GLOBAL PST CONSORTIUM

Grid-forming technologies: Necessity, capabilities, & impacts

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Foro XM – 18 May 2023

GLOBAL PST CONSORTIUM

nationalgridESO

NREL Transforming ENERGY

IEEE Advancing Technology for Humanity

VTT

AEMO Australian Energy Market Operator

CSIRO

EPRI Electric Power Research Institute

EirGrid Group

Imperial College London

Fraunhofer CINES

DTU

olade Organización Latinoamericana de Energía

ercot

ESIG Energy Systems Integration Group

California ISO

CSIR Touching lives through innovation

ENERGINET

ASEAN Centre for Energy • ACE •

Agenda: Grid Forming Technologies

1. What are grid-forming (GFM) inverter technologies?

2. What are the potential benefits of GFM?

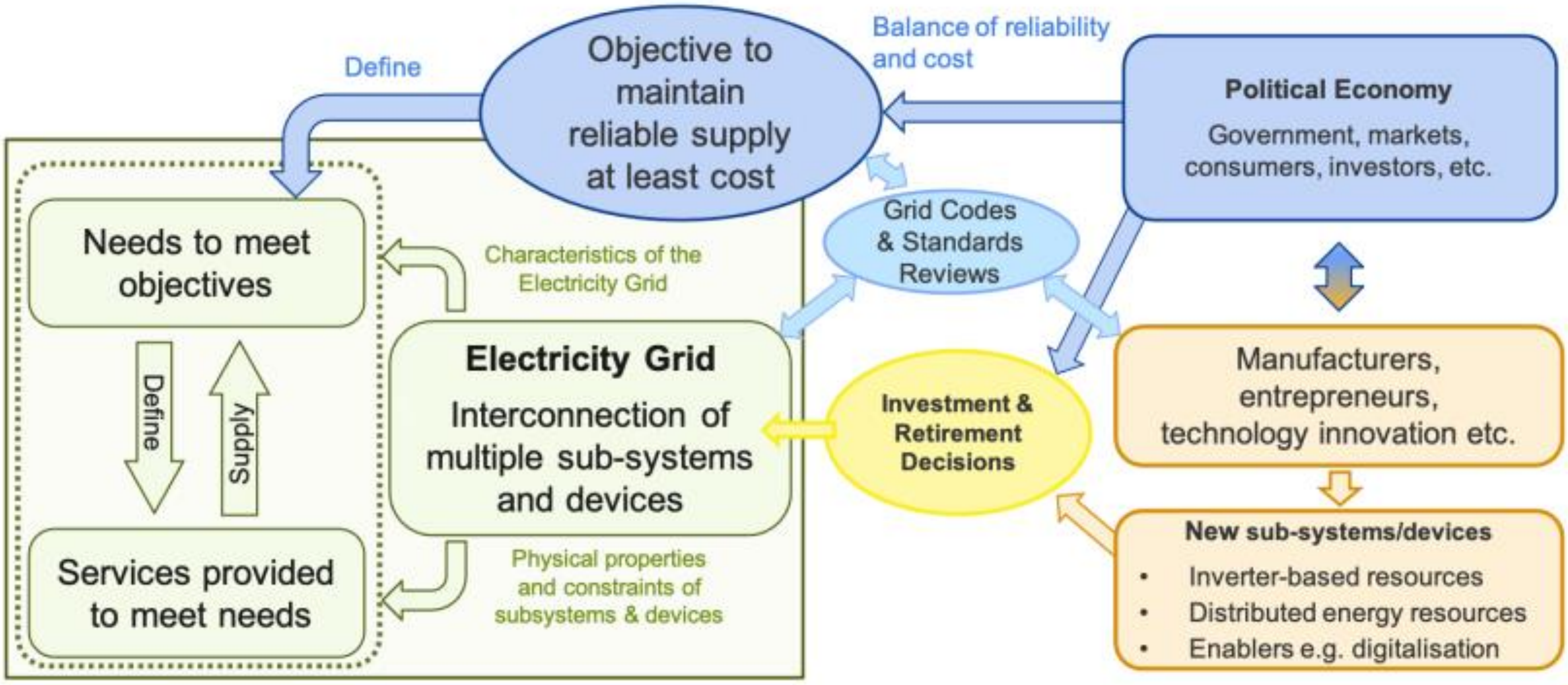
3. When are GFM technologies needed or useful?
    - ➢ How does GFM work under different conditions?
    - ➢ What kinds of systems probably don’t need GFM (yet)?
    - ➢ When is it a good idea to deploy GFM even if it isn’t “needed yet”?

