AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Grid-Forming Inverters: A Voluntary Specification

Public webinar

29 June 2023

We acknowledge the Traditional Owners of country throughout Australia and recognise their continuing connection to land, waters and culture.

We pay respect to their Elders past, present and emerging.

This meeting will be recorded

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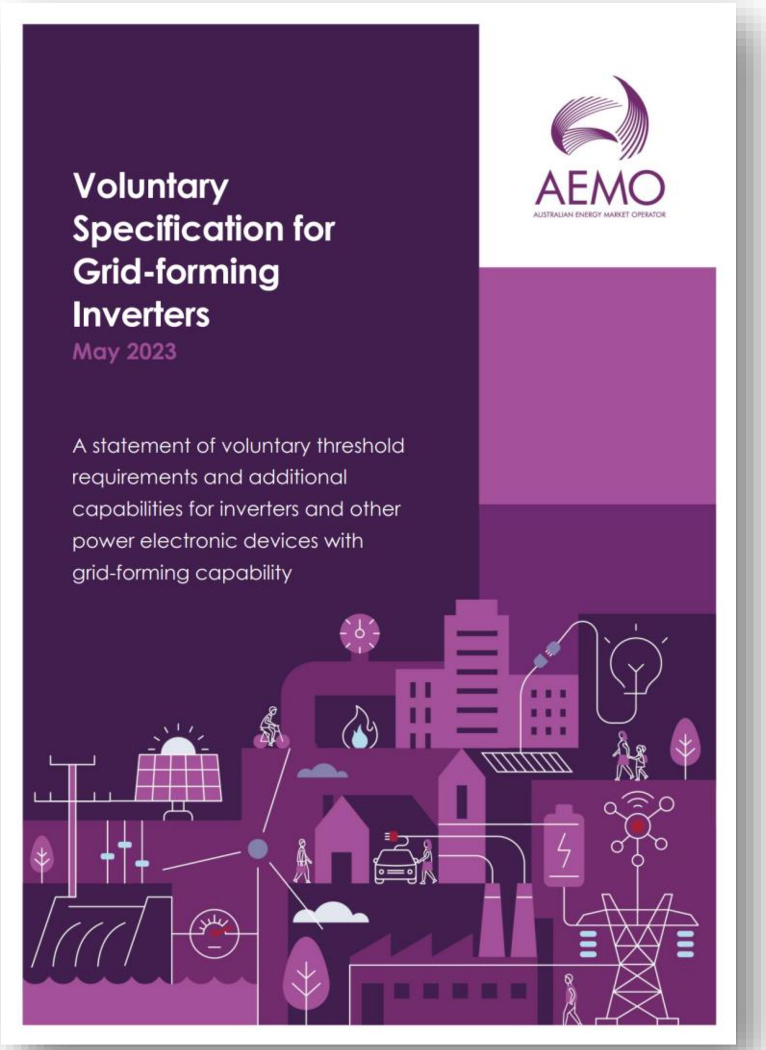
Agenda

1. Voluntary grid-forming inverter specification development

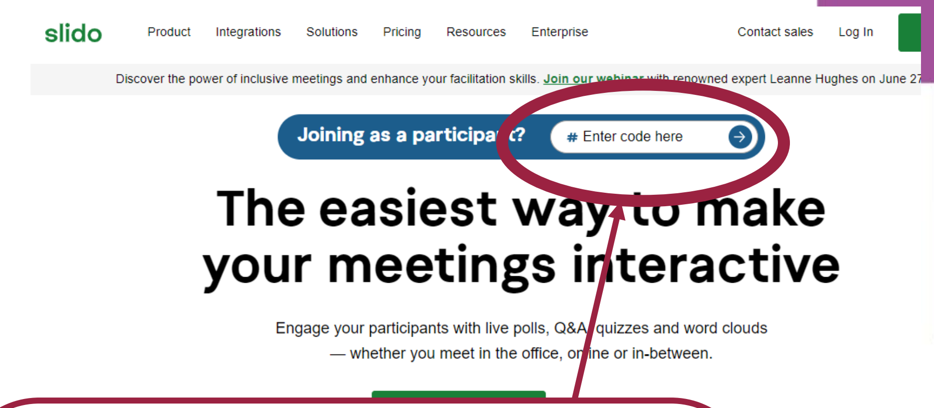
2. Overview of specification



Interactive session

- Slido will be used to manage the Q&A segments of this presentation
  - Add your own questions and vote for questions posted by other attendees

