Grid Forming Inverter-Based Resources

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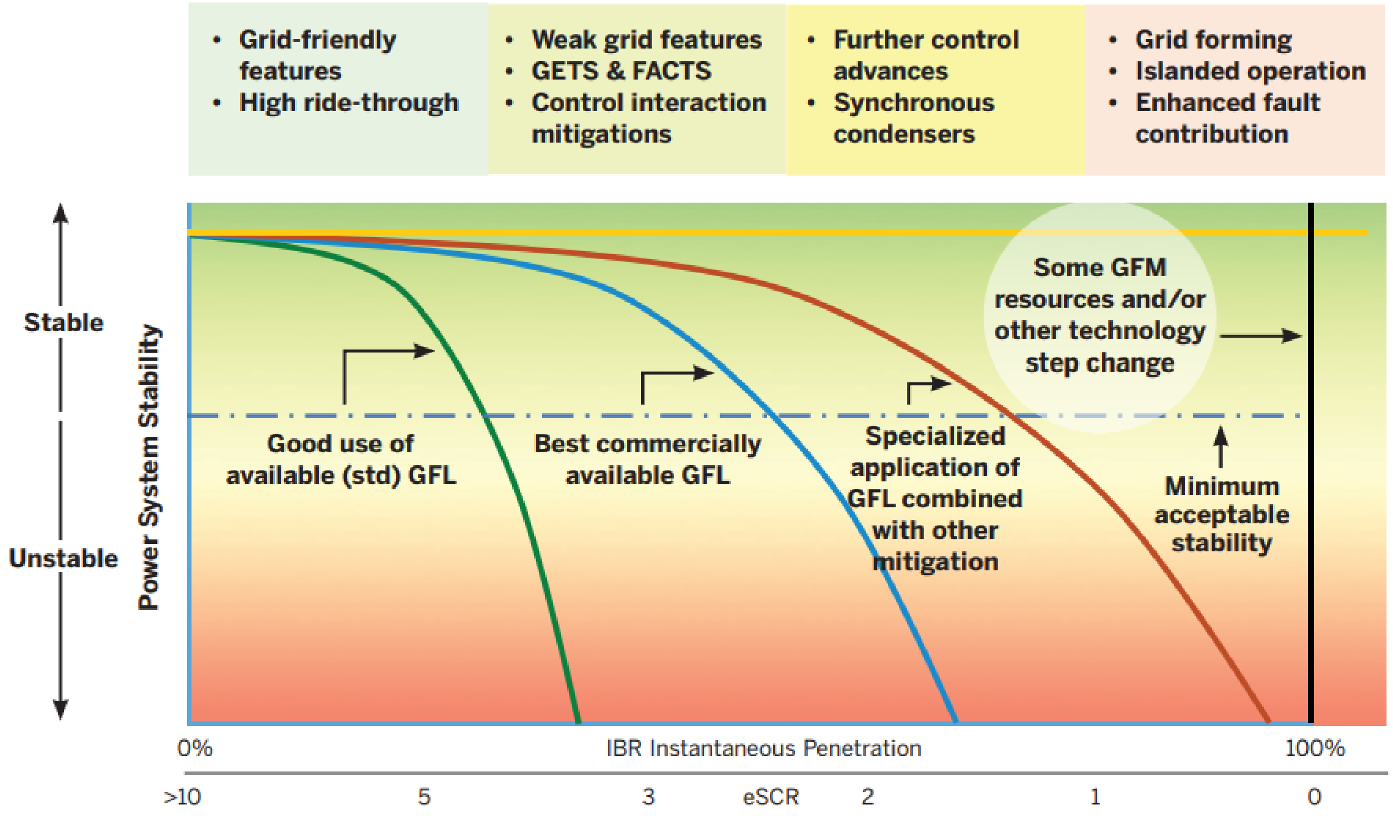
Technology Enabler to Promote the Shift to 100% Renewable Future