4. What are potential system impacts, particularly of multiple GFM installations?
    - ➢ What considerations are important when deploying GFM?

5. What is next with these technologies?
    - ➢ Examples of demonstration projects and standards development

System needs and services
& inverter-based resource capabilities

System Needs and Services



Source: https://globalpst.org/wp-content/uploads/GPST-IBR-Research-Team-System-Services-and-Needs-for-High-IBR-Networks.pdf

System Needs

Equipment & Control Stability
- Fault Ride-Through Needs
- Small Signal Stability Needs
- Needs to avoid control interactions
- Equipment Protection Needs

Network Stability & Power Quality
- Synchronization and Angle Stability Needs
- Frequency Regulation Needs
- Voltage Regulation Needs
- Damping Needs

Security & Service Quality
- Energy Needs
- Capacity Needs
- Protection Needs
- Restoration Needs

Source: https://globalpst.org/wp-content/uploads/GPST-IBR-Research-Team-System-Services-and-Needs-for-High-IBR-Networks.pdf

What are grid-forming technologies?
Where are they deployed today?

What does GFM mean?
What are GFM technologies?

TODAY → TOMORROW

Grid Following	Grid Forming Base	Grid Forming +
• Locks to the voltage waveform • Acts likes an AC **current source** • Regulates power slowly to meet device needs	• Control SW only modifications • Acts as an AC **voltage source** • Fast provision of power & current to help stabilize the grid • Can potentially be retrofitted	• Add Energy Storage • Acts as an AC **voltage source** • Fast provision of power & current to help stabilize the grid • Additional fault support capability • Can expand to Islanding & Black Start

Source: GE

- Example technologies: battery storage, wind or solar inverters
- There are different levels or “flavors” of GFM that may address various system needs.

Where are GFM Technologies Deployed Today?

- Several BESS for microgrids & black start of simple cycle gas turbines (GE)
- BESS on St Eustatius island (SMA)
- Dersalloch Wind Farm in Scotland (Siemens Gamesa)
- Dalrymple BESS in South Australia (Hitachi ABB)
- Hornsdale BESS in South Australia (Tesla)
- Drivers behind GFM trials in Australia
- Great Britain projects (National Grid ESO) projects
- United States
  - California: GE BESS for Black Start & SM stability support
  - Hawai’i: GFM batteries used to stabilize system frequency
  - Alaska: GE BESS for remote grid stability (1996)
- Ireland – EirGrid
  - 2023 pilot of GFM control algorithms on existing IBRs

What are potential benefits of grid-forming technologies?

