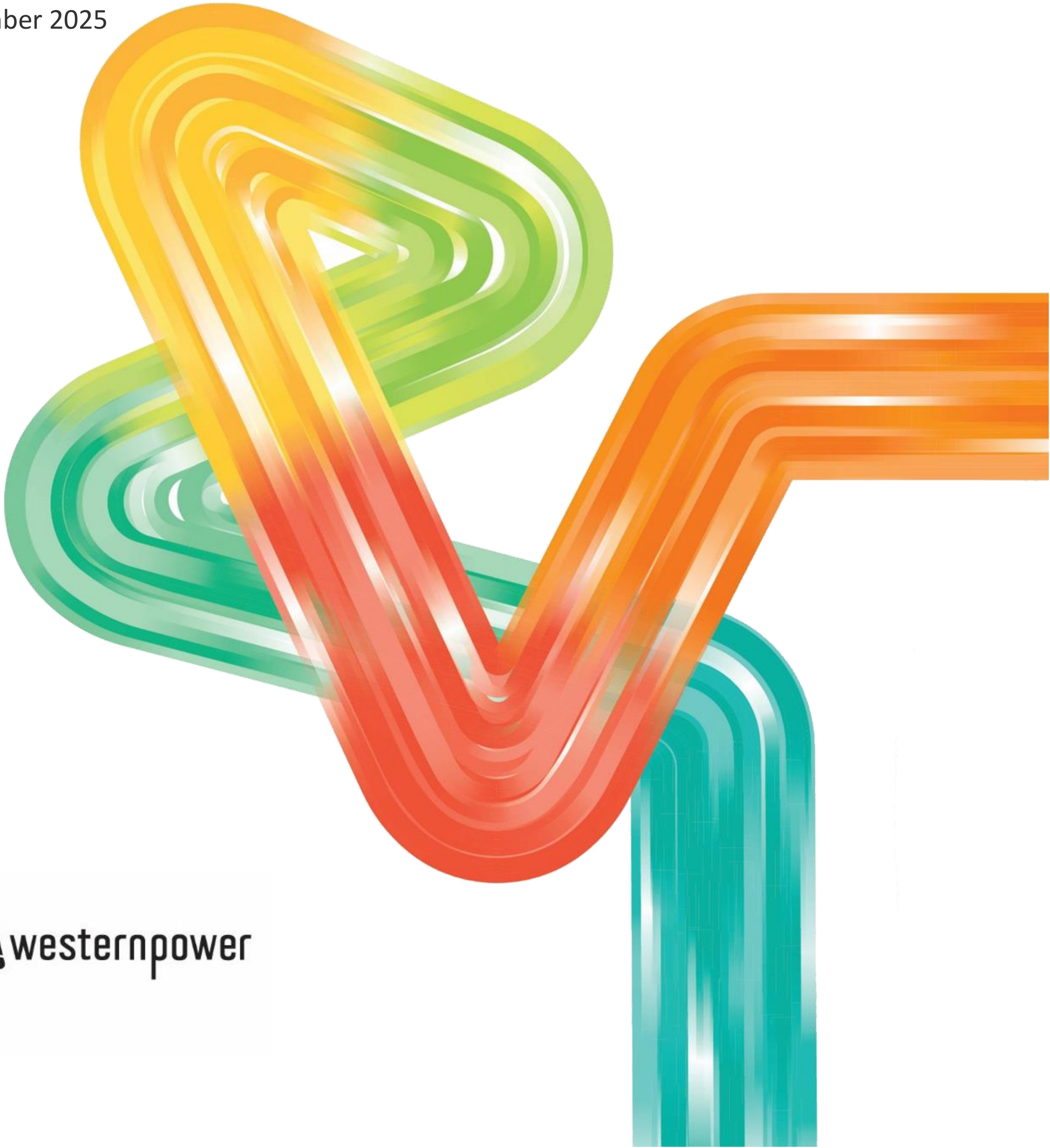
Power System Security and Reliability Standards Review - Proposals 6 to 11

User Facility Standards for Grid Forming and Grid Following Inverters

Consultation Paper

Public

December 2025



An appropriate citation for this paper is:

Power System Security and Reliability Standards Review - Proposals 6 to 11

Western Power

363 Wellington Street
Perth WA 6000
GPO Box L921 Perth WA 6842

T: 13 10 87 | Fax: 08 9225 2660
TTY 1800 13 13 51 | TIS 13 14 50

Electricity Networks Corporation
ABN 18 540 492 861

enquiry@westernpower.com.au
westernpower.com.au

Contents

List of tables

Abbreviations

The following table provides a list of abbreviations and acronyms used throughout this document. Defined terms are identified in this document by capitals.

Term	Definition
AAS	Automatic Access Standard – the "Automatic" or higher performance level of the user facility technical requirements (above the minimum access standard), used as a design and negotiation benchmark.
AEMC	Australian Energy Market Commission – the rule-making body for the National Electricity Rules in the National Electricity Market.
AEMO	Australian Energy Market Operator – operates the Wholesale Electricity Market in WA and the National Electricity Market in eastern/southern Australia and publishes planning studies such as the annual Electricity Statement of Opportunities.
AS 4777.2	Australian Standard 4777.2: Grid connection of energy systems via inverters – Part 2: Inverter requirements. Used as a reference for small-scale inverter performance.
BESS	A Battery Energy Storage System is an installation of batteries, inverters and controls that can absorb, store and discharge electrical energy to and from the grid.
ESM Rules	The Electricity System and Market Rules for the WEM in Western Australia
ESOO	Electricity Statement of Opportunities – AEMO's 10-year reliability and investment outlook, published for both the National and Wholesale Electricity Markets.
ENTSO-E	European Network of Transmission System Operators for Electricity – publishes guidance and studies on high-penetration power-electronic systems and grid-forming converters
EPWA	Energy Policy WA – the WA Government body responsible for energy policy, including the Electricity System and Market Rules and the Power System Security and Reliability Standards review.
ESS	Essential System Services – services such as frequency control, system strength, inertia, etc., required to maintain secure and reliable power system operation.
FFT	Fast Fourier transform (FFT)–based blocks - a signal-processing block that uses a discrete FFT over a window of sampled data (typically one or more power-frequency cycles) to estimate the frequency components, including the fundamental phasor, of voltages and currents.
GFL	Grid-Following inverter – an inverter-based resource that synchronises to an existing grid voltage waveform and follows it, relying on the grid for strength and reference.
GFM	Grid-Forming inverter – an inverter-based resource that establishes and controls its own voltage and frequency reference, contributing to system strength and stability.
IBR	Inverter-Based Resource – generation or storage plant (for example, solar PV, wind with full converters, or battery systems) interfaced to the grid via power electronic inverters.
IEEE 2800	IEEE Std 2800-2022 – IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems, used as a key international reference for access standards
MAS	Minimum Access Standard – the lowest performance level that a User Facility must meet under the access standards framework.
NEM	National Electricity Market – the interconnected wholesale electricity market in eastern and southern Australia (separate from the WEM in WA).

Term	Definition
NER	National Electricity Rules – rules that govern the NEM, including technical access standards (e.g. Schedule 5 requirements).
NESO	National Energy System Operator – Great Britain's electricity system operator, whose GB grid-forming requirements (including GBGF-I) are referenced.
NSP	Network Service Provider – an entity that owns or operates a transmission or distribution network under the National Electricity Rules.
OEM	Original Equipment Manufacturer – the manufacturer of plant and control systems.
PSS	Power System Stabiliser – a control function (usually on synchronous generators or equivalent controls on inverter-based resources) that damps power system oscillations.
PSSR	Power System Security and Power System Reliability are given their definitions in the Electricity System and Market Rules. Power System Security and Reliability for the South West Interconnected System is undergoing a review – led by the Coordinator of Energy to consolidate and modernise all security and reliability standards for the SWIS into a single, end-to-end standard under the Electricity System and Market Rules, ensuring they remain fit-for-purpose as the power system transitions.
RMS	Root mean square (RMS) phasor estimator - n algorithm that estimates the complex fundamental-frequency phasor of a voltage or current by computing its root-mean-square (RMS) magnitude and phase over a finite time window (typically one cycle), using sampled waveform data.
SCR	Short-Circuit Ratio – ratio of available short-circuit MVA at the connection point to the plant's rated MVA; used as a measure of system strength at the point of connection.
SWIS	South West Interconnected System – the main electricity network in south-west Western Australia, served by the Wholesale Electricity Market and covered by Western Power's Technical Rules 2016.
VDE FNN	Forum Network Technology / Network Operation in the VDE – the technical body within the German Association for Electrical, Electronic & Information Technologies (**VDE**) that develops grid codes and technical guidelines, including the 2025 guideline on technical requirements for grid-forming capabilities.
WEM	Wholesale Electricity Market – the wholesale electricity market for the south west interconnected system in Western Australia, governed by the Electricity System and Market Rules.

1. Executive summary

Western Australia's electricity sector is undergoing a major transition as the State moves towards lower-emissions supply under the Energy Transformation Strategy (**ETS**)[1]. The State Electricity Objective (**SEO**)[2] now guides electricity decision-making, requiring efficient investment in, and operation and use of, electricity services in the long-term interests of consumers, including with respect to price, quality, safety, security and reliability of supply, and the environment. Planning work such as the South West Interconnected System (**SWIS**) Demand Assessment[3] and Transmission Plan[4] indicates that substantial new transmission, renewable generation and storage will be needed over coming decades, implying a step-change in the volume and characteristics of facilities connecting to Western Power's network and a need for modern, fit-for-purpose technical standards.

A key component of the ETS is the Power System Security and Reliability (**PSSR**) Standards Review. Among other things, the review aims to modernise the technical access standards for user facilities connecting to the SWIS; a particular focus is given to inverter-based resources (**IBRs**). On 19 June 2025, Energy Policy WA published the PSSR Standards Review Consultation Paper[5] that included recommendations (Proposals 6–11) on how the technical requirements under the Electricity System and Market (**ESM**) Rules might be updated to consider grid-forming (**GFM**) inverter-based technologies alongside existing grid-following (**GFL**) inverter-based technologies.

Following consideration of stakeholder feedback, Energy Policy WA engaged Western Power and the Australian Energy Market Operator (**AEMO**) to assist in the development of proposed "interim" technical requirements to provide GFM inverter-based technology with a pragmatic pathway to connection and market participation while the broader PSSR work continues.

This consultation paper has been prepared by Western Power in collaboration with AEMO. It sets out the proposed Technical Requirements and Access Standards for GFL inverter-based technology and the interim Technical Requirements and Access Standards for GFM inverter-based technology. The proposals are informed by stakeholder feedback to the PSSR Standards Review Consultation Paper, the current Appendix 12 Technical Requirements in the ESM Rules, the National Electricity Rules (**NER**) amendments that commenced on 21 August 2025, AEMO's ongoing GFM Access Standards Technical Requirements Review[6] in the National Energy Market (**NEM**), analysis by Etik Energy, and the expertise of Western Power and AEMO as Network Operator and Power System Operator respectively in the SWIS.

