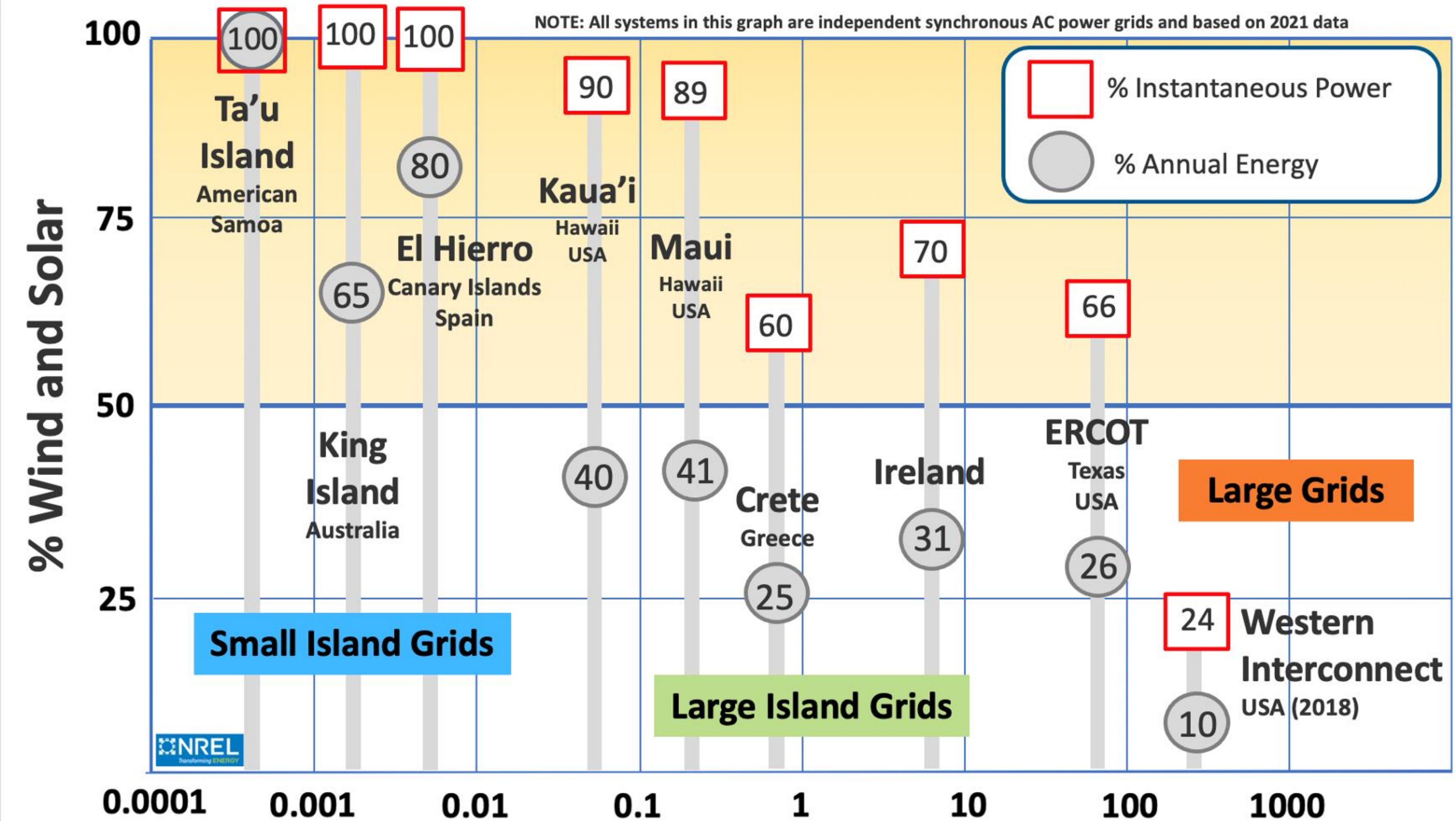
An IBR Future

Julia Matevosyan
Lead Planning Engineer,
Resource Adequacy

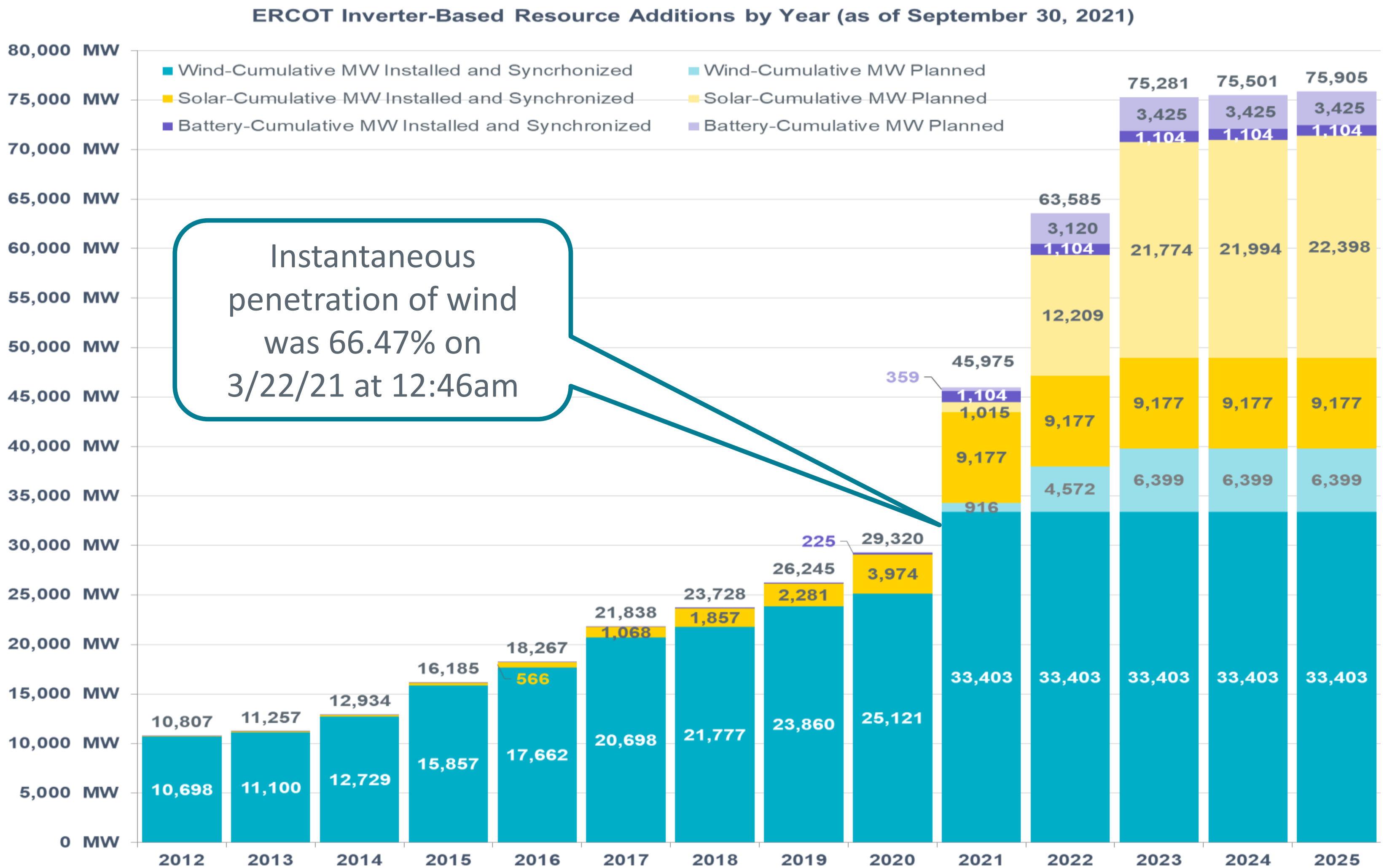
Parts of this presentation are based on the upcoming article: ***Future with Inverter-Based Resources, Finding Strength in Traditional Weakness***, by J. Matevosyan, J. MacDowell, N. Miller, B. Badrzadeh, D. Ramasubramanian, A. Isaacs, R. Quint, E. Quitmann, R. Pfeiffer, H. Urdal, T. Prevost, V. Vittal, D. Woodford, S.H. Huang, J.O'Sullivan, IEEE PES Power and Energy, Nov/Dec 2021

Where are we today?



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

Where are we headed?