- If you are having technical issues during the session, please contact us using the Teams chat panel or email FutureEnergy@aemo.com.au



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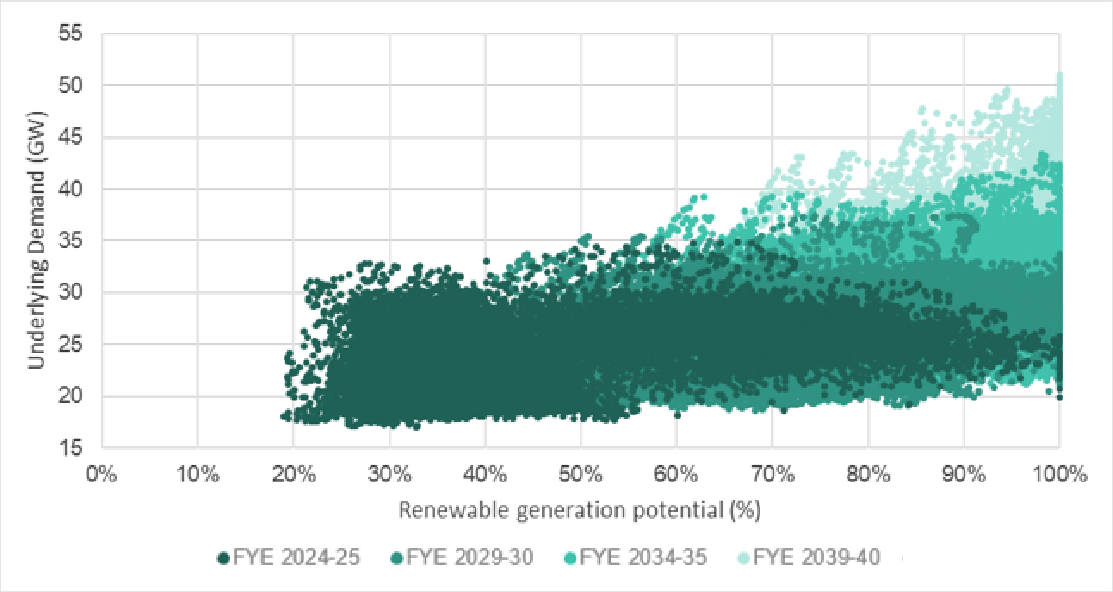
Operating the power system with fewer synchronous generators

