Grid-Forming Inverter Applications

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ENERGY SYSTEMS INTEGRATION GROUP

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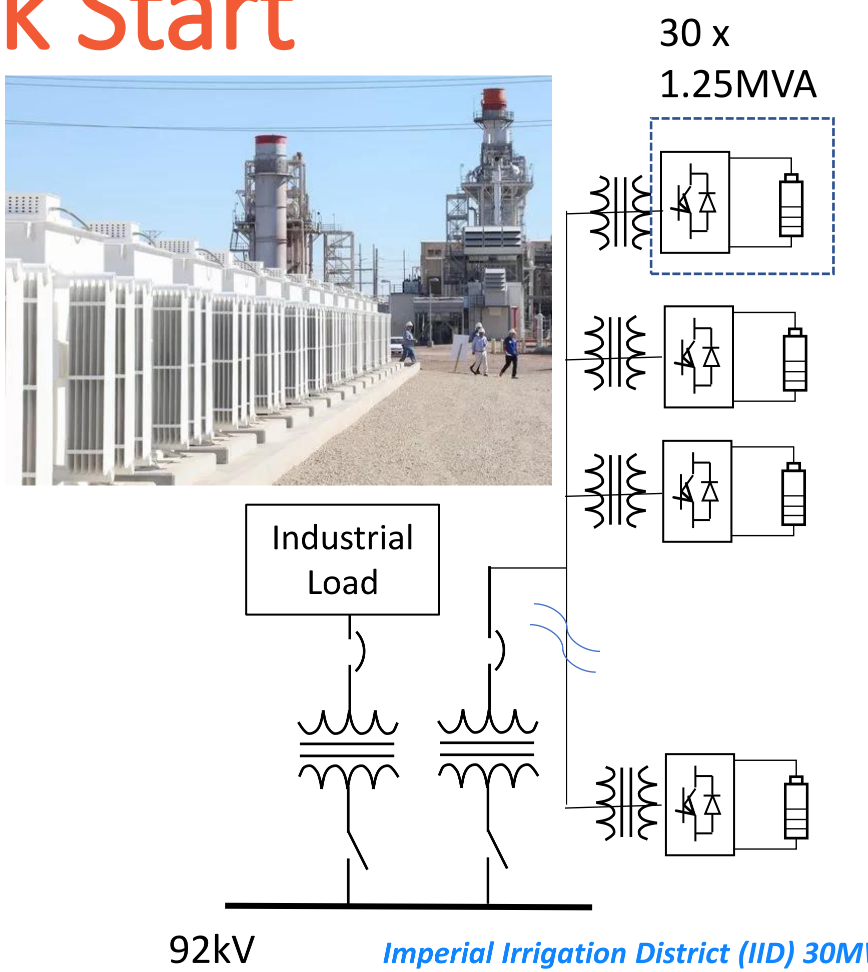
Outline

- Number of BESS for microgrids and 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
- Drivers behind GFM Projects
- Conclusions

GE Grid Forming BESS for Black Start

Key GFM BESS Projects:

- Metlakatla Power & Light 1MW/1.4MWh-1995
- Vernon CA 5MW/2.5MWh- 1996
- Battery Energy Storage System of 30MW/22MWh- IID for GT blackstart, 2017
- Black start of simple cycle HDGT with 7.5 MW x 7.5 MWh BESS, 2019
- Black start of combined cycle HDGT with 13 MW x 13 MWh BESS, 2020
- DOE SETO project – Advanced Grid Forming Inverter Controls, Modeling and System Impact Study for inverter dominated grids, started 2020



Imperial Irrigation District (IID) 30MW, 20MWh BESS project -2017

Source: Shruti D Rao, Sudipta Dutta, Min Lwin, Dustin Howard, Ryan Konopinski, Sebastian Achilles, Jason MacDowell, “Grid-forming Inverters –Real-life Implementation Experience And Lessons Learned”, IET RPG 2021