At a high level, the proposed technical requirements proposed in this consultation paper:

- **Update GFL technical requirements**

  Introduce revised Minimum Access Standards (**MAS**) and Automatic Access Standards (**AAS**) for User Facilities comprising GFL inverter-based technology, aligned as far as practical with the latest NER provisions and IEEE 2800, and explicitly covering phase-angle jump withstand, short-circuit ratio (**SCR**) capability, active and reactive current response, negative-sequence behaviour and disturbance ride-through.

---

1 https://www.wa.gov.au/organisation/energy-policy-wa/energy-transformation-strategy
2 https://www.wa.gov.au/government/document-collections/energy-and-governance-legislation-reform
3 SWIS Demand Assessment.pdf
4 South West Interconnected System Transmission Plan.pdf
5 Power System Security and Reliability Standards Review Consultation Paper.pdf
6 https://www.aemo.com.au/consultations/current-and-closed-consultations/grid-forming-technology-access-standards-technical-requirements-review

- **Introduce an interim GFM package**

  Define a clear, behaviour-based definition of GFM technology for the SWIS (inverter-based technology that behaves as a controlled voltage source behind an effective, controllable impedance and provides a stable sub-cycle response within its current and energy limits). Building on AEMO's ongoing work on GFM access standards in the NEM and emerging international guidance, this paper introduces a focused set of interim MAS obligations for facilities comprising GFM inverter-based technology. These MAS obligations are limited to essential capabilities needed now for power system security and efficient operation in the SWIS. They are intended to represent "no-regrets" capabilities, or baseline requirements that are unlikely to be relaxed in future reforms – with any AAS and higher-end GFM functions intentionally deferred to later phases, once national and international practice is more mature.

- **Align with system strength and oscillation needs**

  Use SCR related requirements and an "oscillation-neutral" minimum standard for GFM to provide a predictable baseline of robustness at weak locations, reducing sole reliance on network reinforcement or conservative operational constraints.

- **Introduce an instability-detection requirement (new)**

  Propose a new requirement for an instability-detection mechanism at the point of connection (initially for GFL inverter-based technology), to detect and manage control-driven instabilities and sub-synchronous oscillations in weak-grid conditions, drawing on recent NER reforms (for example NER clause S5.2.5.10) and emerging experience with inverter-driven oscillations.

This consultation seeks further stakeholder feedback on whether the proposed technical requirements for GFL inverter-based technology and proposed interim technical requirements for GFM inverter-based technology strike an appropriate balance between power system security, technology neutrality, investment certainty and cost to SWIS customers, in a way that achieves consistency with the SEO.

1.1 Summary of proposals

Table 1.1 summarises the proposed refinements to the technical requirements as set-out in section 3.3 (Proposals 6–11) of the PSSR Standards Review Consultation Paper, and highlights the additional new requirement introduced in this consultation paper.

Table 1.1: Summary of refinements to PSSR Standards Review Consultation Paper Proposals

Technical Requirement in the PSSR Standards Review Consultation Paper	Proposal number	Status in this consultation paper
Withstand SCR capability at the connection point – minimum standards for IBRs under low system strength, and conditions under which continuous uninterrupted operation is not required below the withstand SCR	Proposal 6	**Addressed / refined** – this paper refines the MAS for GFL and GFM inverters while removing AAS and clarifies how withstand SCR is demonstrated in practice by using control settings that are consistent with those applied when assessing other access standards.
Voltage phase angle jump response – ability of GFL and GFM IBRs to withstand and remain connected through credible phase angle jumps, and for GFM IBRs to oppose the phase angle jump in addition	Proposal 7	**Addressed / refined** – this paper carries forward the phase-angle jump requirement for IBRs and refines the GFL/GFM-specific thresholds and response expectations.

Technical Requirement in the PSSR Standards Review Consultation Paper	Proposal number	Status in this consultation paper
Active and reactive current response during and after contingencies – including: commencement and rise time, sustainment time / "adequately controlled" behaviour, behaviour at current limitation, use of total current as opposed to the maximum continuous current, negative-sequence current control (GFL only), frequency of current injection, fault ride-through activation thresholds, long-duration faults, fast opposition of voltage magnitude changes (GFM only) and active power recovery	Proposal 8	**Addressed / refined** – this paper sets out MAS and AAS requirements for GFL and GFM IBRs during faults, using more practical success criteria such as "adequately controlled", total current, commencement time, and sustainment time. It removes criteria such as "adequately damped", maximum continuous current, and settling time, while carrying over the long-duration fault envelope from the PSSR consultation. Negative-sequence current control requirements are applied to GFL IBRs at this point.
Disturbance ride-through for multiple disturbances and use of the "end of the disturbance" definition – the requirements for multiple voltage disturbances in quick succession and conditions for continuous uninterrupted operation across multiple events	Proposal 9	**Unchanged* in this paper** – the multi-disturbance ride-through envelope and use of "end of the disturbance" are not re-opened; this paper relies on the wording and structure from the 2024 PSSR consultation.
Damping of power system oscillations (GFM inverter performance) – requirements that facilities not degrade damping or cause poorly damped/unstable modes	Proposal 10	**Addressed / clarified** – this paper refines the GFM requirement into an "oscillation-neutral" do-no-harm minimum standard.
Partial load rejection and the definition of continuous uninterrupted operation – how much load can be shed without disconnection, and how "continuous uninterrupted operation" is interpreted	Proposal 11	**Unchanged* in this paper** – partial load rejection obligations and the revised definition of continuous uninterrupted operation are not further amended here; they remain as proposed in the PSSR consultation paper.
Instability detection mechanism (for IBRs, primarily GFL)	New	**Introduces a new requirement** for IBR facilities to include an instability detection mechanism (aligned with NER S5.2.5.10-style concepts) so that IBR-specific instability can be detected and managed within the agreed performance standard. This concept did not appear in PSSR Standards Review Proposals 6–11 and is therefore a new element for stakeholder consultation in this paper.

*For all "Unchanged" please refer to PSSR Standards Review Consultation Paper.

1.2 Purpose

The purpose of this consultation paper is to seek stakeholder views on the proposed refinements to Proposals 6-11 of the PSSR Standards Review Consultation Paper, as summarised in Table 1.1

Please note that this paper does not prescribe detailed technical requirements for hybrid facilities combining GFM and GFL inverter-based technologies. A consistent treatment of such hybrids has not yet been settled in the NEM or internationally and will be developed in a later stage, once AEMO's GFM access standards work has progressed. In the interim, hybrid proposals will be considered on a case-by-case basis using negotiated performance standards and the principles set out in this paper.

1.3 Stakeholder consultation

Stakeholder engagement has been integral to the development of the proposals for a revised set of technical requirements:

- **PSSR Standards Review – GFL/GFM Technical Requirements**
  The PSSR Standards Review Consultation Paper set out proposed changes to Appendix 12 Technical Requirements for GFL and GFM inverter-based technology. Those proposals were drawn from the *Access standards review for the Wholesale Electricity Market* but were subject to further analysis and refinement by Energy Policy WA in close consultation with AEMO and Western Power.
- **Technical refinement with industry**
  Following that consultation, Western Power, AEMO and Etik Energy collaborated on addressing the robust feedback from industry stakeholders on specific clauses. Feedback from those discussions has informed the refinements reflected in this consultation paper.
- **Alignment with broader national and international work**
  The proposals in this consultation paper are informed by AEMO's work on GFM Access Standards in the NEM, recent Australian Energy Market Commission rule changes, and the use of IEEE 2800 and ENTSO-E guidance in other jurisdictions, to ensure that SWIS requirements are not developed in isolation.

The consultation process associated with this consultation paper provides an opportunity for a wider group of stakeholders to review and comment on the proposed updates and refinements to GFL and GFM technical requirements and access standards within the User Facility Standards framework prior to their finalisation.

To assist in the assessment of submissions and the development of any further refinements (as necessary), stakeholders are encouraged to:

- **identify the relevant requirement, ESM Rule clause or section** of this consultation paper that is the subject of your comment.
- **provide specific reasons for your position**, including any implications for PSSR, project delivery or customer outcomes; and
- **provide supporting information or evidence where possible**, such as experience from existing projects, modelling results, cost estimates or references to relevant standards or international practice.

Submissions can be sent to: energymarkets@deed.wa.gov.au.

All submissions received will be made publicly available on www.energy.wa.gov.au, unless requested otherwise.

The consultation period closes at 5:00pm (AWST), on Friday, 6 February 2026.

Late submissions may not be considered.

2. Introduction

Under current arrangements, the technical requirements for facilities connected in the SWIS and participating in the Wholesale Electricity Market (**WEM**) sit across multiple instruments, chiefly the ESM Rules (including Appendix 12 Technical Requirements) and Western Power's Technical Rules 2016. Recognising this fact, the PSSR Standards Review has made recommendations for a single, end-to-end PSSR standard framework with rationalised (and updated) governance arrangements and technical access standards, including for new technologies.

Section 3.3 of the PSSR Standards Review Consultation Paper set out **Proposals 6–11**, which focus on the suitability of the Appendix 12 Technical Requirements in the ESM Rules for new technologies. Those proposals addressed matters such as:

- withstand short-circuit ratio (Proposal 6);
- voltage phase-angle jump response (Proposal 7);
- active and reactive current behaviour during and after contingencies (Proposal 8);
- disturbance ride-through for multiple disturbances (Proposal 9);
- damping of power system oscillations (Proposal 10); and
- partial load rejection (Proposal 11).

The proposals were based on the Access standards review for the Wholesale Electricity Market[7] report, which in turn drew on the then-proposed NER "Improving Access Standards – Package 1" [8] reforms.

Consultation on the PSSR Standards Review Consultation Paper closed 7 August 2025[9]. Stakeholder feedback indicated that **GFM inverter-based technology may not always be able to comply with technical requirements framed around GFL behaviour**, and that more clarity was needed on the practical pathway for GFM projects to connect and participate in the WEM. In response, Energy Policy WA asked Western Power and AEMO to develop **interim, GFM-appropriate technical requirements**, while the broader PSSR Standards Review continues.

Against this backdrop, Western Power and AEMO have jointly developed updated **technical requirements for GFL inverter-based technology**, and **interim technical requirements for GFM inverter-based technology**, for application within the User Facility Standards framework. Compared with the current Appendix 12 requirements, the proposals contained within this consultation paper:

- introduce updated MAS and AAS for facilities comprising GFL inverter-based technology;
- define a focused, interim MAS for facilities comprising GFM inverter-based technology; and
- modernise key disturbance-response and system-strength-related requirements, while adding one genuinely new element: a point-of-connection instability-detection mechanism for GFL inverter-based technology.

The intent of the proposed refinements to the technical requirements is to support secure and reliable operation of the SWIS with increasing levels of IBRs, provide clearer and more predictable technical requirements for proponents and original equipment manufacturers (**OEMs**), and facilitate efficient, SEO-consistent investment and operation in the SWIS.

