

An aerial photograph of a river flowing through a dense forest. The river is clear, showing rocks and pebbles on the bottom. The surrounding forest is lush green. The title text is overlaid on the middle section of the image.

Grid-Forming Inverter Applications

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- And many others!

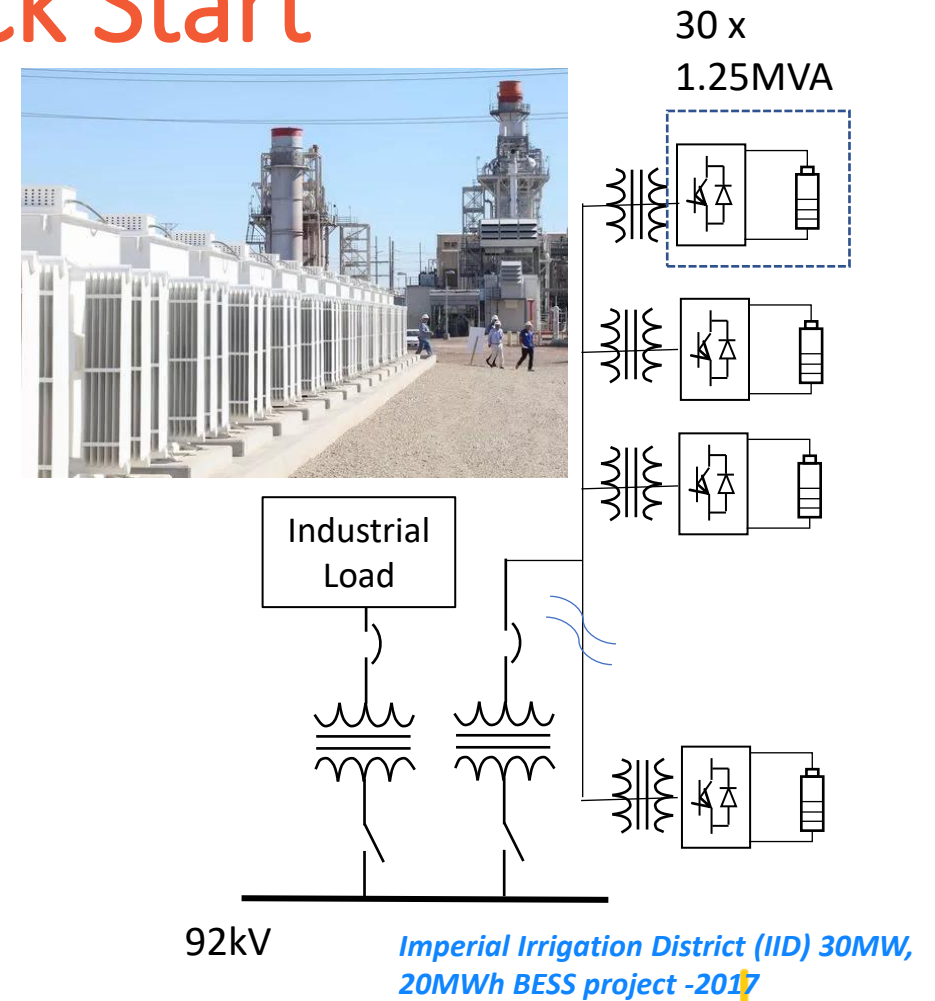
Outline

- 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

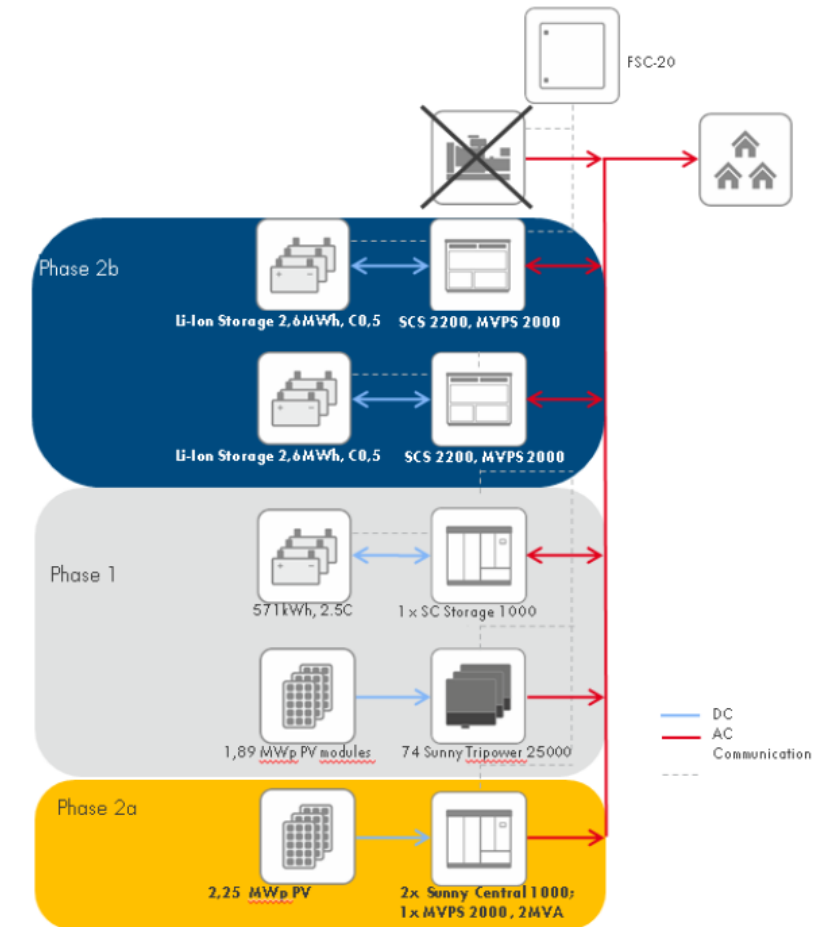


Source: Shruti D Rao, Sudipta Dutta, Min Lwin, Dustin Howard, Ryan Konopinski, Sebastian Achilles, Jason MacDowell, "Grid-forming Inverters –Real-life Implementation Experience And Lessons Learned", IET RPG 2021

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-through 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 trial $H=0.2s$, $4s$ 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 $\text{RoCoF}=-1 \text{ Hz/s}$, $\Delta f=-3 \text{ Hz}$, $H=8 \text{ s}$.
- No significant grid voltage phase steps occurred but small steps were induced (up $\sim 0.2^\circ$).
- 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.