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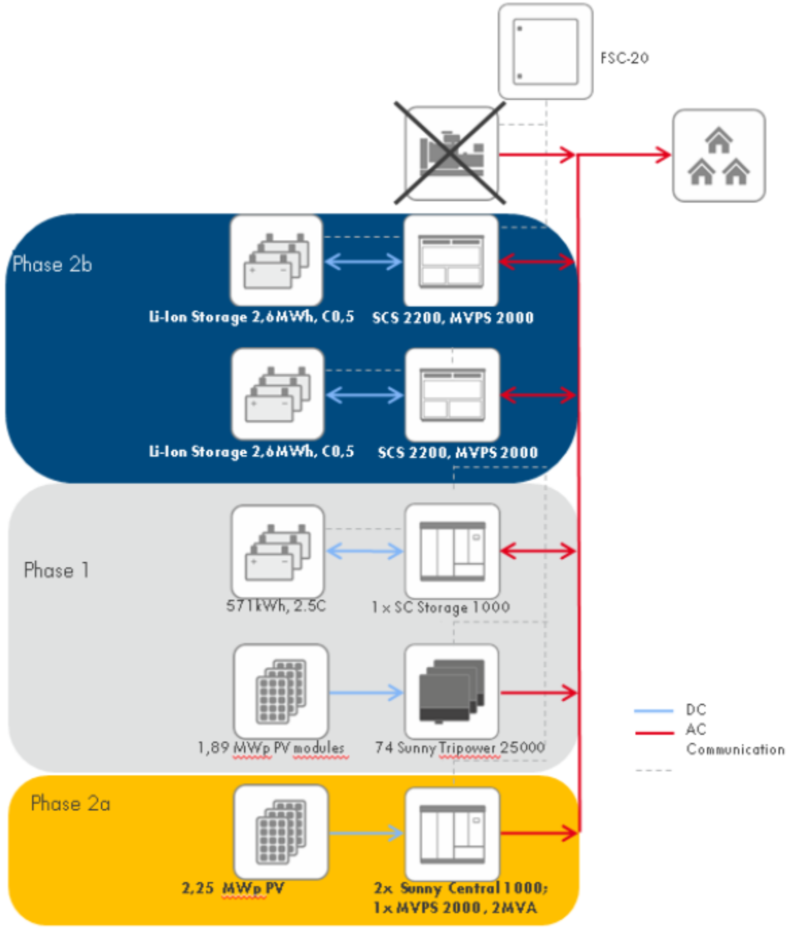
Microgrid example: St. Eustatius

Commercial Pilot deployed in November 2017

- 2.3 MW peak load, 14 GWh yearly energy consumption
- 9 diesel gensets 4 MVA, 4.15 MW PV, 5.9 MWh Li-Ion BESS 2/3 with GFM
- Plant controller sends start/stop signals to gensets, does frequency and voltage control during genset-free operation, transfers frequency and voltage control to the genset controller while the gensets are running
- Load distribution between several parallel GFM units (no communication)
- Diesel-off mode (100% Storage + Solar)
- Seamless immediate load transfer after generation contingency (simultaneous loss of all gensets at peak load), 0.6 Hz frequency dip, restored within 3 s, no load shedding.
- Voltage ride-though for various faults and operating modes.



Source: https://www.smainverted.com/st-eustatius-100-solar-power-in-the-caribbean/
O. Schömann, T. Bülo, C. Hardt, A. Falk, P. R. Stankat “Experiences with Large Grid Forming Inverters on the Island of St. Eustatius, Portability to Public Power Grids”, 8th Solar Integration Workshop, 2018

Testing Existing Siemens-Gamesa Wind Turbines in GFM Mode: Grid-Connected Operation

23 direct-drive full converter wind turbines, 69 MW, operated in GFM mode for 6 weeks (May – June 2019) in Dersalloch, Scotland.

