November 2025

Unlocking Battery Potential

Battery attributes to minimise total system costs

Please direct report enquiries to:

Connections and Development
Powerlink Queensland
Telephone: +61 7 3860 2111
Email: connections@powerlink.com.au

Acknowledgement of Country

Powerlink acknowledges the Traditional Owners and their custodianship of the lands and waters of Queensland and in particular, the lands on which we operate. We pay our respect to their Ancestors, Elders and knowledge holders and recognise their deep history and ongoing connection to Country.

Introduction

As Queensland's energy landscape shifts toward a new mix of generation, Battery Energy Storage Systems (BESS) are becoming a key technology in the development of an economic power system. Their flexibility lends itself to a broad spectrum of services that benefit both the electricity market and the transmission network—including innovative new service types. The challenge is to deploy commercially viable BESS in ways that maximise value for consumers over the long term. Powerlink has produced this document to outline the specific opportunities it sees to achieve this outcome. Nevertheless, under the National Electricity Market's (NEM) open access provisions, Powerlink does not discriminate between proponents and will facilitate connection of all technically compliant BESS.

In considering the potential value of BESS, it is crucial to consider not only their energy capacity, but also their technical capabilities and network location siting. Many valuable features can be incorporated at modest cost if implemented during initial project development and design, compared to retrofitting later, which is often expensive or infeasible. The regulatory framework, under which Powerlink operates, is based on implementing solutions only as and when they are needed. The onus therefore relies on developers to anticipate the future opportunities which may arise over the life of their assets and weighing this against the cost of preserving the capability to provide these services in the future. Powerlink provides this document to support developers undertaking this evaluation and to spur consideration of the opportunity to evolve the regulatory framework in order to realise efficiencies afforded by the flexible nature of BESS, to the betterment of consumers.

This document reflects Powerlink's perspective as a transmission network service provider committed to minimising total system cost over the long term. It reflects our current understanding based on available information. However, future conditions may change and uncertainties remain. Stakeholders are encouraged to undertake their own analysis and form independent views when considering this information.

This document identifies eight emerging opportunities that Powerlink sees for BESS to support the transmission network, and the broader power system:

1. Locating BESS to minimise network power flow
2. Integrating BESS with Powerlink's WAMPAC (Wide Area Monitoring, Protection, and Control) System
3. Response to system emergencies
4. System Strength
5. System Restart
6. Voltage Regulation
7. Synthetic Inertia
8. Damping.

This document explores each of these opportunities, along with any implications for the BESS design or location. For further context, please refer to materials such as Powerlink's Transmission Annual Planning Report (TAPR) and System Strength Regulatory Investment Test for Transmission (RIT-T).

Powerlink is committed to developing the transmission network in a manner which minimises costs and maximises benefits to Queenslanders. BESS will be a significant component in a future grid, and Powerlink looks forward to working with the wider industry to maximise the value that they can provide, in support of this objective.

1. Locating BESS to minimise network power flow

BESS typically charge during periods of low electricity prices and discharge when prices are high. The impact of this arbitrage behaviour on the transmission network depends on where the BESS is located in relation to other generators and loads, and whether the BESS is standalone or embedded:

- A standalone BESS is a BESS installed as a discrete asset with its own network connection. Standalone BESS generally operate in response to regional price signals. While beneficial to the market, if a standalone BESS is located close to other forms of generation operating at times of high market prices, this can lead to increased power flows and competition for network access. This in turn can potentially give rise to a need for network augmentation. In contrast, locating a standalone BESS near variable load centres generally improves network congestion. When variable load consumption is low, electricity prices are usually low, enabling charging of BESS while upstream congestion is likely to be less. When variable load consumption is high, electricity prices are usually high, enabling discharging of BESS to local loads, limiting upstream congestion. This has the effect of "flattening" the net load profile and reducing the need for network augmentation. Locating a standalone BESS near concentrations of variable load[1], and in proportion with the load's scale, has the potential to avoid future network augmentation, and the associated financial cost and social and economic impacts. Taking this approach to locate a standalone BESS is also likely to minimise the risk of network congestion constraining the BESS' operations, maximising its access to the energy market.

- A BESS can also be embedded within a VRE (Variable Renewable Energy) generator, sharing a common network connection. The BESS may be AC or DC coupled. Since the BESS is located behind the generator's grid connection, the plant's operators must fit the combined output of the storage and generation within the connection's capacity, optimising the design and operation accordingly. This arrangement smooths and shapes the generator's output, with congestion managed behind the meter. This behaviour is of significant benefit to the transmission system, since it also smooths power flow through the downstream transmission network, supporting utilisation and reducing potential augmentation requirements attributable to VRE variability. Embedding BESS within VRE generators is therefore beneficial from a transmission perspective, irrespective of where they are located in Queensland. A benefit to the generator of this approach is that there is no possibility for network congestion between the generator and the storage, which may otherwise occur if the BESS is remote from the generation.