NEM renewable penetration

NEM generation potential



Enabling advanced inverters

Define necessary capabilities

Enable connection of grid-forming projects

Enable capabilities on new grid-scale batteries

2021 Advanced inverters white paper recommendations

Engineering Framework

Voluntary specification for grid-forming inverters published 2023

Grid-forming BESS connections fact sheet published 2022

AEMO's ongoing support for ARENA large-scale battery funding round

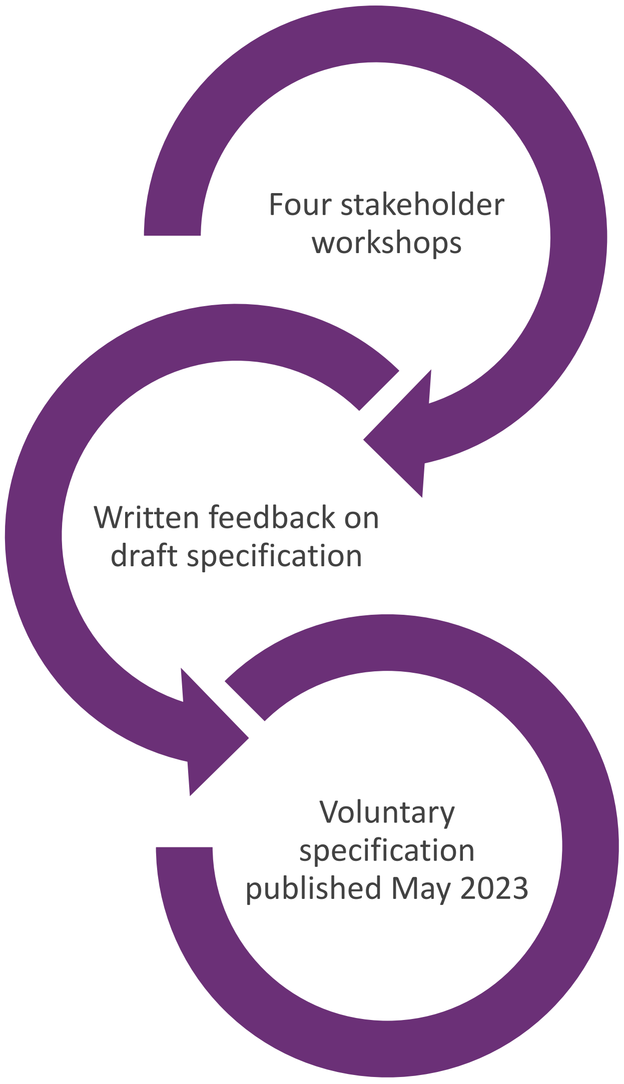
Recent progress

Grid-forming inverters voluntary specification development

- Objective: Define necessary power system support capabilities for grid-forming inverters to guide Original Equipment Manufacturers (OEMs) and developers.

- AEMO commitment: Collaborate with industry to prepare a preliminary document to establish alignment and provide guidance on technical and operational design considerations.

- Context: Begin to develop alignment on system needs and product capabilities ahead of any formal requirements. Specification could be used to inform future regulatory change in technical standards, service specifications, and procurement processes



Informing future regulatory change

AEMO

Voluntary Specification

Core capabilities

- Core functionality that outlines the basic capabilities for an inverter to be seen as ‘grid-forming’
- Implementing these capabilities is expected from all grid-forming devices

Additional capabilities

- Functionality to deliver power system support capabilities that may necessitate material modifications which could result in increased costs to the developer or operator of grid-forming plant
- These capabilities should be agreed with NSPs and AEMO prior to their inclusion in a project

Regulatory change and procurement processes to be informed by Voluntary Specification

- AEMO’s review of NER Schedules 5.2, 5.3 and 5.3A mandated under NER clause 5.2.6A
- Other targeted NER rule change proposals
- Procurement of system strength under new framework
  - Minimum fault level
  - Efficient level/voltage waveform stability
- Future essential system services reform processes

Technical standards review currently underway includes a grid-forming inverters stream that seeks to remove impediments to their connection and avoid limiting their benefit to the power system

Next Steps

- Development of a quantitative test specification addendum to support the voluntary grid-forming inverter specification.

- Ongoing learning and knowledge sharing as connection application and commissioning tasks progress for projects in ARENA’s large-scale BESS funding round

- Join our mailing list at: FutureEnergy@aemo.com.au

Q&A

slido.com Code: #AEMO

Defining ‘grid-forming’

Grid-forming inverter

A grid-forming (GFM) inverter maintains a constant internal voltage phasor in a short time frame, with magnitude and frequency set locally by the inverter, thereby allowing immediate response to a change in the external grid. On a longer timescale, the internal voltage phasor may vary to achieve desired performance.

In this document, the term ‘inverter’ is used in a general sense and is intended to also cover non-generating power electronic devices, such as AC-to-DC converters and STATCOMs.

