Grid Forming Technology in Energy Systems Integration

Julia Matevosyan
Chief Engineer
ESIG

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ENERGY SYSTEMS INTEGRATION GROUP

5/17/2022

Energy Systems Integration Group

ESIG

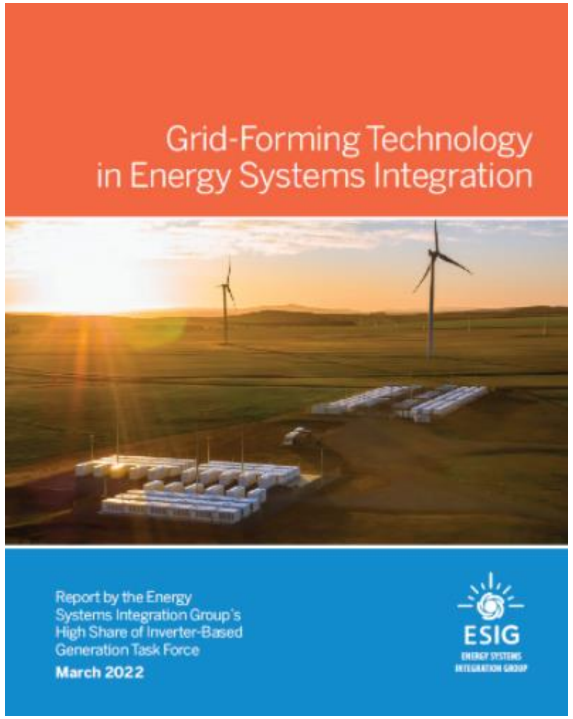
- Energy Systems Integration Group is a non-profit membership-base educational association that provides workshops, discussion forum, resources and education on the evolving electricity and energy systems.
- ESIG supports engineers, researchers, technologists, policymakers and the public with the transformation of energy systems in a way that is economic, reliable, sustainable, thoughtful and collaborative.
- Through a number of working groups ESIG facilitates member discussions on the latest challenges related to energy systems transformation.
- ESIG independent and trusted, forward leaning but not advocating, keeping everyone at the table

