GFM in Australia

ESIG - Benefits of GFM BESS Task Force

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02 August 2024

Content

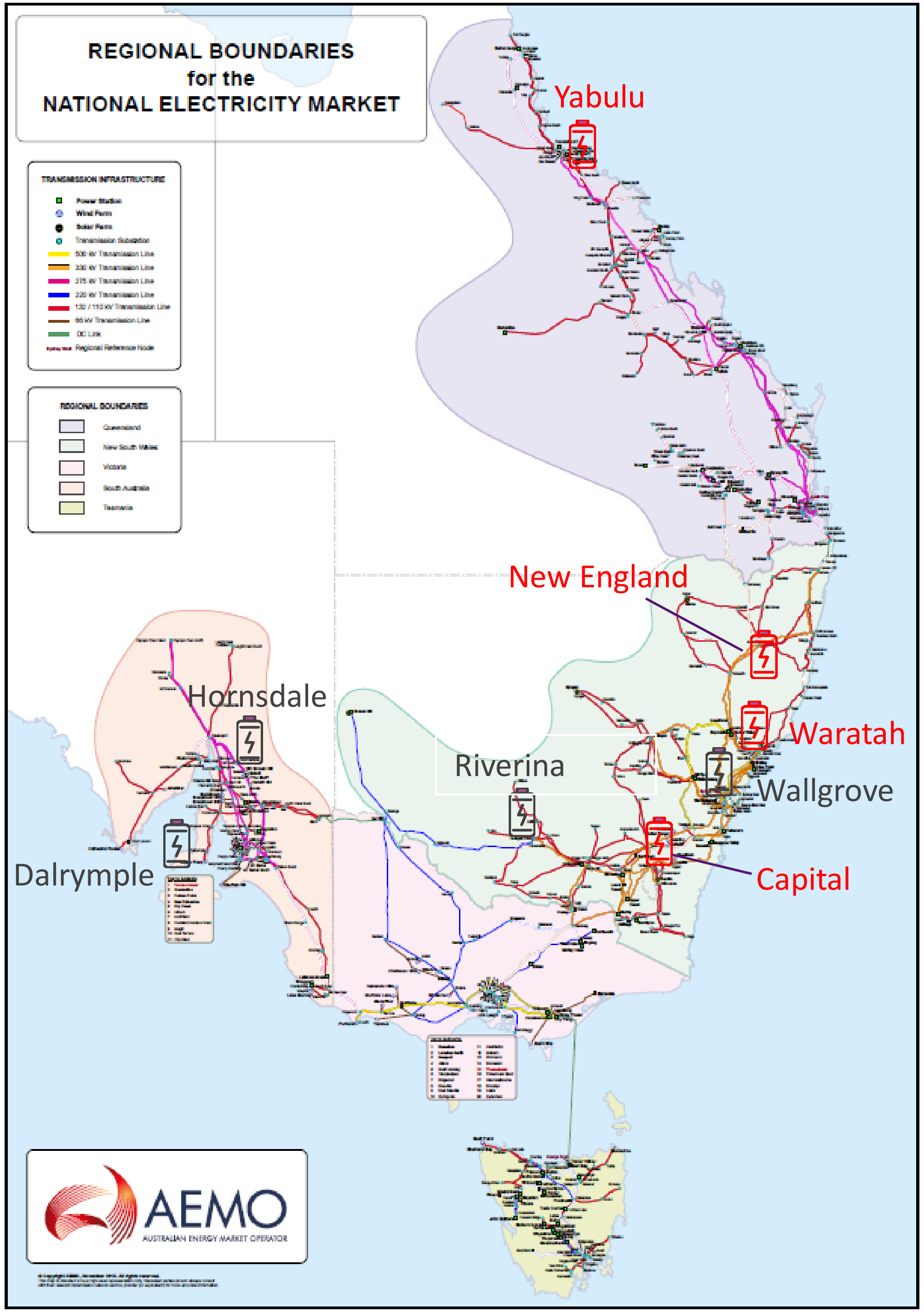
GFM landscape

Field experiences / observations

Modelling to quantify synthetic inertia

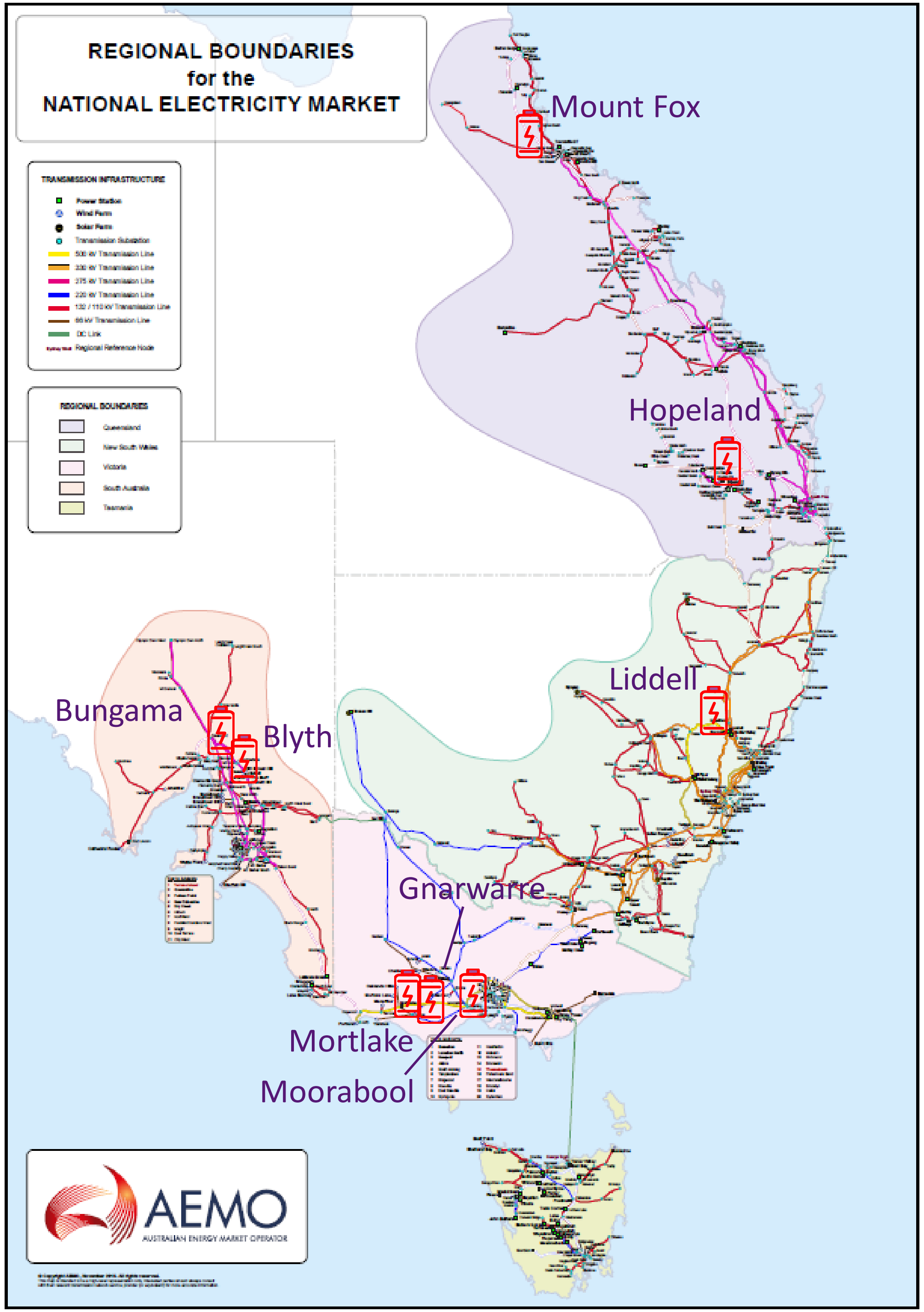
Grid-forming Batteries

- In operation
  - Dalrymple BESS - 30 MW / 8 MWh (SA)
  - Hornsdale Power Reserve (aka Tesla Battery of South Australia) – 150 MW / 193.5 MWh (SA)
  - Wallgrove - 50 MW / 75 MWh (NSW)
  - Riverina/Darlington Point – 150 MW / 300 MWh (NSW)
- 'Anticipated' in the near future
  - Approx 1.2 GW of BESS (excluding ARENA funded GFM BESS)