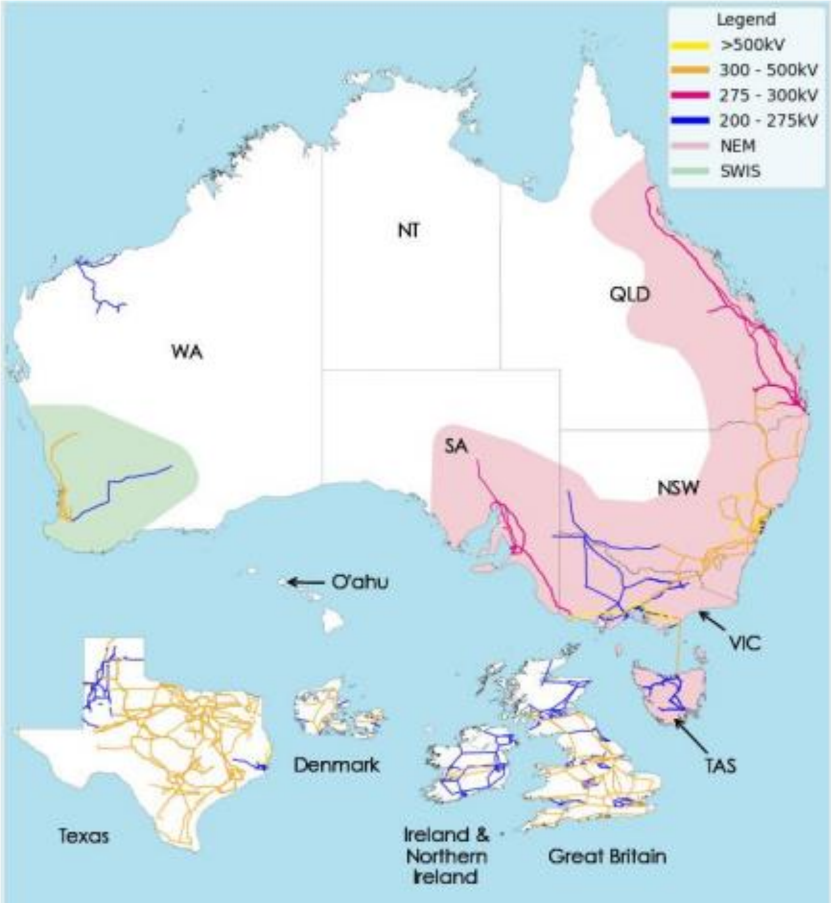


Cumulative MW Planned include projects with signed interconnection agreeements

What are the issues?

- System services inherently provided by synchronous machines are becoming scarce and need to be provided by IBRs
- **Frequency Stability**
  - Low inertia leading to high RoCoF after contingencies
  - Too fast frequency control may introduce oscillations in lower inertia systems
  - Common mode events resulting in loss of multiple IBRs
- **Voltage and Angular Stability**
  - Long distance high power transfer (wind and solar IBR often far from load)
  - Convergence of voltage stability limits on normal voltage range, brittleness of the system
  - Low system strength, voltage oscillations
- **Control Stability**
  - Control interactions

Will we all get see same issues at the same time?



Source: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Future-Energy-Systems/2019/AEMO-RIS-International-Review-Oct-19.pdf

- Small electrical (el.) islands, e.g. Hawaii, are the first to experience a number of issues at once, but are more meshed, coordination is easier, solutions are not necessarily scalable for larger systems;
- Medium el. islands, e.g. Ireland, more meshed, frequency is an issues before other challenges;
- Large el. islands, e.g. GB, ERCOT and mainland Australia, further challenges due to IBRs being far from load centers, in weak grid locations.
- Geographically Large Interconnected Systems, e.g. Central Europe, EI and WI in the U.S., no issues with IBRs for intact system, but high concerns during system splits.

System characteristics and IBR impacts

Frequency Stability Risks

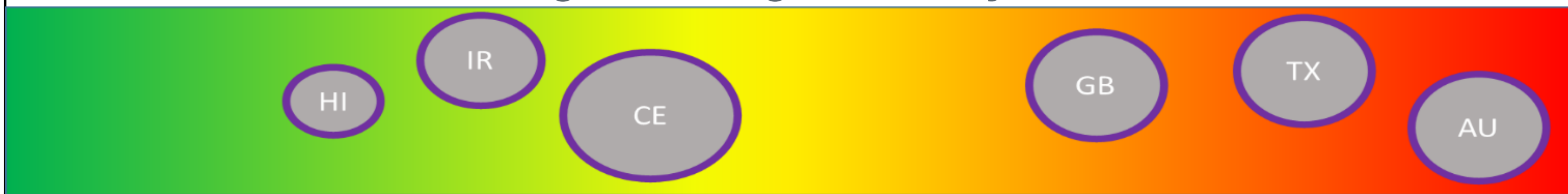
Occasional	Acute	Chronic
• Under intact system conditions, the system is relatively immune to fast and severe frequency events; • Challenges tend to be weighted towards congestion management.	• Frequency control concerns can limit operation; • Periods of poor frequency containment during credible events; • Control of frequency following possible or planned system splits is difficult.	• System often has risk of substantial frequency control problems and high RoCoF.