- Virtual Synchronous Machine control method used.
- Various inertia constants tested during the trail H=0.2s, 4s and 8s.
- Six large underfrequency events with RoCoF up to 0.11 Hz/s and frequency drop up to -0.5 Hz.
- Additionally, large frequency event was induced with RoCoF=-1 Hz/s, Δf=-3 Hz, H=8 s.
- No significant grid voltage phase steps occurred but small steps were induced (up ~0.2°).
- The wind power plant was able to respond to the events autonomously and immediately with power injections as expected with the inertia levels configured.
- No turbine trips due to stalling, over-power, over-current etc. during the grid events.

Limitations:

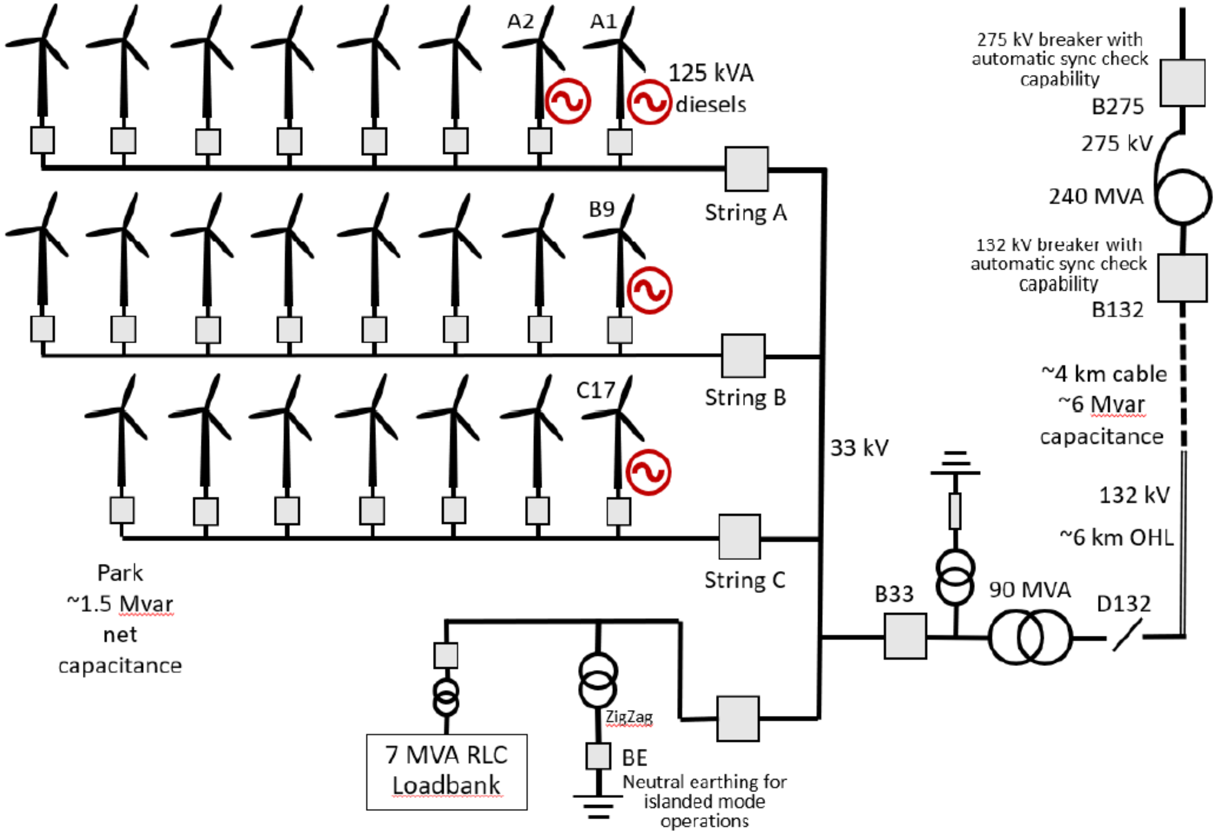
- Turbine's ability to respond may be affected if wind speed is declining during the response.
- Turbine's ability to respond at low or zero power output is extremely low.

