Grid Forming Battery Storage

Julia Matevosyan

Chief Engineer

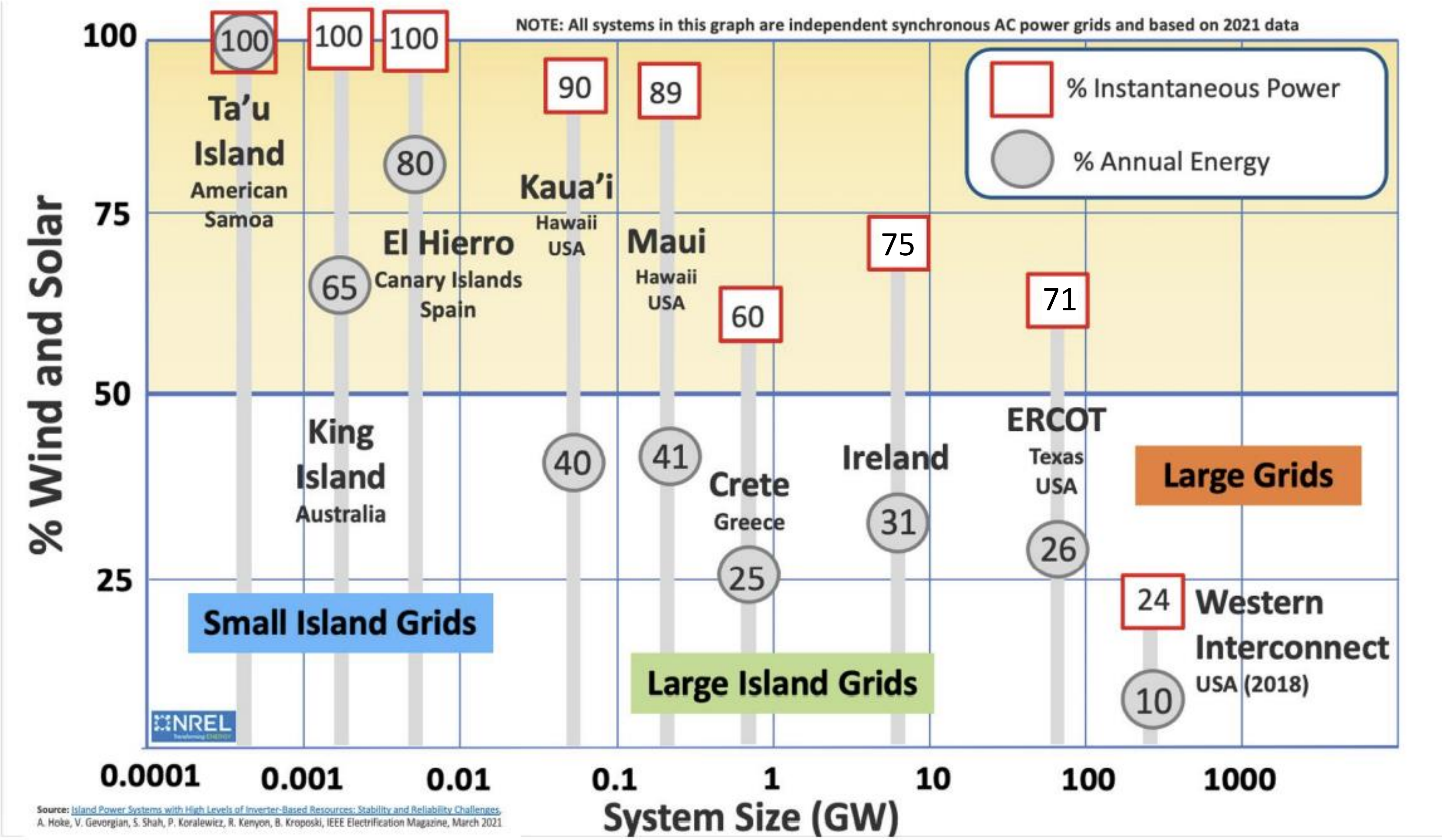
ESIG

6/8/2023

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

©2022 ESIG. All rights Reserved.

Where Are We Today with Inverter-Based Resources?