ARENA funded GFM batteries

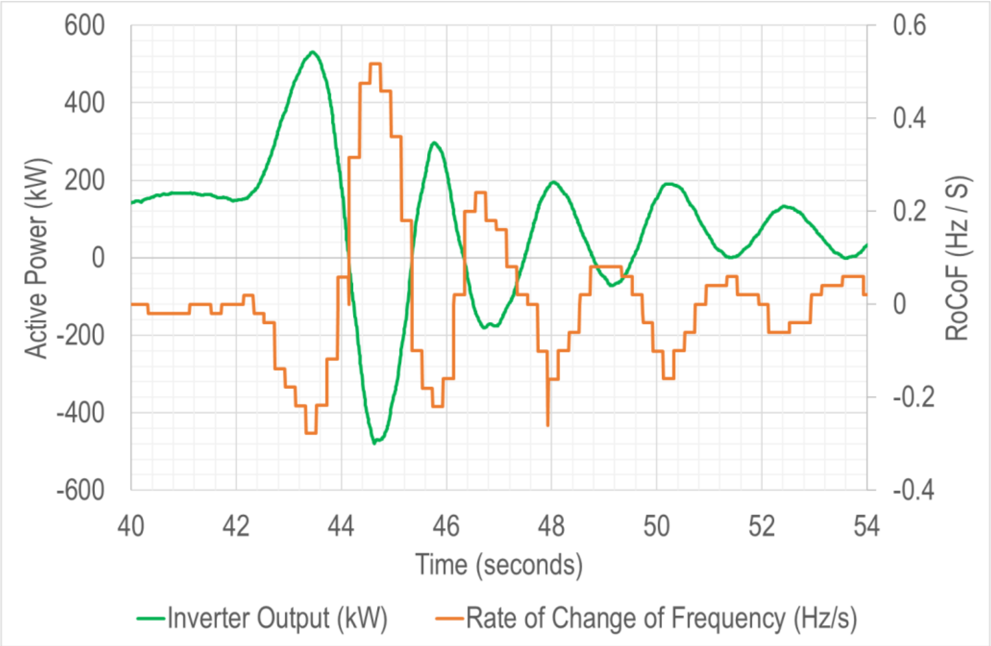
Developer	Capacity	Location	New/Retrofit
AGL	250 MW / 500 MWh	Liddell, New South Wales	New
FRV	250 MW / 550 MWh	Gnarwarre, Victoria	New
Neoen	300 MW / 450 MWh	Moorabool, Victoria	Retrofit
Neoen	200 MW / 400 MWh	Hopeland, Queensland	New
Neoen	200 MW / 400 MWh	Blyth, South Australia	New
Origin	300 MW / 900 MWh	Mortlake, Victoria	New
Risen	200 MW / 400 MWh	Bungama, South Australia	New
TagEnergy	300 MW / 600 MWh	Mount Fox Queensland	New
Total	2.0 GW / 4.2 GWh	NEM, Australia	



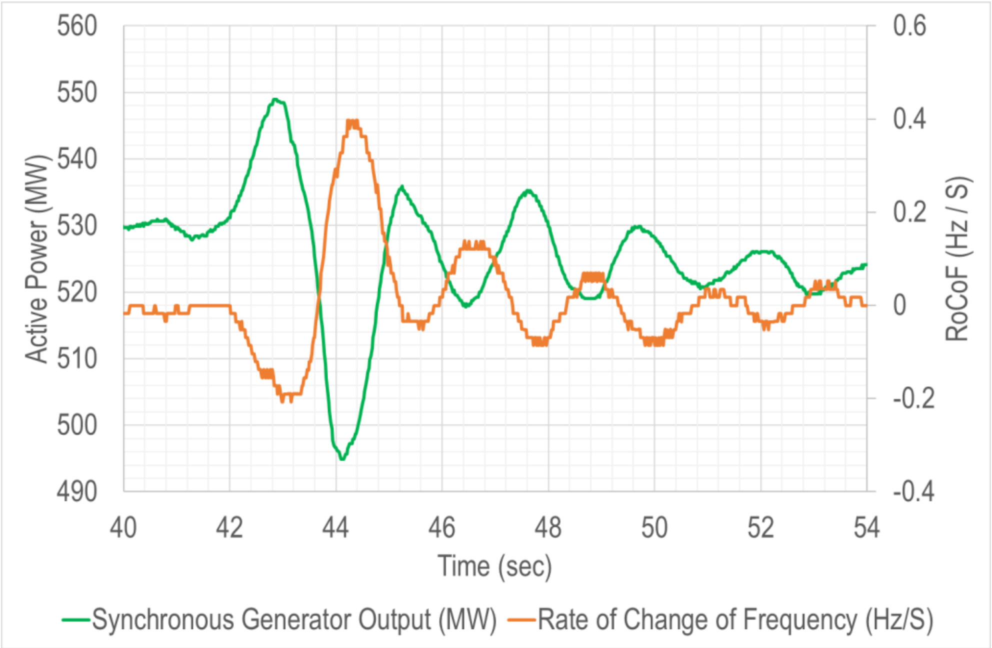
Source: https://arena.gov.au/news/arena-backs-eight-grid-scale-batteries-worth-2-7-billion/