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

Benefits of GFM Technologies

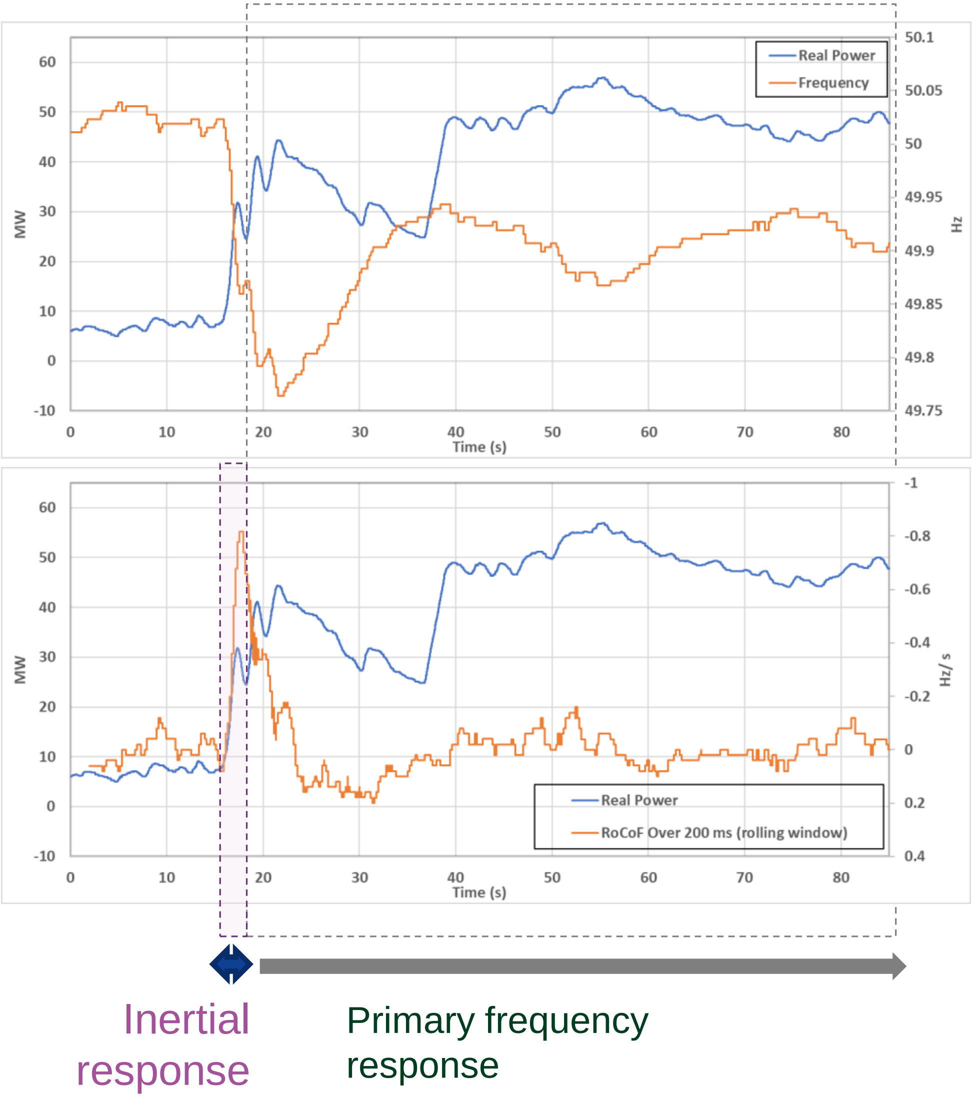
- Allow stable operation in lower SCR environments by providing voltage source
- Equipment control stability
- Fast (nearly instantaneous) frequency support like synchronous machines
- Minimize equipment, plant and grid tripping
- Avoid generation restrictions under prior outage operation guides (MISO/Invenergy example)
- Avoid need for network upgrades due to stability constraints
  - Therefore avoid associated network upgrade project delays
- Black start / system restoration

GFM capability resolves many equipment stability and some grid issues, but it doesn't solve all network issues.

Long distance power transfer in weak networks is still a challenge even with GFM deployed.

GFM Australia Performance Example

- Hornsdale Power Reserve
- Under frequency event on 11/08/2022 (NEM time 1852:35)
- Inertial response is driven by the Rate of Change of Frequency (RoCoF)
- Followed by the primary frequency response



Source: AEMO

Grid forming technologies are not a magic solution to all problems, and they can create challenges of their own that need to be carefully managed

When are GFM technologies needed or useful?

- Under what conditions is GFM most needed?
- What kinds of systems probably don’t need GFM (yet)?
- When is it a good idea to deploy GFM even if it isn’t “needed yet”?

Where are GFM Particularly Useful?