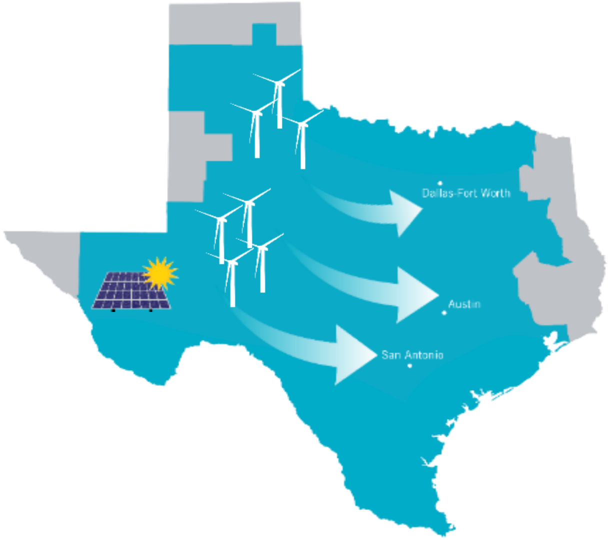


Source: NREL adjusted with latest changes in Irelands and ERCOT

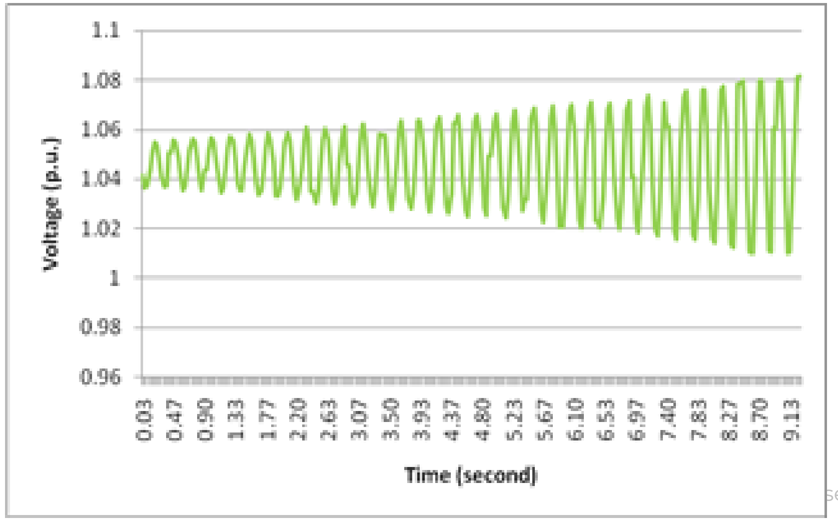
©2022 ESIG. All rights Reserved.

Weak Grid Issues

- Majority of the inverters today are “grid-following” (GFL)
- They read the voltage and frequency of the grid, lock onto that, and inject power aligned with that signal.
- That signal comes from large 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.



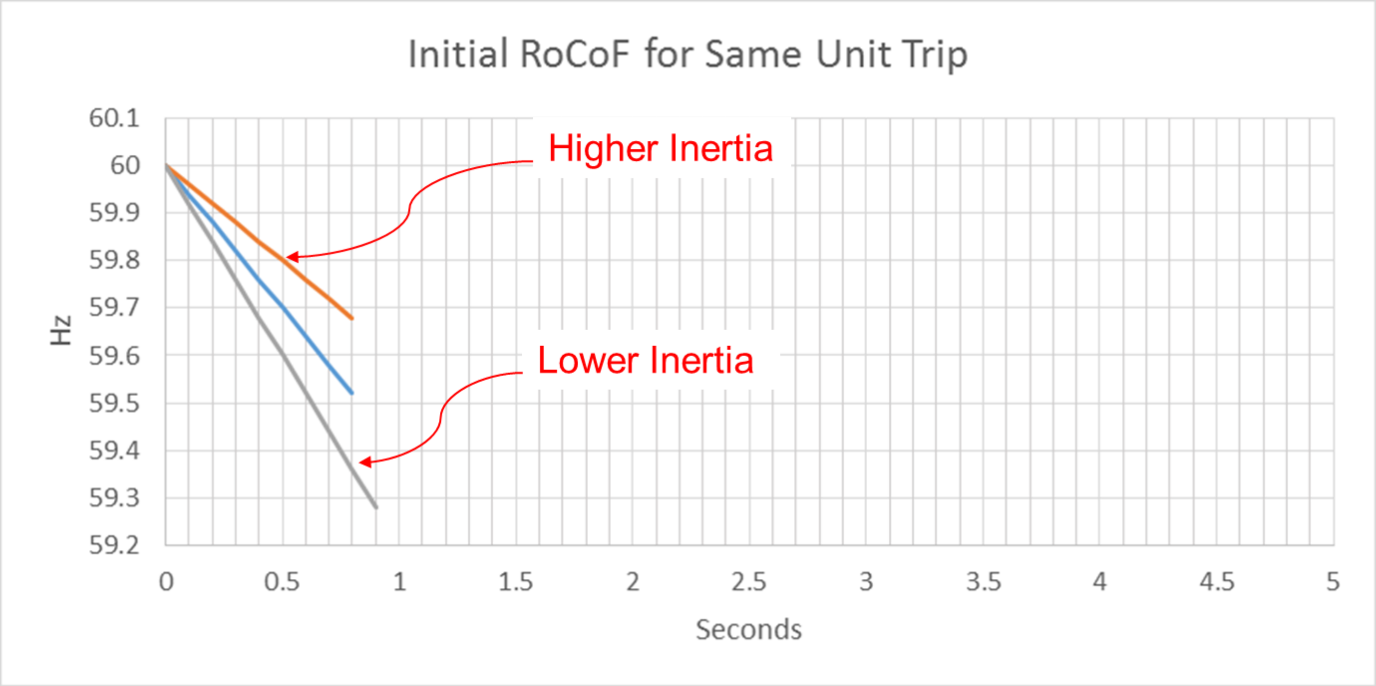
Example of Weak Grid in ERCOT



served.

Inertia Issues

- Following a resource trip, the initial rate of change of frequency (prior to any resource response) is solely a function of inertia. To date, primarily synchronous machines provide inertia to the system
- With increasing integration of inverter-base resources (IBR), there could be periods when total inertia of the system could be low, as less synchronous machines will be dispatched to be online.