Field experience

Synthetic inertial response



Grid-forming Inverter

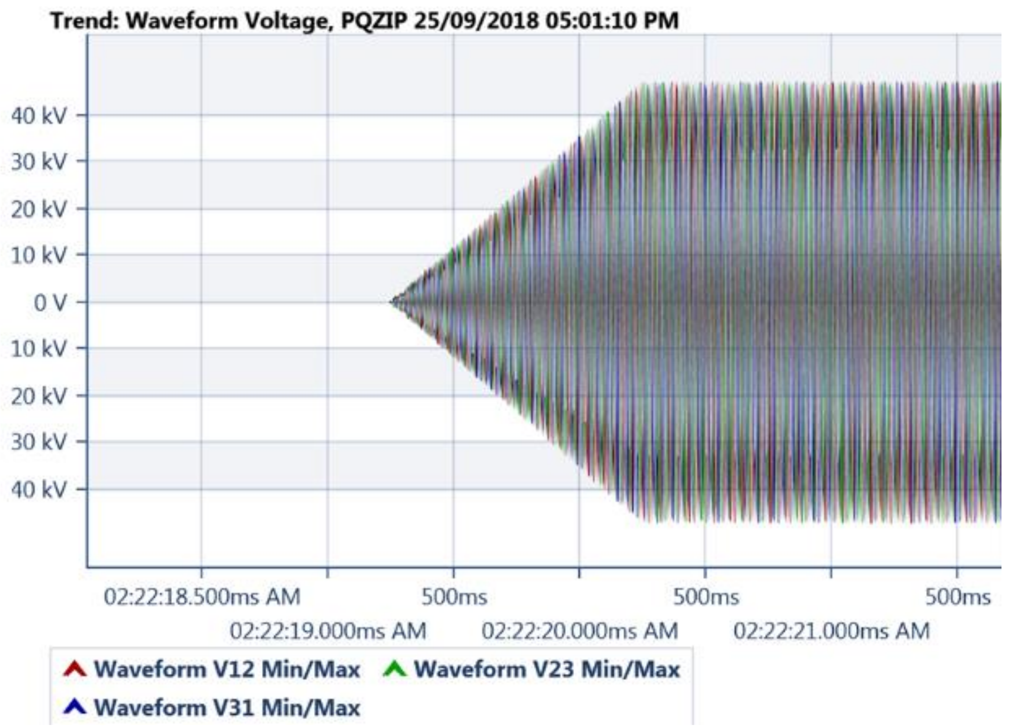


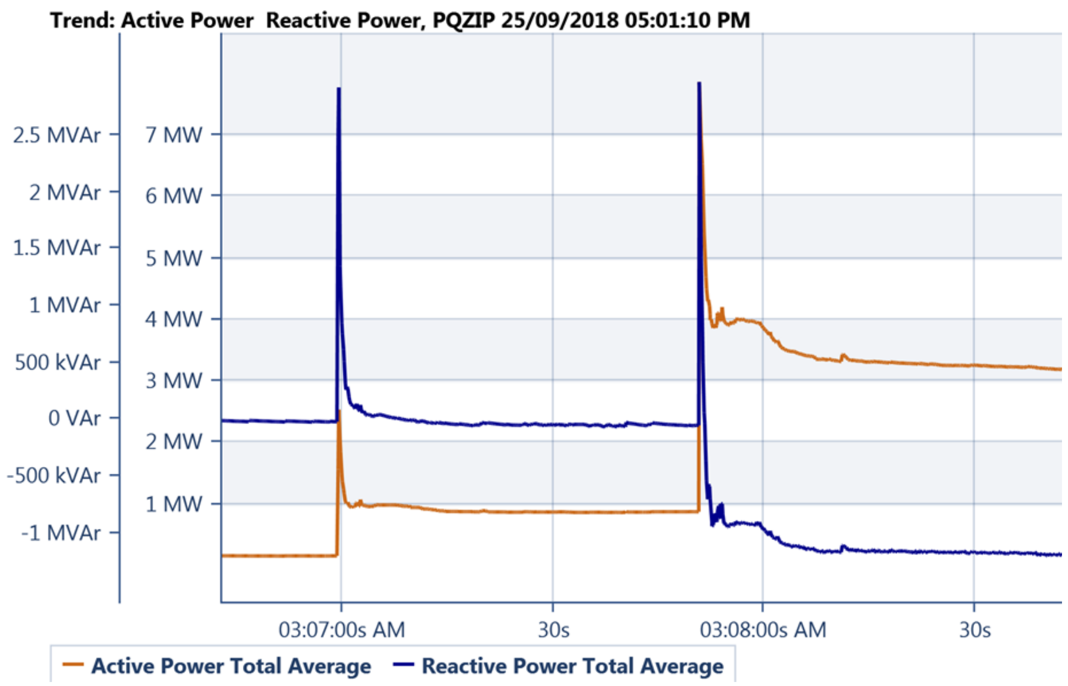
Synchronous Generator

https://www.esig.energy/australian-landscape-of-grid-forming-batteries/

Black start

- Soft energisation
- Load pick up

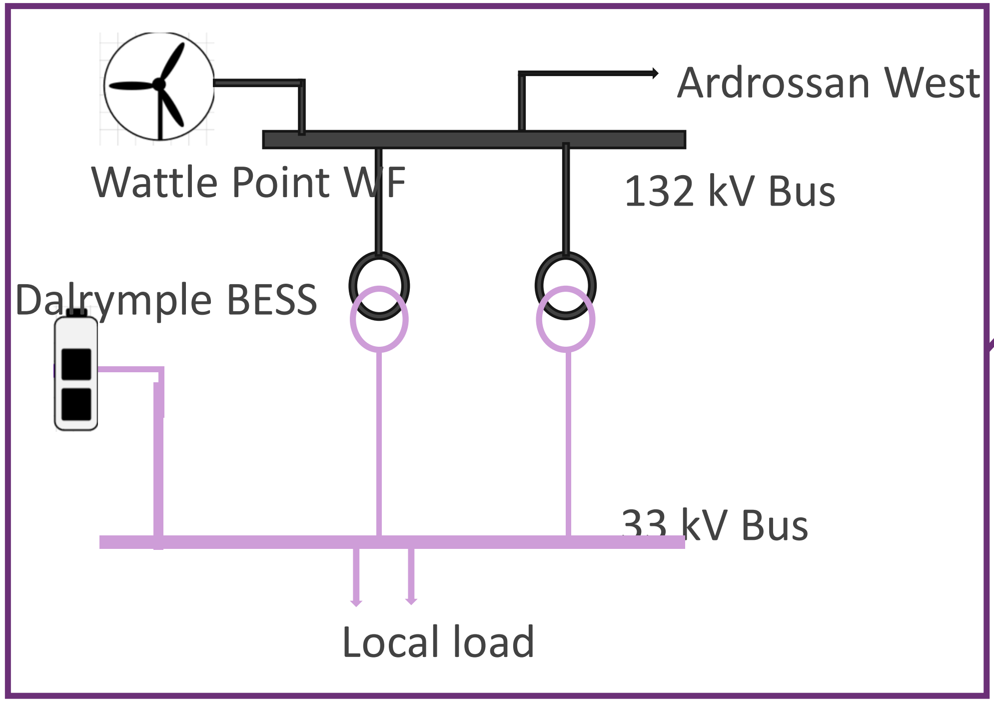


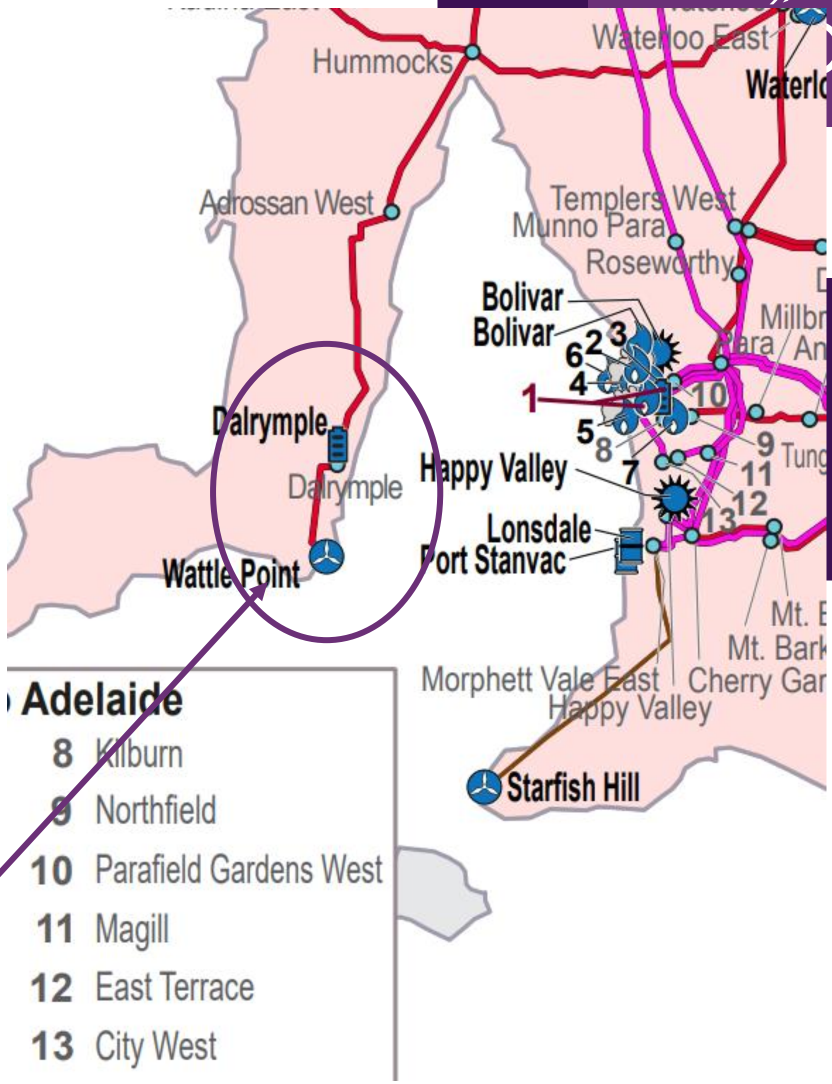


https://www.electranet.com.au/electranets-battery-storage-project/

Islanding

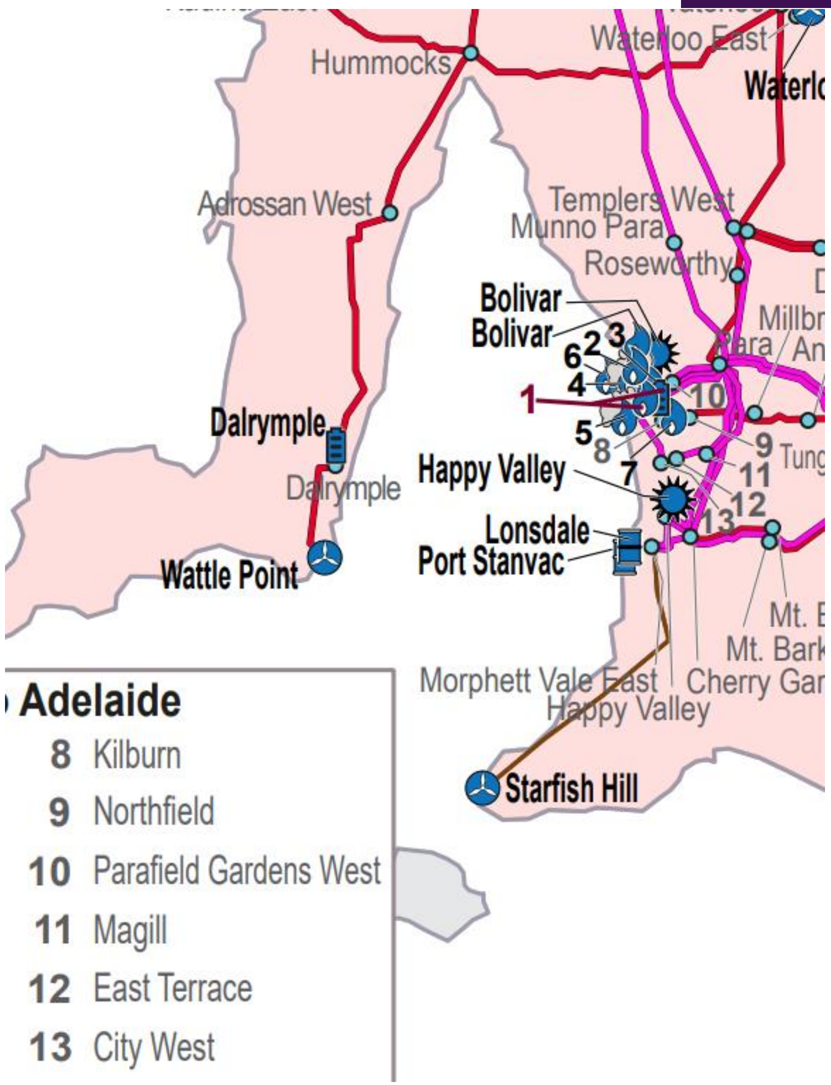
- Surviving loss of the last synchronous generator?
- 132 kV radial connection to Ardrossan West / Hummocks
- Very low SCR
- Interstrip scheme: Trip of Dalrymple – Ardrossan West line triggers the scheme to island BESS + Wind Farm + load
- 30 MW GFM BESS
- 91 MW WF
- ~3MW of load