[7] Etik Energy – "Access standards review for the Wholesale Electricity Market" 2025
[8] https://www.aemc.gov.au/rule-changes/improving-nem-access-standards-package-1
[9] https://www.wa.gov.au/government/document-collections/power-system-security-and-reliability-standards-review

2.1 Guiding principles

When developing the technical requirements proposed in this consultation paper, Western Power was guided by the following principles:

- **System security and reliability first**
  The standards must keep the SWIS secure, stable and reliable as synchronous generation retires, and IBR penetration grows, with requirements such as phase-angle jump withstand/opposition, SCR capability and disturbance ride-through framed around credible contingencies in a weak, low-inertia system.

- **Clear, behaviour-based definition of GFM**
  A practical, observable definition of GFM inverter-based technology is adopted (see Section 3.1), centred on controlled voltage-source behaviour behind an effective, controllable impedance and a stable sub-cycle response to rapid changes in voltage magnitude, frequency and phase angle, within current and energy limits.

- **Technology neutrality at system level**
  The framework should not unduly favour one technology over another: while numerical thresholds for GFL and GFM inverter -based technology may differ, each type of technology is expected to make a comparable contribution to system security, reflecting its capabilities, limitations and role in the system.

- **Alignment with national and international practice**
  Draw, where possible, on the latest NER provisions for IBR access standards, IEEE Std 2800-2022 as an international benchmark, and emerging international GFM guidance (for example from ENTSO-E[10] and Great Britain), adapting only where necessary for the WEM/SWIS.

- **Proportionality and minimum approach**
  MAS focus on minimum capabilities needed now, while more advanced or complex elements – particularly for GFM inverter-based technology – are deferred to later stages when evidence and operating experience are stronger, helping to manage implementation and investment risk.

- **Clarity, predictability and value for customers**
  Requirements are drafted to be clear and testable in commonly used simulation tools and commissioning/compliance programs, to make better use of existing inverter capabilities, minimise unnecessary network reinforcement or conservative operational measures, and support decarbonisation at least cost to SWIS customers.

10 https://www.entsoe.eu/

2.2 Value to the SWIS

The technical requirements proposed in this consultation paper were developed with the intent of:

- **Supporting the secure operation of the SWIS as the grid decarbonises**

  Ensure new inverter-based facilities contribute appropriately to fault ride-through, oscillation behaviour and operation at low system strength, rather than relying solely on synchronous plant or network-level workarounds.

- **Using existing inverter capability efficiently**

  Codify capabilities that modern inverters already provide (for example phase-angle jump withstand, SCR capability and fast current response) as minimum standards, reducing dependence on bespoke reinforcement or conservative operating constraints.

- **Providing clarity for proponents and customers**

  Use a clear MAS/AAS structure, aligned where possible with the NER and IEEE 2800, to support more predictable connection timeframes and lower overall project and system costs.

- **Laying the groundwork for future service frameworks**

  Keep above-minimum capabilities (such as broader system strength provision or active oscillation damping) out of mandatory standards so they can, where appropriate, be explicitly valued in future system strength and Essential System Services frameworks.

2.3 Next steps

Following the close of the consultation period, Western Power will lead the development of an information paper summarising and responding to stakeholder feedback, identifying any proposed refinements to the technical requirements, and outlining potential implementation and transition approaches, for submission to Energy Policy WA.

Energy Policy WA will then use that material, together with stakeholder submissions, to inform the preparation of draft ESM amending rules, which will be subject to further public consultation before any final decisions are made.

3. Summary of assessment and recommendations

3.1 Grid-forming inverter definition

GFM inverter-based technology is an emerging area that continues to develop and evolve. While the NEM has not yet published a formal definition for 'grid-forming', several international frameworks exist that describe the typical characteristics of this type of inverter.

A clear definition is needed to determine when a facility should be assessed against GFM-specific technical requirements rather than the GFL pathway.

The proposed definition in this paper is intended to:

- act as an early classification test for Generator Performance Standards (**GPS**) assessment;
- provide a consistent basis for applying any GFM-specific obligations or trade-offs; and
- ensure that any flexibility is only available where verified GFM behaviour is present, rather than partial or assumed functionality.

Table 3.1 below compares six high-level GFM attributes used across international frameworks, including AEMO's work in the NEM. It shows whether each attribute is explicit and central, present but secondary, or not evident in the definitional framing. The intent is to identify the common and core attributes that can be adopted for the SWIS without importing jurisdiction-specific detail.

Table 3.1: Comparison of GFM attributes across key frameworks

Technical Requirement	AEMO NEM Review Aug 2025	ENTSO-E Oct 2025	VDE-FNN Oct 2025	NESO Sep 2025	NERC Sep 2023	Included in the SWIS proposed definition?
Voltage-source behaviour (acts as a voltage source behind an impedance)	✓	✓	✓	✓	✗	Yes
Internal voltage source, internal phase or internal phasor concept explicitly referenced	✓	✓	✓	✓	✓	No
Autonomous opposition to rapid changes in voltage magnitude, frequency, and phase angle is stated as a defining trait	✓	✓	✓	Implicit	✓	Yes
Sub-cycle time focus embedded in the definition	✓	✓	✓	✓	✓	Yes
Controllable/effective impedance explicitly specified, i.e. virtual impedance	✗	✓	✓	✗	✗	Combined with the voltage source behaviour
Loss of the last synchronous machine explicitly referenced	Being investigated	✓	✗	✗	✓	No

3.1.1 Proposed GFM definition

A GFM facility is an IBR that behaves as a controlled voltage source behind a controllable impedance and autonomously delivers a stable sub-cycle response to rapid changes in voltage magnitude, frequency, and phase angle, within its current and energy limits.

The supporting rationale for the definition is provided in section 3.1.2 below. This definition is based on the most current common characteristics of GFM inverter-based technology. As this technology and related standards evolve (for example through work in the NEM and international bodies), the definition may be reviewed and updated in future amendments to the ESM Rules.

3.1.2 Supporting rationale

The proposed definition is considered suitable for adoption in the SWIS for the following reasons:

- **Terminal-behaviour focus**
  The definition is anchored in externally observable dynamic terminal behaviour and does not depend on any particular set of technical limits encoded in regulation. Framing GFM as a controlled voltage source behind an effective, controllable impedance aligns with the most consistent cross-jurisdictional theme: a Thevenin-equivalent interpretation of GFM behaviour at the unit terminals.

- **Explicit inclusion of controllable impedance**
  Controllable (or “virtual”) impedance is the primary mechanism by which terminal current is shaped during fast disturbances in a way analogous to the immediate electromagnetic response of a synchronous machine. Including both the ‘controllable impedance’ characteristic feature and the voltage-source behaviour within the definition is appropriate as it clarifies the intended dynamic character of GFM technology without over prescribing design and operational requirements.

- **Sub-cycle response as a defining pillar**
  Sub-cycle response distinguishes GFM from GFL control philosophies during the first instants of a disturbance and is consistent with intuitive expectations of synchronous machine behaviour. Making sub-cycle performance explicit reflects international practice, where very fast voltage magnitude, frequency and phase angle control response is treated as central to GFM capability, which remain a challenge for GFLs in supporting system security.

- **Recognition of current and energy limits**
  Explicitly stating that behaviour is “within its current and energy limits” avoids implying that GFM capability requires unlimited fault current or unlimited inertia-like energy delivery. This bounded framing supports technology neutrality across different IBR types, including battery energy storage systems (**BESS**), hybrids and other inverter-based technologies with diverse primary energy sources.

- **Exclusion of internal phasor concepts from the core wording**
  Internal voltage phase / internal phasor language used in some frameworks is not included as a standalone definitional attribute. These internal quantities cannot be independently verified with black-box models and are already captured implicitly by the combination of voltage-source behaviour behind a controllable impedance and stable sub-cycle response. Excluding them reduces compliance ambiguity without changing the underlying physical meaning.

- **Exclusion of “loss of last synchronous machine” from the core definition**
  Scenarios involving loss of the last synchronous machine are better treated as validation cases or advanced capability pathways, as they invoke additional control objectives (e.g. islanded operation, resynchronisation, protection coordination). Embedding such scenarios in the core definition risks over-

extending baseline obligations for all GFM connections, including those where island-capable operation is not a system need.

Taken together, these elements provide a clear minimum basis for GFM capability in the SWIS. The definition focuses on terminal behaviour, sub-cycle performance and practical current and energy bounds, providing a stable foundation on which WEM-specific technical requirements can be built without revisiting the core definition.

3.2 Summary of proposed technical requirements

Proposals 6–11 of the PSSR Standards Review Consultation Paper set out revised technical requirements for GFL and GFM inverter-based technology. Western Power and AEMO have reviewed and taken into consideration of stakeholder feedback, subsequent developments in the NEM, and experience with recent SWIS connections to develop a proposed refined set of technical requirements.

In this consultation paper:

- Facilities comprising **GFL** inverter-based technology are assigned updated **MAS** and **AAS**.
- Facilities comprising **GFM** inverter-based technologies are assigned a **MAS only** at this stage, with higher-end GFM capabilities deferred until AEMO's NEM work and international practice are more mature.
- Several key aspects of **disturbance response and operation at low system strength** are modernised and better aligned with recent NER and IEEE 2800 provisions.

The proposals are intended to:

- support secure and reliable operation with increasing levels of IBR in the SWIS;
- provide clearer and more predictable technical requirements for proponents and OEMs; and
- facilitate efficient investment and operation consistent with the SEO.

Table 3.2 summarises, for each technical requirement:

- the corresponding PSSR Standards Review Consultation Paper proposal and ESM Rules clause;
- the existing ESM Rules requirements;
- the proposed refined MAS/AAS for GFL inverter-based technology;
- the proposed refined interim requirements for GFM inverter-based technology; and
- the rationale for each refinement in respect of GFL or GFM.

Where the proposed technical requirements remain unchanged from the *Access standards review for the Wholesale Electricity Market* - as reflected in the PSSR Standards Review Consultation Paper, this consultation paper does **not** repeat the detailed rationale provided in Section 4. Such items are flagged in the "Refer to" column as PSSR Standards Review Consultation Paper **(unchanged)**.