CE- Central Europe, TX-Texas, GB-Great Britain, AU-Australia, IR-Ireland, HI-Hawaii

Source: J. Matevosyan, et al. Future with Inverter-Based Resources, IEEE PES Power and Energy, Nov/Dec 2021

System characteristics and IBR impacts

Voltage and Angle Stability Risks



Local	Regional	System-wide
• Electrical distances are limited; • Interface collapse and system separations a remote concern; Local voltage support issues possible.	• Significant power imports and exports with dynamic constraints being an occasional factor; • Separation tends to be a high-impact low-frequency event.	• System has high power transfer over ac transmission interfaces, for which voltage instability and angular separation is a primary concern and often imposes operating constraints.

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System characteristics and IBR impacts

Control Stability Risks

Local	Regional	System-wide
• Some specific locations (e.g. individual nodes or small areas) with low system strength and risk of control interactions.	• Entire regions of very high IBR and little or no synchronous generation with ac transmission to other stronger areas.	• Entire system has extended periods of very low or even zero synchronous short circuit contribution.

CE-Central Europe, TX-Texas, GB-Great Britain, AU-Australia, IR-Ireland, HI-Hawaii

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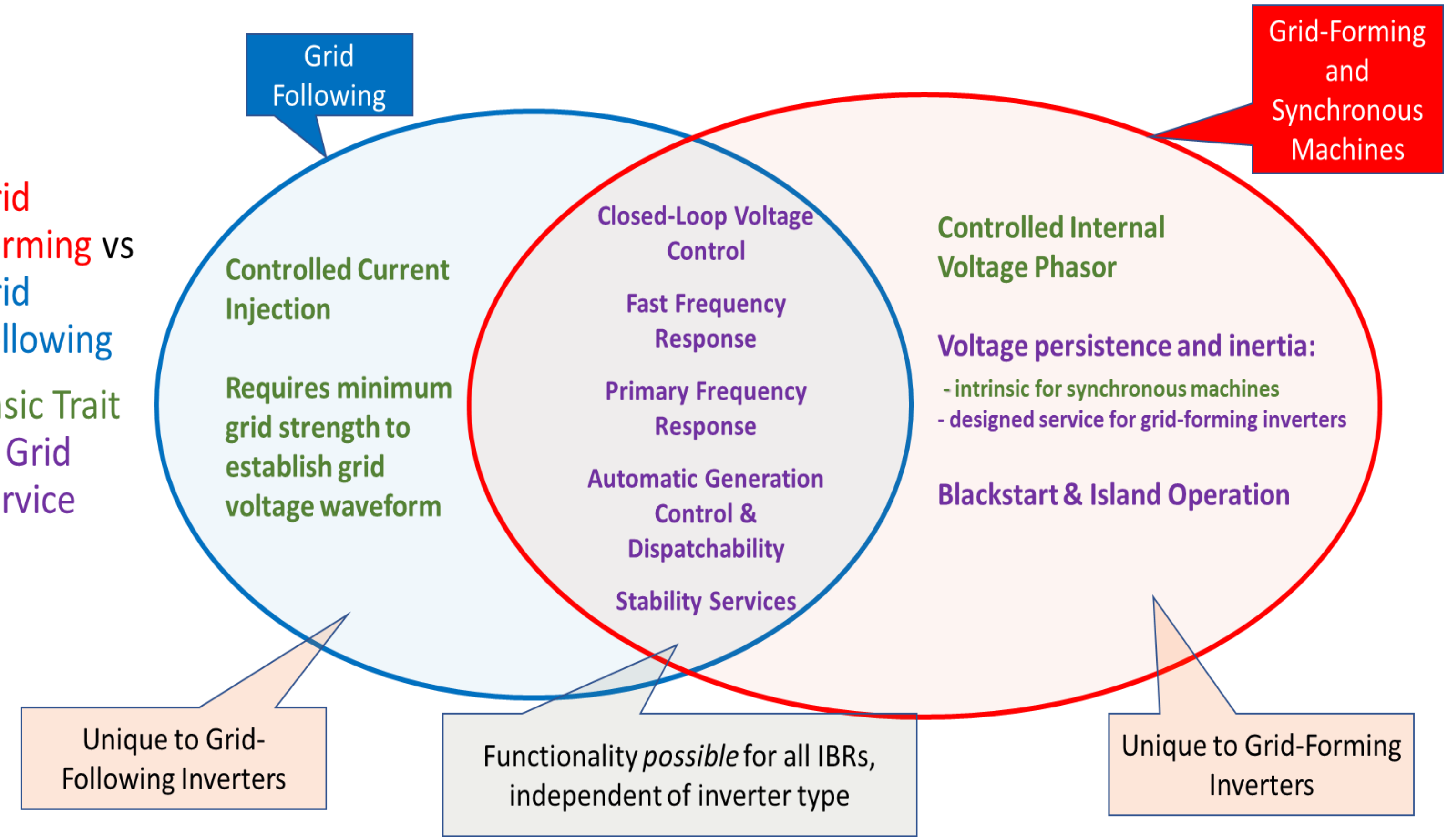
What can IBRs help with?