Core and additional capabilities

Core

- Voltage source behaviour
- Frequency domain response
- Inertial response
- Surviving the loss of the last synchronous connection
- Weak grid operation and system strength support
- Oscillation damping

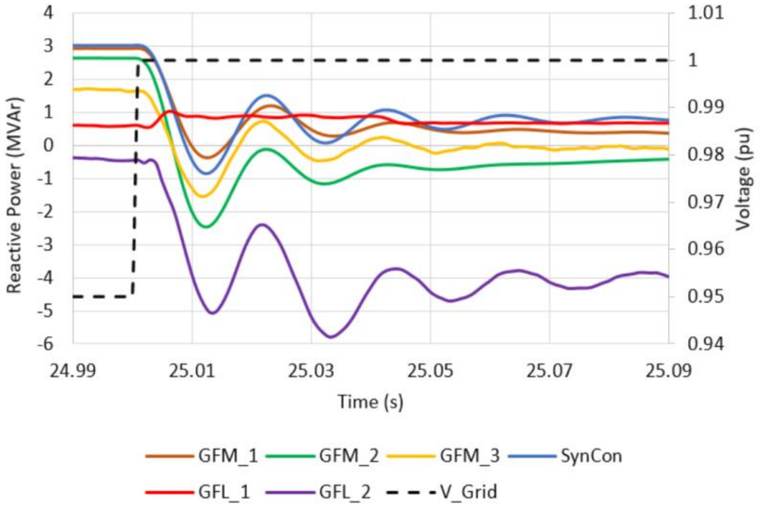
Additional

- Headroom and energy buffer
- Current capacity above continuous rating
- Black start capability
- Power quality improvement

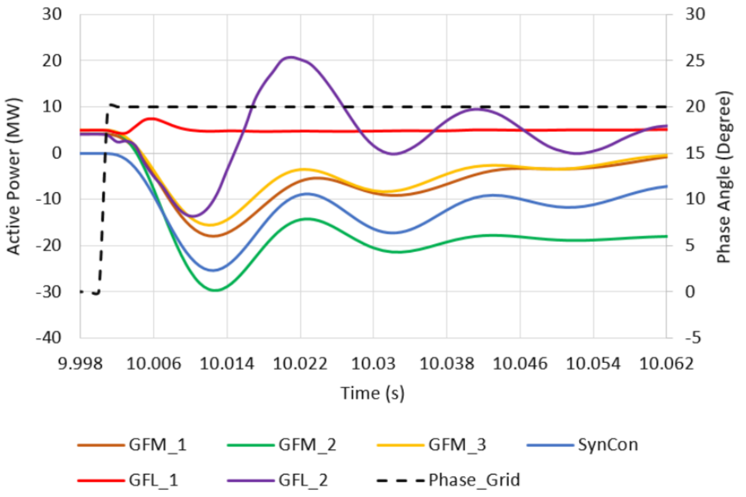
Voltage source behaviour

- Voltage source behind an impedance
- Key objective is to control voltage waveform, as opposed to control output current
- The internal voltage phasor is constant within the *short* time frame following a disturbance
  - Enables GFM inverter to inherently prevent fast changes in the voltage and phase angle
- Active power output of a GFM inverter is determined by the internal voltage phasor, the PoC voltage phasor, and the sine of the load angle (not via current).
- A GFM inverter shall be capable of synchronising with other generation sources on the power system