Table 3.2: Summary of proposed technical requirements

Technical Requirement	PSSR Standards Review Proposal	Applicable Clause in ESM Rules	Existing ESM Rules requirement	Proposed GFL requirements	Proposed GFM requirement	Refer to
Withstand SCR	Proposal 6	New	No requirement	**MAS:** SCR ≤ 3, **AAS:** SCR ≤ 2	**MAS:** SCR ≤ 2; **AAS:** not proposed at this stage	Section 4.1
Settings used for demonstrating withstand SCR	Proposal 6	New	No requirement	General requirement: the settings used must not be different from the settings required for compliance with other technical requirements, unless otherwise agreed with AEMO and the Network Operator.	Same as GFL	Section 4.1
SCR boundaries where the facility is expected to remain stable	Proposal 6	New	No carve out	Continuous uninterrupted operation is not required if the network operating conditions result in the system impedance increasing above that agreed with AEMO and the Network Operator	Same as GFL	Section 4.1
Voltage phase angle jump response	Proposal 7	New	No explicit phase angle jump requirement for IBRs, except that no vector shift relays are allowed.	**MAS:** withstand ±25° **AAS:** not applicable	**MAS:** withstand ±25° and provide fast opposition with sub-cycle (≤20 ms) initiation **AAS:** not proposed at this stage	Section 4.2

Technical Requirement	PSSR Standards Review Proposal	Applicable Clause in ESM Rules	Existing ESM Rules requirement	Proposed GFL requirements	Proposed GFM requirement	Refer to
Voltage phase angle jump during the fault	Proposal 7	New	No requirement	General requirement: Remain in operation for any change in the phase angle of individual phases caused by the occurrence and clearance of balanced and unbalanced faults, provided that the positive-sequence angle change does not exceed this criterion.	Same as GFL	Section 4.2
Reactive current commencement time during contingencies	Proposal 8	**MAS:** A12.9.3.7 **AAS:** A12.9.2.7	No requirement	**MAS:** ≤ 40 ms **AAS:** ≤ 20 ms	**MAS:** ≤ 20 ms **AAS:** not proposed at this stage	Section 4.3
Reactive current rise time during contingencies	Proposal 8	**MAS:** A12.9.3.7 **AAS:** A12.9.2.7	**MAS:** ≤ 70 ms **AAS:** ≤ 40 ms – for both GFL and GFM	**MAS:** ≤ 80 ms **AAS:** ≤ 40 ms	**MAS:** ≤ 80 ms **AAS:** not proposed at this stage	Section 4.4
Negative sequence control during contingencies	Proposal 8	A12.9.1.6(c)	The ratio of the negative sequence to positive sequence components of the reactive current contribution must be agreed with AEMO and the Network Operator.	**MAS:** negative-sequence current leading negative-sequence voltage by about 90°, with clear prioritisation	**MAS or AAS** are not proposed at this stage (GFM negative sequence behaviour left to future work)	Section 4.5
Behaviour at current limitation	Proposal 8	New	None	Not applicable	**MAS:** uses a revised definition of the term “adequately controlled” as per NER	Section 4.6

Technical Requirement	PSSR Standards Review Proposal	Applicable Clause in ESM Rules	Existing ESM Rules requirement	Proposed GFL requirements	Proposed GFM requirement	Refer to
Frequency of current injection during contingencies	Proposal 8	A12.9.1.6	No requirement	General requirement: during the fault, injection of active and reactive current from the Generating System and each of its Asynchronous Generating Units must have a fundamental-frequency component same as the fundamental-frequency of the terminal voltage.	Same as GFL	Section 4.7
Fast opposition of voltage magnitude changes	Proposal 8 (links to 7)	A12.9.2.5(a)	No requirement	Not applicable	**MAS:** reduce the sensitivity of voltage magnitude to a given change in current within 20 ms after the disturbance, compared to when the facility was not connected.	Section 4.8
Fault ride-through activation thresholds	Proposal 8	A12.9.2.5 and A12.9.3.5	**MAS:** 80% and 120%; **AAS:** uses voltage ranges, for example, A12.9.2.5 specified an under-voltage range of 85–90% and an over-voltage range of 110–115%.	**MAS:** 80% and 120% **AAS:** 85% and 115%	**MAS:** same as GFL	Section 4.9
The use of total current during contingencies	Proposal 8	A12.9.1.6(a)	Uses maximum continuous current	**MAS:** total current will replace the maximum continuous current	**MAS:** same formulation	Section 4.10

Technical Requirement	PSSR Standards Review Proposal	Applicable Clause in ESM Rules	Existing ESM Rules requirement	Proposed GFL requirements	Proposed GFM requirement	Refer to
Reactive current sustainment time during contingencies	Proposal 8	New	No explicit requirement	General requirement: The facility must substantially maintain the response required under subparagraph (1) until the end of the disturbance, or until another point agreed with the Network Operator and AEMO (consistent with the NER).	Same as GFL	Section 4.11
Active power recovery following contingencies	Proposal 8	A12.9.2.5(b) and A12.9.3.5(b)	Same	**MAS:** within a period of time agreed by AEMO and the Network Operator **AAS:** ≤ 100 ms	**MAS:** within a period of time agreed by AEMO and the Network Operator **AAS:** not pursued at this stage	PSSR Standards Review Consultation Paper **(unchanged)**
Reactive current settling time during contingencies	Proposal 8	**MAS:** A12.9.3.7 **AAS:** A12.9.2.7	**AAS:** ≤ 70 ms **MAS:** ≤ 70 ms	**MAS & AAS:** Removed settling time requirement	**MAS & AAS:** Removed setting time requirement	PSSR Standards Review Consultation Paper **(unchanged)**
Reactive current injection ratio during contingencies	Proposal 8	**MAS:** A12.9.3.5 (a) **AAS:** A12.9.2.5 (a)	**MAS:** ≥2% **AAS:** ≥4%	**MAS:** ≥0% **AAS:** ≥4%	**MAS:** ≥0% **AAS:** Not proposed at this stage	PSSR Standards Review Consultation Paper **(unchanged)**
Long duration faults	Proposal 8	A12.9.3.7 and A12.9.3.8	Where AEMO and the Network Operator require the Generating System to sustain a response duration of 2 seconds or less	**MAS:** Reduce 2 seconds to 450 ms; replace adequately damped with adequately controlled **AAS:** not applicable	**MAS:** same as GFL **AAS:** not applicable	PSSR Standards Review Consultation Paper **(unchanged)**

Technical Requirement	PSSR Standards Review Proposal	Applicable Clause in ESM Rules	Existing ESM Rules requirement	Proposed GFL requirements	Proposed GFM requirement	Refer to
Disturbance ride-through for multiple disturbances	Proposal 9	**MAS:** A12.9.3.3 **AAS:** A12.9.2.3	Refer to current A12.9.2.3 (**AAS**) and A12.9.3.3 (**MAS**)	Refer to the *Access standards review for the Wholesale Electricity Market*		PSSR Standards Review Consultation Paper **(unchanged)**
Damping of power system oscillations	Proposal 10	**MAS:** A12.4.3.2 **AAS:** A12.4.2.2	Existing requirements apply to all technologies but stem from synchronous generator requirements and are not well-suited to IBRs.	No direct requirement, except the new definition of "adequately controlled" as proposed in the *Access standards review for the Wholesale Electricity Market*	**MAS:** "oscillation-neutral" in 0.1–100 Hz band **AAS:** not applicable	Section 4.12
Partial load rejection	Proposal 11	A12.6.1.5 and the definition of ''continuous uninterrupted operation''	Refer to current A12.6.1.5	Refer to the *Access standards review for the Wholesale Electricity Market*		PSSR Standards Review Consultation Paper **(unchanged)**
Instability detection mechanism	-	New	None	Consistent with NER S5.2.5.10 (post NER version 234)	Not proposed at this stage	Section 4.13

4. Detailed assessment and recommendations

This section sets out the refined rationale and value add for each of the technical requirement proposed in Proposals 6-11 of the PSSR Standards Review Consultation Paper, and the one new requirement proposed in this consultation paper.

This section includes technical requirements for phase angle jump withstand and opposition obligations, withstand SCR, common settings for SCR and other standards, damping of power system oscillations, and the suite of active and reactive current response obligations during and after contingencies as set-out in Table 3.2.

For each refinement, it is explained:

- why the refinement is needed in the context of the SWIS;
- how it relates to the proposed changes to the NER for updated technical requirements, and also to emerging international practice; and
- what practical benefit making the refinement delivers for developers, OEMs and the broader industry, and for Western Power and AEMO in being able to fulfil their obligations in relation to power system security and reliability.

4.1 SCR withstand capability

4.1.1 Rationale

Withstand SCR

Under the revised proposal, only a MAS is specified at this stage, with the corresponding AAS to be developed as part of the broader system strength framework.

The proposed MAS values are:

- **GFL inverter-based technologies:** capable of continuous uninterrupted operation down to an agreed withstand SCR of **3.0**.
- **GFM inverter-based technologies:** capable of continuous uninterrupted operation down to an agreed withstand SCR of **2.0**.

These minimum levels are informed by AEMO's WEM ESOO[11], which indicates that several transmission locations in the SWIS are projected to operate with effective SCR values below 3.0 and, in some cases, below 2.0. In that context, materially higher minimum withstand SCR thresholds would either:

- require widespread auxiliary equipment (for example synchronous condensers); or
- effectively prevent connection at locations that are technically acceptable if modern inverter capability is used.

Recent NER versions, including NER clause S5.2.5.15 on withstand SCR, are primarily intended for GFL inverter-based technology and do not prescribe detailed requirements for GFM inverter-based technology, instead deferring to AEMO's ongoing work on appropriate performance standards.

[11] 2025 Wholesale Electricity Market Electricity Statement of Opportunities

AEMO's NEM position for GFM inverter-based technology, outlined in its Grid-forming Technology Access Standards Approach Paper[12], is broadly consistent with the original proposal for the SWIS, with GFM withstand SCR values of 1.8 (MAS) and of 1.2 (AAS). The original proposed SCR values of and 2.0 (MAS) for GFM and 3.0 (MAS) for GFL are therefore closely aligned with this thinking, which is itself informed by extensive internal studies, consultation with OEMs and NSPs, and the wider NEM experience. This alignment provides a reliable frame of reference and avoids introducing arbitrary thresholds.

In applying these requirements, it is important to distinguish clearly between facility capability and network limitations, particularly transfer capacity. Network conditions can reduce the effective SCR at a given site, particularly during periods of high power consumption, such as operation of battery energy storage systems in charging mode and occasionally in generating mode. These limitations are well understood and distinct from the inverter's inherent capability. Where an inability to meet the withstand SCR is attributable to network conditions rather than plant design, power dispatch can be reduced to a level at which those limitations are no longer binding. Such issues are best managed through guidelines such as the existing Generator Performance Standard : Guideline for the Assessment of Technical Requirements[13] or a new system strength impact assessment guideline. This is consistent with current NEM practice, rather than being hard coded into the rules themselves.

The proposed minimum withstand SCR values of 2.0 for GFM and 3.0 for GFL are intended not to favour one technology over another, but to ensure each technology contributes appropriately to system security. In this sense, technology neutrality does not mean identical numerical thresholds for all facilities; rather, it means that, taken as a whole, different technologies are expected to make a broadly comparable contribution to system security. GFM inverter-based technology is expected to deliver superior performance under very low SCR conditions and, in some cases, may show slightly inferior fault ride-through behaviour than GFL in other respects. Provided any such differences do not compromise system security, these trade-offs are acceptable.

Without this balance, there is a risk that GFM would, in practice, be tuned to behave little differently from a lower performing GFL inverter-based technology, or even less robustly in some respects, which would undermine the purpose of introducing GFM capability in the first place.

Settings used for demonstrating withstand SCR

NER clause S5.2.5.15(d) permits facility capability to be demonstrated with any appropriate control or protection settings, including settings that differ from those used to meet other performance standards. This flexibility may, in some cases, allow GFM inverter-based technology to be tuned specifically to withstand SCR tests at very low notional SCR values, while more conservative settings, translating to a lower technical performance, are used in operation and for all grid connection studies. In practice, this means that the full low SCR capability demonstrated in studies is not realised in service. AEMO's Grid-forming Technology Access Standards Approach Paper cautions against this outcome and stresses the need for consistency between the parameters used to demonstrate minimum SCR capability and those used to demonstrate compliance with other access standards.