190 Members Globally

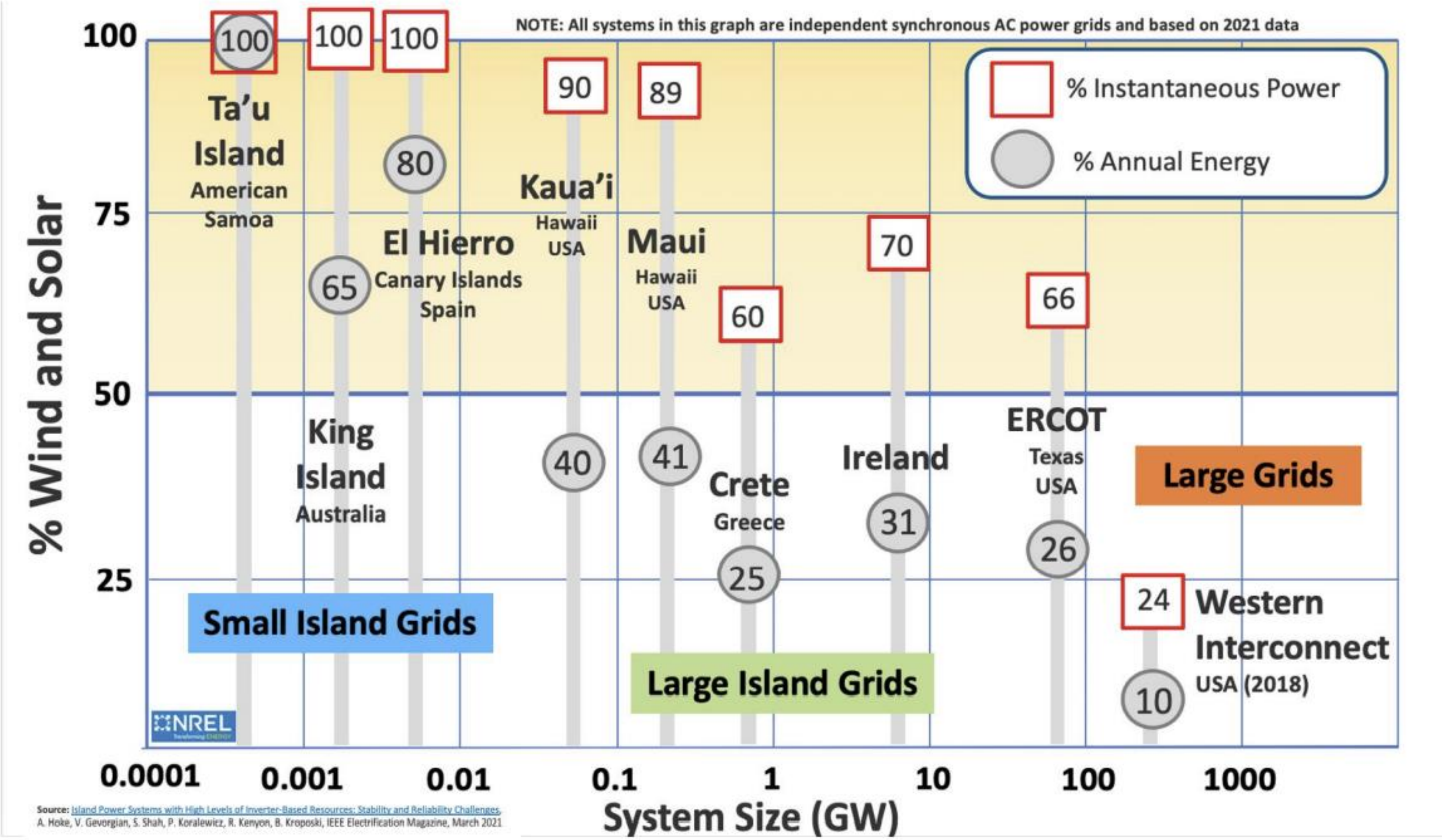
https://www.esig.energy/

Grid Forming Technology in Energy Systems Integration, ESIG Report

- **Grid Forming vs Grid Following Inverter Based Resources**
  - Basic principles and overview of grid forming controls
- **System Needs**
  - What is changing with high shares of inverter-based resources?
  - Trade-off between system needs and resource needs.
- **System Services and Technical Requirements**
  - Breaking chicken-and-egg cycle
  - Global experiences with interconnection requirements and services
- **Advanced Characterization and Testing of Grid Forming Resources**
  - Tests applicable both to grid forming and grid following inverters
  - Tests applicable to grid forming inverters
  - Field Tests
- **Tools**
  - Stability tools, Analytical tools, Economics tools; Need for compatibility
- **Conclusions and Recommendations**

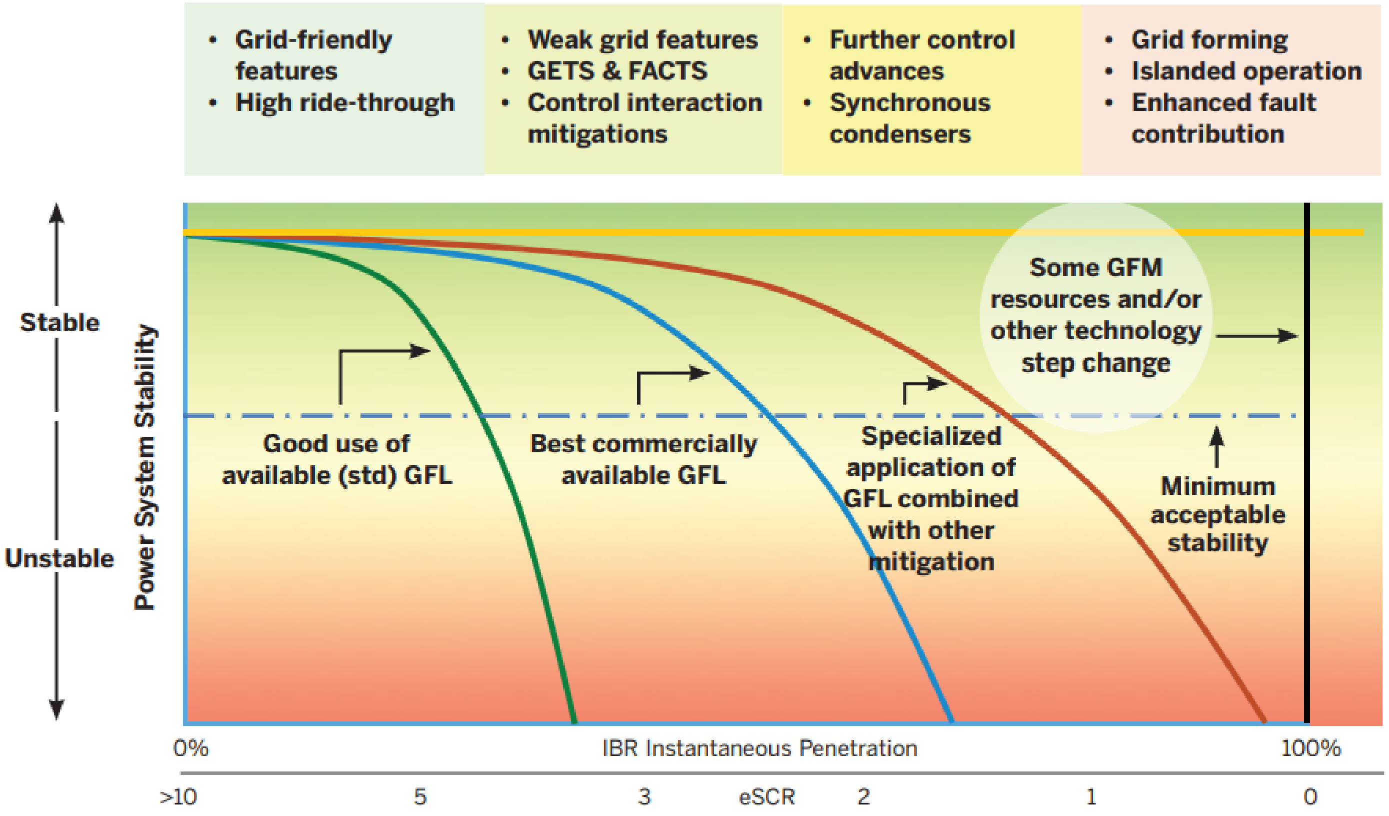


Where Are We Today?