System Benefits of embedding BESS within VRE and locating standalone BESS near concentrations of variable load:

- Defers or reduces future network augmentation, lowering infrastructure costs, community and environmental impacts. This is a significant benefit.
- By reducing network investment needs, it also frees up finite transmission delivery capability to address other needs (e.g. new connections).

[1] **Note:** While areas such as the Surat and Gladstone are key load-centres on Powerlink's network, as they are predominantly industrial, they generally operate with a flat profile, rather than a variable daily profile.

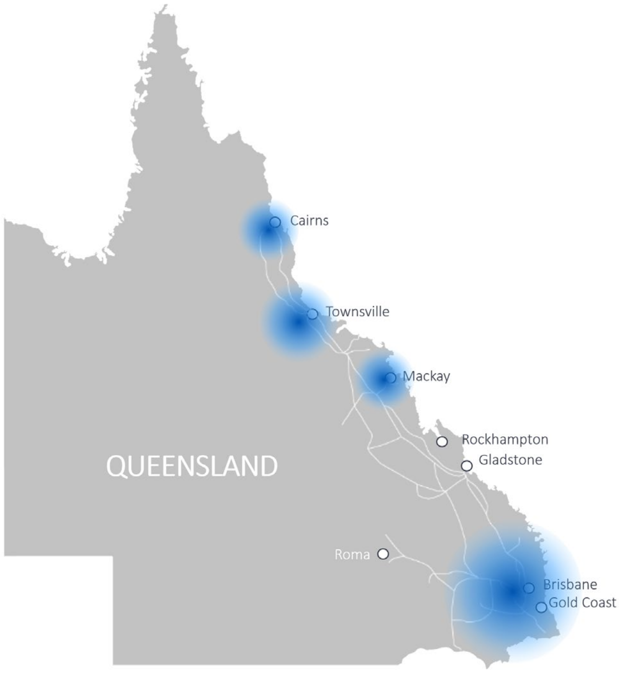

Figure 1: Beneficial locations for stand-alone BESS

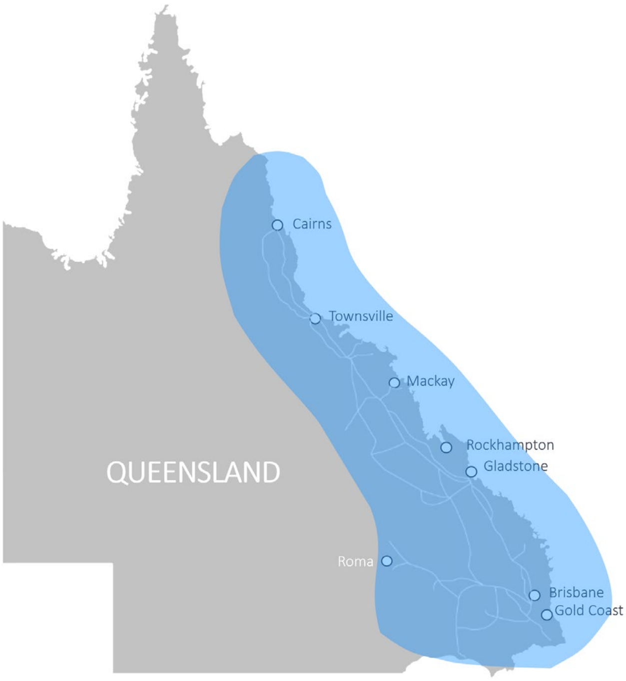

Figure 2: Beneficial locations for BESS embedded within VRE

2. Integrating BESS with Powerlink's WAMPAC System

Network contingencies can lead to a change in the demand/supply balance and cause the power system frequency to fluctuate. Since the power system's frequency can be observed throughout the NEM, BESS can contribute to Frequency Control Ancillary Services (FCAS) by monitoring the system frequency and responding accordingly. However, there are many network contingencies which do not lead to a frequency disturbance, such as the loss of one transmission circuit causing a parallel circuit to overload. BESS can still assist with such situations, but their response needs to be coordinated by control signals supplied by the network operator. Even in situations that cause a frequency disturbance, it is sometimes possible to know the disturbance is going to happen several milliseconds before any frequency disturbance is apparent, which can be used to pre-emptively trigger BESS response. This is valuable because the effectiveness of a response is critically dependent on how rapidly it can be implemented. Power system instability can develop rapidly following a network contingency – the level of response required is closely tied to how quickly it can be implemented.