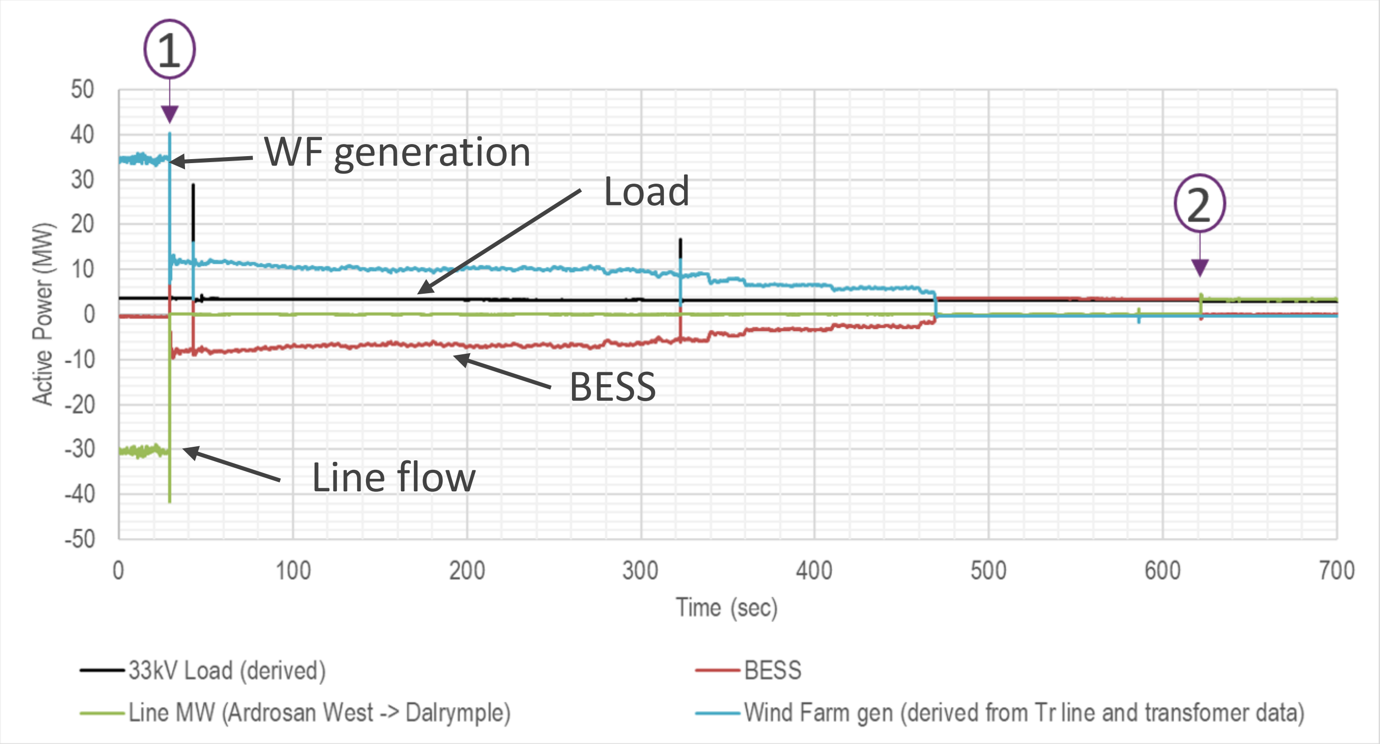
Islanding

- Upstream line trip
  - On four occasions in a single day
  - Resulted in an islanded operation of GFM BESS, WF and local load
- Two ~10 min island operation
- Two ~5min island operation



Event 1

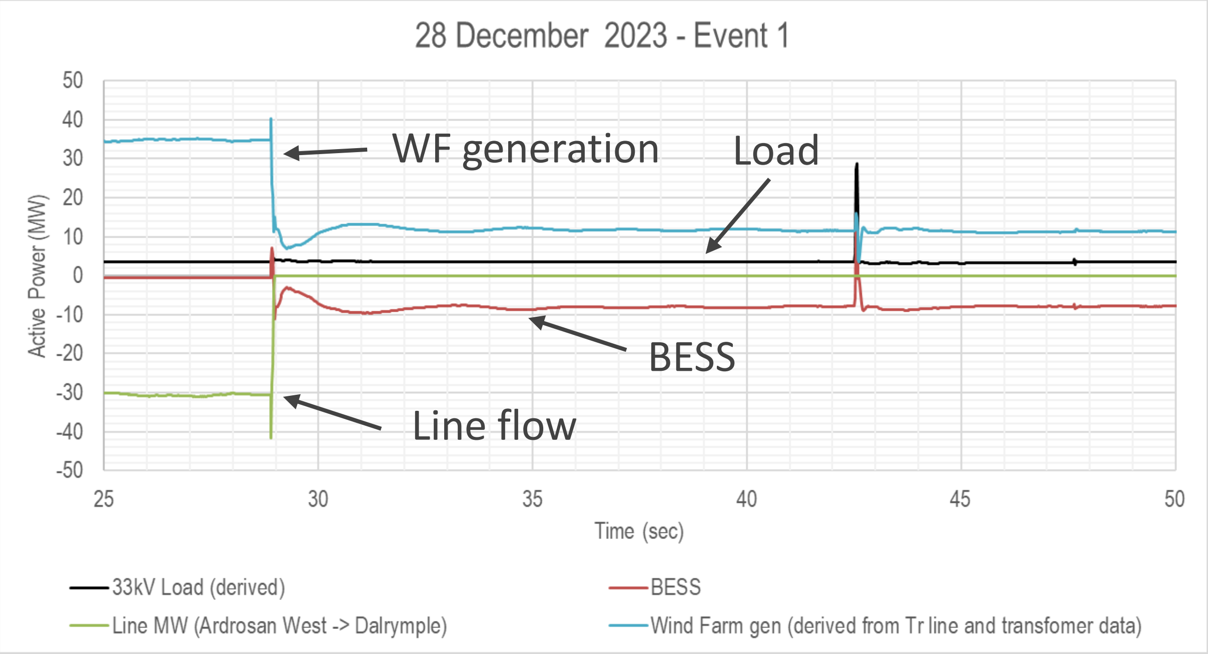
	Pre-event	Post-event
Upstream transmission line	~30 MW (export)	0 MW
Wind Farm	~33 MW	~13 MW
BESS	~0 MW	~10 MW (charging)
Local load	~3 MW	~3 MW



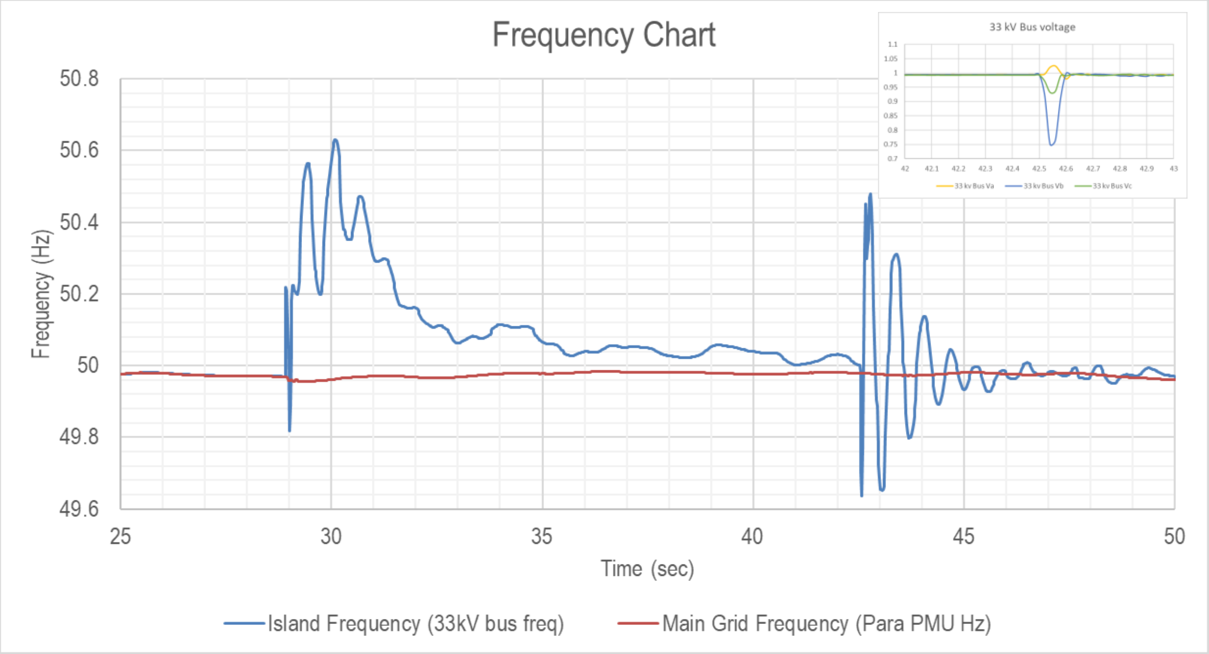
① Formation of an island ② Resynchronization

