Battery Energy Storage System Grid Forming Controls (PAC-2024-2)

Planning Advisory Committee

October 16, 2024

Purpose & Key Takeaways

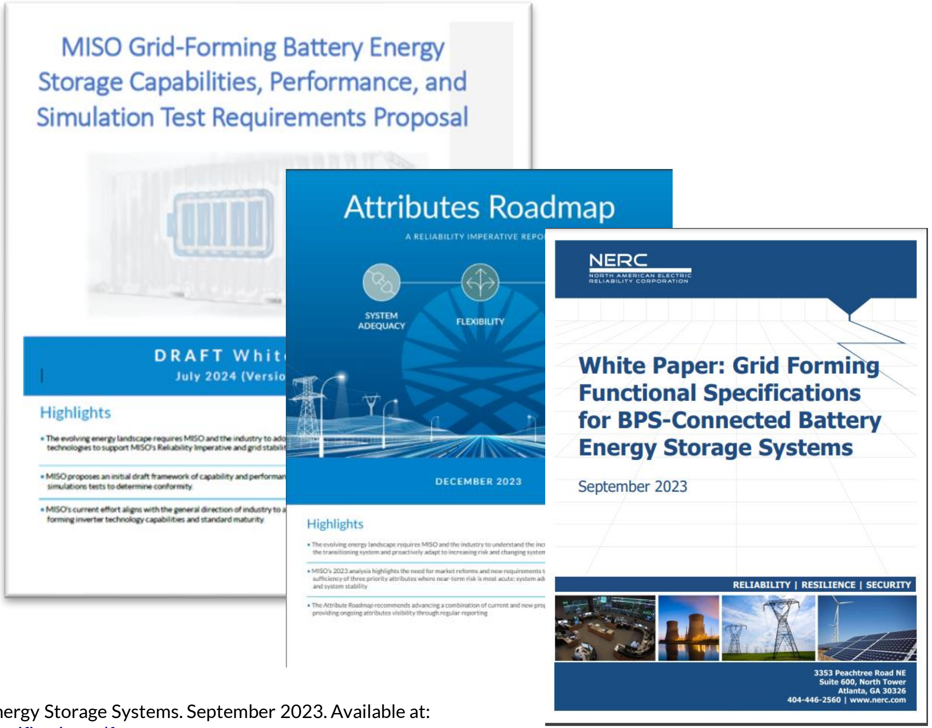
Purpose: Propose grid-forming (GFM) battery energy storage system (BESS) requirements to support system stability

Key Takeaways:

- IPWG Stakeholders worked with MISO to develop GFM BESS performance and testing requirements with implementation proposed for September 2025
- Today MISO is sharing proposed BPM-015 and Tariff changes with PAC stakeholder and requesting additional feedback
- MISO will respond to stakeholder feedback at the November PAC and adjust the proposal as appropriate

MISO is proposing GFM BESS requirements based on NERC recommendations and to support system attribute needs

- NERC's 2023 whitepaper indicated GFM BESS should be adopted, and technology is available today.[1]
- MISO's 2023 Attributes Roadmap built on industry information showing the benefits of GFM controls to support voltage stability, especially under weak grid conditions which are likely to increase in prevalence.[2]
- MISO's 2024 GFM BESS whitepaper describes need, industry readiness and technical details which is the basis for draft BPM-015 redlines.[3]



[1] NERC, White Paper: Grid Forming Functional Specifications for BPS-Connected Battery Energy Storage Systems. September 2023. Available at: https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_GFM_Functional_Specification.pdf
[2] MISO, Attributes Roadmap. December 2023. Available at: https://cdn.misoenergy.org/2023%20Attributes%20Roadmap631174.pdf
[3] Whitepaper posted with September IPWG Meeting Materials

MISO proposes BESS GFM “core” requirements that do not require holding capacity or energy in reserve

- MISO proposes only to adopt “core” requirements in 2024.
- Core capabilities do <u>not</u> require hardware oversizing (e.g., larger inverter or battery).
- These capabilities are enacted through available software settings supported by all state-of-the-art battery energy storage systems.

Core capabilities:

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

Additional capabilities:

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

MISO proposes full implementation starting with DPP 2023, with simulation test results due at Decision Point 2

- DPP 2023 Phase 2 is scheduled for completion in September 2025, providing about one year to prepare for changes
- Given the DPP schedule revision, with kick-off now scheduled for February 28, 2025, MISO views the additional six months as allowing the ramp up time requested by IPWG stakeholders.
- Stakeholder feedback was unanimous that the test results should be submitted at Decision Point 2, at least for the initial implementation.

MISO has worked with IPWG stakeholders throughout 2024 to develop Grid Forming (GFM) specifications for Battery Energy Storage Systems (BESS)

	Date	GFM BESS topic objectives
IPWG	January 30	Inform stakeholders of IBR performance planned for development in 2024.
IPWG	March 12	Provide foundational information on GFM BESS specification practices.
IPWG	May 2	Share outline of initial proposed GFM BESS requirements. **Formal feedback request**.
IPWG	June 4	Share first revision of GFM BESS specifications whitepaper. **Formal feedback request**.
IPWG	July 23	Respond to stakeholder feedback and share second version of whitepaper. Introduce proposed GFM BESS implementation plan. **Formal feedback request**.
IPWG	September 3	Respond to stakeholder feedback and share near-final whitepaper, subject to PAC review.
PAC	October 16	GFM BESS performance requirements proposal. **Formal feedback request**.
PAC	November 13	GFM BESS share feedback responses and modifications.