Reactive power response to 5% voltage magnitude step



Active power response to 20° phase angle step

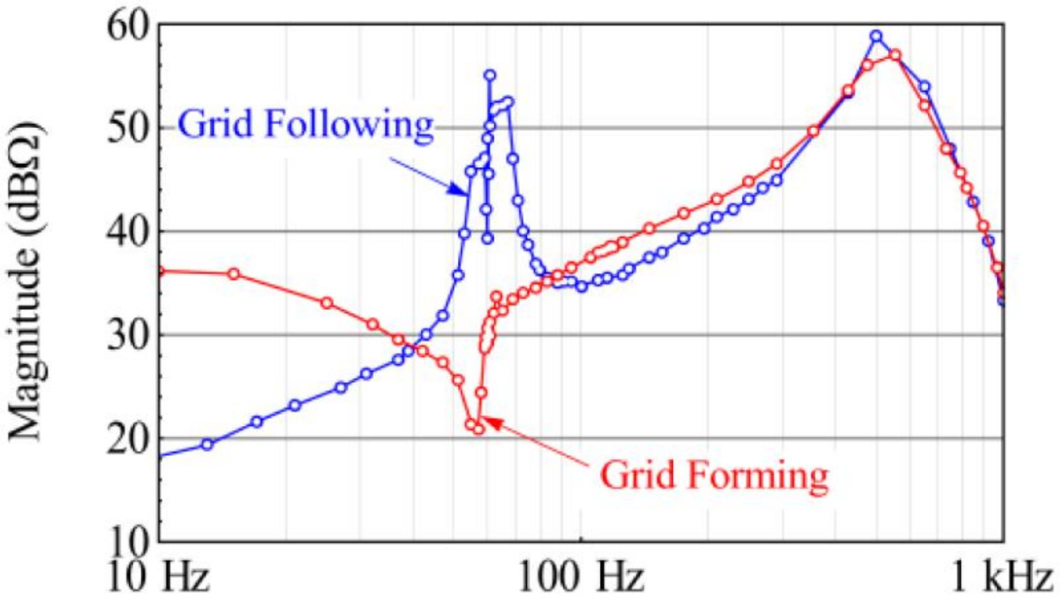


Frequency domain response

- A small-signal impedance scan test can be used to quantify the voltage source behaviour of the GFM resources.

- A small impedance magnitude around the fundamental frequency indicates good voltage source behaviour.