If materially different settings were allowed in the SWIS for withstand SCR testing, there would be a similar risk. GFM inverter-based technology could be set up with special low SCR test settings, chosen primarily to avoid system strength charges or otherwise follow a more favourable assessment pathway, while operational tuning remained closer to that of a lower performing GFL inverter-based technology. From a system security perspective, this is less desirable than treating the facility as GFL, because a GFL inverter-based technology that cannot meet low withstand SCR requirements must either install stabilising

12 Grid-forming Technology Access Standards Approach Paper

13 Generator Performance Standards: Guideline for the Assessment of Technical Requirements

solutions, accept curtailment, or pay system strength charges. By contrast, a GFM inverter-based technology that demonstrates low SCR capability only under artificial test settings could avoid charges while, in practice, behaving less robustly than a well-designed GFL inverter-based technology at the same connection point. For this reason, our current and previous proposals require that the same settings, or settings within a clearly defined and justified tolerance, be used both to demonstrate withstand SCR and to meet other access standards. Any allowable differences should be defined through guidelines rather than embedded directly in the Rules. The detailed criteria for any allowable differences, including how to treat the relationship between minimum system SCR at the site and the withstand SCR used for capability testing, are best developed in access standards assessment guidelines after further studies by Western Power and AEMO, rather than embedded directly in the ESM Rules.

The question of whether a contractual pathway similar to NER clause 5.2.5.15(e), which allows a plant to connect while not meeting the minimum SCR, should be available to all technologies, including GFM inverter-based technology, is primarily a commercial and market design matter, therefore out of scope for this technical proposal. Experience in the NEM indicates that GFM projects have generally been developed to avoid system strength charges by demonstrating robust low withstand SCR capability, rather than by opting to pay for system strength services. Decisions on whether and how GFM inverter-based technology might participate in future system strength charging arrangements can therefore be considered separately from the technical access standards, which are focused on defining the minimum capability expected of GFL and GFM inverter-based technology in the SWIS.

SCR boundaries where the facility is expected to remain stable

The revised proposal retains the clarification that continuous uninterrupted operation is not required when the actual system impedance at the connection point increases above the nominated withstand system impedance. This confirms that the withstand SCR defines the minimum system strength for which continuous operation must be demonstrated, avoids an open-ended obligation at arbitrarily low SCR, and gives developers and OEMs a clear target for compliance studies and model validation, as well as a practical reference point when assessing genuine non-compliance events in the field. Consistent with the new NER, the revised proposal frames this requirement in terms of system impedance by comparing the actual system impedance at the connection point with the nominated withstand system impedance, rather than relying directly on fault level or SCR.

Note that the new NER explicitly accounts for operation outside the envelope; however, as correctly justified in AEMC's determination, it has proposed the term system impedance rather than fault level or SCR. Refer to NER clause S5.2.5.5(d)(10):

> *the system impedance at the connection point being above the highest system impedance for which the plant must be tuned, as nominated by the Network Service Provider under NER clause S5.2.5.13(m), and NER clause S5.2.5.5(l)(9): the system impedance at the connection point being above the highest system impedance for which the plant must be tuned, as nominated by the Network Service Provider under NER clause S5.2.5.13(m).*

While these two sub-clauses are included in multiple fault-ride-through sections of the new Rules, the wording makes them apply to any event, including single faults. AEMC has also reinstated this in their final determination.

As the AEMC notes, requiring a plant to remain in continuous uninterrupted operation for fault levels below those for which it has been tuned puts unnecessary obligations on plant performance, affects the damping of its controls during disturbances, and ambiguity in minimum fault levels can result in a tuning range that sub-optimally utilises available plant performance. Lack of recorded information about plant tuning then hinders future assessment of whether tuning remains adequate as the system changes over time.

Finally, NER clause S5.2.5.13(m) sets out Schedule 5.2 and NSP obligations in this regard.

> *The Network Service Provider must nominate, and the Schedule 5.2 Participant must record in the releasable user guide, the highest and typical system impedances at the connection point for tuning of controls and assessment of compliance for NER clauses S5.2.5.1, S5.2.5.5 and S5.2.5.13. Unless otherwise agreed by the Network Service Provider and AEMO, the highest system impedance must be consistent with the system impedance corresponding to the minimum three-phase fault level at the electrically closest system strength node, with the relevant single credible contingency, and the typical system impedance must be representative of a typical network configuration and typical levels of Schedule 5.2 plant in service.*

We suggest that appropriate responsibilities be established, with Western Power, AEMO and the developer contributing according to their expertise. Western Power is best placed to provide advice on the expected range of system parameters, including minimum and maximum system impedance. However, determining how the facility comprising inverter-based technology should be tuned falls outside Western Power's and AEMO's responsibilities. Even if they possessed the necessary expertise, their limited visibility of black-boxed models means that developers, through their OEMs and consultants, are best placed to decide how tuning should be carried out to meet the rules requirements, using the parameters specified by Western Power and AEMO.

4.1.2 Value-add and necessity for the SWIS

The proposed withstand SCR requirements give Western Power, AEMO and project developers a clear and predictable minimum level of robustness for both GFL and GFM inverter-based technology s in parts of the SWIS that are already, and are expected to remain, weak. Rather than trying to reinforce every weak node or rely exclusively on conservative operational measures, the framework sets a common baseline of low withstand SCR capability that modern inverters can reasonably deliver, as reflected in responses to AEMO's Grid-forming Technology Access Standards Approach Paper. This capability helps unlock viable connection opportunities in areas where SCR is already below 3, and in some cases below 2, without defaulting to widespread installation of auxiliary synchronous condensers.

By requiring withstand SCR capability to be demonstrated using the same, or a tightly justified variant of, the operational control and protection settings, the framework also strengthens the link between what is proven in studies and what is delivered when in service.

4.2 Voltage phase angle jump response

4.2.1 Rationale

Our proposal focuses on minimum capabilities, with a universal minimum phase angle jump withstand capability of 25° for both GFL and GFM inverter-based technology in the SWIS, with an AAS for the GFM inverter-based technology to be investigated further.

The proposed 25° phase angle jump withstand capability is based on IEEE Std 2800-2022[14], which reflects the demonstrated ability of modern IBRs without imposing undue costs. Similar thresholds appear in the following frameworks:

- Several ENTSO-E member states apply a 20° phase angle jump withstand requirement for all technologies[15].
- AS 4777.2[16] Table 4.9 requires continuous operation for a single-phase voltage angle shift of at least 60° and a three-phase positive-sequence shift of at least 20° within a voltage cycle.
- AEMO's dynamic model acceptance test guideline[17] specifies a minimum ±40° phase jump for both GFL and GFM model testing.

National Energy System Operator (NESO)'s System Oscillation Assessment Guidance Note[18] for inverter-based resources specifies step-change tests that include a ±30° phase jump in AC grid voltage angle, providing a useful reference point for phase-jump robustness across both GFL and GFM inverter-based technology.

These requirements demonstrate that a minimum voltage phase angle jump of 25° for the SWIS is technically achievable relative to existing Australian and international practice. Focusing instead on vector-shift protection primarily reflects historical challenges and does not adequately address present-day issues associated with phase angle jumps, which are particularly relevant for a smaller and more weakly meshed power system such as the SWIS.

AEMO's NEM position for the GFM inverter-based technology, is broadly consistent with the PSSR Standards Review Consultation Paper position proposed for the SWIS, including phase angle jump thresholds of 40° and 60° for the minimum and automatic access standards, respectively. Stakeholder responses to AEMO's Grid-forming Technology Access Standards Approach Paper indicate that, while several stakeholders supported a 60° phase angle jump capability, the vast majority considered a range between 20° and 40° both necessary and practical for all technologies, including wind turbines. The proposed 25° minimum for the SWIS sits within this range and reflects that balance of views.

Consistent with the PSSR Standards Review Consultation Paper, GFM capability will encompass both withstanding the imposed phase angle jump and actively opposing it, so that the inverter contributes to restoring a coherent system voltage angle rather than passively following the disturbance. To assess this capability, we recommend retaining a requirement for response initiation within one cycle, noting that this requirement was previously framed as response time but has now been clarified as a response initiation time to avoid ambiguity. Sub-cycle initiation remains a key defining feature of GFM capability, with several international specifications and OEM submissions identifying the ability to suppress a phase angle jump with an initiation time of around 20 ms or less as central to GFM behaviour.

In this broader context, the proposed 20 ms response initiation time is accommodating and a conservative choice, noting that recent ENTSO-E[19] formulations use around 30 ms as the time to achieve a large proportion of the response (for example, about 90%), rather than merely to initiate it. Response initiation time is a property of the control design and is not dependent on whether a facility comprising inverter-based technology is connected in a weak or strong part of the system; indeed, in low system strength

---

[14] IEEE 2800-2022: IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

[15] Energinet RfG – "Requirements for Generators", Appendix 1 (Explanatory document)

[16] AS 4777.2:2020 Grid connection of energy systems via inverters, Part 2: Inverter requirements. Standards Australia

[17] AEMO, Dynamic Model Acceptance Test Guideline

[18] National Grid ESO / NESO, "System Oscillation Assessment of Inverter Based Resources (IBRs)" Guidance Notes, 31 January 2024

[19] ENTSO-E, Grid forming capability of power park modules, October 2025

conditions, a prompt response is more, not less, necessary. This requirement is therefore essential when determining, during the connection process, whether a facility should be assessed under the GFL or GFM pathway.

It is also important to recognise that, in a relatively small and isolated system such as the SWIS, conditions that require effective suppression of phase angle jumps are likely to arise more frequently than conditions that rely on inertial contributions from individual facilities. While synchronous condensers are as capable as GFM inverter-based technology in providing inertial response, they cannot provide phase angle jump suppression. We therefore consider the opposition of phase angle jump and provision of inertia as two equally important attributes of the SWIS power system in transition rather than prioritising one over the other under all conditions.

We also reinstate the original proposal to retain the common requirement on the relationship between phase angle jump withstand and fault ride through, based on the reputable IEEE Std 2800 framework. In practice, this means that generating systems and their asynchronous production units are expected to remain in operation for fault-induced phase angle changes up to the specified positive-sequence angle criterion.

4.2.2 Value-add and necessity for the SWIS

Explicit phase angle jump withstand and opposition requirements set clear expectations for how GFL and GFM IBRs are expected to behave during severe disturbances. They reduce nuisance tripping from vector-shift protection and ensure that all facilities comprising inverter-based technology can withstand moderate voltage angle jumps. For the GFM inverter-based technology, there is an additional expectation that the inverter actively opposes the phase angle jump to help restore a coherent system voltage angle, a fundamental aspect of GFM operation. Phase angle jumps of this type can arise from various events, including fault occurrence and fault clearance.