Stakeholders offered feedback during requirements development and MISO adopted stakeholder suggestions leading to substantial modifications to the proposal

Topic	Comment theme	MISO action
Testing technical specifications	Reduce number of cases for LLSM test	Removed one of the four cases
	Remove large phase jump requirement (60 degrees)	Removed 60 degree phase jump
Process timing	Change test result submission timing from Decision Point 1 to Decision Point 2	Modified requirement to align with Decision Point 2
Hardware oversizing	Consider potential impacts on plant design	Performed extensive OEM outreach and shared information
Applicability	Clarify application to hybrid and co-located units	Clarified proposal applies to BESS with unique POI
Integration with other IBR standards	Clarify how GFM requirements related to MISO's IEEE 2800 requirements	Reviewed IEEE 2800 requirements and offered select exemptions

MISO's initial proposal largely relies on conformity simulation tests to demonstrate GFM BESS capabilities and performance

Capabilities and performance requirements → **Conformity simulation tests**

Capabilities and performance requirements

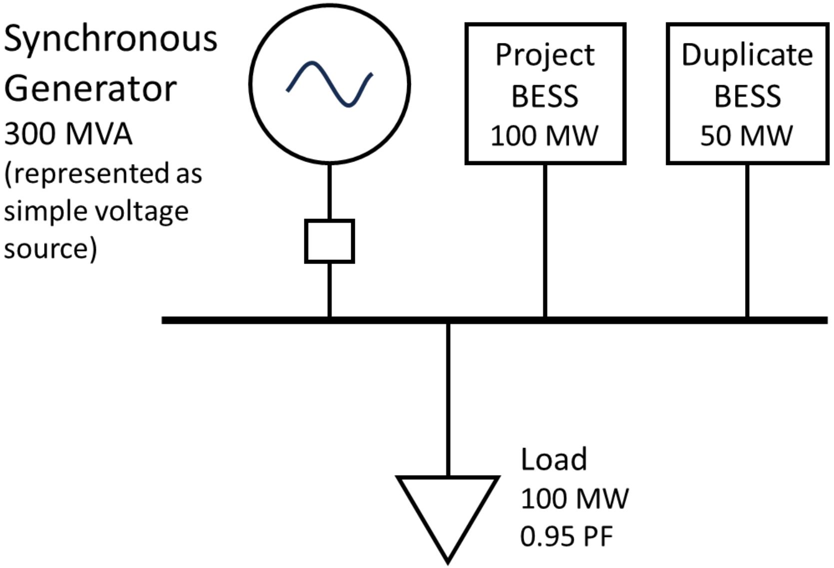
1. **Voltage source characteristics**

Conformity simulation tests

a. **Loss of last synchronous machine tests**
b. **Low SCR with fault**
c. **Phase jump**
d. **Rate of change of frequency**

Details of MISO's approach will align with the NERC whitepaper approach in not defining prescriptive performance requirements (e.g., settling times) but rather defining core capabilities and performance to be evaluated with EMT conformity simulation tests

NERC's loss of last synchronous machine (LLSM) simulation broadly tests grid forming performance and current responses



Three cases proposed, varying the initial conditions prior to SM disconnection

Case	Description	Project Plant[1]	Duplicate Plant[1]	Load[2] (% of project plant rating)
1	BESS Charging	50% charge	50% charge	50%
2	Limit Test	0% exchange	100% discharge	100%
3	Power Balance	50% discharge	50% discharge	75%

[1] "total load" refers to the combined storage and load apparent power in this context

Three additional tests can supplement verification of GFM controls' active and reactive current responses

Low short circuit ratio (SCR) with fault

*Objective**: verify stable reactive current responses.

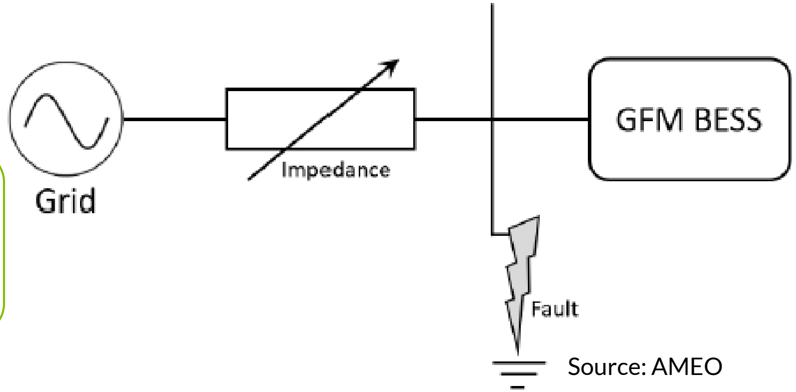
Phase jump

Objective: verify voltage source (GFM) response.

Rate of change of frequency (RoCoF)

Objective: verify stable active power response.

Simulation test set-up (EMT domain)

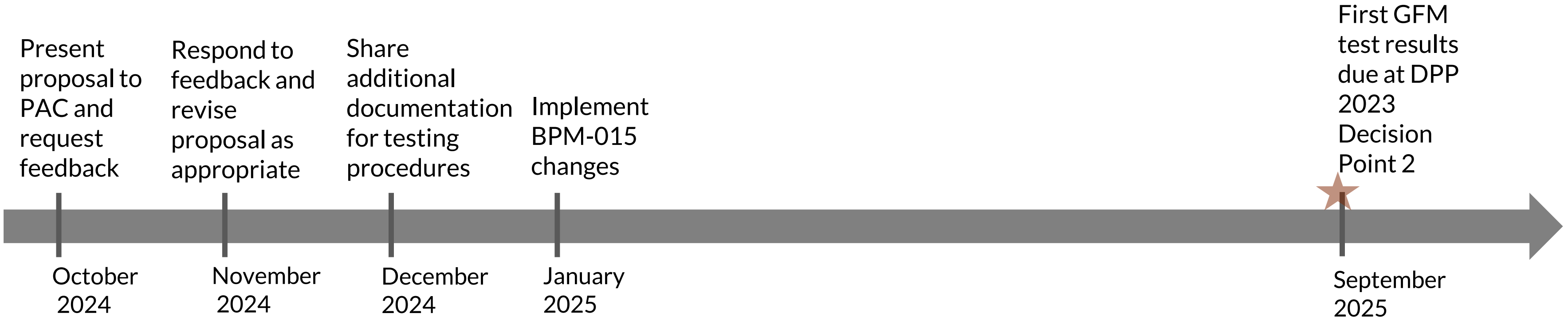


Source: AMEO

*Primary objective is listed here. The simulations test a range of performance, capability, and control stability features.

Next steps:

- Request PAC stakeholder feedback and adjust the proposal as appropriate for review at the November 13 PAC
- In the absence of significant new feedback issues, MISO intends to move towards implementation
- MISO will continue to explore necessary IBR capabilities under Issue PAC-2024-2



Currently proposed timeline, as of August 2024

Stakeholder Feedback Request

MISO is requesting feedback on the **Recommended GFM BESS Requirements (PAC-2024-2)** presented today by October 31, 2024. Specifically, MISO seeks feedback on details of MISO's proposed requirements and simulation test approach, including input on draft BPM-015 language describing:

- Technical requirements
- Implementation timing and approach
- Applicability (i.e., BESS with unique POI)

Feedback requests and responses are managed through the Feedback Tool on the MISO website: https://www.misoenergy.org/engage/stakeholder-feedback/

Questions?