High resolution data provided by ElectraNet

Event 1

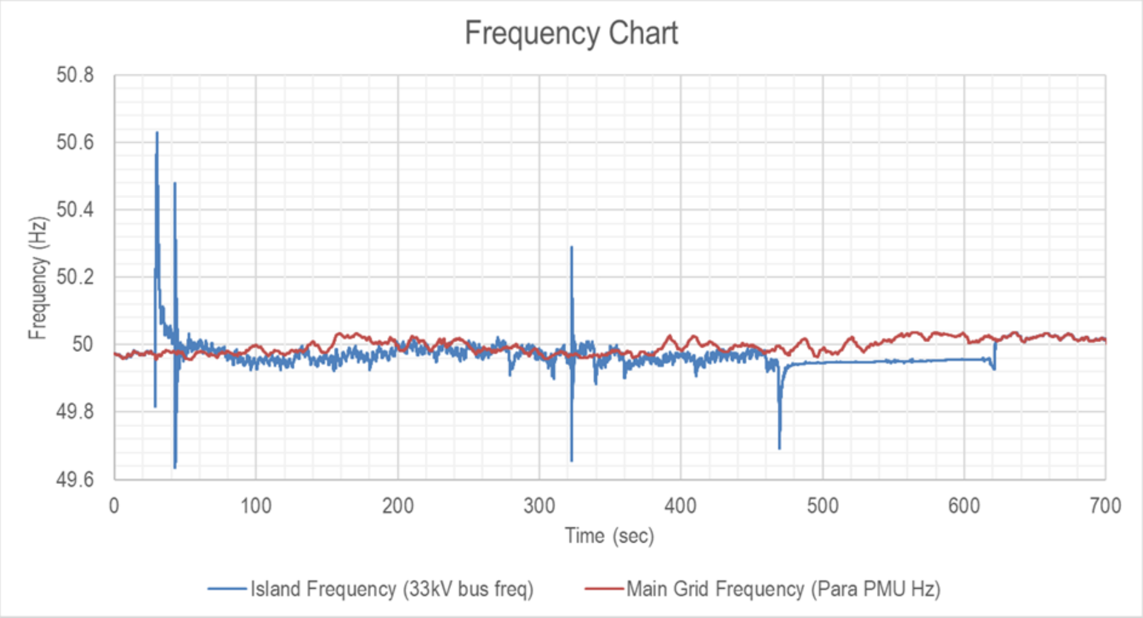


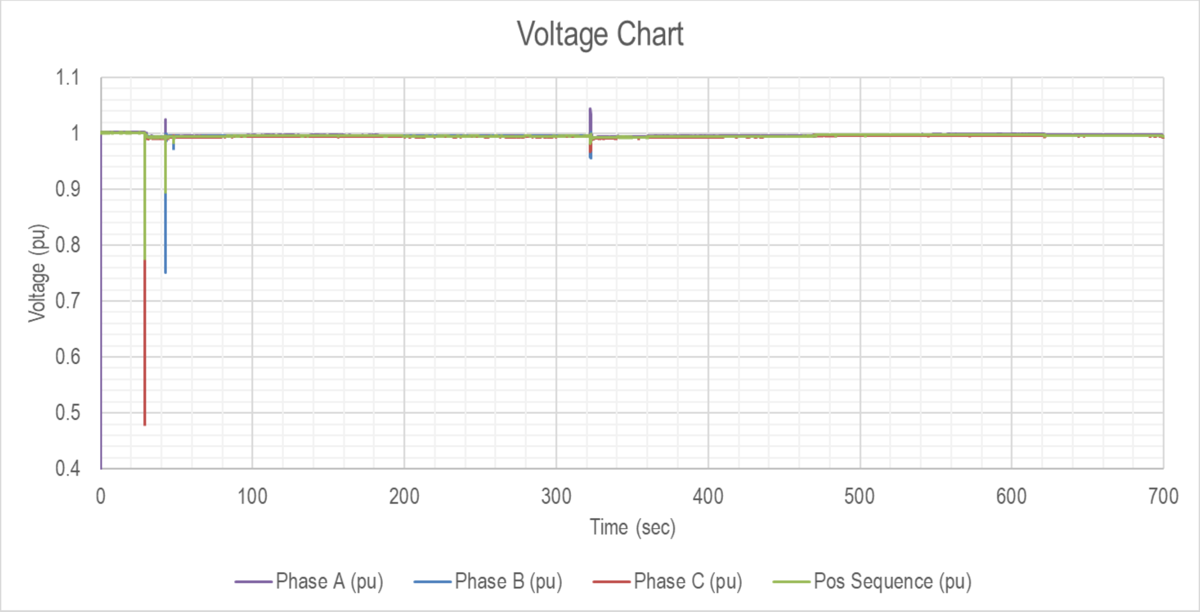
28 December 2023 - Event 1
WF generation
Load
BESS
Line flow
Active Power (MW)
50
40
30
20
10
0
-10
-20
-30
-40
-50
25
30
35
40
45
50
Time (sec)
33kV Load (derived)
BESS
Line MW (Ardrosan West -> Dalrymple)
Wind Farm gen (derived from Tr line and transfomer data)



Frequency Chart
33 kV Bus voltage
Frequency (Hz)
50.8
50.6
50.4
50.2
50
49.8
49.6
25
30
35
40
45
50
Time (sec)
Island Frequency (33kV bus freq)
Main Grid Frequency (Para PMU Hz)

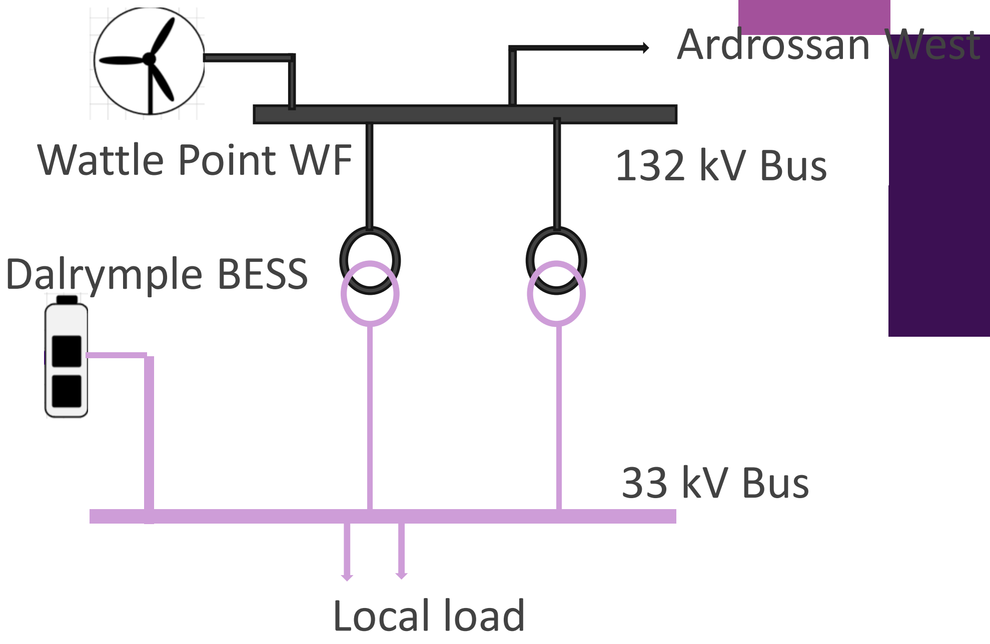
Event 1 – Voltage and Frequency



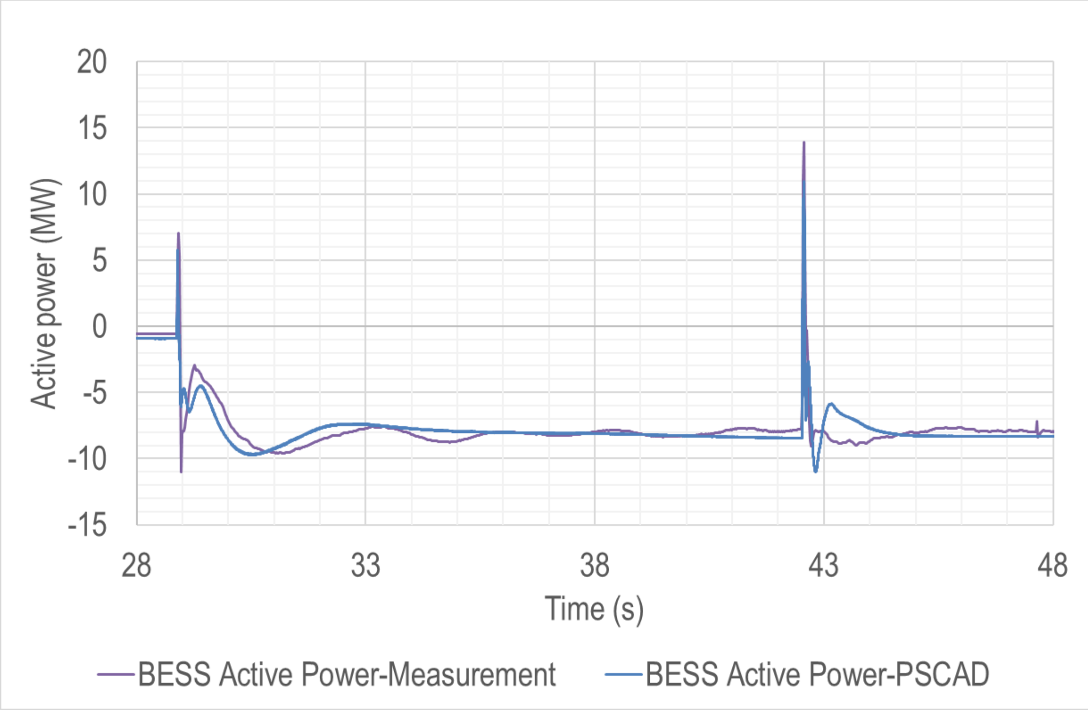


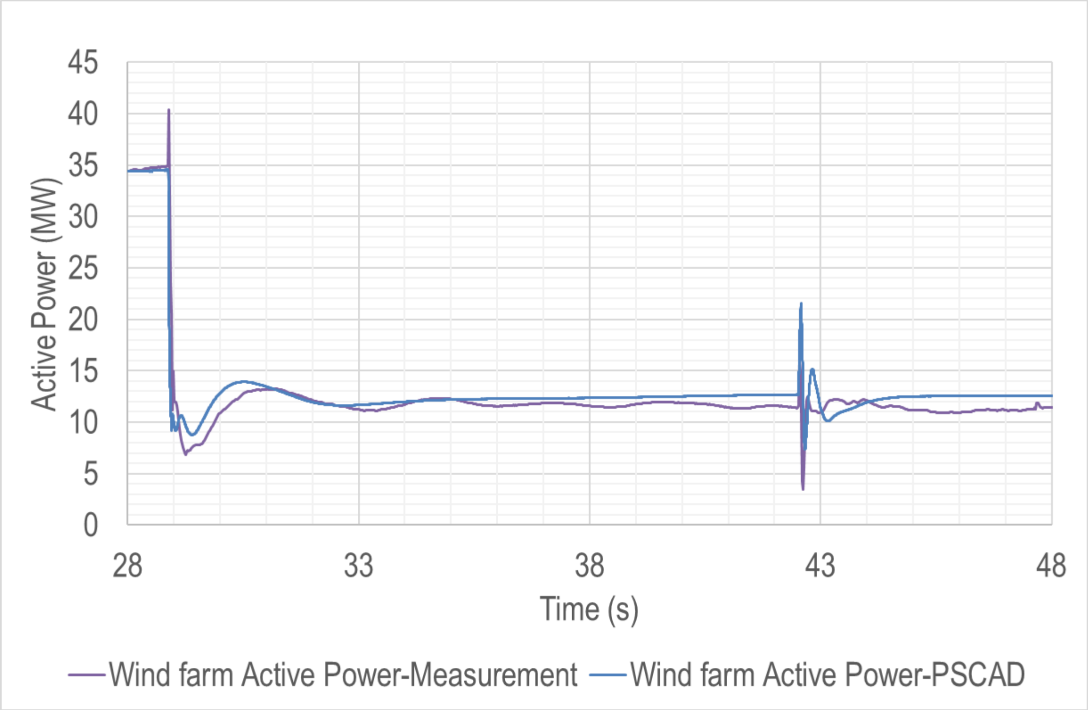
Model validation

- EMT model setup to include the island power system, including:
  - Wattle Point WF
  - Dalrymple BESS
  - 2 x 132/33kV transformer
  - Local load at 33kV Dalrymple bus (standard voltage-dependent load model)
  - Voltage source connected at Dalrymple 132kV bus
- Simulated event
  - A fault at Dalrymple bus 132kV (fault type and depth to match the measurement)
  - Disconnect the voltage source to island the Dalrymple substation
- Some unknowns (yet)
  - Exact composition of the load and its voltage and frequency dependency
  - Frequency measurement (filters and algorithm used by meters)