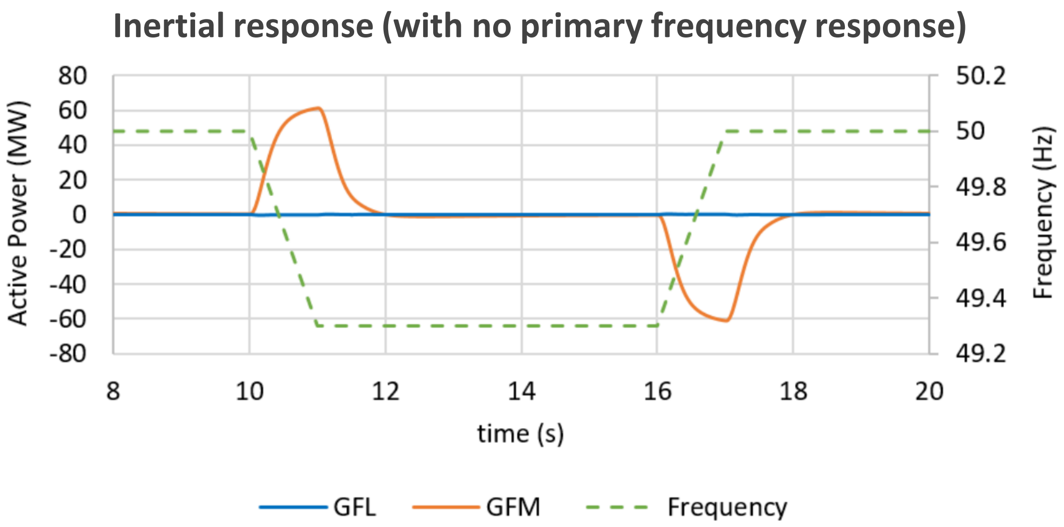
Example frequency domain performance

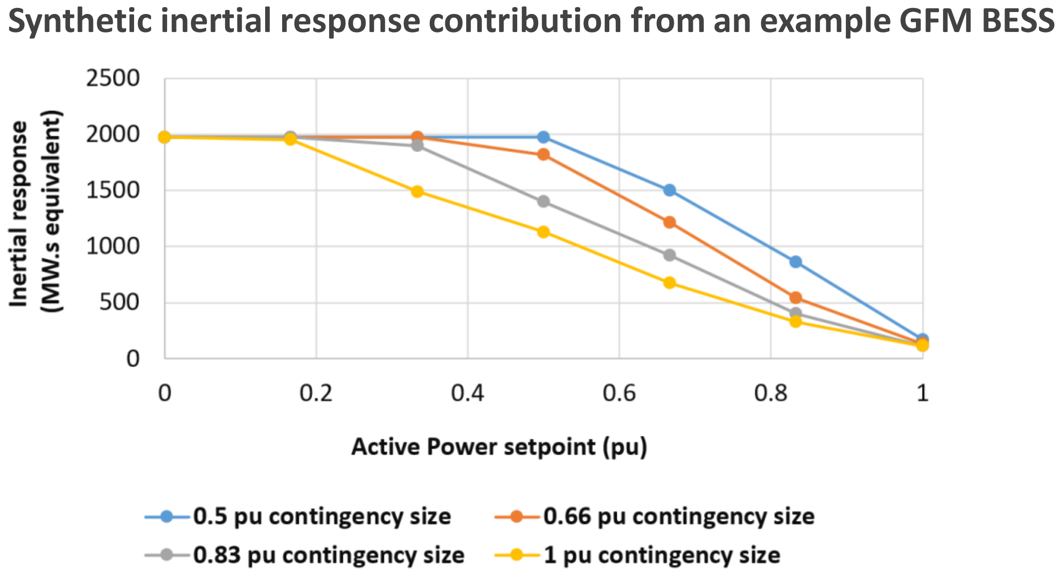


Reference: NREL (https://www.esig.energy/event/webinar-impedance-scan-tools-for-stability-analysis-of-ibr-grids/)

Inertial response

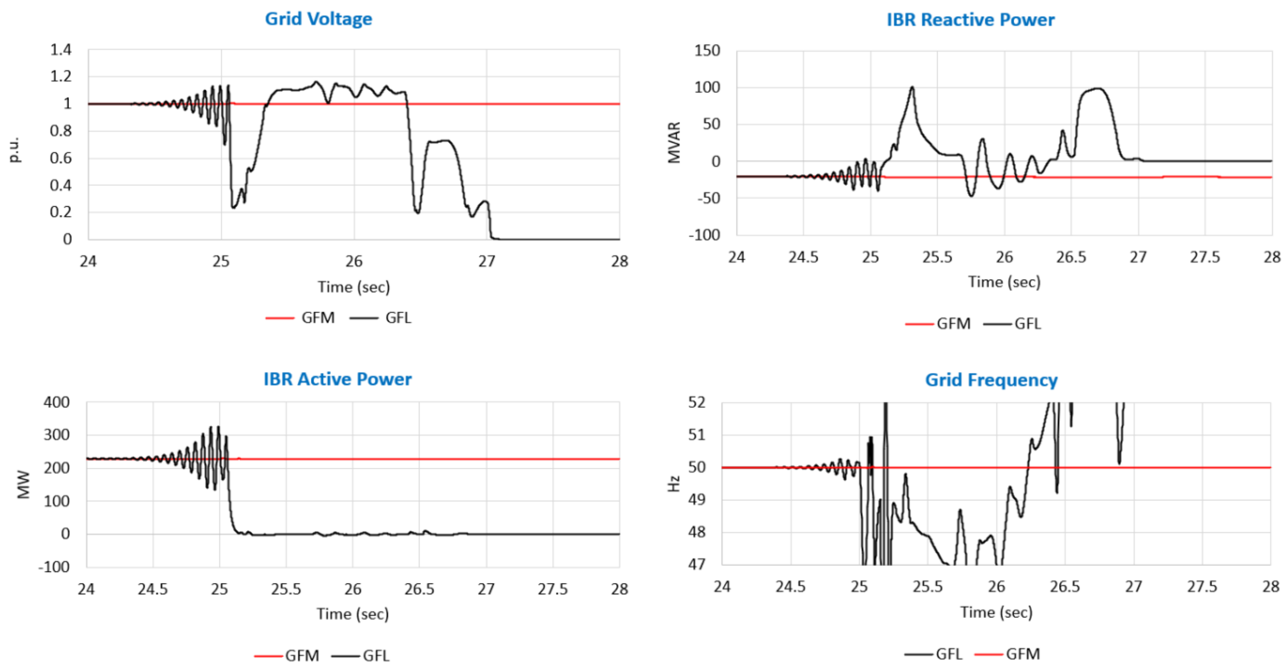
- Provide synthetic inertial response of active power upon a change in system frequency
- Initiation of response should be inherent, not requiring calculation of frequency or RoCoF from waveform measurement
- Provision of an effective inertial response may require power and energy buffers (advanced capability)
- Response dependent on configurable inertia constant, device operating point, current ratings, and RoCoF