- Regions of grid with no synchronous generators and high share of IBR
- Weak grids with control stability risks of grid following IBR
- Electrical islands with low synchronous inertia
- Areas where transmission buildout is particularly complicated/costly
- Areas with disturbances that cause cascading generator outages

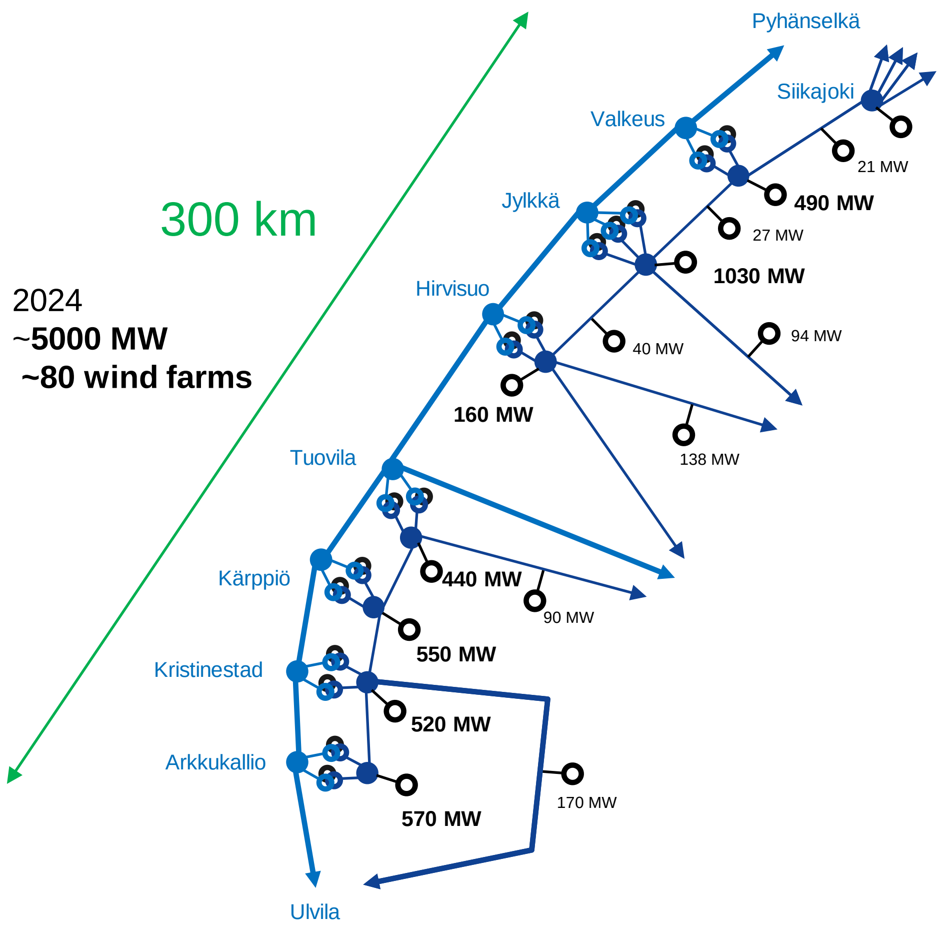


Figure source: FINGRID

What are the potential system impacts and mechanisms for deployment?

(particularly of multiple GFM installations)

- What codes, standards or publications include GFM today?
- What considerations does this suggest are important when deploying GFM?

