Grid-forming BESS Connections

Fact Sheet

This fact sheet contains information relevant to parties seeking to connect battery energy storage systems (BESS) with grid-forming inverter capabilities within the National Electricity Market (NEM), as of December 2022. For additional context, readers are recommended to also review the white paper on the Application of Advanced Grid-scale Inverters in the NEM which is available on the Australian Energy Market Operator (AEMO) website[1].

This document relates to the connection of standalone BESS[2] under rule 5.3 of the National Electricity Rules (NER)[3], which require the negotiation of access standards under NER 5.3.4A and schedule 5.2. Hybrid connections and/or embedded connections under NER 5.3A may require separate consideration by connection applicants. This document does not account for amendments the 'Integrating energy storage systems into the NEM' rule change will introduce into the NER.[4]

While AEMO has taken reasonable care in preparing this document, the information is necessarily general and is not to be construed as advice. Any investor in the NEM should always seek expert technical and regulatory advice specific to their circumstances.

Context

Grid-forming inverters set their own internal voltage waveform reference and can synchronise with the grid or operate independently of other generation[5]. Grid-forming inverters with a firm energy source behind them may be able to replace many of the capabilities historically provided by synchronous generators as the power system moves toward operation with high penetrations of inverter-based resources (IBR). With focused engineering development, grid-forming BESS may be able to deliver capabilities such as inertia and system strength support to the future power system.

AEMO has prepared this document to provide guidance to grid-forming BESS connection applicants by summarising the approach to connecting these projects under current technical and regulatory frameworks, and to highlight NER clauses that require particular attention and early discussion with the relevant Network Service Provider (NSP).

Connection and registration process

The processes for connecting and registering a grid-forming BESS in the NEM remain the same as for a grid-following BESS. However, grid-forming BESS are a comparatively new technology in the NEM, and

[1] https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/application-of-advanced-grid-scale-inverters-in-the-nem.pdf

[2] This does not preclude other types of applications or connection arrangements for the use of grid-forming inverter technology.

[3] Version 189 at time of publication

[4] https://www.aemc.gov.au/rule-changes/integrating-energy-storage-systems-nem

[5] A more detailed definition of grid-forming can be found in AEMO's "Application of Advanced Grid-scale Inverters in the NEM" white paper.

implementations by original equipment manufacturers (OEM) differ in their approach, available operating modes, and level of configurability. Close engagement with the relevant NSP and AEMO is necessary to facilitate new grid-forming connections.

It is critical to contact the relevant NSP early in the pre-feasibility phase to discuss your proposal prior to consideration of plant and model tuning.

Further information on NEM connection and registration processes is available on AEMO's website[6].

Performance tuning

Well-tuned grid forming inverters have the potential to support the operation of grid-following inverters in their vicinity and contribute positively to the stability of the power system. A grid-forming BESS design that seeks to maximise delivery of power system capabilities such as inertia and system strength must also consider how these capabilities might positively or negatively impact its ability to meet the applicable access standards.

Any grid-forming design should also consider whether the performance tuning of the plant might influence its ability to deliver services to the power system, either under current or future NEM mechanisms. Service delivery is not within the scope of this document[7].

Inertia and system strength are valuable capabilities that can support power system stability, but maximising their provision may not be appropriate or viable at all network locations.

Assessment and access standards

Subject to a number of conditions, BESS connection applicants can negotiate with an NSP (who is advised on some matters by AEMO) on the access standards for their proposed connection to the power system under NER schedule 5.2. For each technical requirement in schedule 5.2, negotiation can occur within a range between an automatic access standard (where a connection cannot be denied access on the basis of that technical requirement) and a minimum access standard (below which a connection must be denied access).

The current technical requirements were not developed with specific consideration of grid-forming inverters. Applicants will need to work closely with the relevant NSP and AEMO to identify ways to optimise the ability of this technology to support the power system within the context of the access standards. This may mean, particularly for NER clauses S5.2.5.5 and S5.2.5.13, that a performance standard other than the automatic access standard could be preferred.