Patrick Dalton
pdalton@misoenergy.org

Appendix

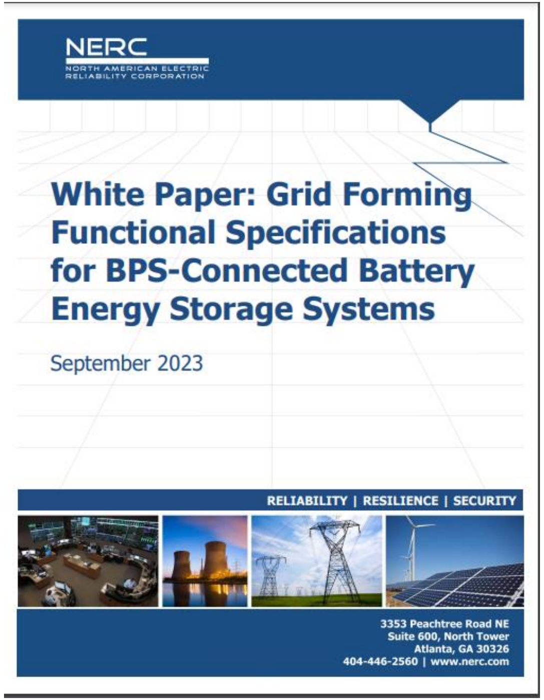
Resources on Grid Forming Specifications

Entity	Document	Link	Year
FINGRID	Grid Code Specifications for Grid Energy Storage Systems SJV2019	https://www.fingrid.fi/globalassets/dokumentit/en/customers/grid-connection/grid-energy-storage-systems-sjv2019.pdf	2021
FINGRID	Specific Study Requirements for Grid Energy Storage Systems	https://www.fingrid.fi/globalassets/dokumentit/fi/palvelut/kulutuksen-ja-tuotannon-liittaminen-kantaverkkoon/specific-study-requirements-for-grid-energy-storage-systems-en.pdf	2023
FINGRID	Modelling instruction for PSS/E and PSCAD models	https://www.fingrid.fi/globalassets/dokumentit/fi/palvelut/kulutuksen-ja-tuotannon-liittaminen-kantaverkkoon/fingrid-modelling-instruction-for-psse-and-pscad-models-2024_01_12-002.pdf	2024
NERC	White Paper: Grid Forming Functional Specifications for BPS-Connected Battery Energy Storage Systems	https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_GFM_Functional_Specification.pdf	2023
AEMO	Voluntary Specification for Grid-forming Inverters	https://aemo.com.au/-/media/files/initiatives/primary-frequency-response/2023/gfm-voluntary-spec.pdf	2023
AEMO	Application of Advanced Grid-scale Inverters in the NEM	https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/application-of-advanced-grid-scale-inverters-in-the-nem.pdf	2021
AEMO	Voluntary Specification for Grid-forming Inverters: Core Requirements Test Framework	https://aemo.com.au/-/media/files/initiatives/engineering-framework/2023/grid-forming-inverters-jan-2024.pdf?la=en	2024
NGESO	Great Britain Grid Forming Best Practice Guide	https://www.nationalgrideso.com/document/278491/download	2023
NGESO	GC0137: Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability (formerly Virtual Synchronous Machine/VSM Capability	https://www.nationalgrideso.com/document/159296/download	2021
UNIFI	Specifications for Grid-forming Inverter-based Resources Version 1	https://www.energy.gov/sites/default/files/2023-09/Specs%20for%20GFM%20IBRs%20Version%201.pdf	2022

Also see ESIG: Grid-Forming Technology in Energy System Integration, 2022
Comparison of Current GFM Equipment Specs, 2022

The NERC whitepaper also highlights the system stability benefits of commercial availability of grid-forming controls for battery energy storage systems

- The paper has several takeaways and recommendations relevant to Attributes:
  - GFM technology has been shown to operate reliably and provide stabilizing characteristics in transmission systems with high IBR.
  - GFM technology is commercially available and field-proven.
  - All newly interconnecting BPS-connected BESS should consider GFM controls.
  - Now is the time to begin the process of establishing GFM functional specifications for BESS in interconnection requirements, using NERC's functional specifications.
  - Careful testing and validation of GFM performance is still needed before broad deployment.


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

White Paper: Grid Forming Functional Specifications for BPS-Connected Battery Energy Storage Systems

September 2023

RELIABILITY | RESILIENCE | SECURITY

3353 Peachtree Road NE
Suite 600, North Tower
Atlanta, GA 30326
404-446-2560 | www.nerc.com

NERC, White paper: grid forming functional specifications for BPS-connected battery energy storage systems. September 2023. Available at: https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_GFM_Functional_Specification.pdf

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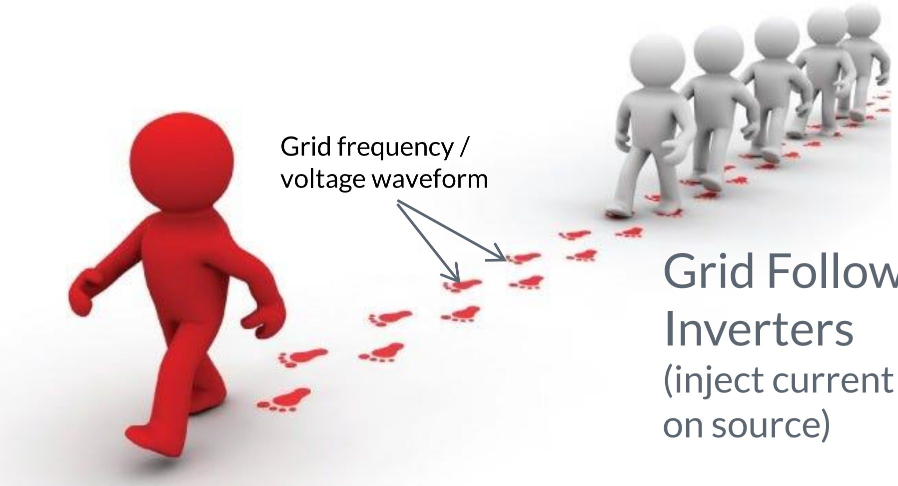
MISO developed several principles for the 2024 BESS GFM development effort

- Supporting system reliability is primary aim of requirements.
- Consider Original Equipment Manufacturer (OEM) equipment and plant design capabilities as a key input, in addition to the system reliability need.
- Keep requirements as simple as possible.
- Avoid conflicts with IEEE 2800-2022, which applies to all IBR (including BESS).
- Focus new process and data exchange requirements on crucial features.
- Choose flexibility over delay if needed, given the urgency and opportunity to act now.
- Avoid material impacts on storage operations (e.g., power dispatch and state of charge management) in developing “core capability” requirements.
- Position requirements for extensibility as future needs emerge.