- Grid Forming vs Grid Following
- Basic Trait vs Grid Service



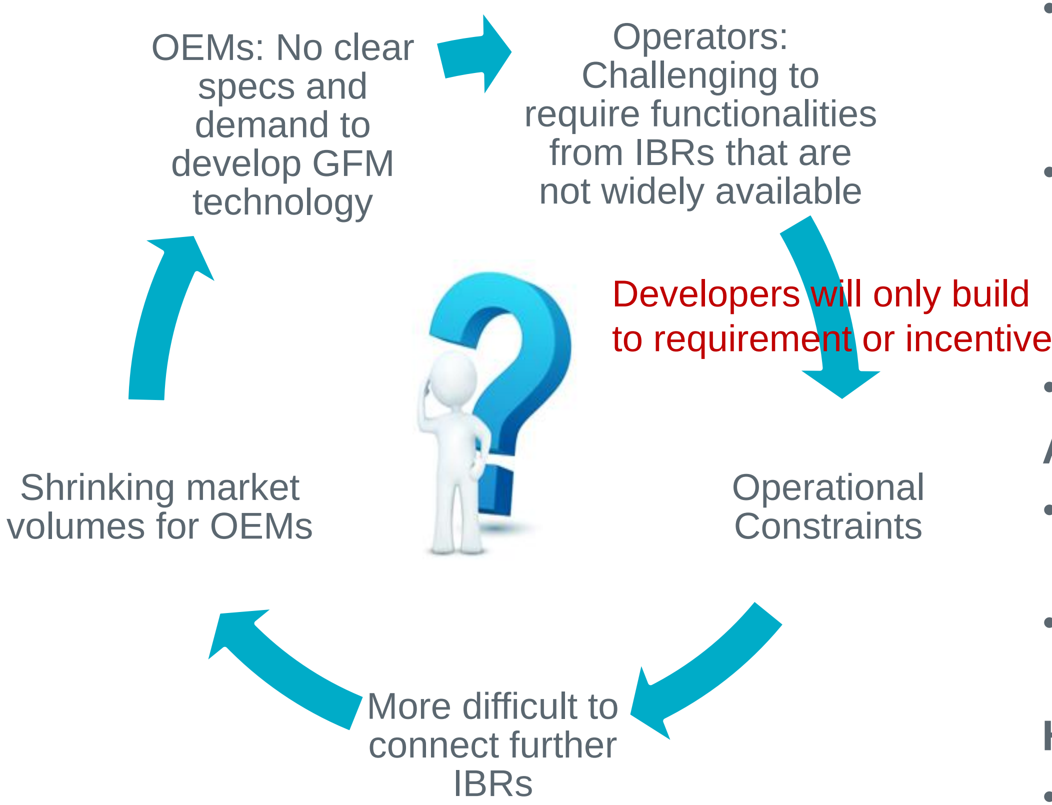
Source: J. Matevosyan, et al. Future with Inverter-Based Resources, IEEE PES Power and Energy, Nov/Dec 2021

What is state-of-the-art for Grid-Forming (GFM) IBRs?