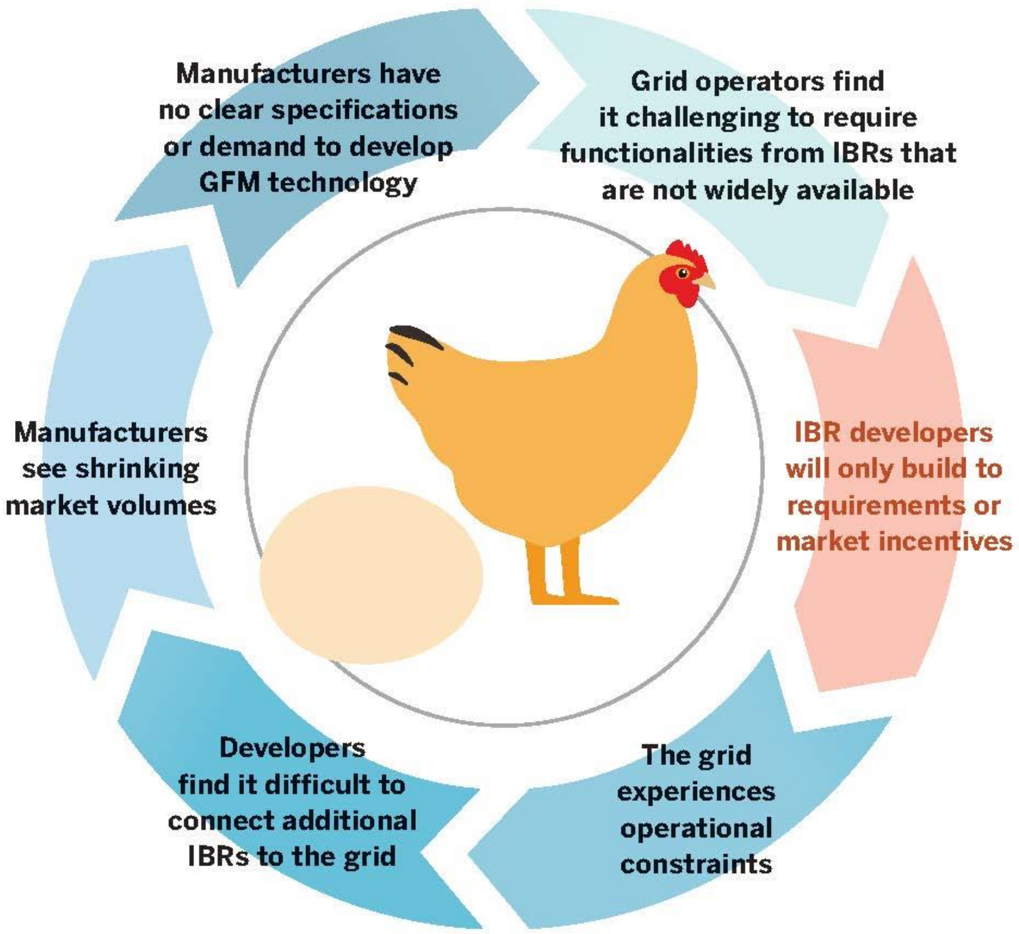


- Majority of the inverters today are “grid-following”
- They read the voltage and frequency of the grid, lock onto that, and inject power aligned with that signal.
- That signal comes from synchronous generators.
- The further wind and solar generation pockets are from synchronous generation, the “weaker” 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 Definition

- **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.

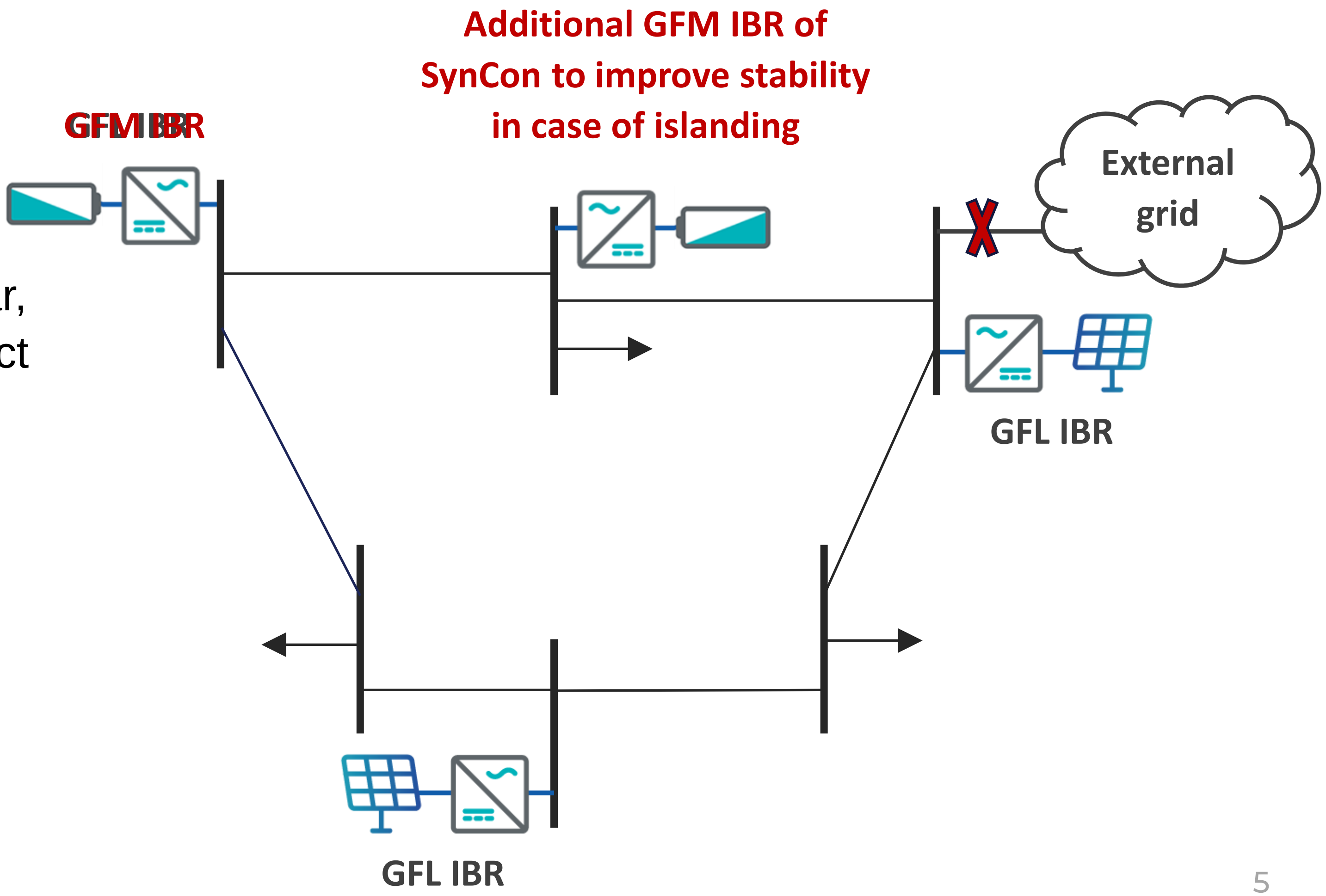
The Circular Problem of Requirements and Deployment of Advanced IBR Controls