©2022 ESIG. All rights Reserved.

Summary of Issues with High Shares of GFL IBRs

- GFL IBRs do not contribute to system inertia or system strength
- IBRs displace synch. gen. exacerbating weak grid and inertia issues
- GFL IBRs require sufficient system strength to operate and sufficient inertia (if providing frequency response)
- Possible operating issues at high shares of GFL IBR:
  - Deeper frequency deviations after contingencies due to diminishing inertia
  - Inverter control interactions, due to low system strength
  - Failure to ride through disturbances in reduced system strength conditions
  - Protection issues
  - Diminishing black start capability

©2022 ESIG. All rights Reserved.

System Strength and Inertia Solutions

- There is a limit of how many GFL IBRs that can be accommodated (due to system strength and inertia issues)
- System operators may limit the output of IBRs and supply the remaining load with synchronous generators to ensure sufficient system strength and/or inertia (e.g. Australia, Ireland, Texas)
  - Such operational constraints in the long run may impact further development of IBRs
- Alternatively, other supplemental equipment is added to the grid, costs and benefits need to be carefully assessed
- Grid forming (GFM) inverter technology is also being considered in recent years. GFM IBRs can create their own voltage and frequency signal (islanded operation) or operate in coordination with other GFM resources supporting stability of an interconnected grid.

©2022 ESIG. All rights Reserved.

GFM Batteries are a Low-Hanging Fruit

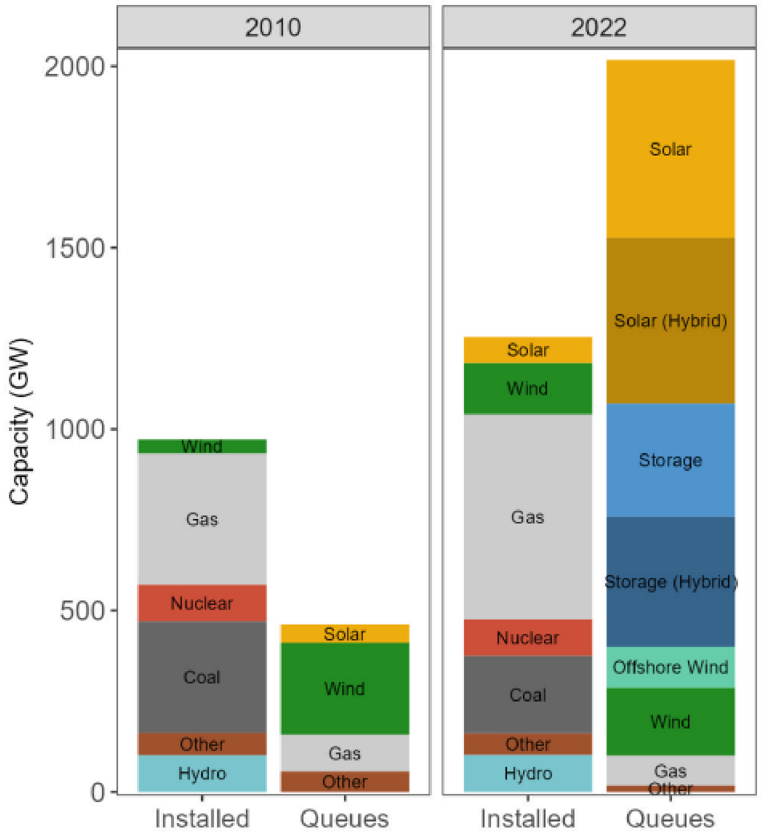
- GFM controls can potentially be implemented on any type of IBR including new solar and wind
- GFM behavior requires a certain amount of energy buffer, which for wind and solar resources means continuous operation below their maximum available power production.
- In addition, GFM control in wind turbines may result in greater and more frequent mechanical stress.
- The battery is the energy buffer, and only software modifications to a battery's controls are needed to make the battery a GFM resource – **batteries are the low-hanging fruit for GFM application**.
- Note, retrofitting existing GFL batteries to GFM may potentially bring additional costs and delays (model updates, re-studies, changes to various contractual agreements)