Credible contingencies in the SWIS can readily produce positive-sequence angle changes of 25° or more, and our own studies indicate that today's system can already be subject to phase angle jumps of at least 30°. If IBRs cannot withstand or oppose these events, Western Power and AEMO would need to rely more heavily on synchronous inertia and additional system strength and inertia services, increasing the risk of unplanned disconnection of IBRs and driving unnecessary investment in synchronous machines, with the resulting undue cost borne by consumers. Western Power, therefore, considers the proposed requirement to be a modest minimum access standard.

4.3 Reactive current commencement time during contingencies

4.3.1 Rationale

Recent NER versions include NER clause S5.2.5.5A(g)(2), which specifies an automatic access standard requiring the positive-sequence reactive current response opposing the voltage change to commence within 10ms. NER clause S5.2.5.5A(n)(4), which outlines the relevant minimum access standard, specifies a commencement time of 40ms. Our proposal fully aligns with this framework for GFL inverter-based technology and reflects the current NER intent.

International requirements consistently treat sub-cycle response, that is, less than 20ms, as a defining feature of GFM controls. In Europe, several national and project-specific GFM specifications interpret "instantaneous" response as a response initiation time of around 5ms. Several stakeholders, including OEMs responding to AEMO's GFM Approach Paper, also noted that 20ms is slow for modern GFM technology, with some proposing an initiation time of around 5ms for GFM behaviour. Our proposed commencement time of 20ms for GFM inverter-based technology is therefore already at the relaxed limit of what is seen internationally and in NEM technical discussions. For further context, recent ENTSO-E requirements treat 30ms as the time required to reach a substantial proportion of the response, i.e. 90 per cent, whereas the commencement time generally corresponds to a smaller response magnitude.

When comparing GFM behaviour with that of synchronous machines, it is recognised that synchronous machines respond to voltage and angle disturbances almost instantaneously, and system security management relies on this near-instantaneous response. Sub-cycle response requirements for GFM therefore reflect an attempt to approximate this well-established synchronous benchmark in inverter form, rather than to exceed what synchronous machines already deliver.

The maximum possible response magnitude is not always desirable under low system strength conditions. However, a fast commencement time does not necessarily yield a large response magnitude. It is a control indicator that shows the inverter has deviated from its pre-disturbance state. How high or low the SCR is will affect the magnitude and shape of the response, not the initiation of control action, and a prompt initiation is particularly desirable under low system strength conditions.

There are recognised practical challenges associated with assessing the sub-cycle response of GFM facilities. They primarily arise from the continued use of legacy techniques implemented in simulation tools and do not reflect GFM technology or the underlying capability of those tools. Root mean square (**RMS**) phasor estimators and fast Fourier transform (**FFT**) based blocks introduce at least one cycle of delay. However, several well-proven mathematical approaches are available that reduce calculation latency to below half a cycle. These methods can be implemented by users in widely used simulation tools, without requiring intervention from the software vendor, and they substantially reduce artificial delays. As a result, the actual sub-cycle response capability of GFM inverter-based technology can be credibly demonstrated in simulation environments.

Collection-grid impedance, especially in large wind farms, can slow the observed response at the connection point. The default assessment remains at the connection point, consistent with NER practice. Where there is a demonstrable material difference between terminal and connection point signals, assessment at inverter terminals can be negotiated rather than shifting the default for all facilities.

4.3.2 Value-add and necessity for the SWIS

By adopting an explicit commencement time requirement in the SWIS, aligned with the NER and informed by international experience, project developers are provided with a clear and achievable performance target. OEMs can then use a consistent and widely accepted reference point for product design and tuning.

If this requirement is not adopted, responses may vary significantly between projects, including situations where an above-minimum access standard becomes the determining factor for system security. In that case, a facility may comprise GFM inverter-based technology but, in practice, deliver an equal or inferior response than a facility comprising GFL inverter-based technology. The underlying system need does not disappear, and Western Power and AEMO would then need to procure additional genuinely capable GFM inverter-based technology and synchronous condensers to respond to disturbances within a cycle. The people of Western Australia would ultimately bear the cost of those extra measures.

4.4 Reactive current rise time during contingencies

4.4.1 Rationale

Reactive current rise time during faults is another key determinant of how effectively IBRs support voltage and remain connected under voltage disturbances. The SWIS proposal, therefore, retains an explicit reactive current rise-time obligation for both GFL and GFM inverter-based technology, with assessment by default at the connection point, but allows measurement at unit terminals where agreed with AEMO and Western Power, consistent with the NER. This provides a clear, testable benchmark for connection studies and compliance assessments, rather than leaving the acceptable response time to case-by-case negotiation.

For GFL inverters, which are inherently current-controlled devices with relatively predictable dynamics, the proposed requirement largely continues existing practice. It aligns with the NER AAS for positive sequence reactive current rise time limit of 40ms, providing continuity for proponents, and we therefore propose that both the minimum and ideal access standards for GFL inverter-based technology in the SWIS be consistent with the NEM arrangements. For GFM inverters, practical experience has shown much wider variability in reactive current dynamics, including significant changes in response magnitude for similar fault conditions. At this stage, we only propose a minimum rise time requirement for GFM inverters, aligned with the GFL minimum, and a defined upper bound on rise time; therefore, plays an important role in maintaining system security by setting a clear minimum expectation on how quickly the reactive current must build up, while still leaving OEMs freedom to optimise internal control structures.

International work already points in the same and rather more stringent direction. The recent ENTSO-E technical report on GFM capability specifies that the reactive current response should reach approximately 90 per cent of the expected value within 30ms, effectively a rise time requirement. However, these proposals are not yet codified in Australian technical requirements, and AEMO's Grid-forming Technology Access Standards Approach Paper instead focuses on reviewing how rise time should be defined and measured for GFM inverter-based technology and notes that further investigation is needed before tighter numerical thresholds are adopted. In this context, adopting an NER style 80ms rise time requirement (or a longer time agreed with Western Power and AEMO, under NER clause S5.2.5.5(o)(3)) for the SWIS is intended as a minimum that is consistent but more relaxed than emerging international practices. The AAS for the GFM inverter-based technology will be developed once the ongoing Australian and global work on GFM rise time metrics has matured.

4.4.2 Value-add and necessity for the SWIS

Aligning the GFL reactive current rise time requirements in the SWIS with the NEM MAS and AAS provides immediate consistency for proponents and operators, avoids the need for bespoke SWIS-specific thresholds, and supports the reuse of existing modelling and studies approaches. For the GFM inverter-based technology, adopting the same 80ms minimum requirement gives a clear baseline that guards against unacceptably slow responses, yet remains significantly more relaxed than emerging international expectations, such as ENTSO-E's 30ms guidance. This creates space for further investigation and industry learning before specifying AAS for GFM inverter-based technology in a later stage.

4.5 Negative-sequence control during contingencies

4.5.1 Rationale

It is proposed that the SWIS technical requirements for negative-sequence control be aligned with the IEEE 2800 approach for GFL IBRs, while deferring more detailed requirements for GFM IBRs to a later stage. IEEE 2800 requires, for unbalanced faults, that IBRs be capable of providing negative-sequence current with the negative-sequence current phasor leading the negative-sequence voltage by nominally 90°, with a tolerance of approximately ±10°, and that a defined prioritisation between positive- and negative-sequence current components be provided when current limits are reached. This primarily supports the management of voltages on healthy phases and, to some extent, the correct operation of protection systems that rely on negative-sequence current.

Consistent with the original proposal, it is therefore proposed to introduce new criteria that would replace sub-clause A12.9.1.6(c) of the ESM Rules for GFL IBRs only at this stage. These criteria would require the GFL inverter-based technology, during unbalanced faults, to provide negative-sequence current that leads the negative-sequence voltage by nominally 90° with no more than 10° drift, and to follow a clear prioritisation of positive- and negative-sequence components under current-limiting conditions. The requirement is framed around providing an appropriate negative-sequence current response, rather than mandating negative-sequence current injection only, recognising that in some cases absorption of negative-sequence current may be more effective in meeting system needs.

In Europe, ENTSO-E requirements and the ENTSO-E and German FNN20 Recommendations go further by introducing explicit negative-sequence impedance characteristics or k-factors, in particular for the GFM inverter-based technology. These frameworks recognise that, for the GFM inverter-based technology, the negative-sequence response is not an inherent physical property but is determined by the chosen control design. While those developments are highly relevant, the SWIS proposal is deliberately designed as a minimum requirement that allows further investigation to proceed before specifying detailed GFM performance. At this stage, the additional ENTSO-E or FNN-style impedance and k-factor requirements for the GFM inverter -based technology are not adopted, and the scope is limited to an IEEE-2800-type phase-angle and prioritisation requirement for the GFL inverter-based technology.

A clear distinction is drawn between GFL and GFM inverters. GFL inverters behave as controlled current sources, for which it is technically and practically reasonable to specify explicit negative-sequence current behaviour based on IEEE 2800. GFM inverters behave as controlled voltage sources, and all aspects of their response, including negative-sequence performance, are controlled functions rather than inherent physical properties, so more detailed requirements should be developed with care in a subsequent stage

4.5.2 Value-add and necessity for the SWIS

Clarifying the negative-sequence control requirement provides direct value for both system security and project delivery in the SWIS. The current provision in sub-clause A12.9.1.6(c) of the ESM Rules is difficult to interpret and implement in practice, leading to inconsistent implementation, protracted technical debates, and uncertainty for proponents, OEMs, and Western Power, AEMO and ultimately not helping any party. Replacing it with a simple, IEEE Std 2800-aligned phase-angle and prioritisation requirement removes this ambiguity, gives a common target for studies, models and protection settings, and provides a low-cost, minimum uplift in baseline performance while preserving scope to refine GFM expectations in a later stage.

4.6 Behaviour at current limitation during contingencies

4.6.1 Rationale

The proposed requirement applies only to GFM inverter-based technology, because the performance degradation of ideal voltage-source behaviour under current limitation is a GFM-specific issue. In practice, current limits are frequently reached during facility operation, particularly during faults, so it is important to set clear, enforceable boundaries for how the GFM inverter-based technology should behave once those limits are reached.

By contrast, GFL inverters are inherently current-controlled devices, and their behaviour is already governed by their current-control design and existing access standard obligations on active and reactive

[20] VDE FNN Guideline: Grid-forming capabilities (English translation, October 2025)

current injection and prioritisation. A separate requirement for the GFL inverter-based technology is therefore not considered necessary at the MAS level.

The clause requires GFM units that are operating at or above their maximum continuous current to:

- remain compliant with other withstand obligations,
- provide a predictable combination of active and reactive current that is consistent with the total current level,
- maintain stable control through transitions into and out of current limiting, and
- avoid behaviour that degrades system security, system strength or quality of supply.

These requirements are consistent with AEMO's NEM Grid-forming Technology Access Standards Approach Paper, particularly the view that GFM inverter-based technology must remain stable when operating at active current or total current limits. This sets a minimum “do no harm” standard for behaviour under current limitations, recognising that a GFM unit may not operate as a perfect voltage source in these conditions.

In this sense, the clause both:

- relaxes any implied expectation that full, ideal voltage-source performance must be maintained under severe current limitation, and
- provides clear guidance on what is and is not required of the facility in those conditions.