Source: NREL

Technology Enabler to Promote the Shift to 100% Renewable Future



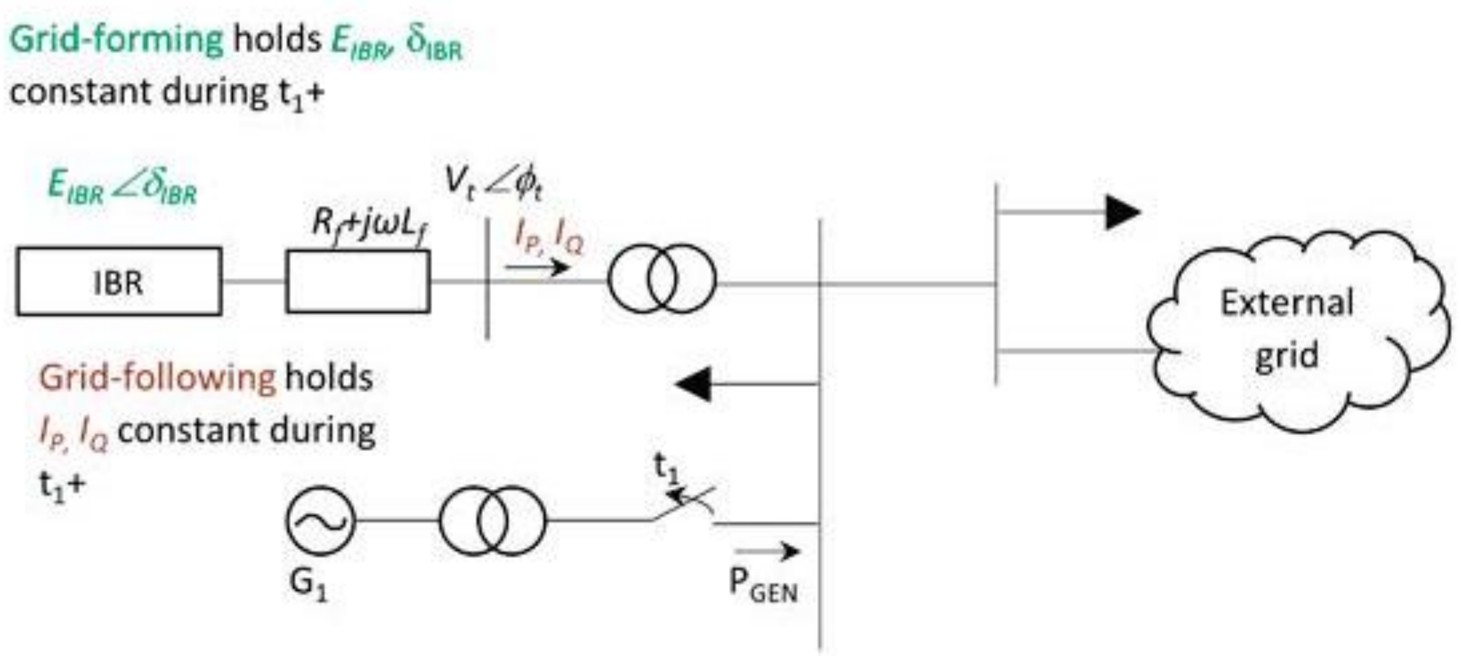
- Majority of the inverters today are "grid-following"
- They read the voltage and frequency of the grid, lock onto that, and inject power aligned with that signal.
- That signal comes from synchronous generators.
- The further wind and solar generation pockets are from synchronous generation, the "weaker" the grid.
- The signal is then easily perturbed by power injection from wind and solar resources, making it hard for inverters to lock onto it correctly.
- This may lead to local instability issues.

Grid Forming

- **Grid-Forming:** The primary objective of grid-forming controls for IBRs is to maintain an internal voltage phasor. When grid-forming controls are applied in bulk power system (BPS) connected IBRs, the voltage phasor is held constant in the sub-transient to transient time frames. This allows the IBR to immediately respond to changes in the external system and provide stability in the controls during challenging network conditions. This phasor must be controlled to maintain synchronism with other devices and control active and reactive currents to support the grid. When grid-forming controls are applied in non-BPS connected IBRs (for example black-start or microgrids), this synchronization functionality is removed or limited, and the voltage phasor may be held relatively constant over time. This allows the plant to operate in an electrical island and define the grid frequency.
- There are many variations of both grid-forming and grid-following converter controls. Both are subject to physical equipment constraints including voltage, current and energy limits, mechanical equipment constraints (on WTGs) as well as external power system limits.

Grid Following vs Grid Forming

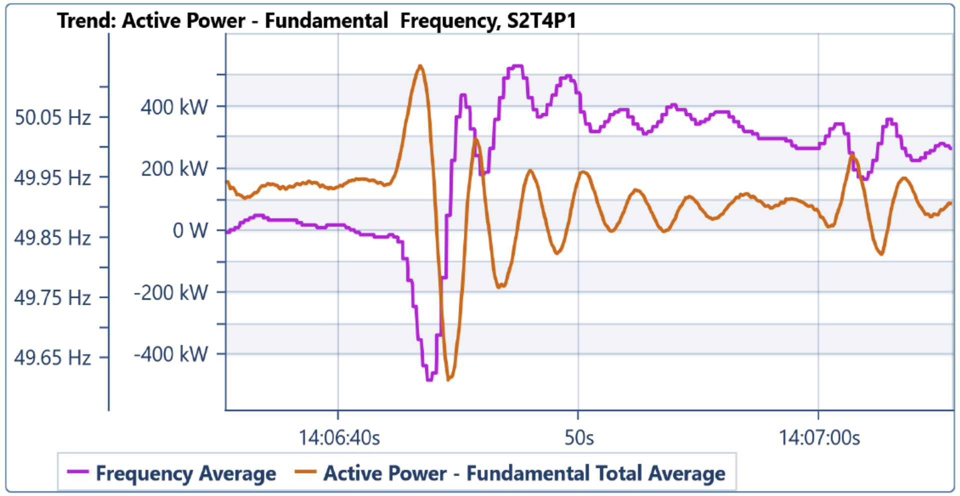
- A new class of inverters with advanced control -"grid forming" inverters.
- These advanced inverter controls can be designed to have stabilizing effect in weak grid areas and improve stability for existing grid following inverter-based resources.
- They can also provide other grid services.