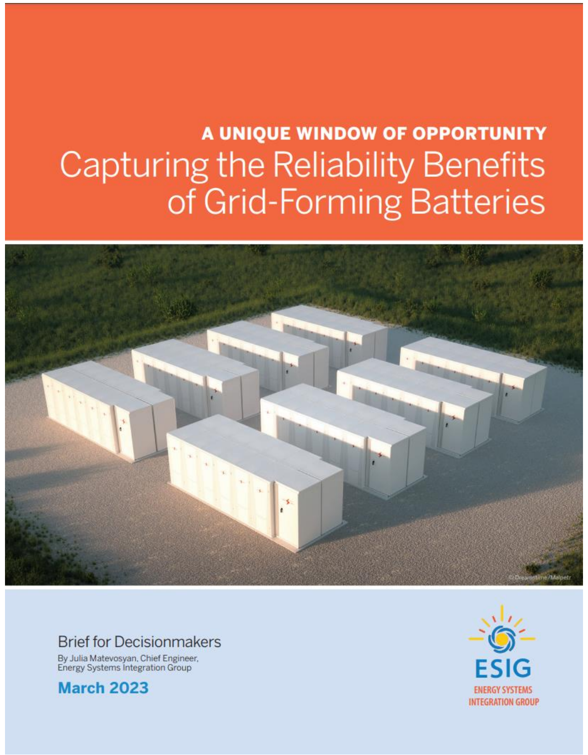
Source: Neoen Australia

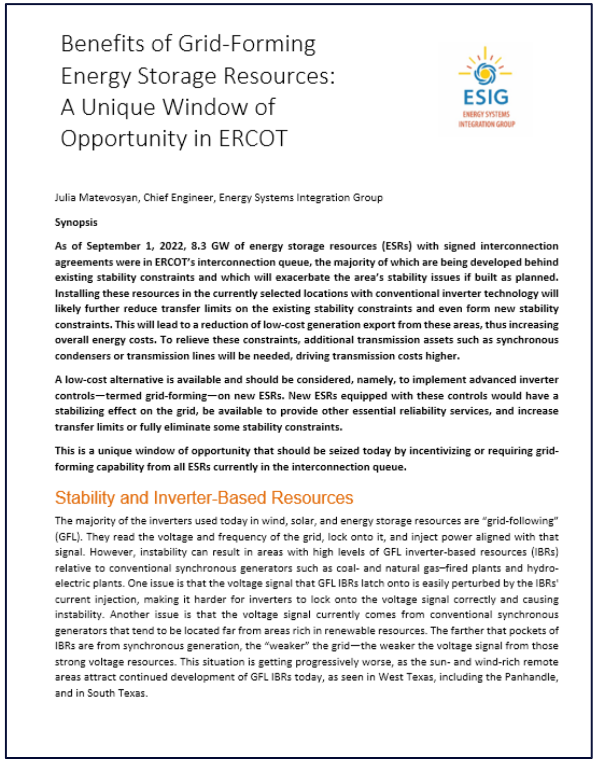
A number of batteries with GFM controls have already been deployed around the world, and further development is happening at unprecedented speed

Grid Forming Batteries a Unique Window of Opportunity

Entire U.S. Installed Capacity vs. Active Queues







Benefits of Grid-Forming Energy Storage Resources: A Unique Window of Opportunity in ERCOT

Julia Matevosyan, Chief Engineer, Energy Systems Integration Group

Synopsis

As of September 1, 2022, 8.3 GW of energy storage resources (ESRs) with signed interconnection agreements were in ERCOT's interconnection queue, the majority of which are being developed behind existing stability constraints and which will exacerbate the area's stability issues if built as planned. Installing these resources in the currently selected locations with conventional inverter technology will likely further reduce transfer limits on the existing stability constraints and even form new stability constraints. This will lead to a reduction of low-cost generation export from these areas, thus increasing overall energy costs. To relieve these constraints, additional transmission assets such as synchronous condensers or transmission lines will be needed, driving transmission costs higher.

A low-cost alternative is available and should be considered, namely, to implement advanced inverter controls—termed grid-forming—on new ESRs. New ESRs equipped with these controls would have a stabilizing effect on the grid, be available to provide other essential reliability services, and increase transfer limits or fully eliminate some stability constraints.

This is a unique window of opportunity that should be seized today by incentivizing or requiring grid-forming capability from all ESRs currently in the interconnection queue.

Stability and Inverter-Based Resources

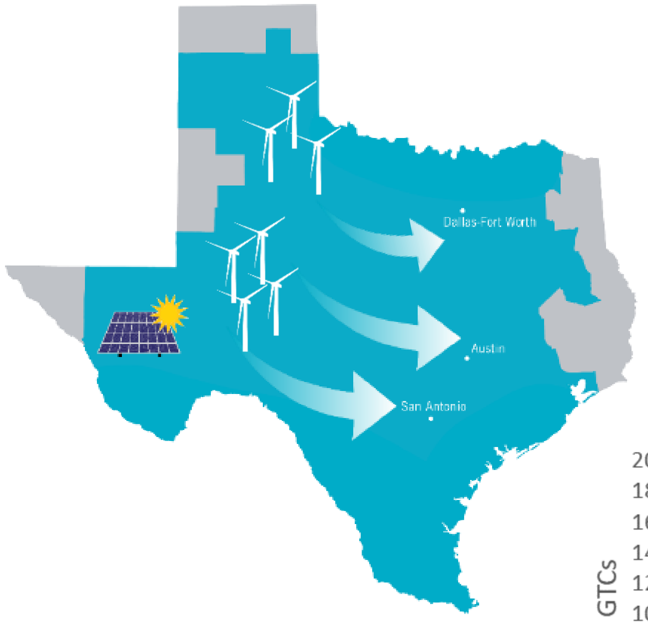
The majority of the inverters used today in wind, solar, and energy storage resources are "grid-following" (GFL). They read the voltage and frequency of the grid, lock onto it, and inject power aligned with that signal. However, instability can result in areas with high levels of GFL inverter-based resources (IBRs) relative to conventional synchronous generators such as coal- and natural gas–fired plants and hydro-electric plants. One issue is that the voltage signal that GFL IBRs latch onto is easily perturbed by the IBRs' current injection, making it harder for inverters to lock onto the voltage signal correctly and causing instability. Another issue is that the voltage signal currently comes from conventional synchronous generators that tend to be located far from areas rich in renewable resources. The farther that pockets of IBRs are from synchronous generation, the "weaker" the grid—the weaker the voltage signal from those strong voltage resources. This situation is getting progressively worse, as the sun- and wind-rich remote areas attract continued development of GFL IBRs today, as seen in West Texas, including the Panhandle, and in South Texas.