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
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Comparison at a Glance

Specs	GC0137	OSMOSE	VDE/FNN	UNIFI (draft)	HECO
Response to phase-jump	Yes, defines response time (< 5ms) and size of phase-jump angle (5 deg)	Yes, similar to GC0137	Yes, Provides a time-dependent profile with a minimum sustain time	Yes	Yes, high level
Inertial Response / Immediate Active Power	Yes, defines response time (< 5ms)	Yes, defines response time (< 5 ms) and proposes to set min sustain time	Yes (implicit), frequency change test	Yes	Yes, high level
System Strength/ Immediate Reactive Power / Response to voltage Step	Yes, defines response time (< 5 ms)	Yes, defines response time (< 5 ms)	Yes, verified through voltage step tests	Yes (improve system strength)	Yes, high level
Fast Fault Current (balanced and unbalanced)	Yes, defines response time (< 5 ms) and time to full response (< 30 ms)	Yes, defines response time (< 5 ms) , discusses active/reactive current share and pos/negative sequence prioritization	TBC	Yes, at high level and by definition	Yes, high level

This specification generally apply within equipment limits and all requirements applicable to GFL IBRs also apply (unless conflicts with GFM requirements above)

Comparison at a Glance

Specs	GC0137	OSMOSE	VDE/FNN	UNIFI (draft)	HECO
Low SCR operation	Yes	Yes, by definition	Yes	Yes	Yes, high level
Active/Reactive power sharing	Yes (implicit in other req.)	Yes (implicit in islanded test)	Yes (implicit in islanded test)	Yes	Yes, high level
Damping of voltage and frequency oscillations	Yes, defines response time (<5 ms)	May be	Yes	Yes	Yes, high level
Islanded operation	Yes	Yes	Yes	Yes	Yes, high level
Counter Harmonics	No (existing requirements for GFL apply, additional requirements may be agreed bilaterally)	No (requirement not to contribute to harmonics as applied to GFL is already challenging)	Yes	Yes	Yes, high level
Black start	Yes, if applicable	Yes, if applicable	Yes, if applicable	Yes, if applicable	Yes, if applicable

These specifications generally apply within equipment limits and all requirements applicable to GFL IBRs also apply (unless conflicts with GFM requirements above)

Deployment Considerations:

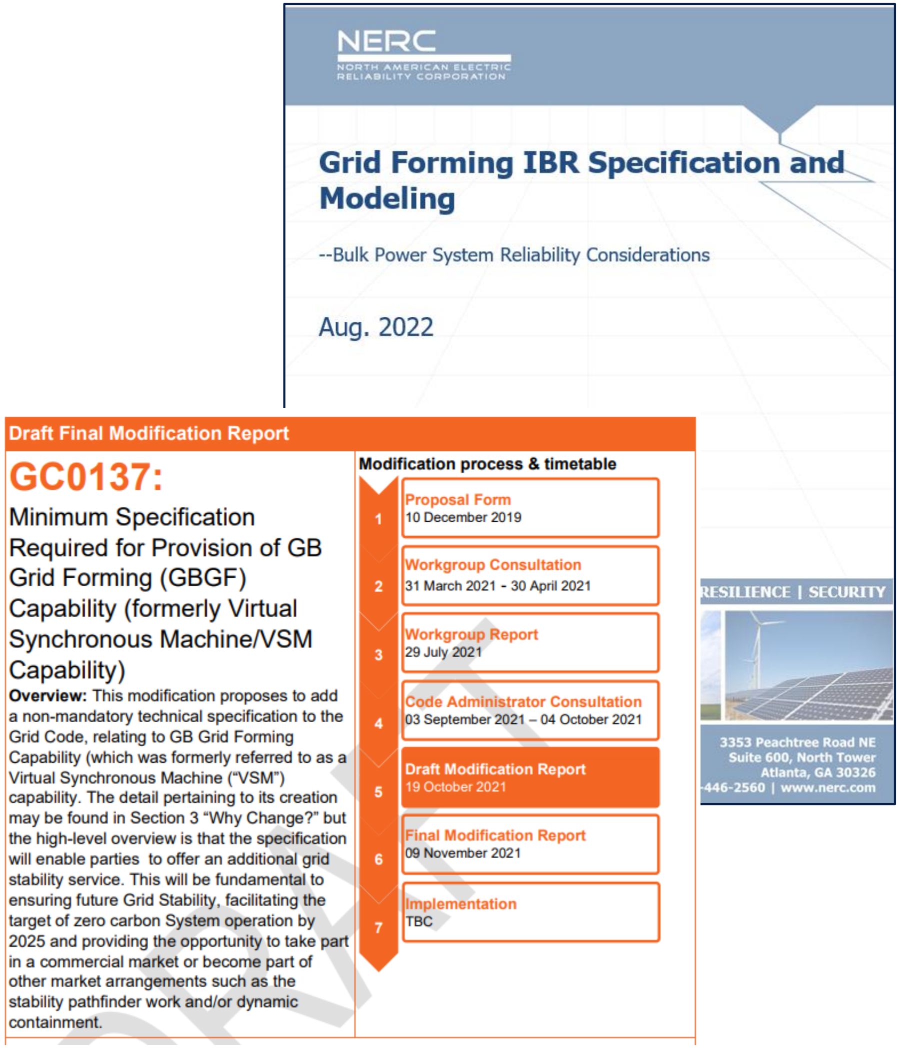
- Markets for different services that the power system needs signal the type, volume, and location of technology deployment
- Grid-forming technology deployment should be compatible with, and have minimum impact on, the existing modeling, assessment, and performance monitoring practices