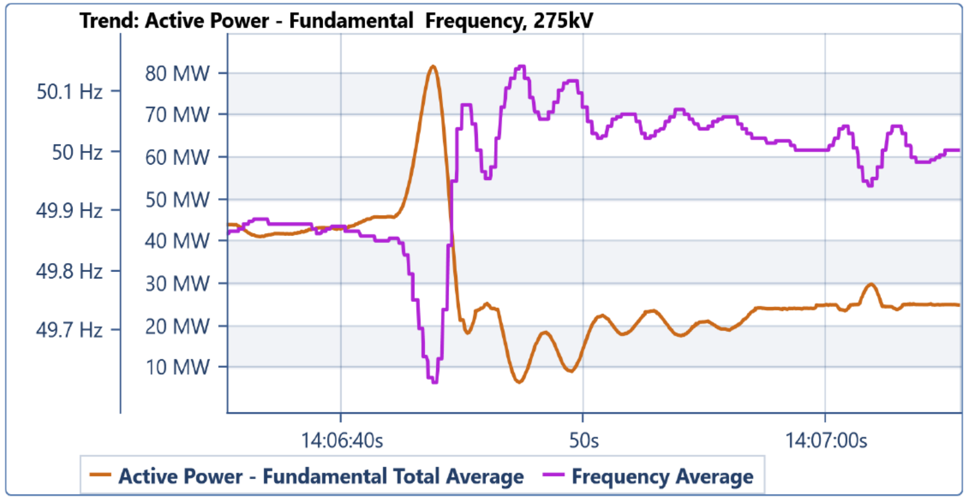
GFM IBR IBR's Active Power Injection in Inertial Timeframe (one example of GFM functionality)

- In spring 2021, while two inverters in the Hornsdale Power Reserve were trialing virtual machine mode (VMM), a large coal power plant tripped and resulted in a large frequency change.
- During the event, the inverters acted to slow it down initial rate of change of frequency.
- The inherent active power response of the inverter in VMM immediately after the coal generator trip differed from the overall frequency response of the entire plant, dominated by response from remaining GFL inverters on the droop control.

GFM Inverter's Inherent Active Power Response at the Hornsdale Power Reserve Plant During a Generator Trip Event



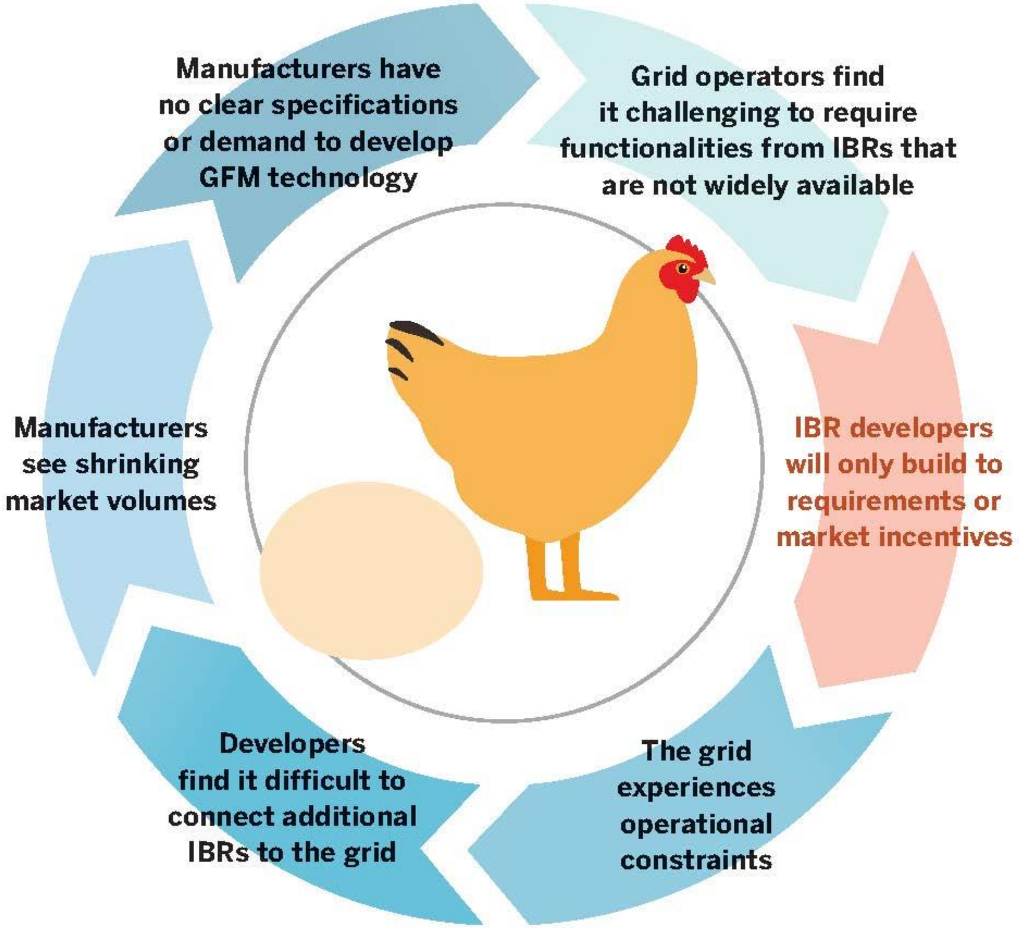
The Entire Hornsdale Power Reserve Plant Response During a Generator Trip Event



Grid Following vs Grid Forming

Inverter Attribute	GFL Control	GFM Control
Reliance on grid voltage	Relies on well defined grid voltage	Actively maintains internal voltage magnitude and phase
Dynamic behavior	Controls current injected into the grid (appears as a constant current source in the transient timeframe)	Set voltage magnitude and frequency/phase (appears as a constant voltage source in the transient timeframe)
Reliance on PLL for synchronization	Needs PLL or equivalent fast control for synchronization	Does not need PLL for tight synch. of current controls. May use PLL to synch. overall plant response to the grid.
Ability to provide black start	Not usually possible	Possible if designed with sufficient energy buffer and overcurrent capability
Ability to operate in low grid strength conditions	Stable operation range can be enhanced with advanced controls but limited to a minimum level of system strength	Stable operation range can be achieved without minimum system strength requirement (long-distance high-power transfer issue still not resolved)
Field deployment and standards	Has been widely used commercially, standards exist	Deployed primarily on batteries in a few pilots, limited experience in interconnected power systems. Existing standards do not yet define required functionalities well.