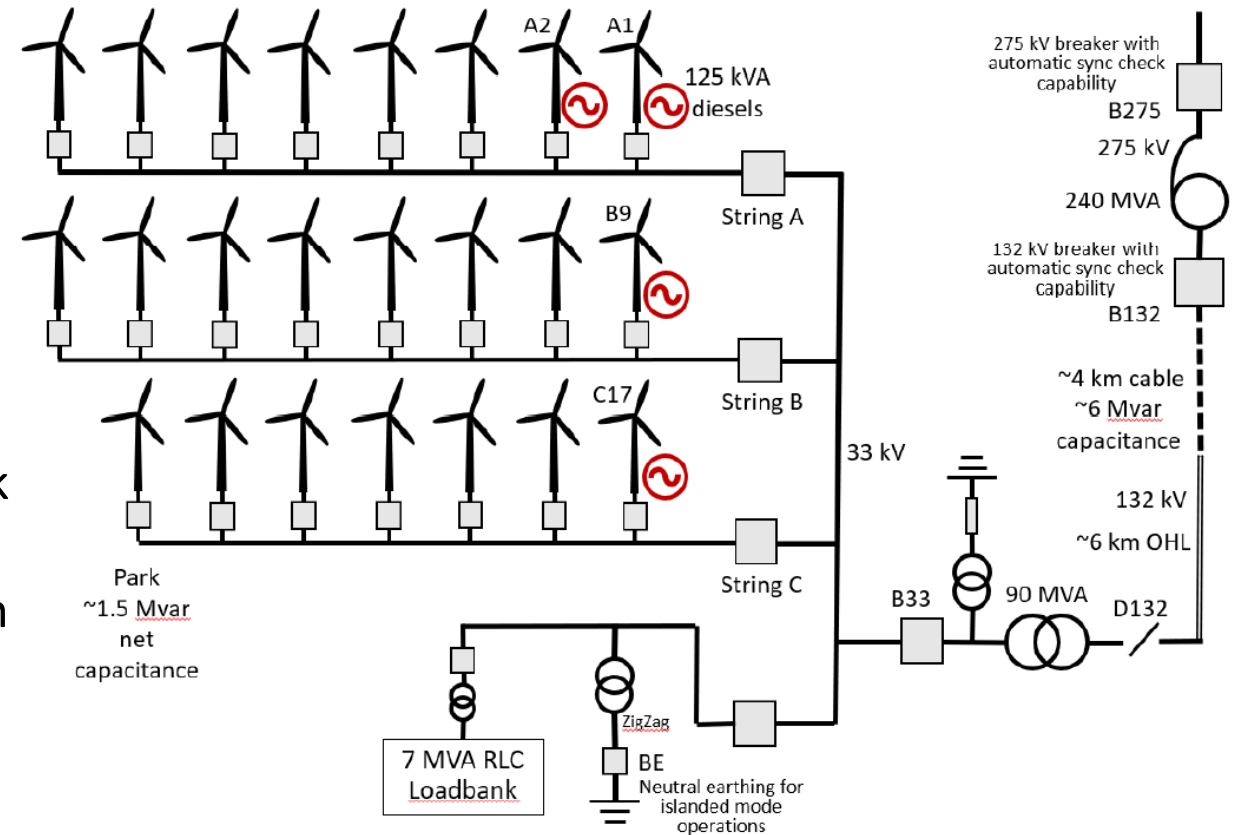
Source: A. Roscoe, et.al. "Practical Experience of Operating a Grid Forming Wind Park and its Response to System Events, 18th Wind Integration Workshop, 2019



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 the 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

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 weak grid, so a *“phasor voltage control”* was developed based on direct control of the converter’s internal ac voltage amplitude and phase.



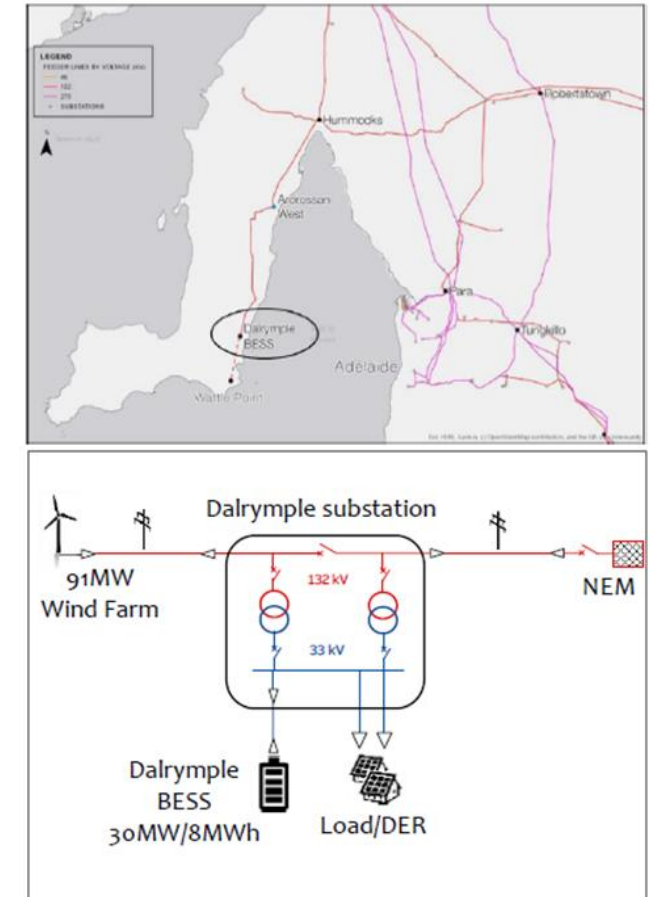
Source: <https://www.cce.umn.edu/documents/CPE-Conferences/MIPSYCON-Papers/2014/MackinacHVDCConstructionandTesting.pdf>