Source: A. Roscoe, et.al. "Practical Experience of Operating a Grid Forming Wind Park and its Response to System Events, 18th Wind Integration Workshop, 2019

Testing Existing Siemens-Gamesa Wind Turbines in GFM Mode: Island Operation and Black Start

In August-October 2020 it was successfully demonstrated that Dersalloch wind farm

- Can operate autonomously in islanded mode with small number of wind turbines operating in GFM mode.
- Can re-synchronize from islanded to grid-connected mode of operation.
- Can black-start the wind farm from a few black start-capable wind turbines, extending energization to the transmission network all th way up to 132kV/275kV transformer and re-synchronization with the grid.



Source: A. Roscoe, et.al. "Practical Experience of Providing Enhanced Grid Forming Services from an Onshore Wind Park", 19th Wind Integration Workshop, 2020

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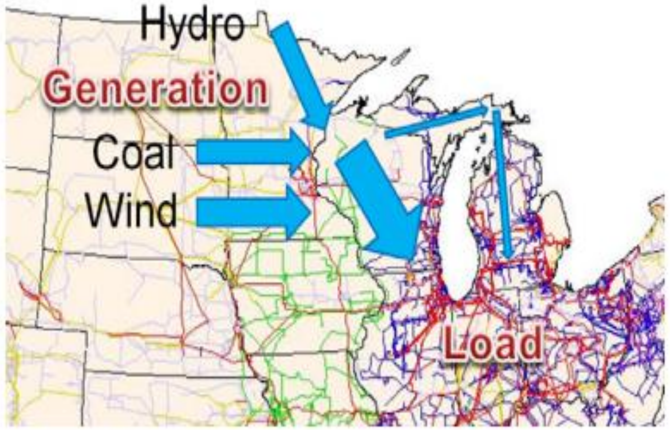
Mackinac Back-to-back VSC HVDC for power flow

- 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 on Michigan's Upper Peninsula, near the Straits Substation and in line with an existing 138 kV AC cable double-circuit across the Straits of Mackinac
- Voltage source converter (VSC) technology was selected over classic HVDC technology: 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*.



Source: https://www.cce.umn.edu/documents/CPE-Conferences/MIPSYCON-Papers/2014/MackinacHVDCConstructionandTesting.pdf
https://library.e.abb.com/public/181cbb7702cd43d0c1257d650024a088/Mackinac%20HVDC%20Converter%20Automatic%20runback%20utilizing%20locally%20measured%20quantities.pdf

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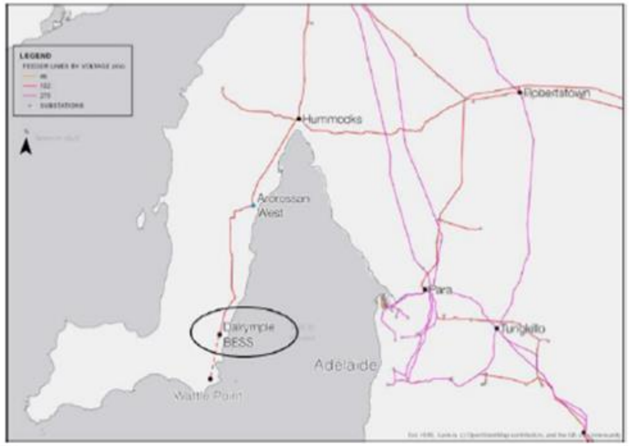
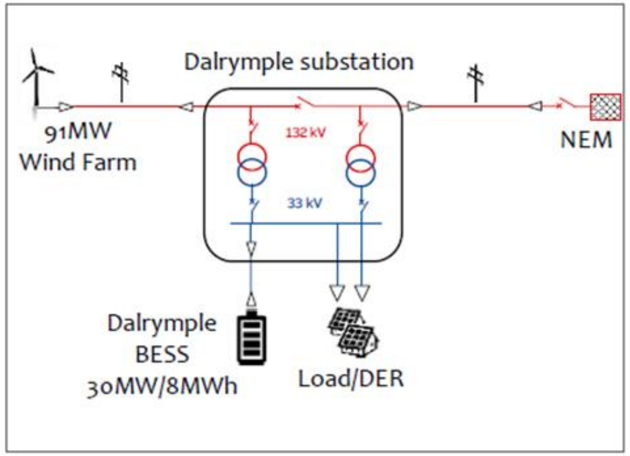
Hitachi ABB Energy Storage for Commercial Renewable Integration (ESCRI) in GFM mode