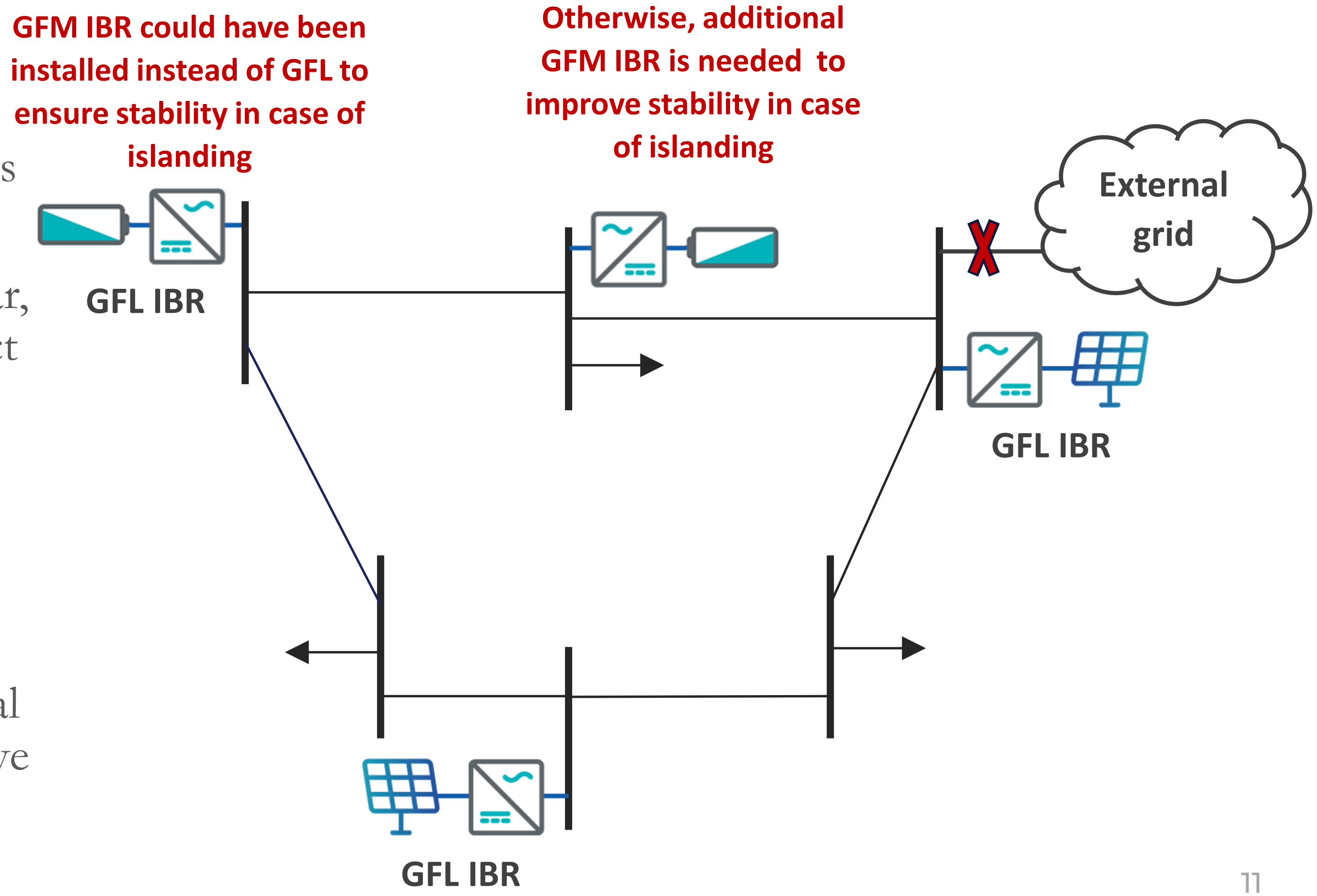
The Circular Problem of Requirements and Deployment of Advanced IBR Controls