https://www.esig.energy/grid-forming-technology-in-energy-systems-integration/

Source: LBNL, Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection, https://emp.lbl.gov/queues

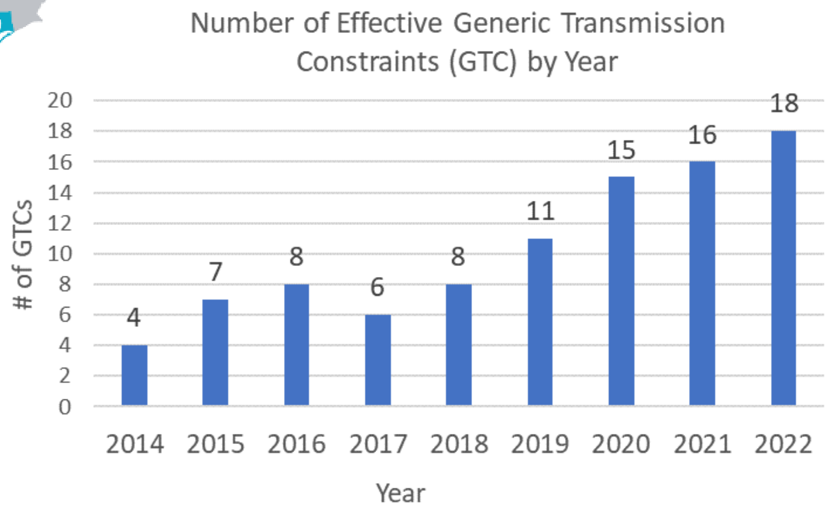
©2022 ESIG. All rights Reserved.

Stability-Related Constraints & Renewable Curtailments, with Example of ERCOT

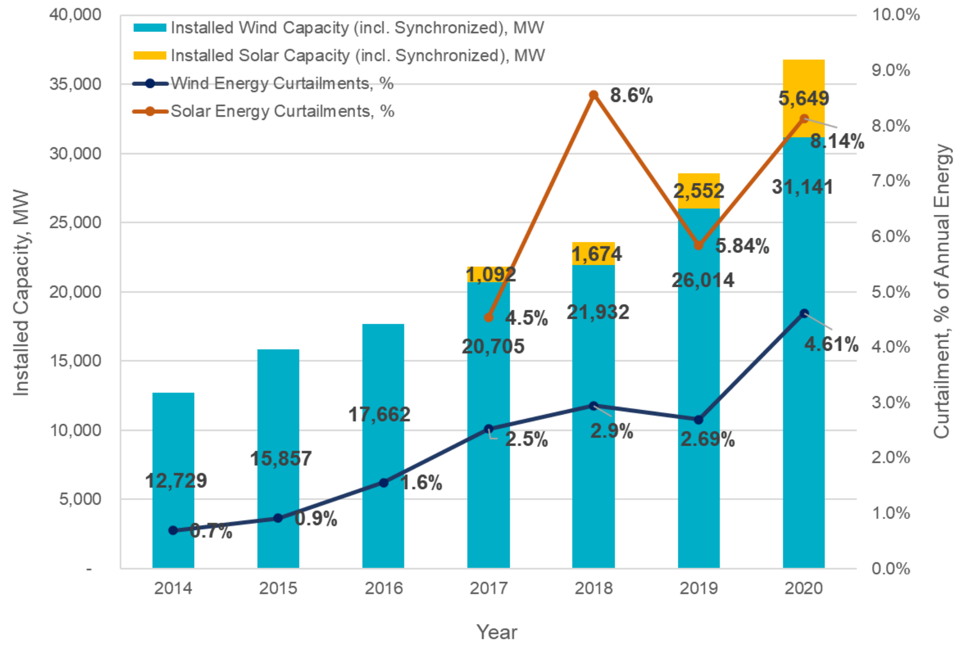


Peak Load – 80 GW
Wind - 37.7 GW
Solar – 15 GW
Battery – 3 GW

71% instantaneous IBR penetration in April 2022



Growth of Wind and Solar Curtailments as More Capacity is Added to the ERCOT Grid, 2014-2020

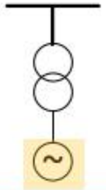


©2022 ESIG. All rights Reserved.