WAMPAC is a Powerlink platform that can reliably and rapidly detect phenomena on the grid and coordinate the necessary response. The platform is used to implement a range of applications such as Remedial Action Schemes (RAS) and System Integrity Protection Schemes (SIPS). Integrating BESS into WAMPAC enables BESS to rapidly charge or discharge in response to transmission operator signals following a network contingency, supporting grid stability.

Implementing a WAMPAC interface does not affect the operation of the BESS, rather it sets up the BESS to be able to provide network services should it elect to. The opportunity and impact of providing network services on the BESS would vary, case-by-case. Many transmission applications only require a response if a critical network contingency occurs (which is typically rare). In some cases, to provide the required response, the BESS may need to maintain a certain level of charge or a certain amount of headroom. In the future it is possible that network services may be procured on a flexible basis, just as FCAS is today.

System Benefits:

Integrating with WAMPAC is foundational, in that it creates opportunities to utilise BESS for a range of services in the future. This may allow for:

- More cost-effective and timely augmentation of the transmission network, compared to traditional approaches.
- Access to more cost-effective solutions would mean that lower levels of congestion are required to demonstrate net-positive market benefits to relieve the congestion (to satisfy the RIT-T), resulting in lower levels of congestion.
- Augmentation options which can be deployed quickly and with low risk of social-licence issues can help provide confidence to the market that issues which arise can be dealt with in a timely manner.

The ability to procure network support on a flexible basis may give rise to a range of benefits, including:

- The potential to increase windows to implement outages on the network to facilitate timely and cost-effective maintenance and expansion activities.
- Supporting a more agile approach to balancing reliability vs. investment risk management in an increasingly uncertain environment
- Facilitating greater flexibility in network design and infrastructure delivery.

Technical Requirements:

- Implement an interface between the BESS and Powerlink's WAMPAC platform. A draft interface specification has been developed, based on industry standard IEC61850 GOOSE protocol. The interface communicates information about the BESS' availability to Powerlink and receives control signals from Powerlink. Powerlink's design team is available to meet with counterparties to explain and receive feedback on the draft interface specification, with a view to making it as straightforward as possible for counterparties to implement.
- Ensure a consistently fast and reliable response from the battery to control signals**.** The value of network services provided by BESS is critically dependent on how quickly the response can be implemented (measured in milliseconds). Achieving fast responsiveness may be easier at the time of design and implementation. Consistency in this response is also critical.
- The interface, and the BESS' response to signals needs to be verified during the BESS design and commissioning process. There may be occasional ongoing testing to verify that the interface is still functional.

Most Effective Locations:

- Beneficial throughout the network as needs will evolve over the lifespan of each BESS.