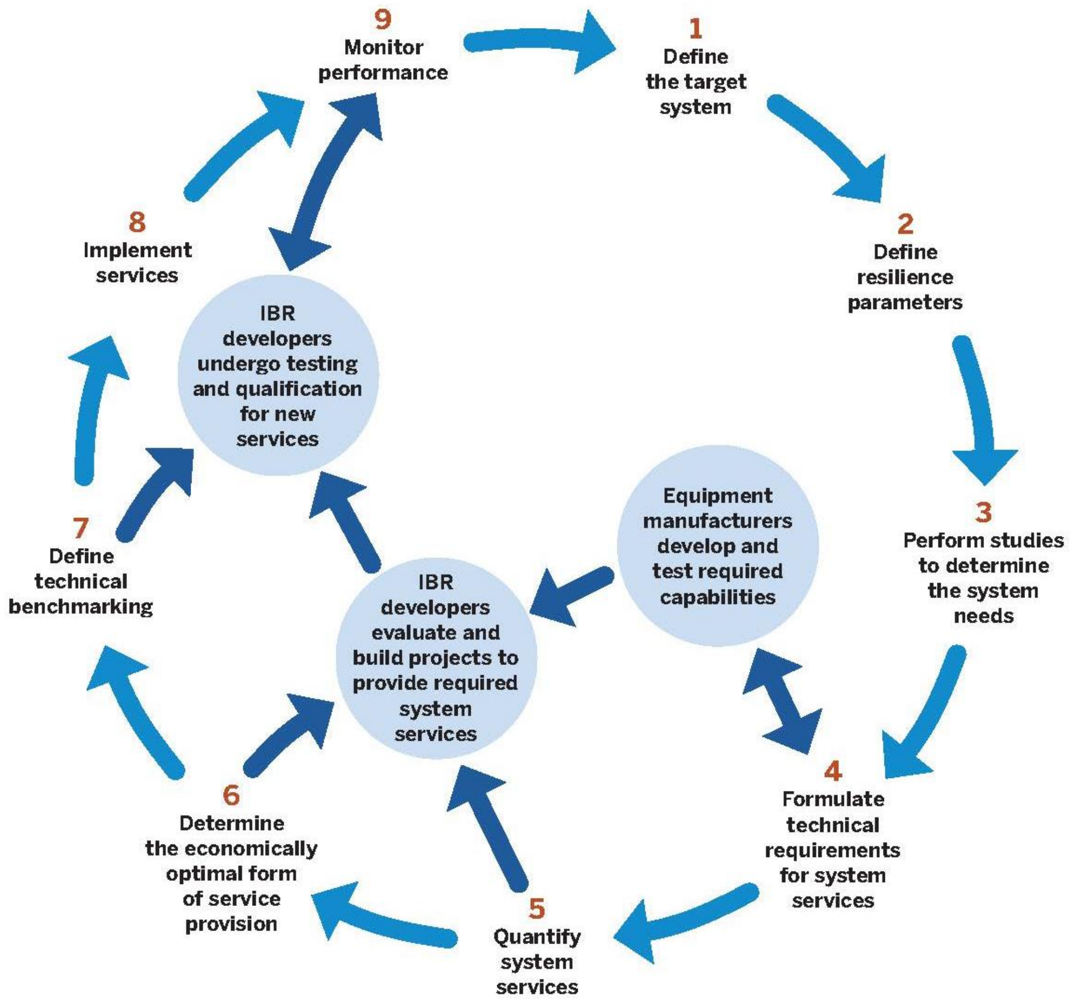
- Which comes first, the requirement for a capability or the capability itself?
- How do grid operators know what performance or capability is possible from new equipment, and therefore what they could conceivably require?
- How can they go about evaluating the costs and benefits of having such equipment on the grid?
- What drives manufacturers to invest in new technology without it being mandated or otherwise incentivized by the market?

Cost of Inaction

- The failure to find an exit from the circular problem could hinder our ability to meet energy transition targets and increase the costs of this transition.
- Around the world there are thousands of solar, wind, and battery resources waiting to connect to the grid.
- These resources, in the absence of clear requirements and market incentives for GFM functionality, will be built using today's grid following technology.
- This will increase systems' needs for additional reliability support from other sources and drive up costs.



Solving the Chicken-and-Egg Problem Through Adoption of a System Needs Perspective