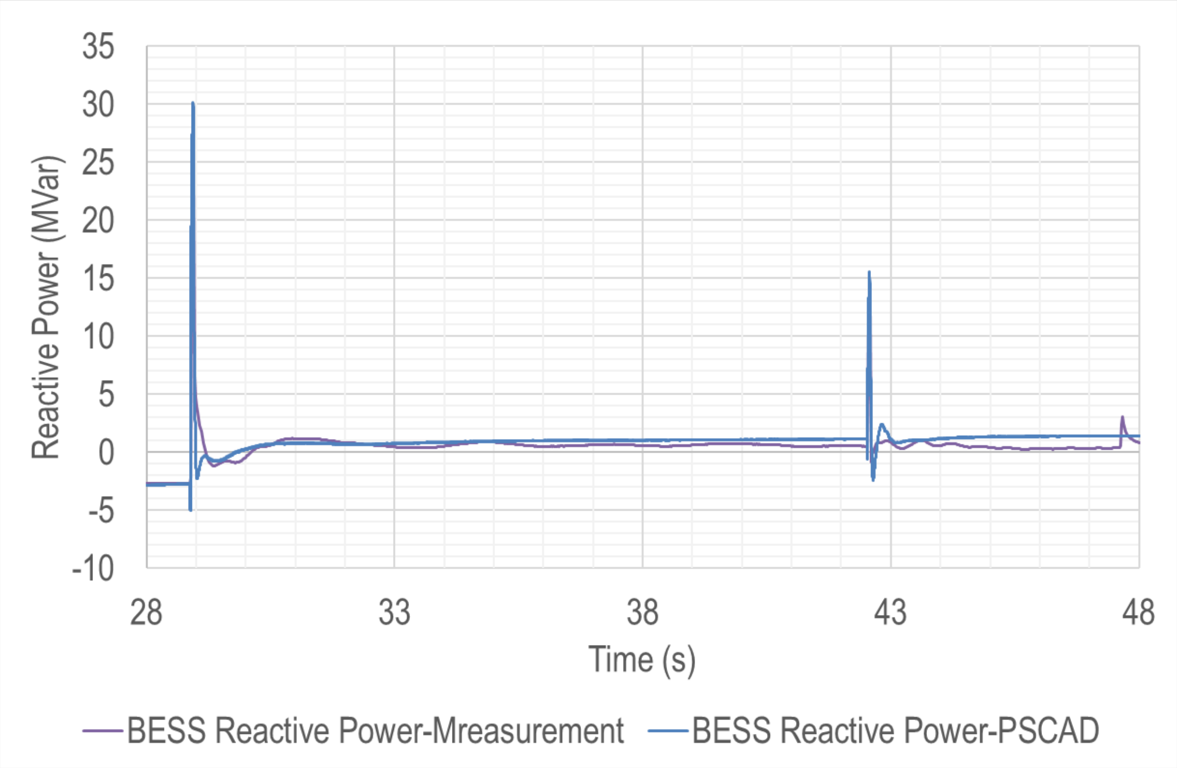


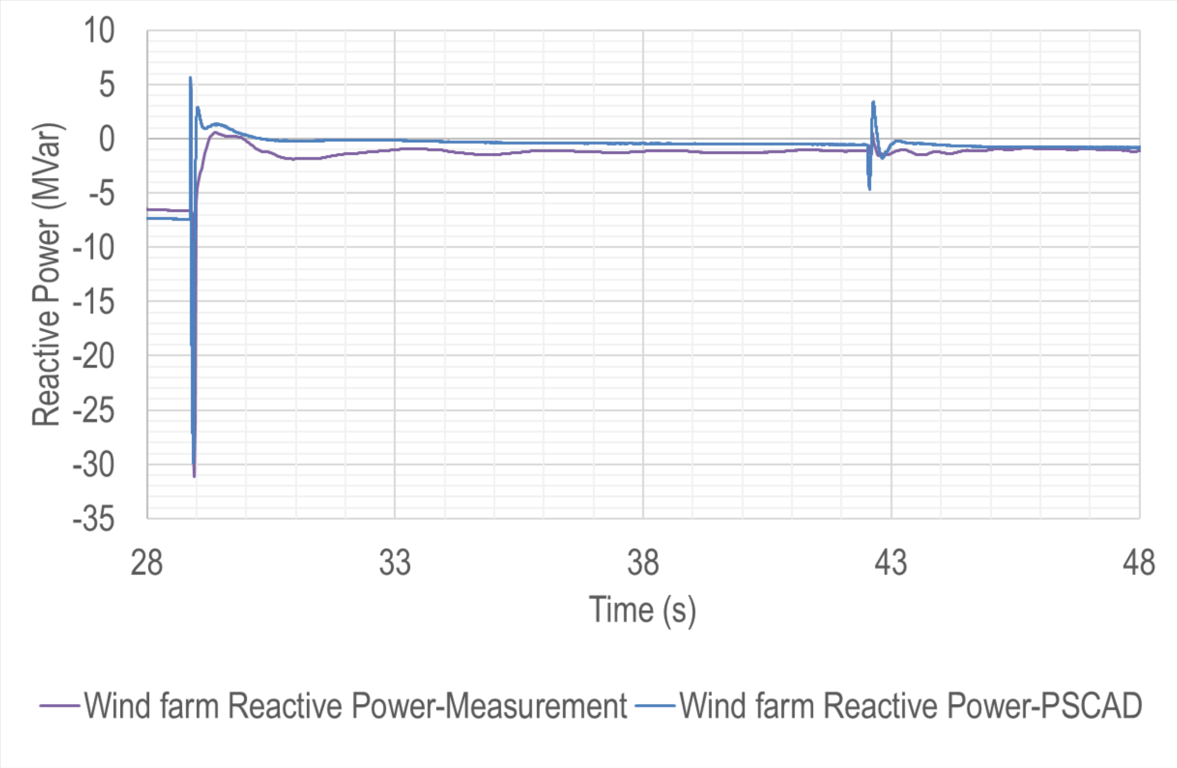
Event 1 – Active power



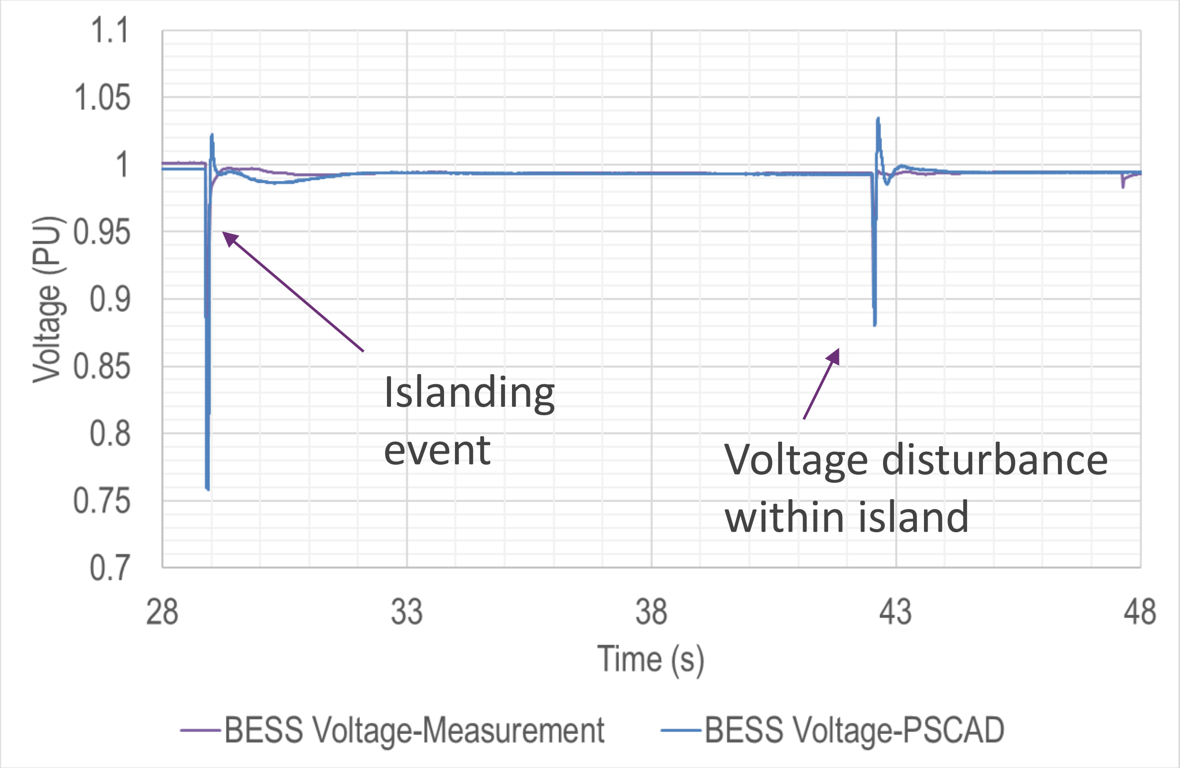


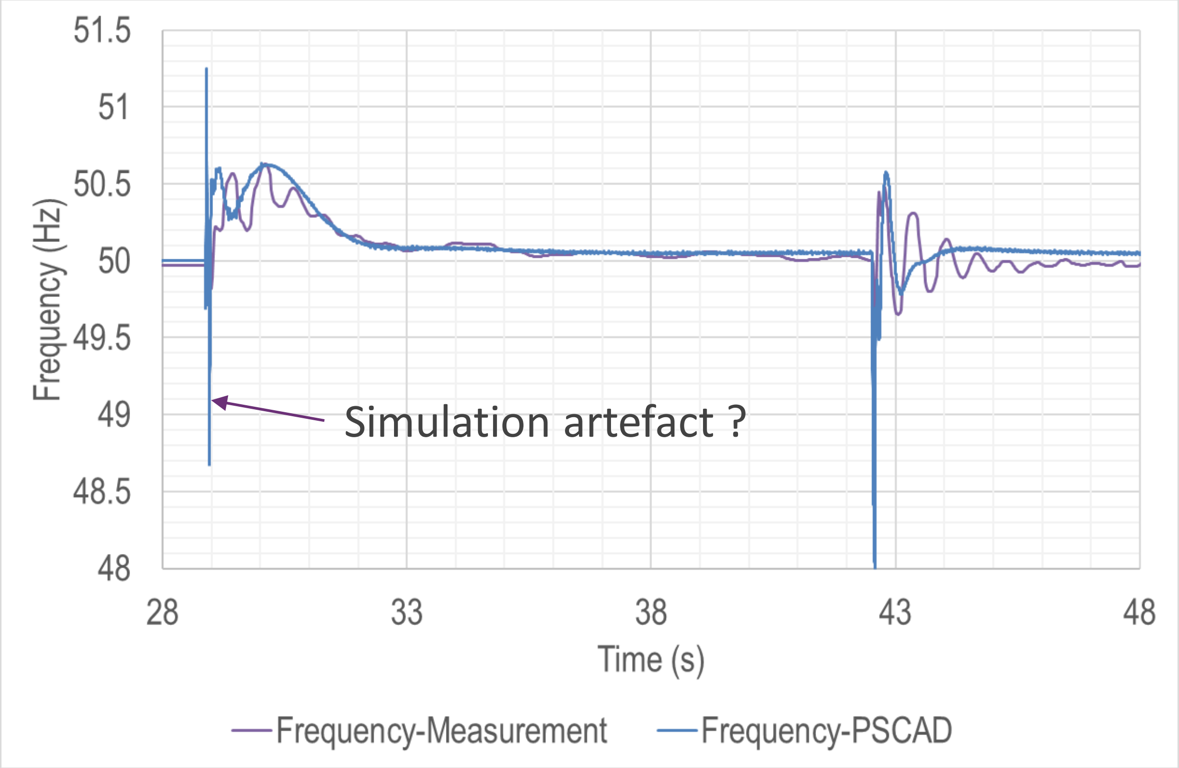
Event 1 – Reactive power





Event 1 – Voltage and frequency





Demonstrated capabilities

- Islanding capability (surviving loss of the last synchronous generator?)
- Synthetic inertial response
- Black-start
- Riding through voltage disturbance in an island
- Voltage and frequency control

Complexities!

- ***Aggressive virtual inertia response*** *causes* ***voltage stability*** *issue under* ***low fault level*** *conditions.*

- *..in networks with* ***lower system strength****, increasing inertia is observed to induce greater* ***voltage swings during frequency change tests****. This effect can potentially* ***trigger or retrigger Fault Ride-Through (FRT) conditions****, thereby introducing voltage instability problems into the network. Consequently, there is an* ***inherent trade-off between inertia response and voltage stability****.*

https://arena.gov.au/assets/2024/01/AGL-Broken-Hill-Grid-Forming-Battery-Lessons-Learnt-Report-1.pdf