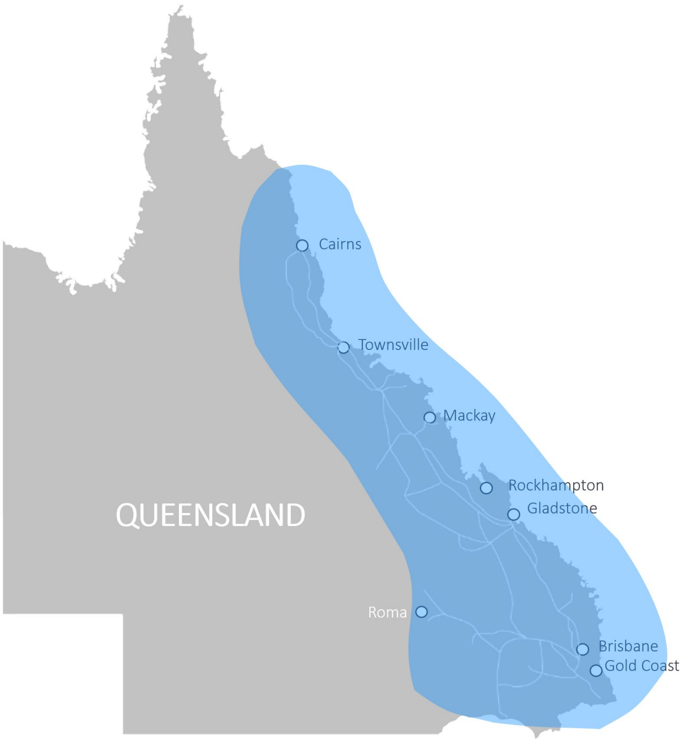

Figure 3: Beneficial locations for integrating BESS with WAMPAC

3. Response to system emergencies

Maintaining power system stability is critical. The power system is said to be "secure" if it is operating in a state where it will continue to be stable following any single "credible" contingency. In the National Electricity Market (NEM), a credible contingency is ordinarily defined as the loss of any single transmission circuit or generator. Occasionally, the concurrent loss of multiple transmission circuits or generators is declared by AEMO to be credible and the usable capacity of the network is reduced to a level where the network will remain stable should this double-contingency event occur. But occasionally multi-contingency events can occur for which the power system has not been secured, resulting in instability. These are referred to as "non-credible" contingencies. The risk of non-credible contingencies is low, but ever-present. To manage this risk, the National Electricity Rules (NER S5.1.8) requires TNSPs to implement emergency control schemes which automatically shed load and generation as required to attempt to arrest any instability before it has an opportunity to cascade into a black system. The rules allow for up to 60% of total system load (NER 4.3.1(k)), to be part of such schemes. Customers are not paid for providing this function.

BESS function as a load while they are charging, and as such, may be included in such schemes. There are also emergency schemes which trip generation. However, rather than tripping a BESS, it would often be preferable to send it a dispatch target. For example, if it were possible for the BESS to rapidly switch from charging to discharging, it could reduce the requirement to shed consumer load.

For BESS that are already integrated into WAMPAC, it would be beneficial to the system if they would consent to following emergency-control signals from WAMPAC, in lieu of being tripped. Such controls would only be within the availability envelope being indicated by the BESS to WAMPAC immediately ahead of the event and would only persist until the power system was re-secured. The incidence of this occurring would be very rare.

System Benefits:

- Enhances system resilience during severe contingencies, reducing the risk of cascading failures and system black events.
- Minimises interruption to end-use consumers.

Technical Requirements:

- Implement and demonstrate fast, reliable WAMPAC interface response to emergency controls.

Most Effective Locations:

- This would be beneficial everywhere. Emergency events are unpredictable, so broad geographic coverage is valuable.

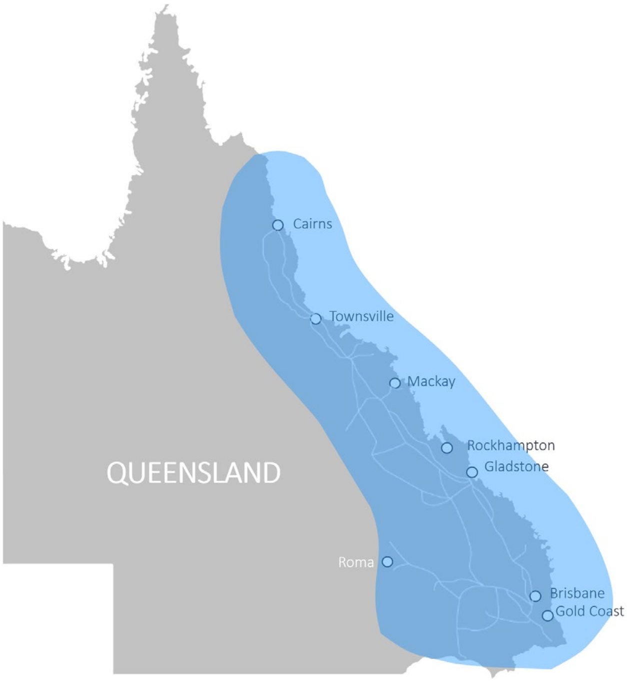

Figure 4: Beneficial locations for BESS providing response to system emergencies

4. System Strength

System strength refers to the ability of the grid to maintain stable voltage and support fault currents. We distinguish the "efficient" level of system strength need to support the operation of grid-following inverter based generation, from the "minimum" level needed to ensure critical grid functions can operate such as system protection and switching voltage control equipment. Presently, grid-forming BESS can contribute to the efficient level of system strength. Investigations are continuing into the extent to which BESS can contribute to the minimum level.

System strength is a locational service, best supplied near areas of need. In the context of Queensland, AEMO has defined five distinct system strength nodes (Ross, Lilyvale, Gin Gin, Western Downs and Greenbank).

System Benefits:

- There is an ongoing need for efficient system strength to support the ongoing uptake of grid-following inverter-based renewable generation. Obtaining this from BESS is likely to be more cost-effective than other common solutions.

Technical Requirements:

- Grid-forming inverter technology with appropriate tuning per the requirements in Powerlink's System Strength RIT-T PACR Appendix J.
- Maximise online availability for continuous contribution.

Most Effective Locations:

- Distribute BESS across the network to avoid concentration of system strength resources in one area. There are already a number of grid-forming BESS located in Southern Queensland.