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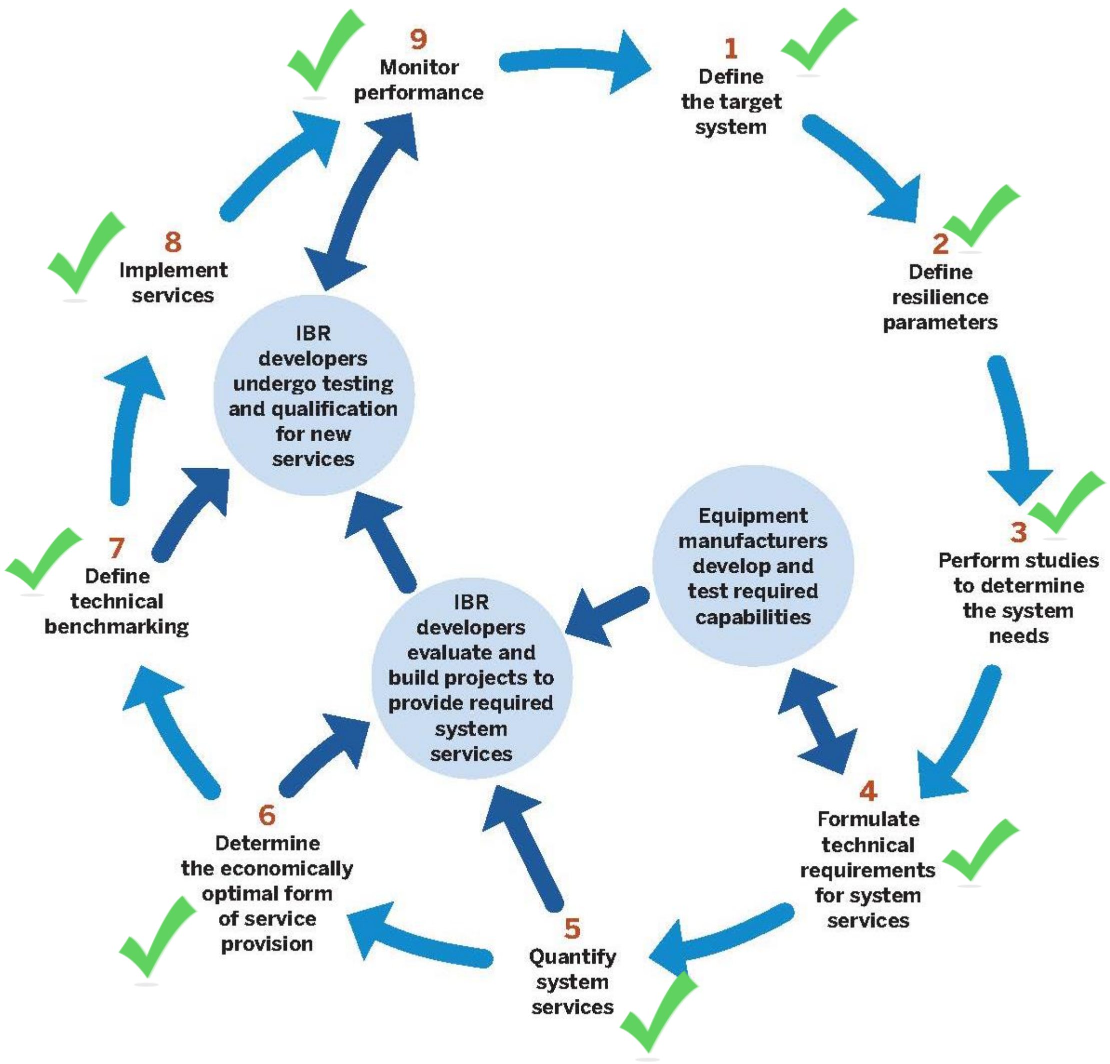
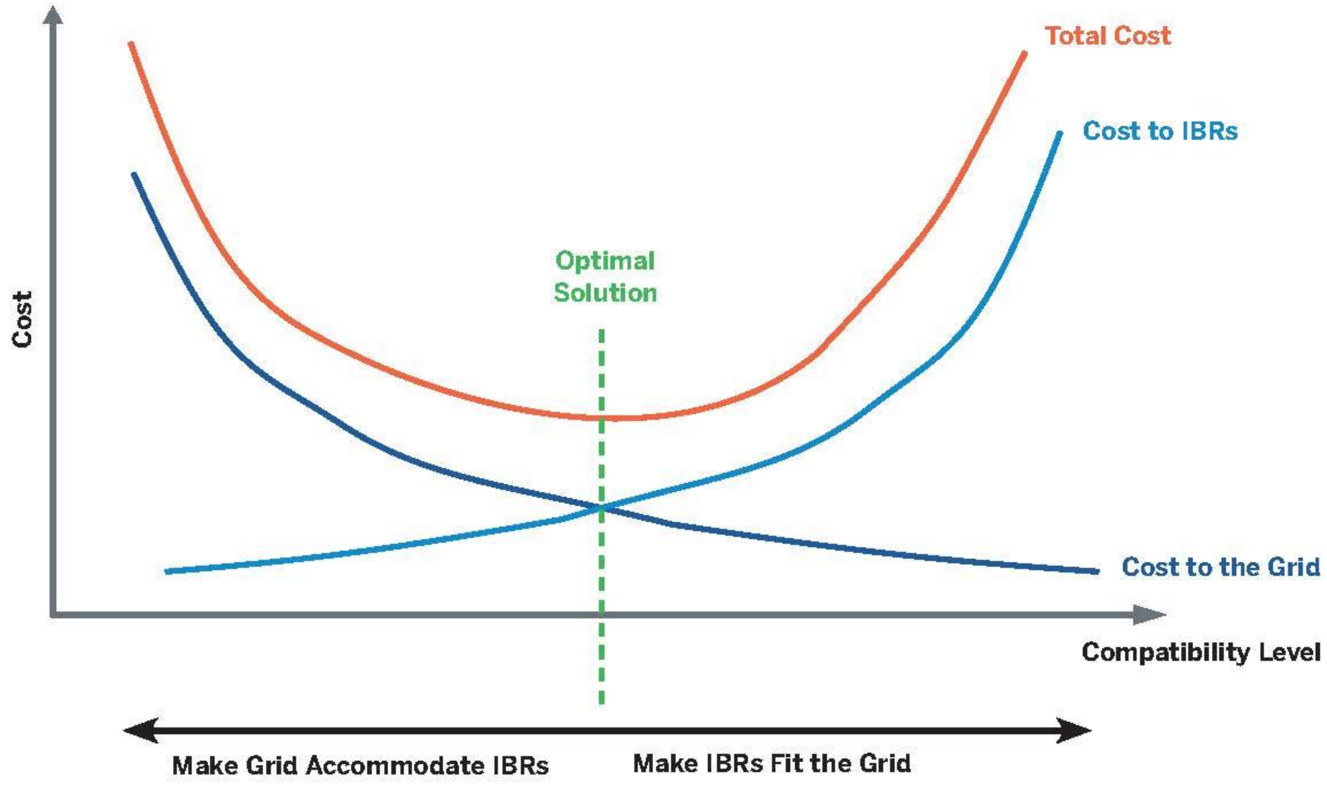


Example of National Grid Electricity System Operator:

- Carried out a number of studies of system performance with a large share of IBRs (incl.100 % IBR), steps 1-3.
- Developed performance requirements for GFM capability (to be procured as a service), consistent with steps 4 and 7.
- At the same time, launched a series of competitive tenders, called Stability Pathfinder, to procure new system services needed with the changing generation mix—specifically, system strength support and RoCoF mitigation. This is consistent with steps 5, 6, and 8 above.
- Along with evaluating the projects offering into Stability Pathfinder tenders, next steps will be to develop market-based services as well as performance evaluation requirements for those services, consistent with steps 8 and 9.