Surviving the loss of the last synchronous connection

- Operate stably in a grid that does not contain any other GFM inverters or synchronous machines
  - This is owing to the GFM inverter's capability to generate its own voltage reference.
- Remain in uninterrupted operation for a transition from a grid containing synchronous machines to one that does not, without external controls or communications
  - Provided it remains within its current limits, and subject to power transfer capability of the network not being exceeded
- Enablement of this capability should be agreed in advance with relevant NSPs and AEMO (islanding is not always desirable)

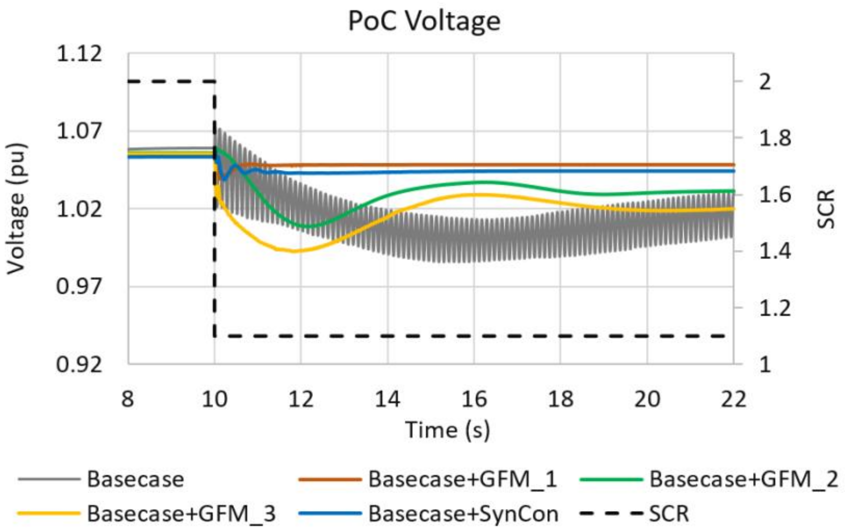


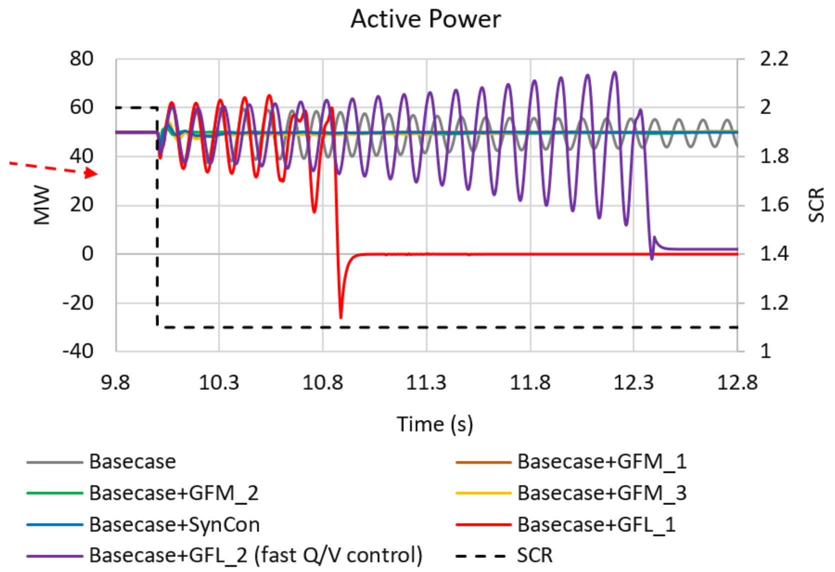
Note: the last synchronous connection to the grid is lost at t=24 s.