MISO is sharing this background to inform stakeholders of principles underlying MISO’s approach to developing GFM BESS performance requirements.

"Grid Forming" controls are fundamentally different from "Grid Following" controls, establishing a voltage source and resisting voltage and frequency changes through fast power responses

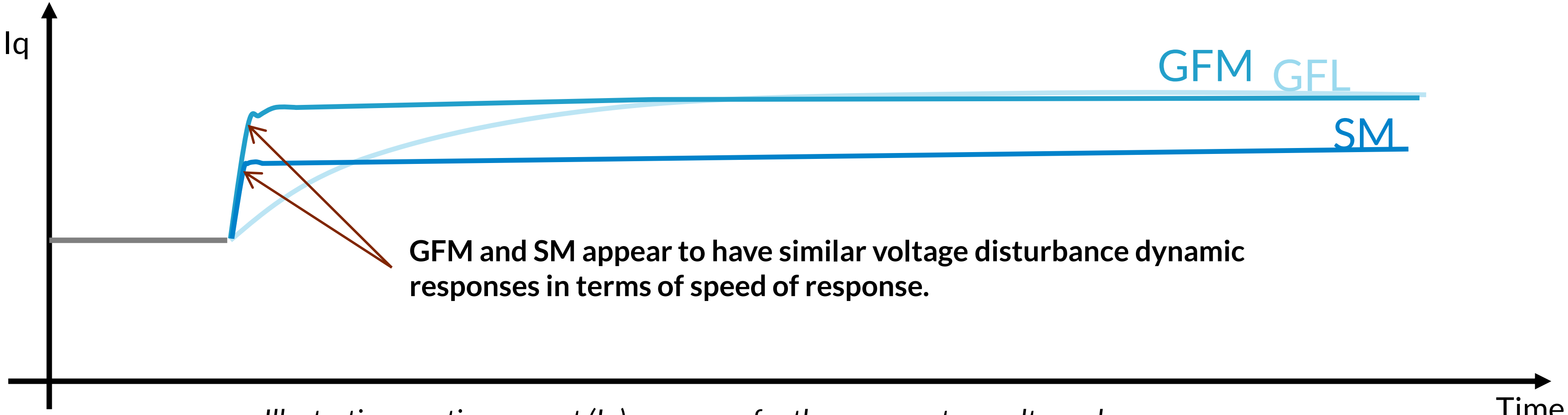
- **Grid-forming** controls have dynamic responses that mimic synchronous machines.
  - Supports grid strength by acting as voltage source with inherently fast responses to voltage magnitude or phase changes.
- In contrast, **grid-following** controls have different dynamic responses.
  - Current source that requires external current source; does not support grid strength.
  - Dynamic power responses can act counter to system needs (e.g., slow and/or in "wrong" direction).



MISO

The voltage source characteristics of grid-forming controls cause natural, fast power responses that may contribute to dynamic stability support

- **Speed of the response** is important as stability concerns increasingly shift to faster (dynamic) time-frames.
- **Magnitude of response** is important as this is the “effort” to regulate voltage.



Illustrative reactive current (Iq) responses for the same system voltage change

Notes: Slide presented as part of MISO’s 2023 Attributes work.
Power responses can be limited by hardware ratings and affect system stability support capabilities.

MISO is taking a stepped approach to introducing GFM requirements with the 2024 focus on system strength and frequency support

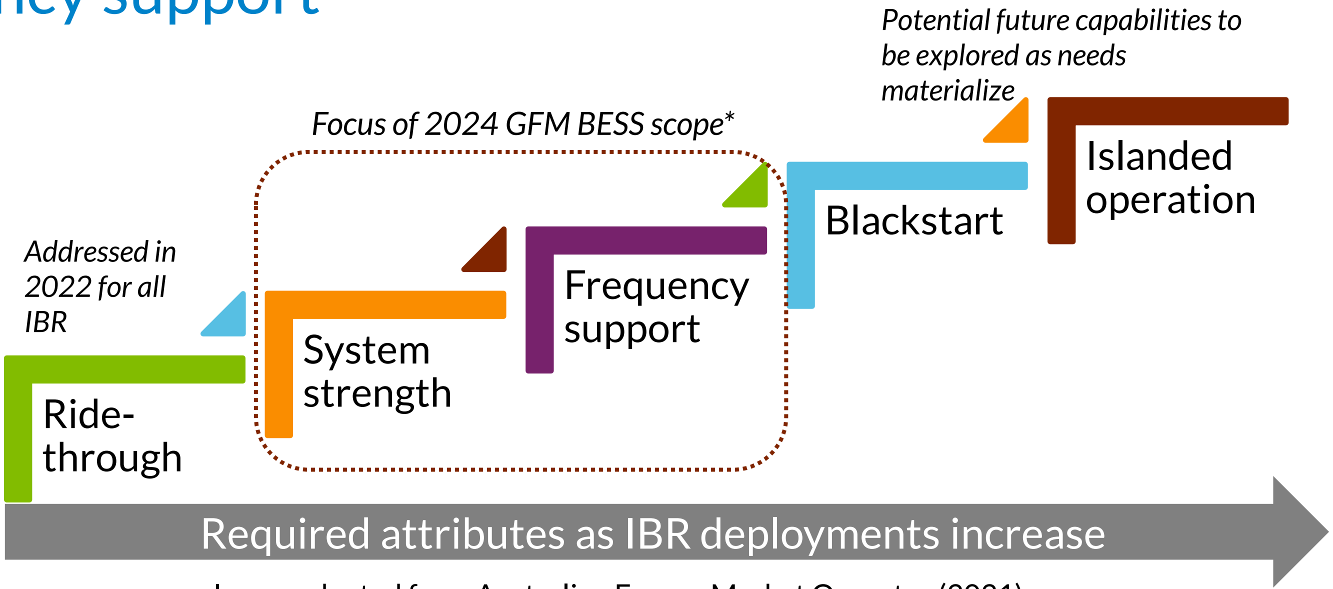


Image adapted from Australian Energy Market Operator (2021)

*In the future, efforts may be initiated to foster additional system strength and frequency support (e.g., reserve capacity).