Synchronous vs. asynchronous

Several of the access standards defined in NER Schedule 5.2 differ depending on whether the generating unit is synchronous or asynchronous[8].

Grid-forming BESS are asynchronous generating units, by definition, for the purposes of connection applications.

The assessment process for a grid-forming BESS is therefore the same as for any other asynchronous generator. However, the performance of this

[6] https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/participate-in-the-market/network-connections and https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/participate-in-the-market/registration

[7] For further information on system security framework developments under the NEM2025 program, see: https://aemo.com.au/initiatives/major-programs/nem-reform-implementation-roadmap

[8] Asynchronous generators are often referred to as inverter-based resources or non-synchronous generators. The terms synchronous and asynchronous are used here in line with their definitions in NER chapter 10.

technology differs from other asynchronous generators (such as grid-following inverters) and can in some instances be designed to mimic the behaviour of a synchronous machine. This can have implications for their ability to comply with some NER schedule 5.2 requirements.

Application of NER schedule 5.2 to grid-forming BESS

Applicants seeking to connect a grid-forming BESS must comply with all relevant access standards. Within these standards, close attention should be paid to specific clauses where the control methodologies and behaviour of this technology could lead to a grid-forming inverter performing differently from grid-following inverters that applicants may be more familiar with.

Specifically, AEMO recommends that applicants carefully assess that their proposal meets the requirements of the following clauses:

S5.2.5.4 Generating System Response to Voltage Disturbances

Grid-forming inverters may respond almost instantaneously to voltage disturbances. Near instantaneous response to counteract voltage disturbance is a beneficial characteristic that helps to stabilise the network voltage.

A grid-forming inverter will begin increasing its injection of reactive current at voltages above 90% of connection point normal voltage, and some implementations might exceed the steady-state reactive current values that are consistent with reactive power requirements of NER clause S5.2.5.1.

Applicants should ensure that for operation in the range 90% to 110% of connection point voltage the generating system is able to maintain *continuous uninterrupted operation*[9] for its active power. Overload capability with sufficient time duration to coordinate with transformer tap operation may be used to manage temporary current increases in this voltage range, beyond steady-state values, and to maintain *continuous uninterrupted operation*.

S5.2.5.5 Generating system response to disturbances following contingency events

The assessment of this clause seeks to verify plant is able to remain in continuous uninterrupted operation for a range of contingency events and ensure that the plant does not have a negative impact on the system it is connecting to. A grid-forming inverter opposes the voltage change caused by a fault and opposes a frequency rate of change caused by a supply-demand imbalance. It will also change active power in response to a voltage angle change, which can assist in limiting vector shift and improve stability. Because of these characteristics the grid-forming inverter has the potential to contribute positively to the power system by reducing the impact of contingency events, but inappropriate tuning can also have adverse impacts on the power system. There are often trade-offs between tuning for various characteristics. The performance characteristics of grid-forming inverters will need to be tuned to ensure negative impacts to the system are limited, while maximising the aspects of this technology that are beneficial to the power system.

Tuning for optimal power system performance might require the grid forming inverter to be modelled by the NSP-appropriate wide area model and might be an iterative process.

There are some aspects of the current NER clause S5.2.5.5 wording that are not well targeted to the performance characteristics of grid-forming inverters, including paragraph (g) of the automatic access standard and paragraph (o) in the corresponding minimum access standard which consider reactive current commencement, rise time and settling time.

[9] Within the meaning of the NER.

These provisions are challenging because the reactive current response of grid-forming inverters may not settle to a steady value over the duration of the fault. This may affect rise time as well as settling time. In addition, the rapid reactive current response may change the voltage profile of the fault, affecting the calculated rise time.

Noting that a connection applicant must demonstrate performance that is 'no less onerous' than the minimum access standard, AEMO supports a flexible approach to drafting of generator performance standards for grid-forming BESS in these instances, for these subclauses. For example, AEMO and the NSP could decide not to specify requirements for response durations, on the basis that the system is instead required to commence its response immediately following a change in voltage at the inverter terminals.