European frameworks, including ENTSO-E guidance and German FNN recommendations, expect GFM units to preserve voltage-source behaviour even when current-limited. At this stage, the SWIS proposal adopts a narrower, more relaxed minimum requirement, focused on stability and on avoiding adverse interactions rather than imposing a whole European-style obligation, while still aligning with the direction of emerging international practice.

4.6.2 Value-add and necessity for the SWIS

This requirement clarifies how GFM inverters are expected to behave once current limits are reached, avoiding both unstable or poorly damped operation and any implied obligation to act as an ideal voltage source under all conditions. It strikes a practical balance, focusing on maintaining stability and not degrading system security within the realistic limits of GFM control. This clarity reduces open-ended negotiation over individual projects and supports consistent compliance assessment for both proponents and system operators.

4.7 Frequency of current injection during contingencies

4.7.1 Rationale

The proposed requirement that active and reactive current injection during faults must have a fundamental frequency component equal to the fundamental frequency of the terminal voltage is intended to prevent significant non-fundamental current components that could destabilise the wider system.

The wording is adopted from IEEE 2800, which formalises the same expectation and has already been adopted as good practice in a reputable international standard. Experience in the NEM and internationally has shown that, under network faults exacerbated by low system strength conditions, inverter controls can produce oscillatory current at sub-synchronous or inter-harmonic frequencies, for example, 5–40 Hz. If not controlled, these components can excite sub-synchronous resonances and control-driven modes in nearby generating units or network elements, degrading damping and, in extreme cases, driving otherwise stable facilities into unstable behaviour.

Requiring injected current to be confined to the fundamental frequency, therefore, acts as an important safeguard against harmful interactions between facilities and the network. For clarity, this requirement does not mean that inverters must always inject current at exactly 50 Hz. It requires current injection to track the actual system fundamental frequency, even when this deviates from nominal, for example, 47–52 Hz during disturbances, and to avoid unintended components at other frequencies. In this way, the clause is compatible with both GFL and GFM control philosophies, while providing assurance that non-fundamental current injections that could destabilise other facilities or the network are avoided.

4.7.2 Value-add and necessity for the SWIS

This requirement provides a clear and practical safeguard against destabilising non-fundamental current injections, using wording that is already well established in IEEE 2800. By aligning closely with a reputable international standard, the SWIS gains a proven, testable benchmark that:

- supports consistent modelling and compliance assessment;
- reduces debate about acceptable behaviour during faults; and
- gives confidence that new IBRs will not introduce harmful low-frequency resonances into the network.

4.8 Fast opposition of voltage magnitude changes

4.8.1 Rationale

Sub-clause A12.9.2.5(a) of the ESM Rules captures a core characteristic of GFM inverter-based technology: the ability to oppose fast changes in voltage magnitude at the connection point.

Recent amendments to the NER clause S5.2.5.5A embed sub-cycle commencement times for positive-sequence reactive current response, with commencement times of 10 ms for the automatic access standard and 40 ms for the minimum access standard. International specifications similarly treat response initiation times below around 20 ms as a defining feature of GFM controls.

The intent of sub-clause A12.9.2.5(a) of the ESM Rules is to adopt the same philosophy for the SWIS by requiring GFM controls to commence opposing voltage magnitude disturbances within a sub-cycle timeframe, rather than framing the requirement in terms of changes in system-wide voltage sensitivity with and without the facility. In other words, the focus is on how quickly the GFM inverter-based technology responds, not on a comparative study of system behaviour.

Concerns about the practicality of assessing sub-cycle behaviour do not require the performance measure itself to be weakened. As noted in the commencement time rationale, sub-cycle response can be demonstrated in standard electromagnetic transient tools using calculation methods that avoid one-cycle RMS or FFT delays. Where collection-grid impedance materially slows the apparent response at the connection point, it remains open – in justified cases – to assess performance at inverter terminals and translate that to connection-point behaviour, rather than rewriting the clause around a system-sensitivity metric.

4.8.2 Value-add and necessity for the SWIS

Fast opposition of voltage magnitude disturbances is widely recognised internationally as a defining attribute of GFM controls. Specifying this behaviour in the SWIS:

- sharpens the distinction between GFL and GFM pathways for connection studies if this behaviour is not met, the project should be treated as GFL for the purposes of access standards and system studies;
- helps ensure that within-cycle voltage support is actually delivered by the GFM inverter-based technology, rather than implicitly relying on synchronous machines;
- supports secure operation in a weak, inverter-dominated system, by ensuring that the GFM inverter-based technology provides the fast voltage-support behaviour that the rest of the system planning and operations will assume.

4.9 Fault ride-through activation threshold

4.9.1 Rationale

For the MAS in the SWIS, the proposed use of 80% and 120% positive-sequence voltage at the connection point as the fault ride-through activation thresholds is intended as a minimum formulation.

The requirement does not mandate that GFM inverters must use a particular internal voltage-activation threshold in their control systems. Instead, it specifies the latest point by which the GFM reactive current response must have commenced, whether or not a discrete threshold is used internally.

These threshold levels are at the low end of existing GFL requirements in the NER and are chosen so that:

- for a well-designed GFM inverter behaving as a voltage source, a sub-cycle response will already have begun by the time the voltage reaches 80% (undervoltage) or 120% (overvoltage); and
- the thresholds provide a transparent and verifiable benchmark for minimum performance, avoiding situations where voltage falls well below 80% (or rises well above 120%) without an appreciable GFM response having commenced.

In effect, the activation thresholds define the latest acceptable trigger point for the required reactive current response at the MAS level, while leaving scope for faster or more sophisticated behaviour to be implemented and recognised under AAS or negotiated standards.

4.9.2 Value-add and necessity for the SWIS

Using 80% and 120% positive-sequence voltage as the activation thresholds:

- provides a consistent trigger for connection studies and performance assessment, so that all GFM projects are evaluated against the same minimum expectation and in a way that is broadly aligned with GFL behaviour;
- reduces the risk that system security continues to rely predominantly on synchronous machines because GFM capabilities are weaker or more variable than assumed; and
- supports predictable and timely voltage support during disturbances in a weak, inverter-dominated SWIS.

4.10 The use of total current during contingencies

4.10.1 Rationale

The proposed standard uses the facility's total current as the reference quantity for fault response in sub-clause A12.9.1.6(a) of the ESM Rules. The intent is to ensure that any short-term over-current capability already designed into GFL and GFM inverter-based facilities is actually available to support the network during faults, *without* requiring any additional current capability beyond the equipment's design ratings.

Under the MAS, active current is not permitted to increase during a fault. In practice, this means constraining the d-axis (active) current so that, for example:

$$i_{d,\text{fault}} \leq i_{d,\text{pre}} \Rightarrow P_{\text{fault}} \leq P_{\text{pre}}$$

while allowing the total current to increase up to the facility's short-term current limit, with the q-axis (reactive) component prioritised for voltage support:

$$I_{\text{tot}} = \sqrt{i_d^2 + i_q^2}$$

Total current directly corresponds to the d- and q-axis components (*Id*, *Iq*), which are the quantities used to define active and reactive current injections, including their positive- and negative-sequence components. Using total current as the reference, therefore, provides a direct and physically meaningful comparison with the facility's actual current capability, without overlooking any part of the current contribution or making assumptions about how current is split between active and reactive components.

4.10.2 Value-add and necessity for the SWIS

Using total current as the fault ride-through reference quantity gives all parties a single, technology-neutral measure of fault support. It does not require any additional current rating or hardware from OEMs; instead, it makes better use of the capabilities that are typically already available in modern inverters.

For proponents and system operators, this approach:

- simplifies connection studies and compliance testing, because the same current metric can be applied to both GFL and GFM inverter-based technology, regardless of the internal control strategy or how active and reactive current, or positive and negative sequence currents, are shared; and
- improves within-fault support in the SWIS at effectively no additional cost, by ensuring that the facility's available short-term current capability is focused on providing reactive support when it is most needed.

4.11 Reactive current sustainment time during contingencies

4.11.1 Rationale

Prior proposed wording for sustainment time was as follows:

- For faults cleared within primary protection clearance times, the sustainment time is equal to the fault duration, during which the magnitude of reactive current injection should not deviate by more than 2 per cent, or as otherwise agreed with the Network Operator and AEMO, relative to the value at the rise time.
- For faults cleared within circuit breaker failure clearance times, the sustainment time is equal to the fault duration, unless otherwise agreed with the Network Operator and AEMO. The maximum permissible reduction in reactive current injection during the sustainment time should be agreed with the Network Operator and AEMO.

To align more closely with the new NER provisions and to reduce unnecessary prescriptions for a MAS, we are also comfortable adopting wording consistent with NER clause S5.2.5.5a(m)(2), for example:

"Subject to paragraph (o), a schedule 5.2 plant, for disturbances caused by a type of fault described in clause S5.2.5.5(k)(2),

(1) ….

(2) must substantially maintain the response required under subparagraph (1) until the end of the disturbance, or until another point agreed with the Network Service Provider and AEMO."

In our view, using "substantially maintain" in a MAS appropriately removes specific numerical thresholds while still signalling that the reactive current response must not drop materially during the disturbance unless explicitly agreed with the Network Operator and AEMO.

4.11.2 Value-add and necessity for the SWIS

This requirement helps ensure that the facility does not reduce its initial reactive current injection to the point that, by the end of the fault, it has largely withdrawn its support or is absorbing reactive current, either of which could destabilise voltage and adversely affect the operation of protection relays[21]. By mirroring the NER "substantially maintain" concept:

- the SWIS obtains a consistent, proven minimum behaviour from inverter-based technology during faults;
- proponents have clear alignment with national practice, reducing the need for bespoke WA-specific tuning; and
- there is flexibility for Western Power and AEMO to agree alternative profiles or tighter requirements where justified by local conditions, without embedding highly prescriptive thresholds in the MAS.

Stakeholders are invited to comment on whether adopting this "substantially maintain" formulation for the MAS is appropriate for the SWIS, and whether any additional guidance or examples would be helpful in interpreting this requirement.

4.12 Damping of power system oscillations

4.12.1 Rationale

In both the NEM and the WEM, synchronous generators are not only expected to avoid creating poorly damped oscillations, but they are also explicitly required to damp power system oscillations. For GFM inverter-based technologies , AEMO's GFM Approach Paper distinguishes between two related concepts: "oscillation-neutral" operation, where GFM controls do not degrade overall damping or cause sustained oscillations, and "oscillation-damping" capability, where GFM controls actively increase damping. This proposal intentionally focuses on this "do-no-harm" obligation for GFM inverter-based technology as a MAS, rather than replicating the synchronous-style obligation to provide active damping. However, this distinction between oscillation-neutral performance as a minimum requirement and active damping as a potential ideal standard may not have been sufficiently clear in the original drafting.

This structure is also consistent with emerging international practice. For example, the European InterOPERA project, which proposes GFM functional requirements for ENTSO-E's HVDC Network Code, identifies positive damping power as one of five core GFM functions, alongside phase-jump and inertial active-power response, and treats it as a mandatory capability for GFM units[22]. Similarly, Great Britain's GFM guidance for inverter-based resources (GBGF-I) requires GFM inverter-based technology to contribute

[21] Etik Energy, Grid-forming and Grid-following Inverter Fault Current Contribution.