MISO is clarifying application to "stand-alone" battery energy storage systems

- MISO's proposal applies to BESS plants that have a unique POI.
  - In other words, the POI is not shared with another resource type (BESS + PV).
- Both hybrids and co-located plants share a POI among the multiple resources and are therefore excluded from the initial requirements.
  - BESS surplus interconnection requests that share a POI with another resource type would also be excluded.
- MISO understands this reduces the population of storage from the roughly 29 GW of "Storage" reported for DPP-2023 applications (23% of total submission by capacity) but views this as practical first step to phase in grid-forming capabilities.

An initial proposal for integration of GFM requirements with IEEE 2800-2022 is introduced in the whitepaper

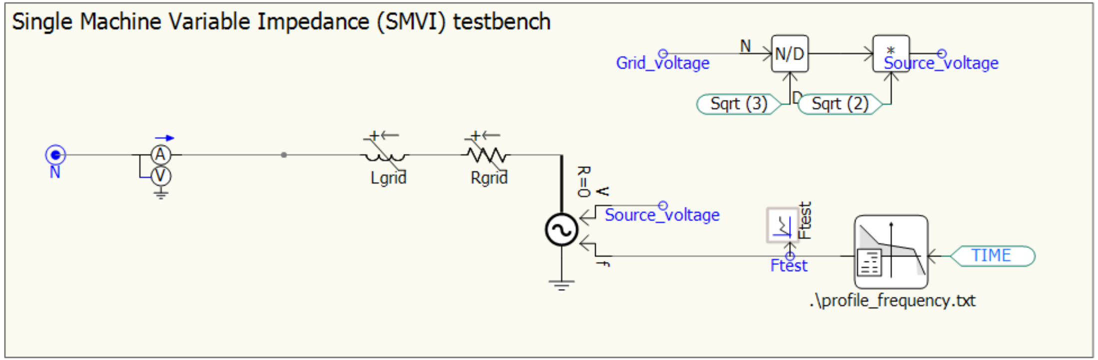
- MISO shares a list of IEEE 2800 requirements adopted by MISO that may need to be exempted or modified to achieve desired GFM response.
- MISO offers draft requirements that could enact these changes.

IEEE 2800	Subclause name	Potential issue	Recommended action
4.7	Prioritization of IBR responses	Incompatibility with GFM fundamental operation (e.g., prioritization between ridethrough and current responses).	GFM exemption
7.2.2.1	Voltage ride-through – General	Definition of permissive operation region in Table 11 and Table 12	Only allow current blocking or tripping for self-protection in permissive operation region.
7.2.2.3.2	Low and high voltage ride-through capability	Refers to performance in Table 13. Defaults to reactive current priority mode.	Exempt Table 13. Exempt reactive current priority, if affecting GFM operation
7.2.2.3.3	Low and high voltage ride-through performance	Permissive operation region allows current blocking	Only allow current blocking or tripping for self-protection in permissive operation region.
7.2.2.3.4	Current injection during voltage ride-through	Specifies type and amount of current injection. References 7.2.2.3.5 performance. Mentions "automatic voltage control"	GFM exemption
7.2.2.3.5	Performance specification [during voltage ridethrough]	Specific step response time	GFM exemption
7.2.2.6	Restore output after ride-through	Specific active power recovery time and rate	GFM clarification that rate should not constrain natural response
7.3.2.1	Frequency disturbance ride-through requirements – general	References 7.3.2.3.2 and 7.3.2.3.4	Only allow current blocking or tripping for self-protection in permissive operation region.

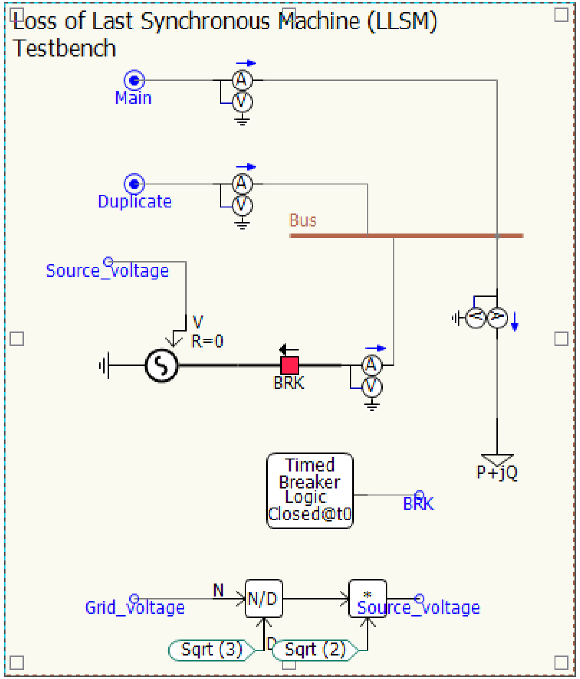
Table 2. Summary of IEEE 2800-2022 exemptions or modification for IBR GFM

To support stakeholder implementation, MISO is making available PSCAD test components that automate test sequences

While MISO is unable to support individual stakeholder testing, MISO will share test procedure guidance documentation after finalizing requirements in PAC



Frequency changes, phase angle jumps, faults, and SCR changes are implemented for the three tests SMVI



LLSM test sequence is implemented

For access to the test bench PSCAD library and supporting files, email Patrick Dalton (pdalton@misoenergy.org)

GFM controls will naturally provide both system strength and frequency strength, unless responses are control-limited

Given the natural GFM control response, and potential implications of current limiting, MISO suggests evaluating all “core” capabilities.