- 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.

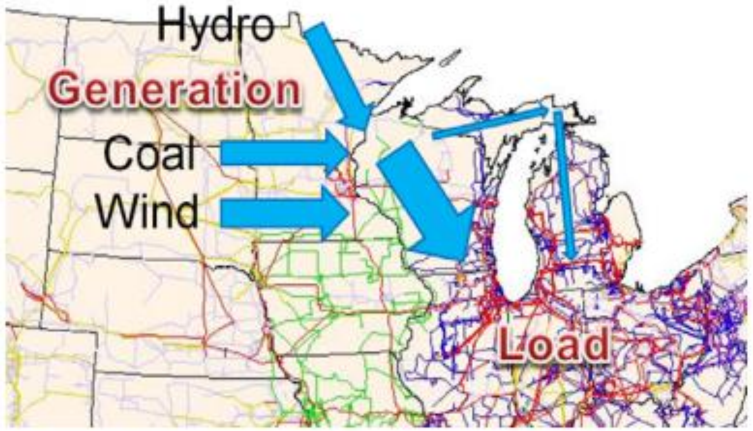


Handful of GFM Projects and First Interconnection Requirements for GFM

- Number of BESS for microgrids
- Black start of simple cycle gas turbines (GE)
- BESS on St Eustatius island (SMA)
- Dersalloch Wind Farm in Scotland (Siemens Gamesa)
- Mackinac back-to-back VSC HVDC Flow Control Project (Hitachi ABB)
- Dalrymple BESS in South Australia (Hitachi ABB)
- Hornsdale BESS in South Australia (Tesla)
- More GFM BESS underway in Australia
- Grid forming requirement for any new resources with BESS in Hawaii
- Stability Pathfinder in Great Britain (National Grid ESO), Phase 2 awarded five GFM BESS
- Proposed (non-mandatory) Grid Forming Interconnection Requirements in Great Britain (National Grid ESO)

Mackinac Back-to-back VSC HVDC for power flow

- Hitachi ABB 200 MW bi-directional back-to-back HVDC Light converter station, commissioned in 2014, to help control power flow, enhance grid stability and support integration of additional IBRs
- The station is situated on Michigan's Upper Peninsula, near the Straits Substation and in line with a pre-existing 138 kV AC cable double circuit across the Straits of Mackinac
- Voltage source converter (VSC) technology was selected over classic HVDC technology as it: provides better voltage/reactive control, provides stability in weak grid conditions, power oscillation damping, governor-like frequency control, supports islanded operation, has black-start capability (using South-side as energy buffer).
- South-side converter (connecting to strong side of the grid) is current-controlled,
- North-side converter connects into extremely week grid, so a "*phasor voltage control" was developed based on direct control of the converter's internal ac voltage amplitude and phase*.



[Grid –Forming Technology in Energy Systems Integration]

THANK YOU

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