Complexities!

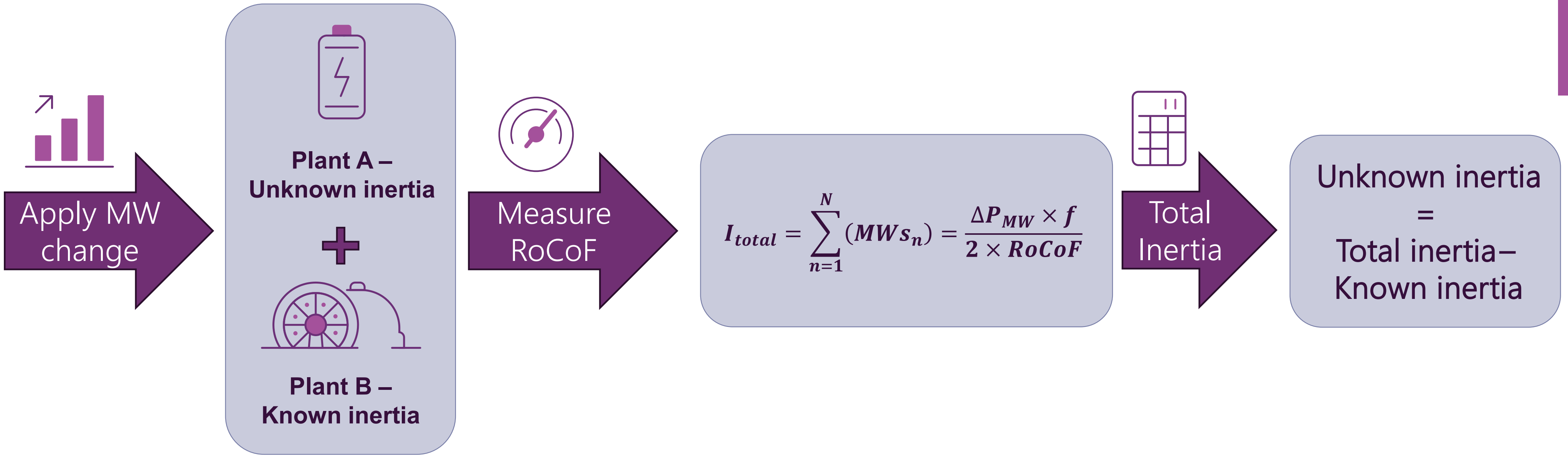
- *During **grid-forming mode**, if the terminal voltage drops due to a network fault or voltage disturbance, it **does not trigger the transient reactive current (TRC) support**, which is a characteristic of grid-following mode. Controlling the reactive current injection during faults is **essential to comply** with the **National Electricity Rules (NER)** requirements stated in clause S5.2.5.5. Recent changes to the NER rules have provided some relaxation in the reactive current response to network disturbances.*

https://arena.gov.au/assets/2024/01/AGL-Broken-Hill-Grid-Forming-Battery-Lessons-Learnt-Report-1.pdf

Synthetic Inertia

Quantifying Synthetic Inertia of Grid-forming Battey Energy Storage System – (Simulation based approach)

Methodology

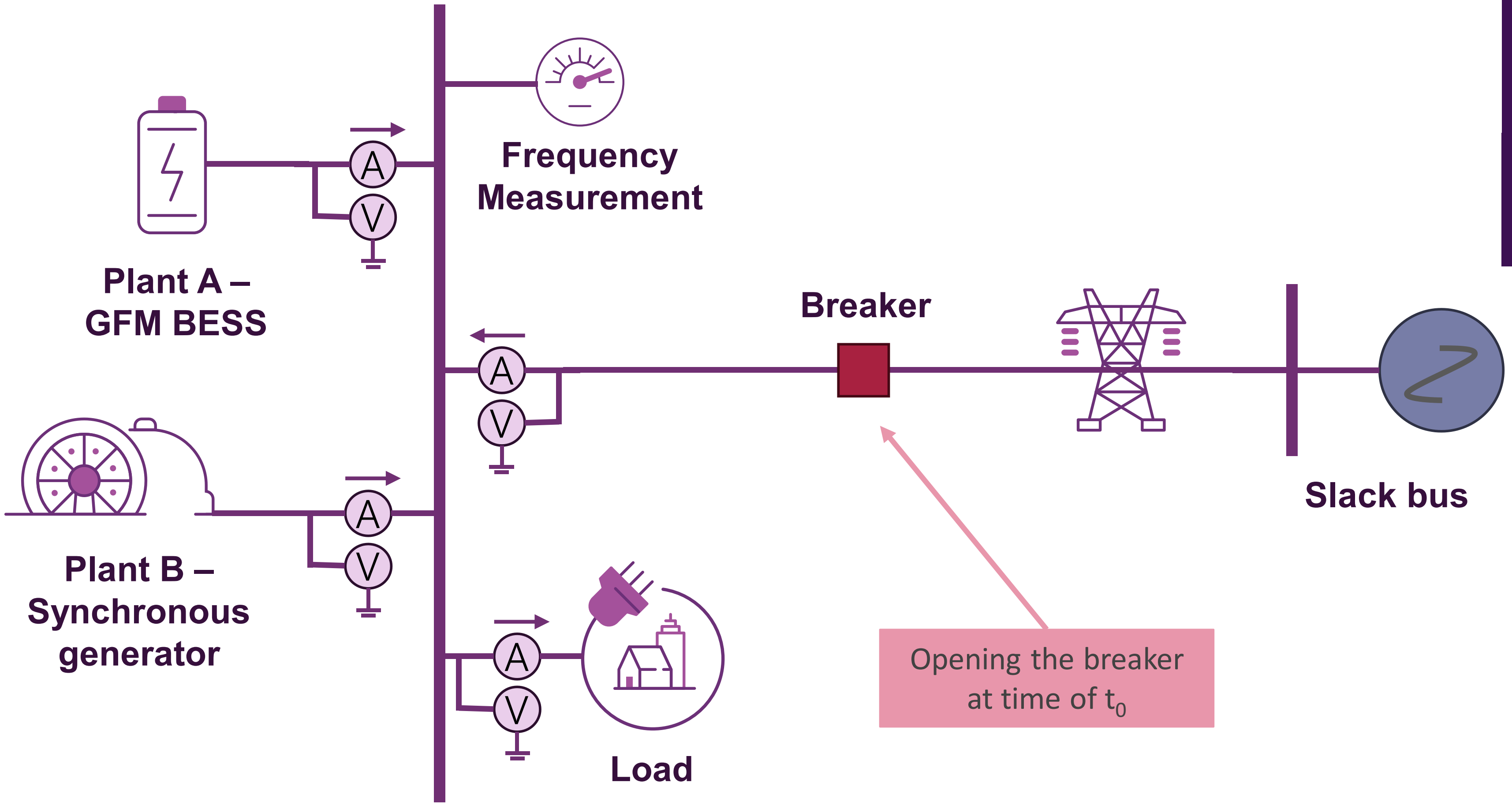


This approach is an extension of load rejection test for synchronous generators that has been to determine synchronous machine inertia constraint. The load rejection test has been used by the industry for many years.