<https://library.e.abb.com/public/181cbb7702cd43d0c1257d650024a088/Mackinac%20HVDC%20Converter%20Automatic%20runback%20utilizing%20locally%20measured%20quantities.pdf>



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

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 ($\ll 1.5$). 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.

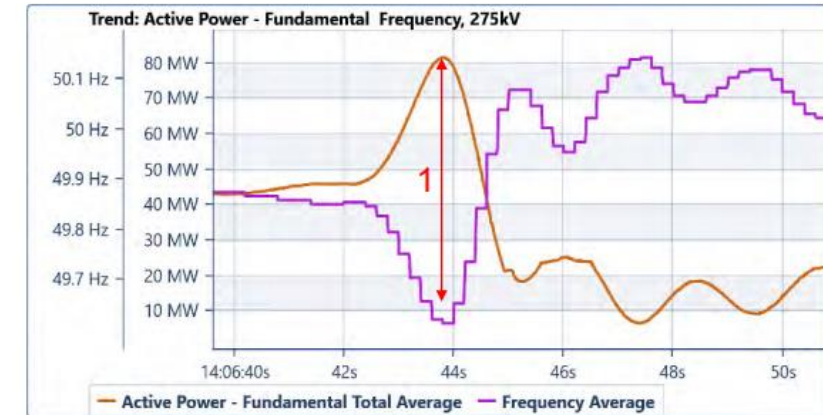
Source: [Grid Forming Energy Storage System addresses challenges of grids with high penetration of renewables \(A case study\) \(electranet.com.au\)](https://www.electranet.com.au)



Tesla Hornsdale BESS

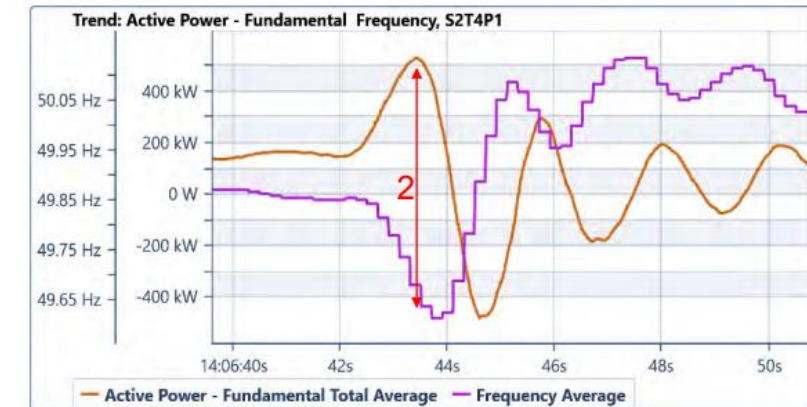
- BESS co-located with the Hornsdale Wind Farm in South Australia
- Installed in 2017, 100 MW/129 MWh provided energy and FCAS
- In 2020 expanded to 150 MW/194 MWh
- Two inverters currently operate in Virtual Machine Mode (VMM)
- The VMM runs in parallel with the conventional GFL component
- During grid 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>

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/>



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?



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