In suggesting an exploration of frequency strength, MISO is not proposing storage “overhead / energy buffer” requirements.

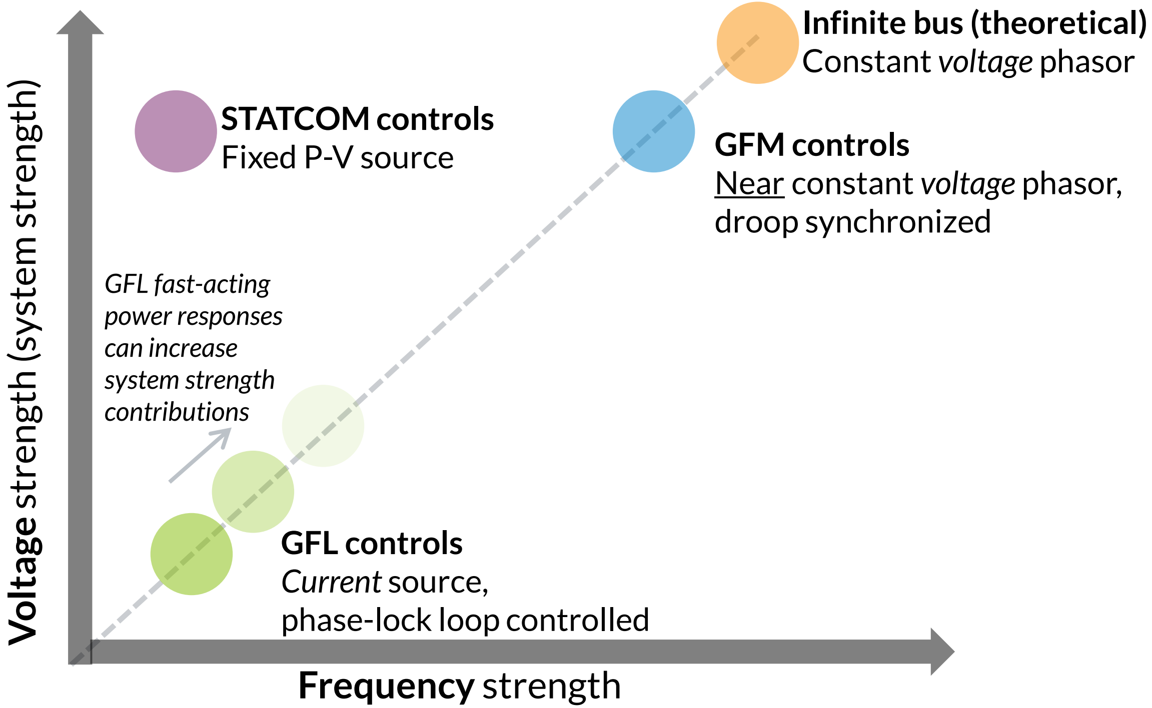


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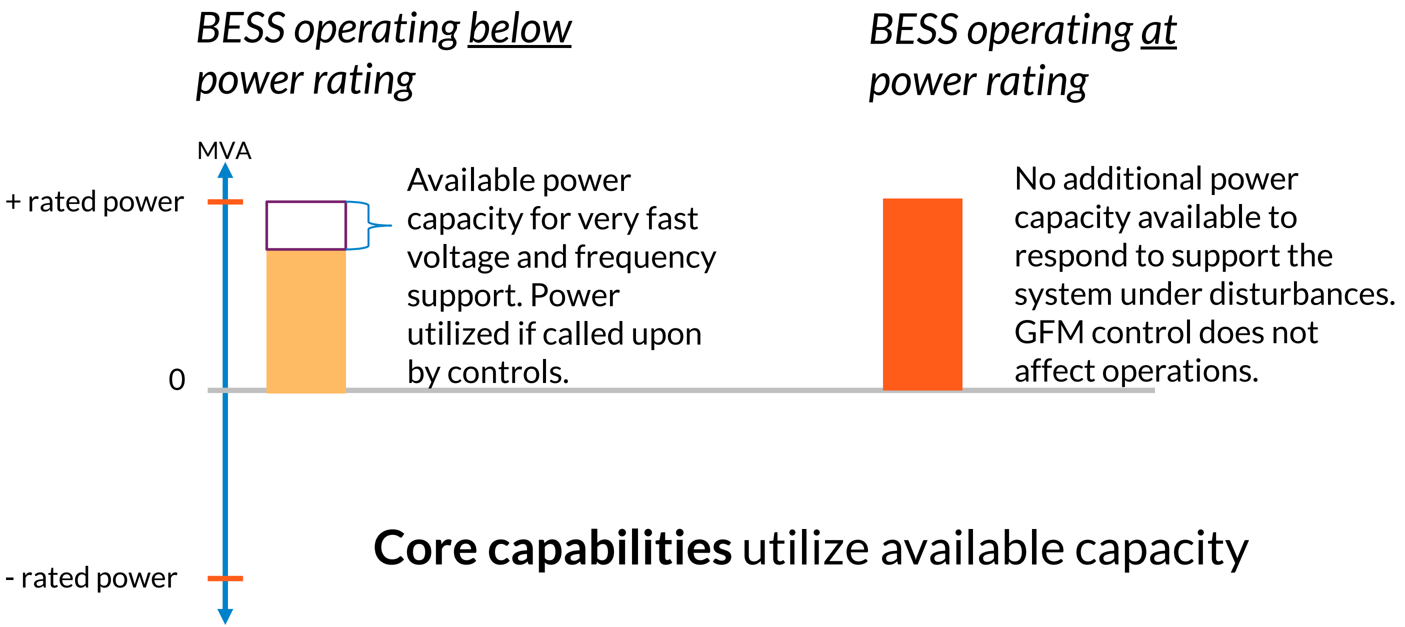
Image is adaptation from work at the Imperial College of London, presented to G-PST.