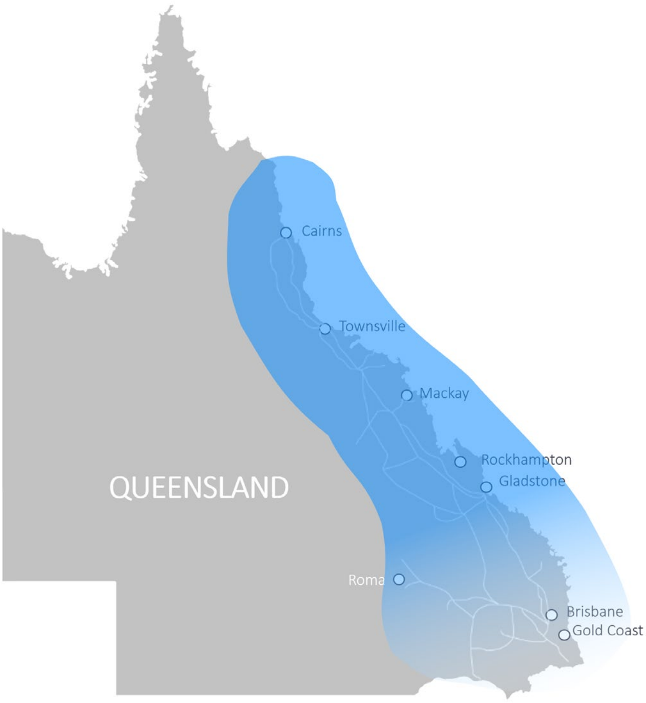

Figure 5: Beneficial locations for BESS providing system strength

5. System Restart

A system black condition occurs when there is a cascading failure of the power system, resulting in a condition where all generation has tripped, all supply is lost, and system voltages drop to zero. Many generators require external power to supply their auxiliary load during startup, or a strong voltage waveform to synchronise with – this is ordinarily supplied from the grid but is unavailable during a black start condition. AEMO contracts with a number of generators to maintain the ability to restart independently of external supply. These generators can re-energise the grid and be used to restart other generators and progressively restore load. However, this relies on network connectivity between the available restart source and the generation needing to be restarted. If a section of the grid became disconnected from available restart sources (e.g. as a result of physical damage to the network), the network would first need to be restored before that section of the grid could be restarted, which would increase the duration and impact of the outage. Hence, there is system value in maximising the number and geographic distribution of potential restart sources.

Grid forming BESS are not dependent on an external voltage reference to operate, and have the potential to support system restart, although this feature is not commonly implemented. Implementation varies between vendors - in some cases it may just involve commissioning the feature, while in others it may require design changes (e.g. implementing backup power supply for the BESS controllers). It may also be necessary to implement an alternative controller tuning to enable the BESS to operate stably during the very weak grid conditions that would be experienced during a restart. There is no ongoing implication of having system restart capability, aside from occasional testing to ensure that it is still functional.

AEMO enters into System Restart Ancillary Service (SRAS) contracts for generators to provide restart capability with high availability. This model may or may not be suitable for BESS, depending on the amount of energy they would need to reserve to support restart if required (which is situation specific). However:

- Even without reserving energy, a BESS operating commercially would still opportunistically have sufficient energy to provide support for much of the time, helping to reduce the overall risk for modest cost. Especially if this feature were implemented routinely on new BESS, it would likely yield a meaningful increase in resilience for the vast-majority of the time. Additionally, provided the BESS was tuned to be able to operate stably during restart, a completely empty BESS could still provide voltage support and controllable load, both of which are valuable services that would improve the reliability and pace of the restart process. The SRAS Rule 2020[2] expanded the definition of SRAS to include restoration support services that support the stable re-energisation of the grid. The capabilities for these restoration support services are defined by AEMO in its SRAS Guideline[3] and include the ability to provide stabilising load and/or to control frequency or voltage.
- Although it would not ordinarily be economic to reserve energy capacity to facilitate guaranteed restart, there may be times when this would be appropriate to provide additional firm restart capability at times of elevated risk (e.g. storm, cyclones, floods, bushfires). Presently the framework to support such procurement is not in place, as there have not been resources capable of providing system restart in this flexible manner. This could change in the future.

[2] aemc.gov.au/rule-changes/system-restart-services-standards-and-testing

[3] https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/system-restart-ancillary-services-guideline

System Benefits:

- Acts as insurance against rare but severe system black events. However unlikely, the economic and social consequences of a system black event could be severe – especially if the restart process was protracted. In an expansive state like Queensland, there is the risk of damage to the network which could leave parts of the grid separated from available restart sources. Having a wider range of potential restart sources throughout the state could improve the reliability and pace of system restart, particularly in regional areas where the risk of being separated from traditional restart sources is greatest.