- Dalrymple BESS in South Australia is the largest grid-connected GFM BESS in the world, at 30 MVA and 8 MWh.
- Virtual Synchronous Machine control method is used
- It is the first large scale, grid-forming BESS connected to Australian transmission system
- Commissioned in 2018, near the end of a long 132 kV single-circuit radial feeder close to 91 MW wind farm, local load up to 8 MW and 2 MW of local rooftop PV
- In the first six months of operation, reduced the loss of supply in the area from ~8 hours to 30 minutes.





Source: "Grid Forming Energy Storage: Provides Virtual Inertia, Interconnects Renewables and Unlocks Revenue", https://go.hitachi-powergrids.com/grid-forming-webinar-2020
Contribution to the ESIG White Paper by Luke Robinson, AEMO

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Hitachi ABB Energy Storage for Commercial Renewable Integration (ESCRI) in GFM mode

The services provided by the project include:

- **Inertia** –can provide virtual inertial response of 200 MWs with configurable magnitude and slope, reducing RoCoF after a sudden loss of load or generation. This is different from Fast Frequency Response (FFR).
- **System Strength** –can operate at very low Short Circuit Ratios (<<1.5). It is also able to provide system strength support via short-term fault current overload (up to 2 pu for 2 seconds).
- **Islanded operation** – regulates the frequency in the microgrid by utilizing virtual inertia, primary and secondary frequency control. Additionally, can adjust the system frequency to invoke curtailment of behind-the-meter DER to avoid overgeneration conditions due to rooftop PVs.
- **Black start capability** – can black start the local 33 kV distribution network with 8 MW demand. Voltage is ramped up slowly to prevent high inrush current (soft transformer energization).
- **System Integrity Protection Scheme (SIPS)** – providing fast active power injection into the grid following a significant loss of generation. The GFM BESS can be operating at full capacity within 250 ms if a network event is detected at the interstate AC interconnector, 400 km away in the southeast of South Australia.

Source: Grid Forming Energy Storage System addresses challenges of grids with high penetration of renewables (A case study) (electranet.com.au)

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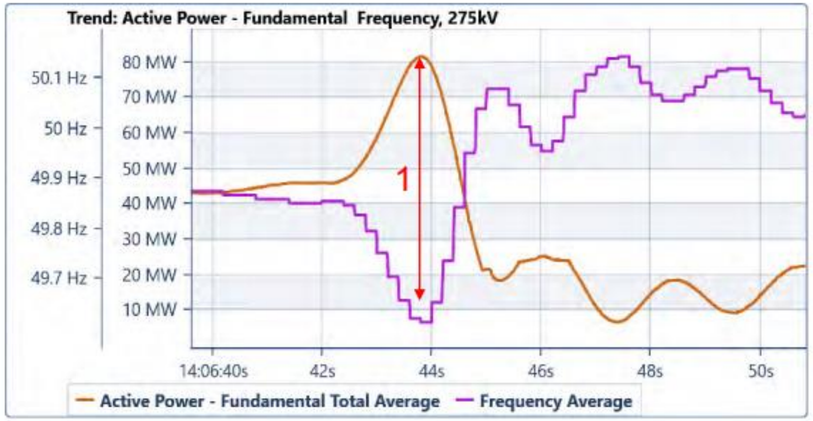
Tesla Hornsdale BESS