MISO is proposing "core" requirements that are not expected to result in hardware oversizing



Core capabilities utilize available capacity

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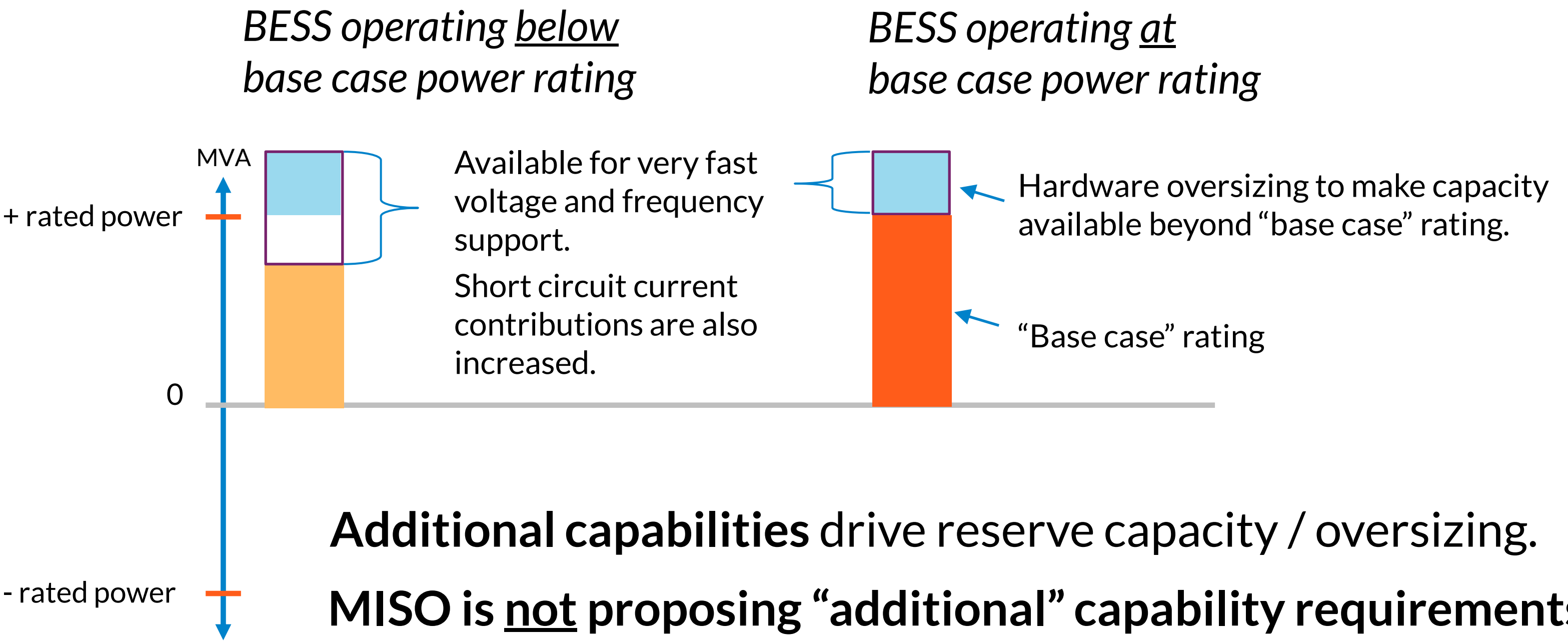
In contrast, "additional" requirements would require holding inverter capacity in reserve, resulting in hardware oversizing



Additional capabilities drive reserve capacity / oversizing.

MISO is <u>not</u> proposing "additional" capability requirements

MISO proposes a framework that separates capability and performance requirements from test requirements to demonstrate conformity

1. Capabilities and performance requirements → **2. Conformity simulation tests**

1. Capabilities and performance requirements

- *Defines performance and capabilities under broad range of normal and abnormal grid conditions.*
- *Different levels of detail can be used to describe functional performance.*
- *MISO's initial proposal will be at a high-level, allowing for industry developments without obsolescence in the near-term.*

2. Conformity simulation tests

- *For practical purposes, must select subset of expected operating conditions to run simulation tests.*
- *Results are used to gauge conformity with capability and performance requirements.*
- *General tests are practical way of validating modeled control performance given today's GFM standards maturity.*

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Note: MISO is evaluating how to integrate GFM BESS requirements with general IBR performance requirements (i.e., MISO's IEEE 2800 adoption) and will share information in the forthcoming whitepaper. The performance requirements may address needed GFM BESS exceptions to general IBR performance.

MISO has been testing OEM models against the proposed requirements for all four tests

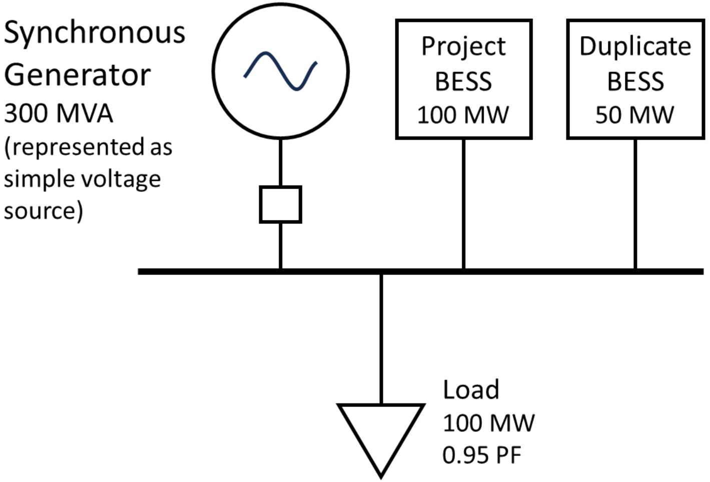
Included today are example results from of the loss of last synchronous machine (LLSM) Case 1

LLSM test sequence

1. Initiate simulation and run until system is stable at the given power flow conditions, without oscillations.
2. Trip the synchronous generator by opening the breaker (no fault).

Pre-trip:

a. Both BESS plants active power outputs match dispatched levels.
b. Synchronous generator active power output matches the rest of the load.
c. Frequency is 1 p.u.
d. Voltage at bus 1 is within 5% of nominal (i.e., 0.95 to 1.05 p.u.).
e. Phase voltage and current waveforms are not distorted.
f. Oscillations are not present in RMS quantities.
g. Reactive power output from all devices should be within limits.