Technical Requirements:

- Grid-forming capability with system restart functionality enabled and commissioned.
- Control system tuning for stable operation under weak grid conditions.

Most Effective Locations:

- Beneficial throughout the grid.

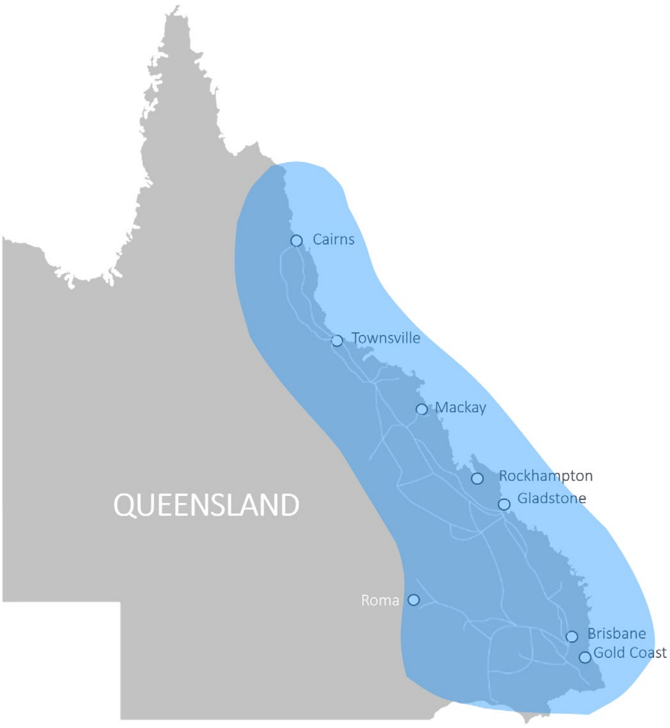

Figure 6: Beneficial locations for BESS providing system restart

6. Voltage Regulation

BESS can regulate the system voltage by injecting or absorbing reactive power through fast inverter controls. In contrast to the 'static' reactive power provided by capacitor banks and reactors, BESS provide 'dynamic' reactive power which is continuously variable in response to system needs up to the agreed performance standard. They can therefore help to mitigate the sudden shocks to system voltage which can occur following contingency events.

Voltage regulation is a localised service. Given Queensland's transmission network topology, voltage stability is often the most limiting factor for network capacity through the backbone. The closure of synchronous generation and flexible operation patterns may increase the need for dynamic reactive power support to maintain existing power transfers. Powerlink's fleet of Static VAr Compensators (SVCs), which are used to provide dynamic reactive power and damping (refer to section 8), require periodic investment which could be offset by BESS.

The National Electricity Rules (NER 5.2.5.1) specify the voltage performance that generators must meet. This includes an 'automatic' access standard that always satisfies the requirement, and the 'minimum' standard that can be negotiated down to. Many developers seek connections below the automatic access standard, but this limits the BESS' capacity to support network voltages.

System Benefits:

- Enhances voltage stability, supporting network capacity.
- Potentially avoids investment in SVC replacements.

Technical Requirements:

- Designing for reactive power range to meet the NER 5.2.5.1 automatic access standard.
- Maximise online availability for continuous contribution.

Most Effective Locations:

- This feature is beneficial throughout the network, as dynamic voltage issues will arise over time.
- There is benefit in the geographical diversity of BESS, to distribute the voltage regulation effect.
- Upcoming voltage-related investments that could potentially be avoided are detailed in Powerlink's TAPR.