What is next with these technologies?

- Where are standards in place or under development?
- Where will the next demonstration projects be located?

Standards & Technical Publications for GFM Technologies

- Great Britain GC 0137: Minimum specifications for provision of GF capability
- Australia NER: defines technical requirements for generators including BESS, AEMO has applied to current GFM BESS
- United States NERC: Grid forming IBR specifications and modeling
- UNIFI consortium draft standards
- ACER/ ENTSO-E’s Requirements for Generators (RFG)
- CIGRE JWG B4/C4.93 “Development of Grid Forming Converters for Secure and Reliable Operation of Future Electricity Systems“
- Hawaii Grid Forming specification
- IEEE P2988: Recommended Practice for Use & Functions of Virtual Synchronous Machines
- IEC TC8 SC8A



NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Grid Forming IBR Specification and Modeling

--Bulk Power System Reliability Considerations

Aug. 2022

RESILIENCE | SECURITY

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Draft Final Modification Report

GC0137:

Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability (formerly Virtual Synchronous Machine/VSM Capability)

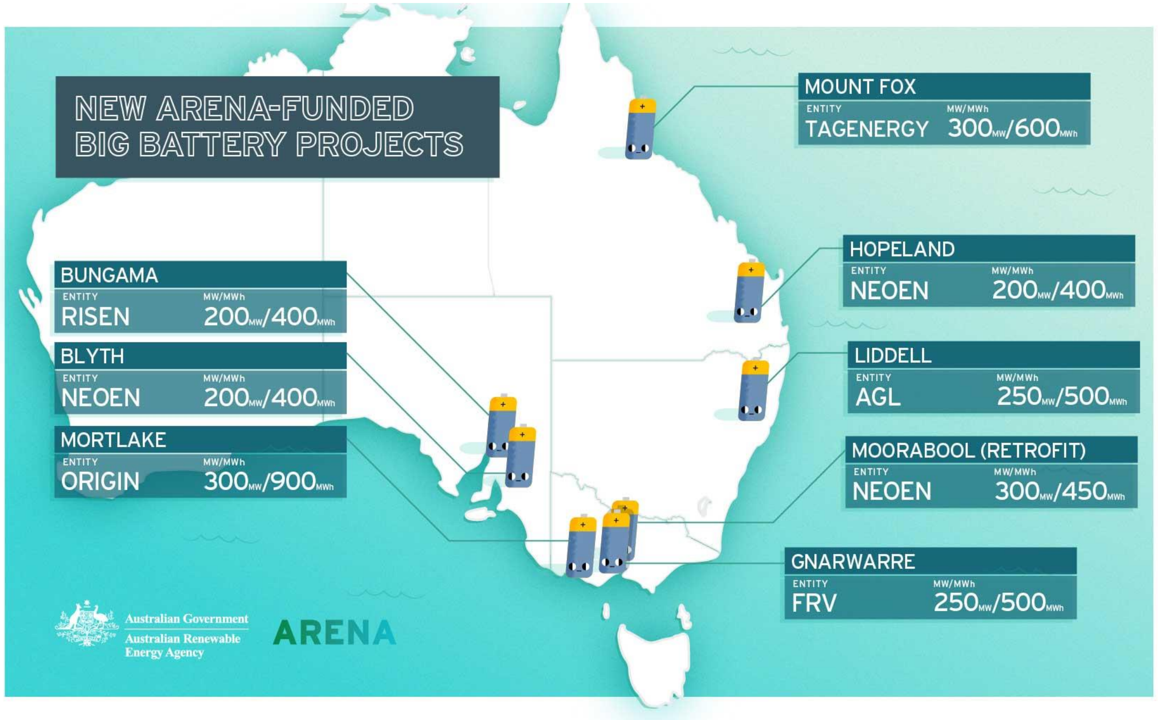
Overview: This modification proposes to add a non-mandatory technical specification to the Grid Code, relating to GB Grid Forming Capability (which was formerly referred to as a Virtual Synchronous Machine (“VSM”) capability. The detail pertaining to its creation may be found in Section 3 “Why Change?” but the high-level overview is that the specification will enable parties to offer an additional grid stability service. This will be fundamental to ensuring future Grid Stability, facilitating the target of zero carbon System operation by 2025 and providing the opportunity to take part in a commercial market or become part of other market arrangements such as the stability pathfinder work and/or dynamic containment.