Current Strategies to Relieve Stability Constraints due to Weak Grids– Adding Transmission Assets

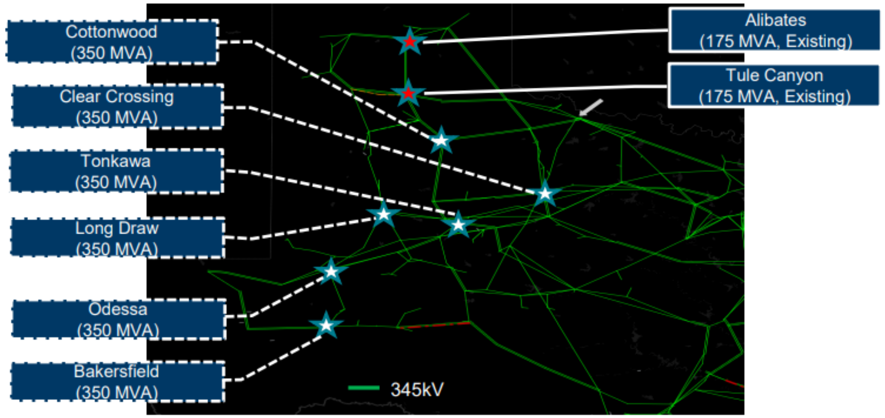
Synchronous Condenser – (w/wo Flywheel)

- Short circuit power and inertia support
- Rotating equipment



Source: Siemens Energy, Ian Ramsay, EIPC Workshop, June 2022

Additional six synchronous condensers with total of 2,100 MVA were identified that will provide effective improvement to WTX.



Source: ERCOT, *Strengthening the West Texas Grid to Mitigate Widespread Inverter-Based Events – Operation Assessment Results*, Regional Planning Group meeting, Feb 2023

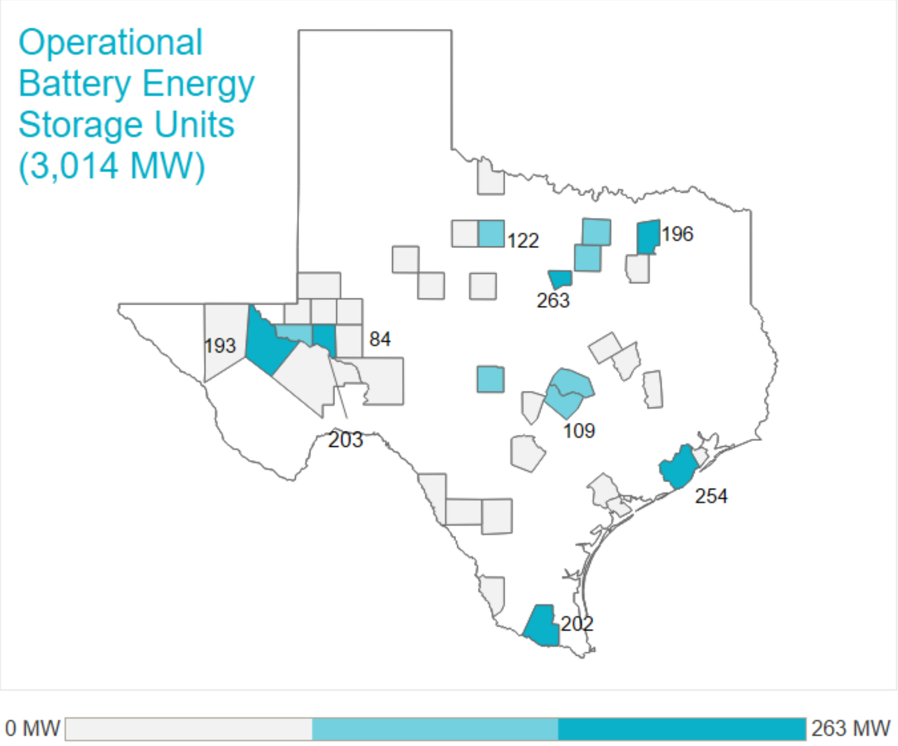
New transmission lines to reduce electric distance between high IBR areas with low system strength and strong grid areas