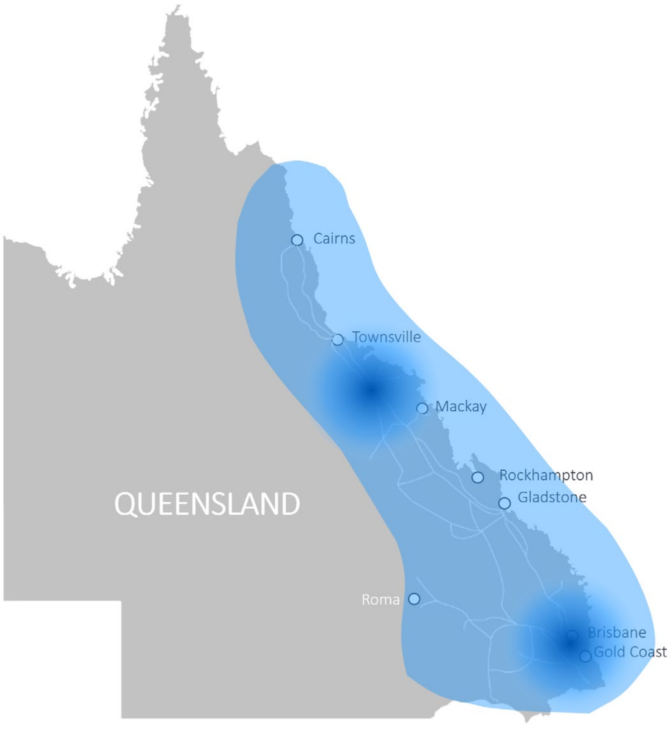

Figure 7: Beneficial locations for BESS providing voltage regulation

7. Synthetic Inertia

Synthetic inertia is the ability of grid-forming BESS to rapidly inject or absorb power in response to frequency changes, mimicking the natural inertial response of synchronous machines. It is a continuous function that the BESS provides, based on how its control system has been tuned, provided whenever this BESS is online. This is distinct from Frequency Control Ancillary Service (FCAS) which involves the BESS controls providing additional response when enabled.

Historically inertia has been provided by synchronous generators. As these retire or operate flexibly, BESS can help replace lost inertia. Most grid-forming BESS currently provide low inertia due to lack of market value, but tuning for higher inertia is generally beneficial.

System Benefits:

- Offsets the need for inertia from other sources.
- Supports system stability as synchronous generation declines.

Technical Requirements:

- Control system tuning for higher inertial response.
- Maximise online availability for continuous contribution.

Most Effective Locations:

- Beneficial everywhere, especially along the strong transmission backbone.

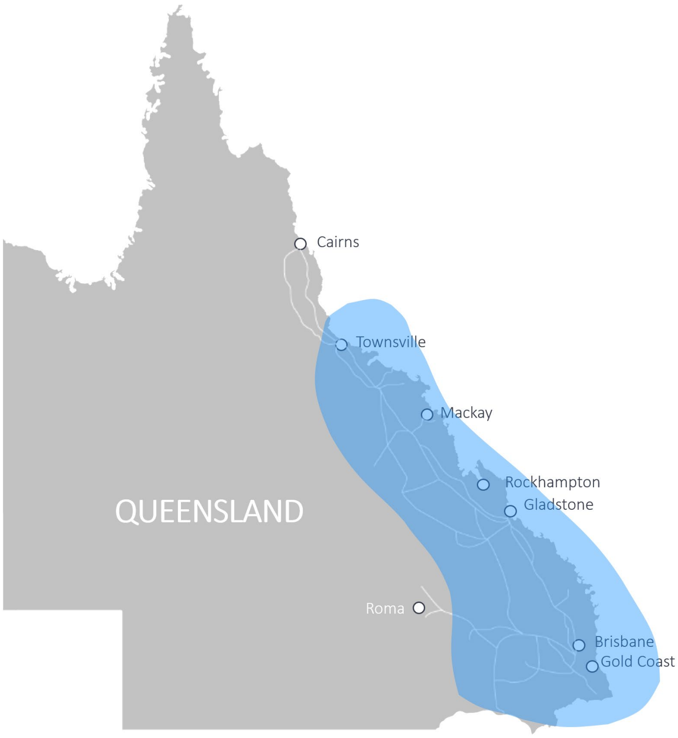

Figure 8: Beneficial locations for BESS providing synthetic inertia

8. Damping

Electromechanical inter-area system oscillations occur when synchronous machines swing against each other following events like faults, sudden load changes, or switching operations. Undamped or poorly damped oscillations are a form of power system instability, and if unchecked, these oscillations can grow and lead to equipment damage and the cascading failure of the power system. Damping mechanisms counteract these oscillations, causing them to diminish over time and returning the power system to a stable operating condition.

The rules require that all potential power system oscillations are effectively damped. Many synchronous generators in the NEM are fitted with Power System Stabilisers (PSS) to modulate the generator's excitation systems to produce a torque that counteracts any rotor angle oscillations. Additionally, many of Powerlink's SVCs are fitted with Power Oscillation Dampers (POD) to modulate the power system voltage to affect the load magnitude in a manner which resists Queensland to New South Wales mode oscillations.

Similar to voltage regulation and system strength, damping is a service that the BESS could provide whenever it is online.

System Benefits:

- Improves power system stability and resilience.
- Cost-effective mechanism for meeting regulatory damping requirements.

Technical Requirements:

- Many BESS natively support damping of inter-area modes – if not, a POD function needs to be implemented.
- Tuning to support system damping. The damping contribution from a BESS depends on how it is tuned. Presently, most BESS pursue a tuning that will avoid them exacerbating any power system oscillations, but not necessarily to support general power system damping. Powerlink can provide situation-specific advice.
- Maximise online availability for continuous contribution.

Most Effective Locations:

- Beneficial everywhere, especially near synchronous generators and synchronous condensers and along the main transmission corridor where it is most effective to damp the inter-area modes of oscillation.