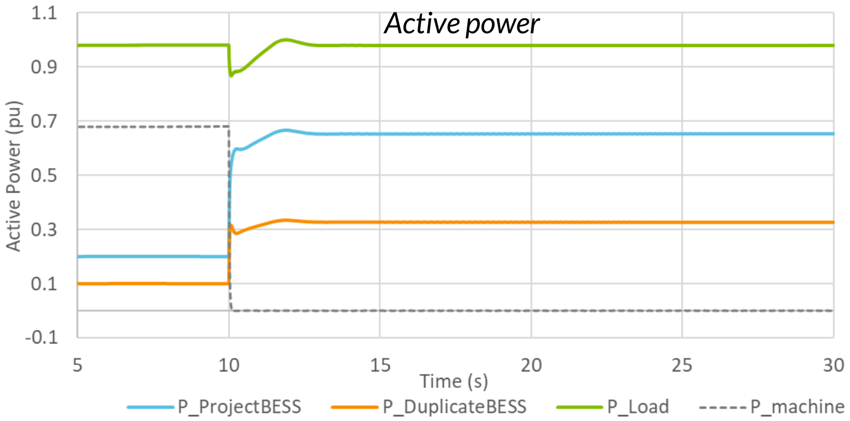


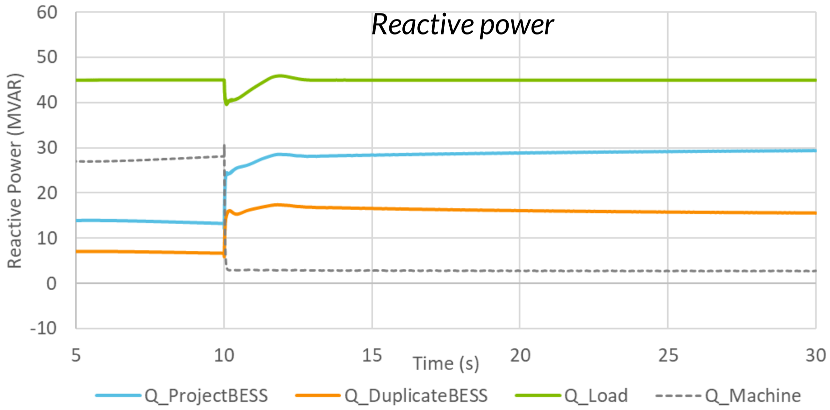
The synchronous generator breaker is opened after pre-trip conditions are met.

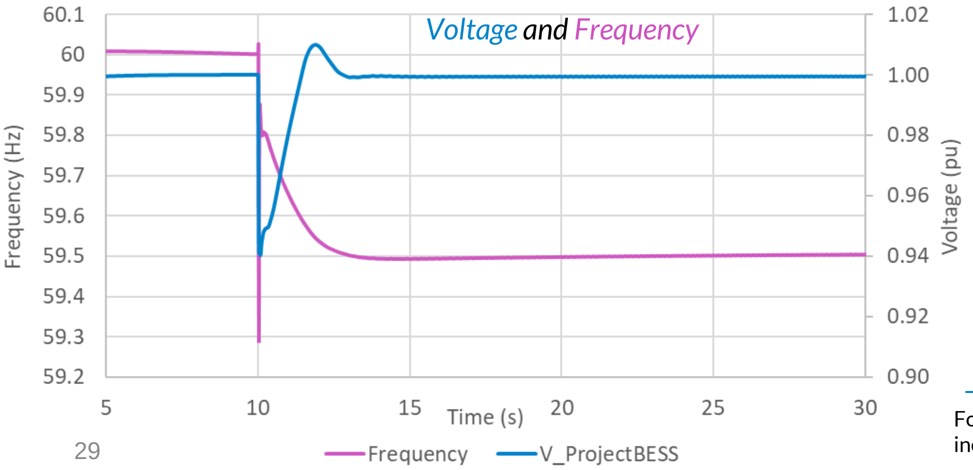
Case	Description	Project Plant[1]	Duplicate Plant[1]	Load[2]
1	BESS Discharging	20% discharge	20% discharge	100%

(1) values are as a percentage of the IBR continuous active power rating. (2) load values are expressed as a percentage of the project plant active power continuous rating. Additional information on the setup is in the whitepaper

Test results show GFM technologies meet proposed requirements while non-GFM cannot (LLSM Case 1 results for GFM)







Post-trip:

a. ☑ Plant output is well controlled with no significant frequency/voltage oscillations.

b. ☑ Voltage settles to a stable operating point.

c. ☑ Final voltage is expected based on droop and deadband settings.

d. ☑ Frequency settles to a stable operating point.

e. ☑ Final frequency is expected based on droop and deadband settings.

f. ☑ Oscillations is adequately damped.

g. ☑ Distortion observed in phase quantities dissipates over time.

h. ☑ Active power immediately moves to meet load requirement and settle according to its frequency droop setting.

Footnotes on the post-trip criteria and examples of all simulation tests, including non-GFM, are show in in the whitepaper

MISO

Grid Forming Specs Landscape At Glance

- **MIGRATE:** EU-funded project on the Massive Integration of Power Electronic Devices (2019)
- **HECO:** Model Energy Storage Power Purchase Agreement (2019)
- **NREL:** Research Roadmap for Grid Forming Inverters (2020)
- **ENTSO-E:** High Penetration of Power Electronic Interfaced Power Sources and the Potential Contribution of Grid Forming Converters (2020)
- **VDE FNN:** Guideline Grid forming behavior of HVDC systems and DC-connected PPMs (2020)
- **NGESO:** GC0137 Minimum Specification Required for Provision of GB Grid Forming Capability (2021)
- **AEMO:** Application of Advanced Grid-Scale Inverters in the National Electricity Market (2021)
- **HECO:** Model Energy Storage Power Purchase Agreement (2021)
- **OSMOSE:** EU-funded project (continuation of MIGRATE) that defined grid forming capability and new services (2022)
- **UNIFI:** Specifications for Grid-Forming Inverter-Based Resources – Version 1 (2022)
- **NGESO:** Great Britain Grid Forming Best Practice Guide (2023)
- **AEMO:** Voluntary Specification for Grid-Forming Inverters (2023)
- **FINGRID:** Specific Study Requirements for Grid Energy Storage Systems (focuses on grid forming requirements) (2023)
- **NERC:** Grid Forming Functional Specifications for BPS-Connected Battery Energy Systems (2023)
- **AEMO:** Voluntary Specification for Grid-forming Inverters: Core Requirements Test Framework

Source: Adopted from UNIFI, GFM Inverter Technology Specifications: Review of Research Reports and Roadmaps