- **BESS in St. Eustatius Island**
  - 2.3 MW peak load, 100% (Solar + storage) operation mode during daytime
  - Load distribution across several parallel GFM units (no communication)
  - Seamless and immediate load transfer after loss of all gensets at peak load
- **Dersalloch Wind Farm in Scotland**
  - 69 MW of wind turbines operated in GFM mode for 6 weeks
  - Wind farm responded to both large underfrequency events and phase steps
  - Island operation (with 7 MW load) and blackstart of wind turbines to energize wind farm and re-synchronize with the grid
- **Dalrymple BESS in South Australia**
  - 30 MW/8 MWh battery connected close to 91 MW wind farm and 8 MW load
  - Provision of inertia, islanded operation, black start capability, weak grid operation, fast active power injection as special protection scheme
  - In the first 6 months, reduced loss of supply in the area from 8 hours to 30 min
- **Hornsdale BESS in South Australia**
  - 150 MW/194 MWh BESS co-located with wind farm, testing Virtual Machine Mode on two inverters
  - Recently in 2020, provided inertial response during a large grid disconnection event

Source: https://www.esig.energy/event/g-pst-esig-webinar-series-survey-of-grid-forming-inverter-applications/

Are we stuck?



Great Britain (NGESO)

- Stability Pathfinder Phases 2 & 3
- Minimum Specification Required for Provision of GB Grid Forming Capability (GC0137)
- Pathfinder Phase 3 will use GC0137 as of Nov 2021 (further changes will not be required from Phase 3 awardees)
- Will maintain Best Practice Guide

Australia (AEMO):

- AEMO requirement for inertia and system strength
- AEMO Advanced Inverter White paper, gradual approach

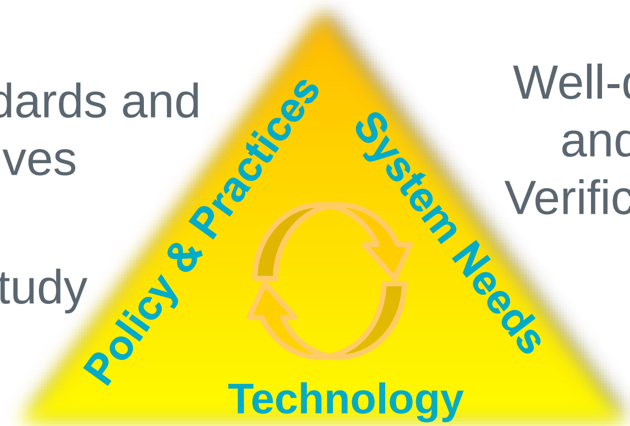
Hawaii:

- Hawaiian Electric Island – Wide PSCAD Studies report, recommends requiring GFM in new BESS for future projects. Clarity on GFM technical requirements should be improved

What is still missing?

Codes, Standards and Incentives

Appropriate Study Tools

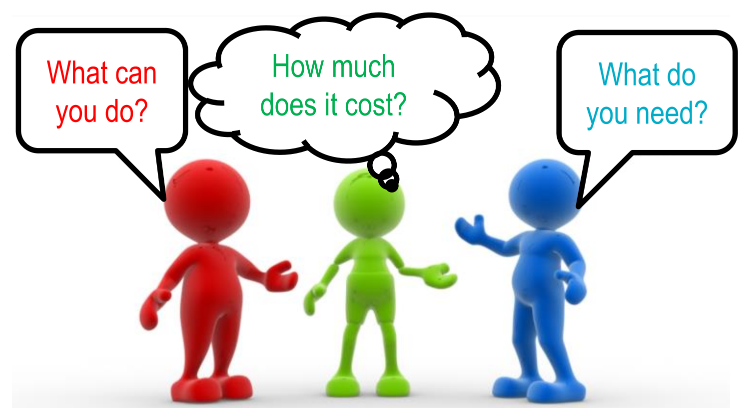


Well-defined Services and Performance Verification Procedures

Understanding of Capabilities and Limitations,
Understanding of Cost Implications,
Appropriate Models.

Stakeholder ecosystem

- Regulators
- System / Grid operators
- Transmission companies
- Generation utilities
- Distribution utilities
- Developers & Investors
- OEMs



Grid Owner/ Operator

Equipment Owner

OEM

Thank you! Questions?

Julia Matevosyan

julia.matevosyan@ercot.com