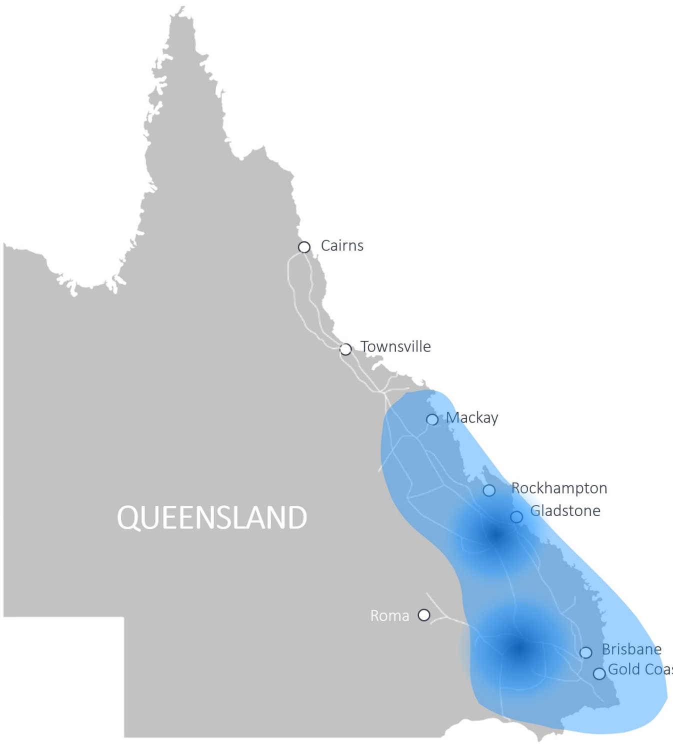

Figure 9: Beneficial locations for BESS providing damping

Summary

A summary of the functions with their technical attributes is provided below. Standalone BESS are best located near concentrations of variable load, but all of the opportunities are generally beneficial throughout the grid. And for grid-forming BESS, many of the opportunities can be realised by integration with WAMPAC panel and intentional tuning.

Opportunity	Technical requirements	Location
Locating BESS to minimise network power flows	N/A	BESS embedded within variable generation is beneficial everywhere Stand alone BESS are best located near concentrations of variable load
WAMPAC integration	• Implement an interface between the BESS and Powerlink's WAMPAC platform. • Ensure a consistently fast and reliable response from the battery to control signals. • The interface, and the BESS' response to signals needs to be verified during the BESS commissioning process	Beneficial everywhere
Leveraging WAMPAC interface to provide response to system emergencies	• Implement and demonstrate fast, reliable WAMPAC interface response to emergency controls.	Beneficial everywhere
System strength	• Grid-forming inverter technology with appropriate tuning per the requirements in Powerlink's System Strength RIT-T PACR Appendix J. • Maximise online availability for continuous contribution.	Beneficial everywhere, but especially in areas away from other grid forming batteries
System restart	• Grid-forming capability with system restart functionality enabled and commissioned.	Beneficial everywhere

	• Control system tuning for stable operation under weak grid conditions.	
Voltage regulation	• Designing for reactive power range to meet the NER 5.2.5.1 automatic access standard. • Maximise online availability for continuous contribution.	Beneficial everywhere, but especially at Greenbank and Strathmore, with upcoming voltage-related investments. Helpful if BESS can spread out.
Synthetic inertia	• Control system tuning for higher inertial response. • Maximise online availability for continuous contribution.	Generally beneficial – especially along the strong transmission backbone.
Damping	• Many BESS natively support damping of inter-area modes – if not, a POD function needs to be implemented. • Tuning to support system damping. • Maximise online availability for continuous contribution.	Beneficial everywhere, especially near synchronous generators and synchronous condensers and along the main transmission corridor where it is most effective to damp the inter-area modes of oscillation.

Conclusion

Powerlink is committed to developing the transmission network in a manner which minimises costs and maximises benefits to Queenslanders.

BESS are fast becoming a key technology in the power grid, and this report identifies a number of specific opportunities for BESS to provide additional benefit to Queensland's transmission system, as well as potential future revenue streams their operators. Powerlink looks forward to working with the wider industry to help realise these opportunities.

Powerlink will continue to monitor developments in BESS technology and the evolving context to identify any further opportunities that arise.

Contact us

Registered office	33 Harold St Virginia Queensland 4014 ABN 82 078 849 233
Postal address	PO Box 1193 Virginia Queensland 4014
Telephone	+61 7 3860 2111 (during business hours)
Email	connections@powerlink.com.au
Website	powerlink.com.au
Social	