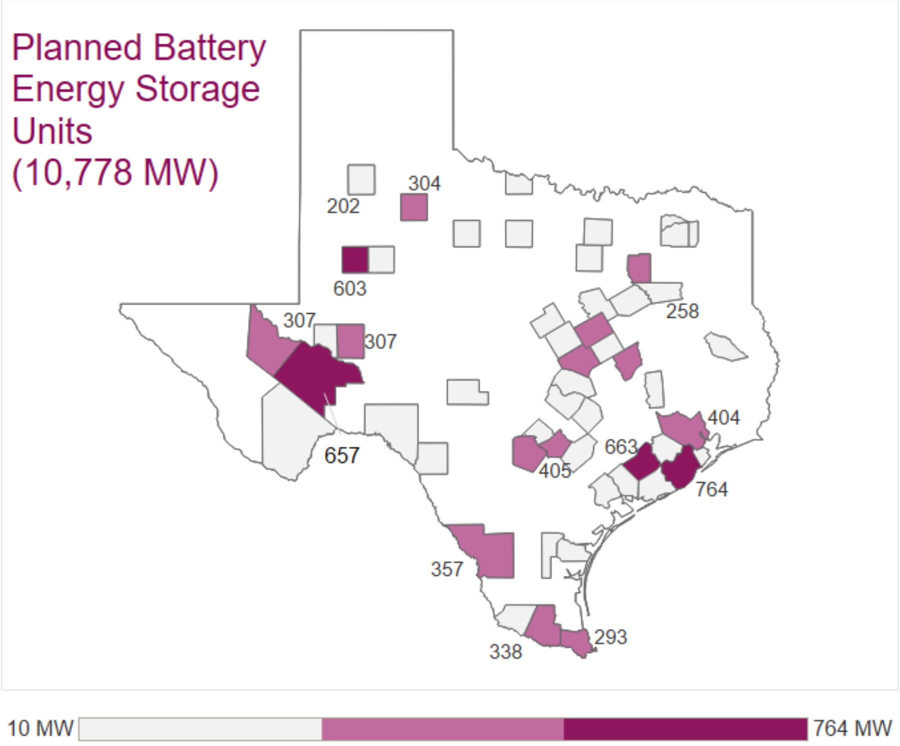
Source: iStockphoto/Yelantsevv

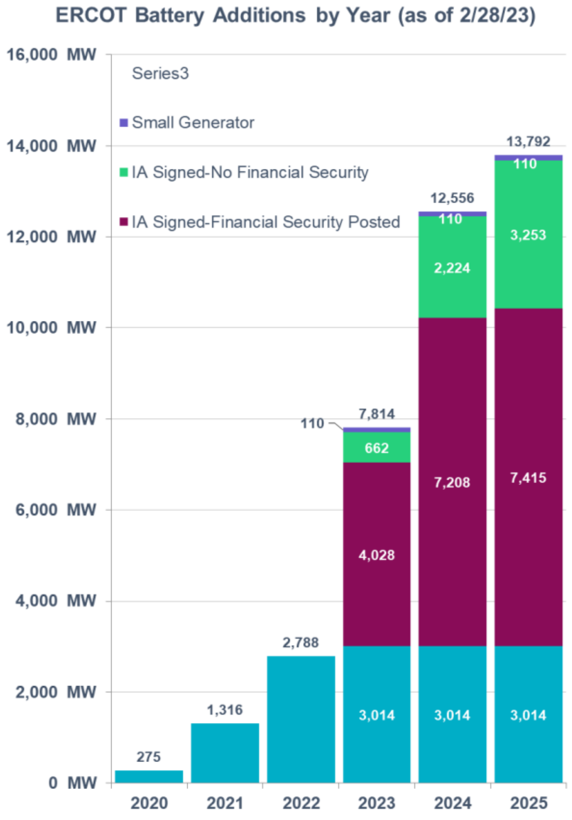
©2022 ESIG. All rights Reserved.

Existing and New Batteries Behind Constraints

In the absence of clear requirements and market incentives for GFM control capabilities, all planned batteries will be built using GFL controls. This may increase systems' needs for additional supplemental devices to improve stability, which will drive-up overall system costs.







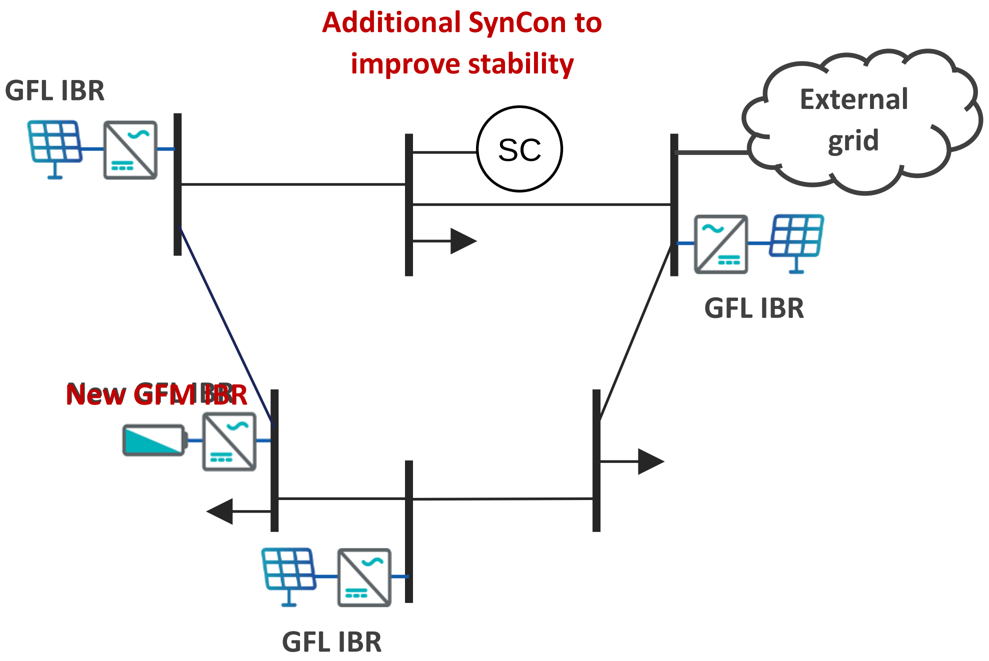
Footnotes: Operational category includes units approved to be Synchronized but not Approved for Commercial Operations. Planned category includes incudes DGRs and planned projects with signed interconnection agreements (IA Signed) thare have not been Synchronized to the ERCOT Grid.