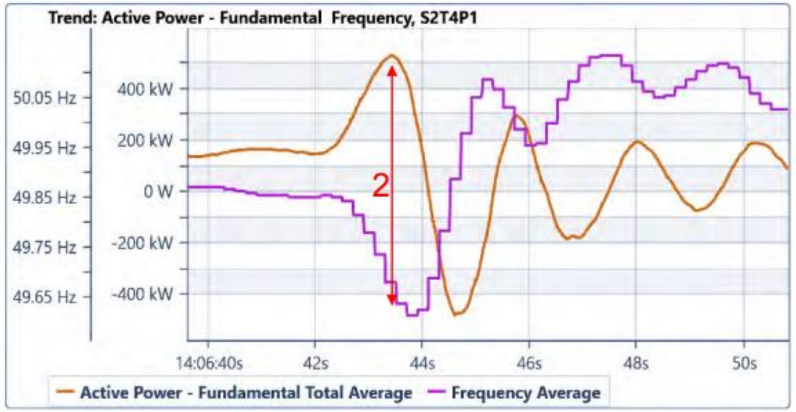
- BESS co-located with the Hornsdale Wind Farm in South Australia
- Installed in 2017, 100 MW/129 MWh provided energy and FCAS
- In 2020 expanded to 150 MW/194 MWh
- Two inverters currently operate in Virtual Machine Mode (VMM)
- The VMM runs in parallel with the conventional GFL component
- During grid disturbances, VMM produces an active power proportional to RoCoF and produces reactive current in response to changes in voltage
- Under stable system conditions, the inverter’s behavior is driven by the current source component
- “Real life”- tested in a frequency event created by a coal plant explosion and subsequent trip of neighboring units on 5/25/2021
- “Virtual machine mode” to the rest of that battery is expected by the end of the year once extensive modelling and testing is complete.

- VMM event captured 25/5/2021
- “H” Constant = 50
- Clear response of VMM responding to ROCOF



Site Response

[1] Max active power response at max frequency deviation



VMM Enabled Inverter Response

[2] Max active power response at max RoCoF

Source: https://reneweconomy.com.au/virtual-machine-hornsdale-battery-steps-in-to-protect-grid-after-callide-explosion/
https://arena.gov.au/assets/2021/06/arena-insights-webinar-advanced-inverters-presentations.pdf

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More GFM BESS underway in Australia

- Torrens Island Power Station (currently gas-fired), north of Adelaide in South Australia, the world's largest 'grid forming' battery 250 MW/250 MWh Wärtsilä battery with SMA inverters (construction to begin fall 2021). The battery will initially operate in grid-following mode, before switching over to become grid-forming, **awaiting regulatory framework and market incentives for grid-forming technologies.**

- The new 50MW/75MWh Wallgrove battery in western Sydney being built by Transgrid will also deploy similar capabilities. Expected to be ready for operation in Q4 of 2021. The battery will provide **fast frequency response and inertia services** to the New South Wales transmission network via Tesla's inertia product known as "Virtual Machine Mode".

Source: https://www.pv-magazine.com/2021/08/10/worlds-largest-grid-forming-battery-to-begin-construction-in-australia/
https://reneweconomy.com.au/transgrid-to-build-australias-first-tesla-megapack-big-battery-in-western-sydney-55391/

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Drivers for GFM Projects

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)
- NGESO will maintain Best Practice Guide, documenting examples of successful projects in compliance with required GFM specifications.

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

Conclusions

- There is a handful of applications of Grid Forming Inverters around the world;
- The applications today are primarily small island/microgrid applications;
- More grid-connected GFM batteries are under way in Australia.
- Stability Pathfinder Phase 2 and 3 will incentivize more grid-connected, utility scale GFM projects in Great Britain
- Batteries are a low hanging fruit for GFM application
- There are large amounts of batteries in the interconnection queues in some systems around the world. This window of opportunity should be seized to future-proof the path towards higher shares of IBRs.

Thank you! Questions?