Weak grid operation and system strength support

- Operate stably under very low short circuit ratio, under normal operating conditions and when exposed to power system disturbances

- Provide support to nearby GFL inverters and enhance their stable operation

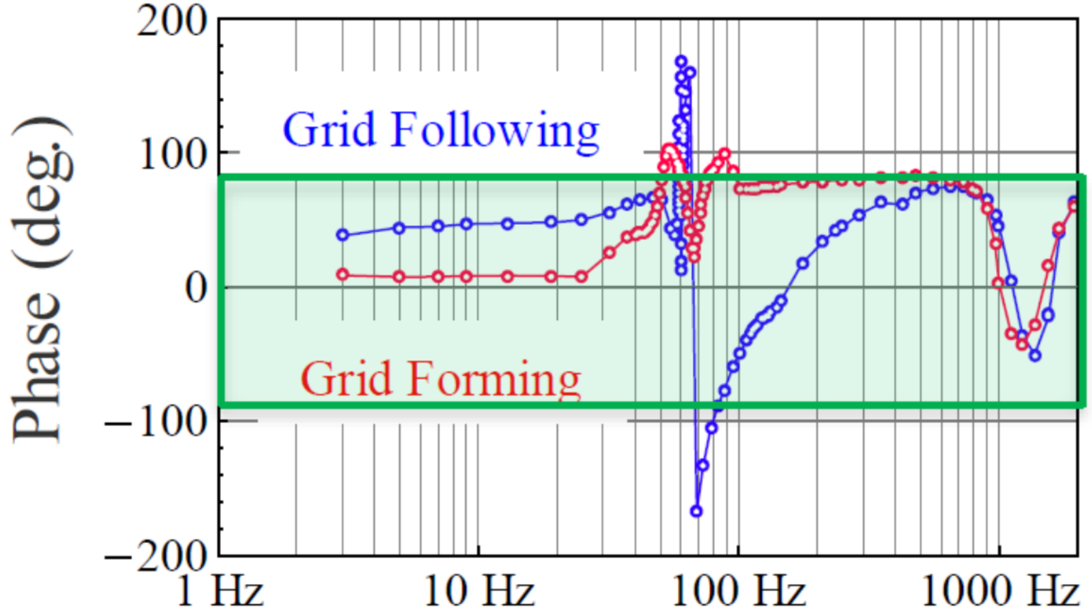




Oscillation damping

- The GFM inverter should be capable of being tuned so that following a disturbance its output is adequately damped
- A small-signal impedance scan across a wide range of frequencies can be used to evaluate the oscillation damping characteristics
  - A GFM inverter should ideally show an impedance phase angle between -90-degree and +90-degree, at most frequencies from 10 hertz (Hz) to 500 Hz

Indicative example of impedance phase angle characteristics



Plot source: National Renewable Energy Laboratory (NREL)

Additional capabilities

Headroom and energy buffer

- Operation into limits restricts the capability of an inverter to provide GFM performance.
- Headroom or buffer required to maximise GFM performance, level is dependent on nature of disturbance and type of response required.

Current capacity above continuous rating

- Overload capability enables a GFM inverter to replicate synchronous machine behaviour more easily during large voltage or frequency disturbances.
- Should be assessed on a project-specific basis and may be influenced by incentives or requirements of procurement or market schemes.

Black start capability

- To initiate or support a system restart process, GFM plants may need additional stored energy and capabilities to energise the plant itself and part of the grid.
- High overload capability may be needed to supply inrush currents.

Power quality improvement

- GFM inverters may improve various aspects of power quality because of their voltage source characteristics, including harmonics, unbalance, and flicker.
- Provision of these capabilities could impact on the GFM inverter's ability to achieve its core capabilities.

Q&A

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Thank you

Please contact us at FutureEnergy@aemo.com.au