Modification process & timetable

1. Proposal Form – 10 December 2019
2. Workgroup Consultation – 31 March 2021 - 30 April 2021
3. Workgroup Report – 29 July 2021
4. Code Administrator Consultation – 03 September 2021 – 04 October 2021
5. Draft Modification Report – 19 October 2021
6. Final Modification Report – 09 November 2021
7. Implementation – TBC

Planned projects in Australia

- Waratah battery in NSW
- ARENA announcement of 8 x 250-300MW grid forming BESSs across mainland NEM



Planned Projects in Great Britain

- Five Grid Forming BESS, resulting from NG ESO Stability Pathfinder
- Commissioned 2024-2026
- Meet GC-0137 grid code requirements
- Deployed via ancillary services markets

GFM Technology Council

PURPOSE - Break the chicken-egg cycle through deployment and commercialization of GFM technology by:

a) identifying GFM features/requirements by system operators
b) supporting technology demonstrations and deploying GFM resources from OEMs
c) GFM resource procurement by developers
d) Standardization, codes and interconnection requirements

METHOD - Cross-pillar I, II and IV collaboration with FSOs, developers, OEMs, software developers, standardizing institutions and other stakeholders

CONFIRMED & POSSIBLE PARTICIPANTS:

Leadership
- ✓ Sten Arendt Stoltze, SVP Orsted (Chair)
- ✓ Jason MacDowell, ESIG/GE
- ✓ Julia Matevosyan, ESIG
- ✓ Charlie Smith, ESIG
- ✓ Mark O'Malley, Imperial College

Developers
- ✓ Orsted (Chair)
- ✓ Enel
- ✓ Invenergy
- ✓ Zenobe
- Nextera
- Iberdrola
- EDF RE
- E.ON
- Acciona

System Operators
- ✓ NG ESO
- ✓ AEMO
- ✓ ERCOT
- ✓ Energinet
- ✓ Eirgrid
- ✓ FinGrid
- ✓ TenneT
- ✓ Amprion
- ✓ 50 Hertz
- MISO
- REE
- Swissgrid

OEMs
- ✓ GE
- ✓ Smartwires
- ✓ Siemens
- ✓ SGRE
- ✓ Hitachi Energy
- SMA
- Mitsubishi
- Toshiba
- Vestas
- Tesla

Software developers
- DigSilent
- Siemens PTI
- GE
- Manitoba Hydro
- EMTP
- Power World
- PowerTech Labs

Thank You

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