Data from ERCOT Resource Adequacy Department - February 2023 Resource Capacity Trend Charts

Grid Forming Controls as an Alternative for Grid Strength Support

- GFM IBRs can be designed to provide, within equipment limits, most of the services that are currently inherently provided by synchronous generators
- GFM IBRs have a stabilizing effect in weak grid areas and improve stability for IBRs with GFL controls
- If GFM controls are implemented on planned IBRs, they may provide more cost-effective alternative to improve stability.

  This is because the improvement is provided by the new IBRs themselves as they are added to the system and addition of supplemental transmission assets may not be needed.



©2022 ESIG. All rights Reserved.

GFM Battery Projects Deployed and Under Construction

Table I.1: GFM BESS Projects Deployed or under Construction			
Project Name	Location	Size (MW)	Time
Project #1	Kauai,USA	13	2018
Kauai PMRF	Kauai,USA	14	2022
Kapolei Energy Storage	Hawaii, USA	185	2023
Hornsdale Power Reserve	Australia	150	2022
Wallgrove	Australia	50	2022
Broken Hill BESS	Australia	50	2023
Riverina and Darlington Point	Australia	150	2023
New England BESS	Australia	50	2023
Dalrymple	Australia	30	2018
Blackhillock	Great Britain	300	2024
Bordesholm	Germany	15	2019

Additionally, in Dec 2022, the Australian Renewable Energy Agency (ARENA) announced co-funding of additional eight large scale GFM batteries across Australia with total project capacity of 2 GW/4.2 GWh, to be operational by 2025

©2022 ESIG. All rights Reserved.

Source: NERC IRPS White Paper, Grid Forming Functional Specifications for BPS-Connected Battery Energy Storage Systems

Grid Forming Specifications Landscape

- **EU- funded MIGRATE project** – proposed high level GFM functions – 2019
- **ENSTO-E, High Penetration of Power Electronic Interfaced Power Sources** (HPOPEIPS) – identified seven properties of GFM plant – 2020
- **VDE/FNN Guideline**: Grid forming behavior of HVDC systems and Power Plant Modules – performance verification procedure for grid forming – 2020
- **Hawaiian Electric Company requested GFM functionality** from all proposed projects that include battery storage – high level functional requirements in combination with required model tests – 2019, 2021
- **National Grid Electricity System Operator finalized GC0137** – non-mandatory GFM specification – Jan 2022
- **EU-funded OSMOSE project** – defined grid forming capability and new services – Apr 2022
- **DOE-funded project UNIFI**, Specifications for Grid-forming Technologies – functional requirements and performance criteria for integrating GFM IBRs in electric power systems – Dec 2022
- **NERC Inverter-Based Resource Performance Subcommittee (IRPS) Grid Forming Functional Specifications for BPS-Connected Battery Energy Storage Systems**: Functional Specifications, Verification, and Modeling –May 2023
- **Australian Energy Market Operator** – working on a draft of voluntary GFM specifications – May 2023

©2022 ESIG. All rights Reserved.

Common Functionalities

- Response to voltage phase angle step
- Response to voltage magnitude step
- Active/Reactive Power Sharing
- Provide Damping
- Counter Harmonics
- Response to RoCoF event (MW loss)
- Response to Faults (balanced and unbalanced)
- Low SCR Operation
- Island Operation
- Black Start

©2022 ESIG. All rights Reserved.

Conclusions on Specifications

- GFM specifications is still a new topic and is developing together with GFM controls
- All specifications are similar in terms of functionalities, with main differences being around level of specificity and if a requirement is explicit or implicit in a certain specified behavior
- Some of the requirements are more specific while others are high level, in some cases accompanied with performance expectations during testing
- Balance is needed between incentivizing desired behavior (as synchronous machines are being displaced) and allowing freedom in control implementation by OEMs
- High level requirements accompanied with more detailed performance guidelines seems to be a preferred approach today
- Some functionalities can be implemented in grid following inverters as well; these shouldn't be included as a part of GFM specifications.

©2022 ESIG. All rights Reserved.

Opportunity to Future-proof Today's Installations

- Deploying GFM control capability in batteries is a low-hanging fruit solution to weak grid issues that increasingly are the cause of stability-related transmission constraints, and renewable curtailments.
- But the opportunity for ISOs/RTOs/utilities to utilize this resource-based solution may soon pass.
- While only a relatively small number of utility-scale batteries are installed in the U.S. today, a significant amount of battery capacity will likely be developed in the next few years.
- Without specifications and/or incentives for GFM, new batteries will be built with GFL controls, exacerbating stability challenges and the need for additional stabilizing equipment such as synchronous condensers or new transmission.
- With specifications and incentives, new batteries will be installed with GFM capability and help to improve grid stability, reduce curtailment, and reduce the need for additional stabilizing equipment.
- ISOs/RTOs/utilities can work with stakeholders to carry out studies of the benefits of deploying GFM technology and initiate pilot projects
- Experience from installations around the world, particularly in Hawaii, Australia, and Great Britain, can be used as a guide.

©2022 ESIG. All rights Reserved.

THANK YOU

Julia Matevosyan

julia@esig.energy

©2022 ESIG. All rights Reserved.