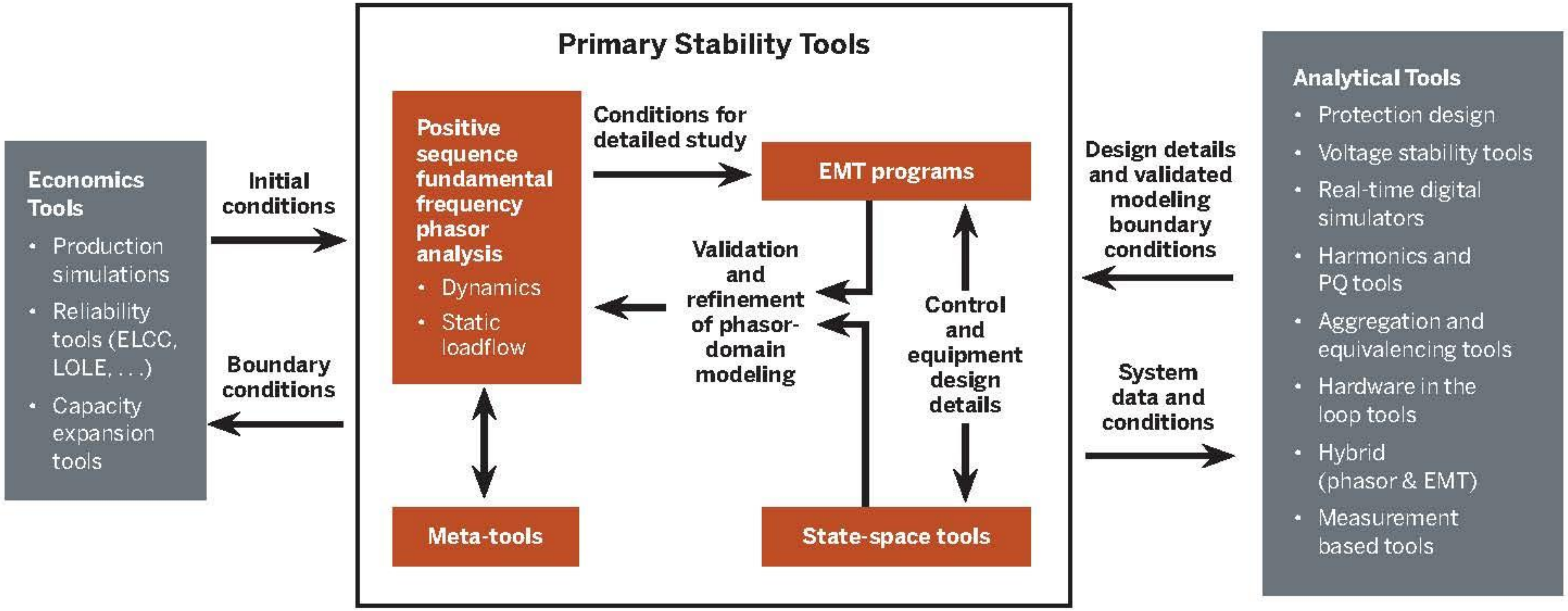
System Needs vs IBR Needs?

Total System Cost as Compatibility Burden Is Moved Between IBRs and the Grid



Role of Tools

Stability Simulation Environment



Source: HickoryLedge.

Conclusions and Recommendations

- GFM technology is one of the necessary enablers for higher IBR penetration.
- Not all GFM IBRs need to have all possible characteristics to provide all services. Services need to be approached from system needs perspective not a specific technology capability perspective.
- Step by step approach of defining and implementing new services is proposed.
- Early adopters such as, e.g., GB are breaking the circular problem through defining grid services based on system needs. This provides clarity for GFM IBR design and incentives for deployment.
- It is recommended that future adopters use higher-level functional requirements as a starting point, with more details on capability verification and performance testing provided in the form of technical guides.
- **GFM capability in batteries is a low hanging fruit. Not incentivizing it today will result in higher costs of supplemental stabilizing equipment in the future.**
- Further reinforcements of transmission system will be necessary to enable long-distance high-power transfer from remote areas rich with renewable resources
- With high shares of IBRs and new technologies there is a need for further development and tighter integration of study tools and processes.

Upcoming Workshops, June 6-9, Denver

ESIG

Workshop #1: Meteorology & Market Design for Grid Services

Tutorial: Forecasting for Energy and Ancillary Service Markets: Role of Storage, Hybrids and DER on Price Formation in an Uncertain Environment

Session 1: Introduction and Opening Plenary: The Increasing Ubiquity of VRE Forecasting

Session 2: Solar and Wind Forecasting R&D Advances

Session 3: Integration of Probabilistic Forecasts into the EMS and MMS – Status and Prospects

Session 4: Dynamic Reserve Applications Panel Discussion

Session 5: Impacts of Climate Change

Session 6: Extreme Weather Conditions

Session 7: High VRE Futures – How Are Markets Evolving?

Session 8: Closing Plenary - Taking Stock: Where are We and What Lies Ahead?

https://www.esig.energy/event/2022-meteorology-and-market-design-for-grid-services-workshop/

Workshop #2: Special Topic: Grid-Forming IBRs

Tutorial: Grid-forming IBRs

Session 1: Defining Technical Requirements and Qualification of Services

Session 2: Defining Target System, Desired Performance and System Needs Studies

Session 3: Grid Forming Capabilities and Challenges (specifications, requirements and cost)

Session 4: Incentivizing New Grid Services

Session 5: Performance Monitoring – GFM Projects and Pilots

Session 6: Performance Benchmarking, Modelling and Testing

Session 7: Research Roadmaps

Session 8: Closing Panel Session – What's Next?

https://www.esig.energy/event/2022-special-topic-workshop-grid-forming-ibrs/

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THANK YOU

Julia Matevosyan

julia@esig.energy