To address these issues in the medium term, AEMO has proposed amendments to NER S5.2.5.5 and suggests that applicants review its submission to the 'Efficient reactive current access standards for inverter-based resources' Rule change[10].

S5.2.5.8 Protection of Generating Systems from Power System Disturbances

Grid-forming inverters often have the capability to survive the formation of an electrical island, and potentially sustain the operation of that island in conjunction with other generators and network assets. This capability will be valuable during islanding and system split events involving few or no synchronous machines. It is recommended that, when agreed upon by AEMO and the NSP, grid-forming BESS remain online during these events wherever stable operation for both voltage and frequency can be maintained.

In some locations, such as in radial areas of the distribution network, specific disconnection functionality or trip schemes may still be required to ensure the BESS is disconnected where islanding is unwanted or inappropriate.

S5.2.5.13 Voltage and reactive power control

The objective in tuning the voltage and reactive controls should be to optimise the performance of the power system, within the range of access standard requirements. The proponent should discuss site-specific connection point conditions and tuning objectives and trade-offs with the NSP.

Tuning of generating systems for this clause should consider optimising the performance across the full range of short-circuit levels anticipated for the connection point. For the high end of the range the response to a step change in voltage will be slower but more stable. At the lower end the performance will be faster but less stable. The power system will generally tolerate slower response at high fault levels, but stability could be reduced further for non-credible contingency events, particularly when fault level prior to the contingency event is low. The tuning should therefore prioritise stability of response at low fault levels over speed of response at high fault levels, where there is a trade-off between them.

Tuning should be focussed on the quality of response for power system disturbances. Although in normal power system operating conditions setpoint steps are not important, response to power system disturbances is of critical importance for maintaining power system security.

[10] Available from the Australian Energy Market Commission (AEMC) website: https://www.aemc.gov.au/rule-changes/efficient-reactive-current-access-standards-inverter-based-resources

Related work

The regulatory landscape around grid-forming BESS is rapidly evolving. AEMO strongly recommends that developers and potential applicants maintain awareness and involvement in reform activities relevant to their projects. For example, as of November 2022 significant reform initiatives include:

- AEMC rule change process on **Efficient reactive current access standards for inverter-based resources**[11] (as referenced above)
- Implementation of **efficient management of system strength on the power system rule**[12], by AEMO[13] and NSPs.
- AEMO's **review of NER Schedules 5.2, 5.3 and 5.3** mandated under NER clause 5.2.6A
- Australian Renewable Energy Agency (ARENA)'s **large scale battery storage funding round**[14]
- System security rule changes being progressed by the AEMC, with implementation as part of the NEM2025 program to be led by AEMO and coordinated through the Reform Delivery Committee (encompassing, in particular, the AEMC's rule change process on an **Operational security mechanism**[15]).
- AEMC rule change process on **integrating energy storage systems into the NEM**[16], and subsequent implementation activities by AEMO[17].
- Jurisdictional frameworks relating to **Renewable Energy Zones** (REZs)
- AEMO's **Engineering Framework**[18], which identifies several priority actions relating to grid-forming BESS.

[11] https://www.aemc.gov.au/rule-changes/efficient-reactive-current-access-standards-inverter-based-resources

[12] https://www.aemc.gov.au/rule-changes/efficient-management-system-strength-power-system

[13] https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag

[14] That will provide up to $100 million to accelerate demonstration of advanced inverter capabilities: https://arena.gov.au/funding/large-scale-battery-storage-funding-round

[15] https://www.aemc.gov.au/rule-changes/operational-security-mechanism

[16] https://www.aemc.gov.au/rule-changes/integrating-energy-storage-systems-nem

[17] https://aemo.com.au/initiatives/major-programs/integrating-energy-storage-systems-project

[18] https://aemo.com.au/en/initiatives/major-programs/engineering-framework