[22] InterOPERA consortium, Grid-forming functional requirements for HVDC converter stations and DC-connected power park modules (PPMs) in multi-terminal multi-vendor HVDC systems, Deliverable D2.2, Jan. 2024.

to the damping of power oscillations through an "active damping power" function, with an equivalent damping factor in the range 0.2–5.0, defined by comparison with a second-order reference system[23]. These frameworks illustrate that positive damping of oscillations is increasingly regarded as an intrinsic GFM capability. In the SWIS context, the proposed minimum requirement is that GFM operation must be at least oscillation-neutral, with the potential for active oscillation damping to be considered an ideal access standard following further work.

In relation to the detailed wording of the clause, several concepts rooted in the synchronous era need to be modernised for application to IBRs, so a direct replication of the NER or ESM Rules would not be appropriate, as detailed below:

- **Sub-clause A12.4.2.2(a) of the ESM Rules** refers to one generating system oscillating "against another" and being "adequately damped". This stems from synchronous machine rotor dynamics and classical eigenvalue analysis. It does not translate directly to IBRs, particularly GFM inverter-based technology whose stability behaviour is dominated by their control systems rather than physical swing modes. After making minor adaptations to the NER definition of "adequately controlled", we consider this a more appropriate concept for IBRs than "adequately damped".
- **Sub-clause A12.4.2.2(b) of the ESM Rules** refers to not degrading the damping of "critical modes", a term that originated from a small number of well-defined inter-area modes in synchronous systems. In IBR-dominated systems, oscillations are typically control-driven, may occur at higher frequencies, and often involve numerous local or facility-specific modes rather than a few system-wide "critical" ones. This makes the identification of critical modes inherently subjective and difficult to demonstrate through simulation. For IBRs, continued use of the term "critical modes" is therefore not appropriate, and its removal is warranted, with the performance focus instead on avoiding amplification or triggering of poorly damped oscillations within the relevant frequency range.
- **Sub-clause A12.4.2.2(c) of the ESM Rules** cites hunting of tap-changing transformer control systems, which reflects historical issues for synchronous generators, where slow reactive power response or poor voltage recovery could drive on-load tap changer into unstable behaviour. For IBRs, and especially GFM inverter-based technology, this example is not directly applicable, since they provide fast dynamic voltage support that tends to prevent rather than cause tap-changer hunting. The more relevant risks lie in higher-frequency control-driven instabilities and interactions between multiple inverter controls, which the existing wording does not address. The clause should therefore make clear that instability arising from control interactions within IBRs can affect the SWIS power system as a whole, not only other equipment at the same connection point.

Oscillation frequencies associated with inverter controls can span a much wider range than the 0–4 Hz band typically associated with synchronous generator electromechanical modes. It is therefore necessary to specify a frequency range that is consistent with the bandwidth of the converter control systems to which the requirements will apply. In the absence of sufficient, broad-based evidence from OEMs, we have proposed adopting a typical converter control bandwidth of 300 Hz as the upper limit, consistent with the ranges discussed in AEMO's GFM Approach Paper. However, we consider that a maximum frequency of 100 Hz is appropriate as a minimum access standard.

Within this framework, the minimum expectation for GFM inverter-based technology is to exhibit oscillation-neutral behaviour, aligned with the first aspect of AEMO's NEM Grid-forming Technology Access Standards Approach Paper. That is, GFM inverter-based technology should be designed and tuned so that its operation does not degrade power system damping or cause sustained oscillations across the agreed

[23] National Energy System Operator (NESO), Grid Forming Guidance Note – Issue 3, based on GB Grid Code Issue 6, Revision 33, 11 June 2025 (GBGF-I technical performance requirements).

frequency range, including sub-synchronous, fundamental and super-synchronous frequencies up to the chosen upper limit, and particularly in low system strength conditions or where other IBRs are electrically close. Where GFM inverter-based technology is designed to emulate synchronous generator behaviour, it may also provide active damping of oscillations in a manner that is consistent with, or functionally equivalent to, a PSS. However, active damping of oscillations has not been considered a MAS; following further investigation, it may be regarded as an AAS. In any case, to avoid confusion with the traditional synchronous generator PSS, it is preferable to use terminology such as “PSS-like function” or “oscillation damping function”, and to describe the minimum requirement in terms of “oscillation-neutral performance” rather than implying that all GFM inverter-based technology must include a conventional PSS.

The resulting structure, with oscillation-neutral performance as a minimum requirement and scope for active damping as an ideal standard, reflects the trend in international practice towards requiring GFM resources to contribute positively to damping of control-driven oscillations, while ensuring that the minimum expectations for GFM in the SWIS are practical, technology-neutral and aligned with the system needs of an increasingly inverter-dominated network.

4.12.2 Value-add and necessity for the SWIS

Not degrading the damping of power system oscillations, that is, providing an oscillation-neutral or passive response, is a fundamental characteristic of GFM controls in both Australian and international definitions. Framing the minimum requirement for GFM inverter-based technology in the SWIS around oscillation-neutral performance, rather than imposing a full synchronous-style damping obligation, means that compliant behaviour can be achieved through appropriate design and tuning of existing control functions, without adding material cost. At the same time, ensuring that new IBRs do not excite or amplify control-driven modes reduces the need for additional system strength and damping measures at the network level and helps protect the GFM inverter-based technology itself from adverse interactions with other GFM or GFL inverter-based technology.

While parallels with synchronous generators are often used to justify expectations on the GFM inverter-based technology, the proposed clause deliberately concentrates on a subset of those expectations. Synchronous generators are typically required both not to worsen damping and to provide active damping of low-frequency modes. By contrast, the SWIS minimum focuses on the “do no harm” aspect, that is, oscillation-neutral operation over a clearly defined frequency range, while leaving active oscillation damping as an ideal or enhanced standard. This approach provides a proportionate, technology-appropriate requirement that supports secure operation of an increasingly inverter-dominated SWIS without over-prescribing how GFM controls must be implemented.

4.13 Instability detection mechanism

4.13.1 Rationale

Control interactions and oscillatory instabilities associated with the operation of several IBRs in close proximity are a credible risk rather than an abstract concern. International experience and events in systems with similar characteristics, including parts of the NEM, show that small-signal and sub-synchronous instabilities can emerge abruptly when many GFL inverter-based technologies operate in weak or changing network conditions, or where there are long radial lines and reduced synchronous generation. Technical investigations of these incidents consistently identify mechanisms directly relevant to a future SWIS with very high instantaneous renewable penetration. Poorly damped voltage–reactive power dynamics at the point of connection, interactions between plant control loops and network impedance, and sub-synchronous oscillatory modes have been observed elsewhere and are plausible in Western Australia if not actively managed.

- The NEM's recent work on reforming NER clause S5.2.5.10 provides a helpful reference point for the SWIS. That process was triggered by these kinds of issues and concluded that a generic requirement that a facility "must not operate unstably" is ineffective unless an objective, independent instability-detection mechanism supports it. Without a clear obligation to detect and respond to instability at the point of connection, Western Power and AEMO are forced to rely on post-event treatment, where constraints and disconnection could be options, which are not desired by any parties.
- A key lesson from the NEM and internationally is that relying solely on inverter-internal measurement and firmware-dependent logic is not robust. Built-in telemetry varies across OEMs, is not always time-aligned or consistently accessible, and can change with firmware updates. By contrast, independent devices installed at the point of connection provide a common reference for voltage, current, active and reactive power, and phase angle, and can apply transparent criteria for detecting unstable behaviour. This approach is already common utility practice in jurisdictions that have experienced oscillatory stability issues.
- An explicit instability-detection requirement, tied to point-of-connection measurements, gives proponents a concrete design target and gives all parties involved a consistent, auditable reference for commissioning and event investigations.
- Within this framework, it is appropriate at this stage to focus on GFL inverter-based technology. GFL controls exhibit well-documented susceptibility to interaction under weak-grid conditions, and their contribution to oscillatory modes is readily observable in the voltage–reactive power and active–reactive power behaviour at the point of connection. As recognised in AEMO's NEM Grid-forming Technology Access Standards Approach Paper, further work is needed before detailed instability-detection criteria can be defined for the GFM inverter-based technology. It is therefore proposed that the instability-detection obligation in the SWIS be introduced for GFL inverter-based technology at this stage, with the treatment of GFM technologies to be revisited once their roles and performance obligations are more fully defined.

4.13.2 Value-add and necessity for the SWIS

Against that background, an explicit instability-detection mechanism for GFL IBRs is both necessary and a clear value add for the SWIS. It directly targets converter-driven and sub-synchronous oscillation risks that increase as synchronous generators retire and IBR penetration rises, and does so in a way that is transparent, enforceable, and consistent across technologies. In practical terms, it provides Western Power and AEMO WA with a tool to prevent unstable behaviour from propagating, while giving developers and OEMs a transparent and objective requirement to design to.

The main benefits can be summarised as:

- **Improved system security:** Instability can be detected and managed promptly, before oscillations spread across the network and necessitate wide-area constraints or involuntary disconnections.
- **Objective, auditable compliance:** Stability performance is assessed against transparent measurements at the connection point rather than subjective judgements after the event. This supports consistent commissioning, incident investigation, and any subsequent compliance reviews.
- **Independence from proprietary controls:** Reliance on a standardised point-of-connection device, rather than internal inverter signals, ensures the requirement remains effective despite firmware

updates or changes in vendor control strategies, and reduces the likelihood of GPS conditions being revisited.

- **Reduced risk of blunt operational measures on individual projects:** By detecting and addressing instability at the connection point, reliance on broad, conservative system-wide constraints or curtailment is reduced, supporting more predictable energy output and revenue for individual projects.

5. Transitional arrangements

Western Power proposes the following transitional arrangements for existing facilities and those undertaking the connections process as to when these proposed standards would apply.

5.1 Existing facilities

Facilities with an executed Electricity Transfer Access Contract (**ETAC**) or with an agreed Access Offer in place at the commencement date of the proposed ESM Rules would continue to operate under the technical standards and Registered Generator Performance Standards agreed under the ETAC or Access Offer.

These facilities would then require to be assessed against the new standards at the time that they undertake a **Relevant Generator Modification**, as described in **Sections 3A.13 and 3A.14 of the ESM Rules**.

This approach is broadly consistent with recent NEM practice, where new technical standards primarily apply to new or materially altered projects rather than to existing contracts and offers.

5.2 Access Offer provided but not agreed

Facilities for which Western Power has provided an Access Offer, but for which the Access Offer has not yet been agreed by all parties at the commencement of the proposed ESM Rules would be permitted to operate under the Registered Generator Performance Standards agreed as part of the Access Offer, until such time as they undertake a **Relevant Generator Modification**.

If the Access Offer expires without being agreed by all parties, then the facility would then be required to meet these new standards prior to a new Access Offer being provided.

5.3 New projects

For projects that have not received an Access Offer by the date that the proposed ESM Rules commence, then the new standards would apply in full.