1. Transpower, GL-EA-010 Generator Testing Requirements: https://static.transpower.co.nz/public/bulk-upload/documents/GL-EA-010%20Generator%20Testing%20Requirements.pdf
2. Inertia estimation of diesel generators based on modified loading rejection tests , C-H Lin et.al. IET Generation, Transmission and Distribution DOI: 10.1049/gtd2.12188 Feb 2021
3. IEC 60034-4-1:2018 Rotating electrical machines - Part 4-1: Methods for determining electrically excited synchronous machine quantities from tests

Test bench setup

- ✓ The inertia of Plant B is known
- ✓ The size of the Plant B is approx. twice as Plant A
- ✓ Frequency control loops are disabled
- ✓ Load is not sensitive to frequency and volage changes
- ✓ A steady state is achieved before breaker opening
- ✓ Amount/direction of the flow over Breaker can be adjusted using generation from A & B and load to achieve various operating points and desired under-frequency and over-frequency events.



Scenarios considered

Operating points

- 11 different operating points
- Charging and discharging modes
- Over and under-frequency events

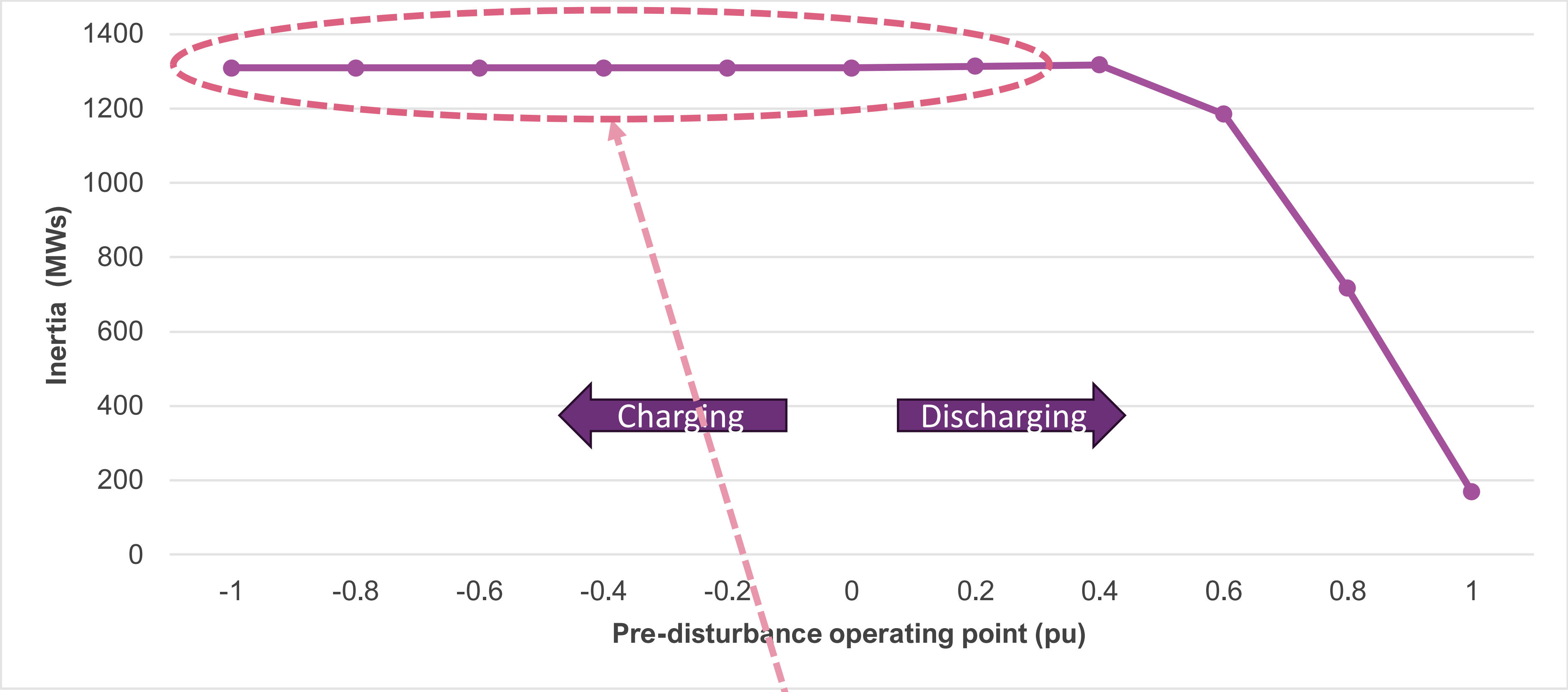
Contingency size/RoCoF

- 3 different contingency sizes resulting in different RoCoF values

Frequency control is disabled to avoid its confounding effect on the synthetic inertia quantification.

1.Pre-disturbance operating point

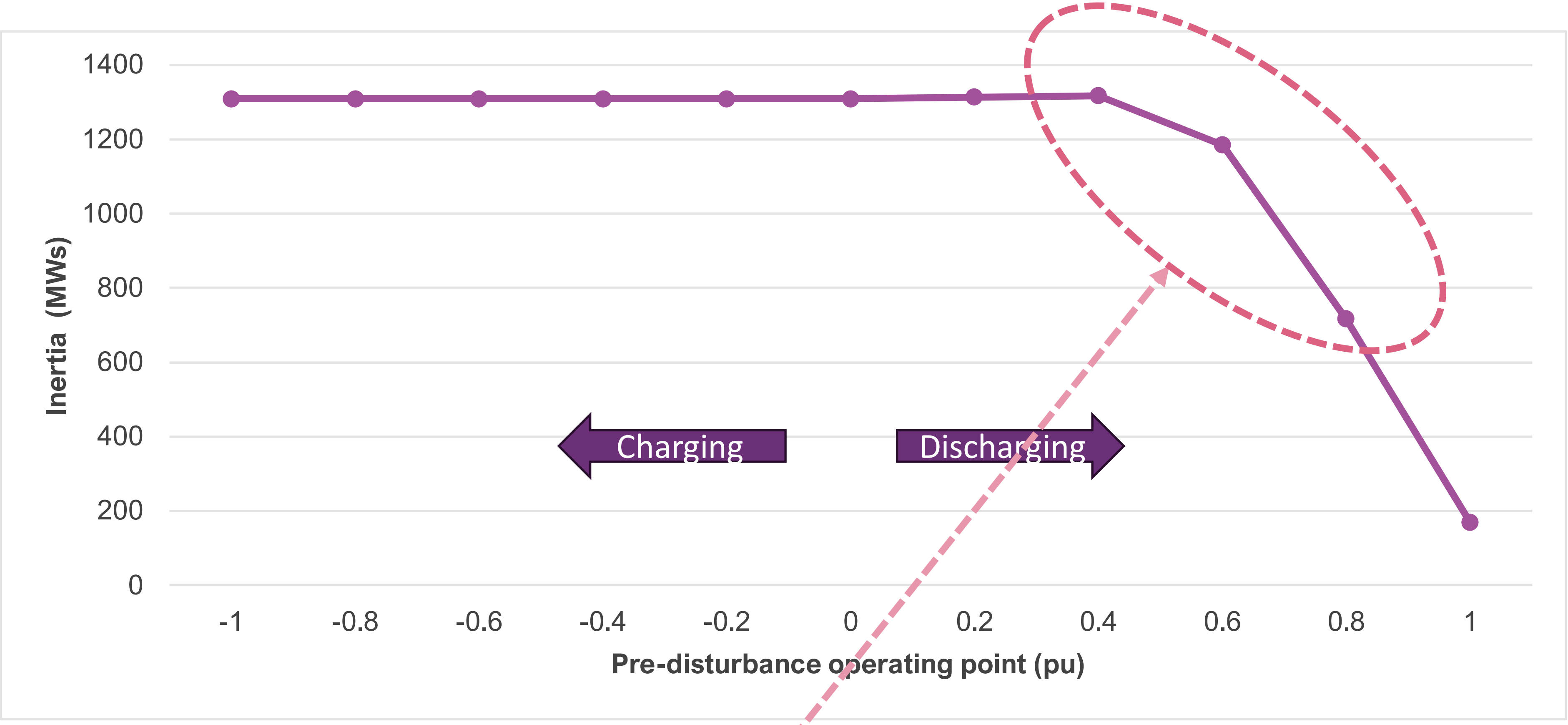
Under-frequency event



When operating in charging mode or low active power setpoints, the synthetic inertial contribution of GFM BESS remains almost constant

1.Pre-disturbance operating point

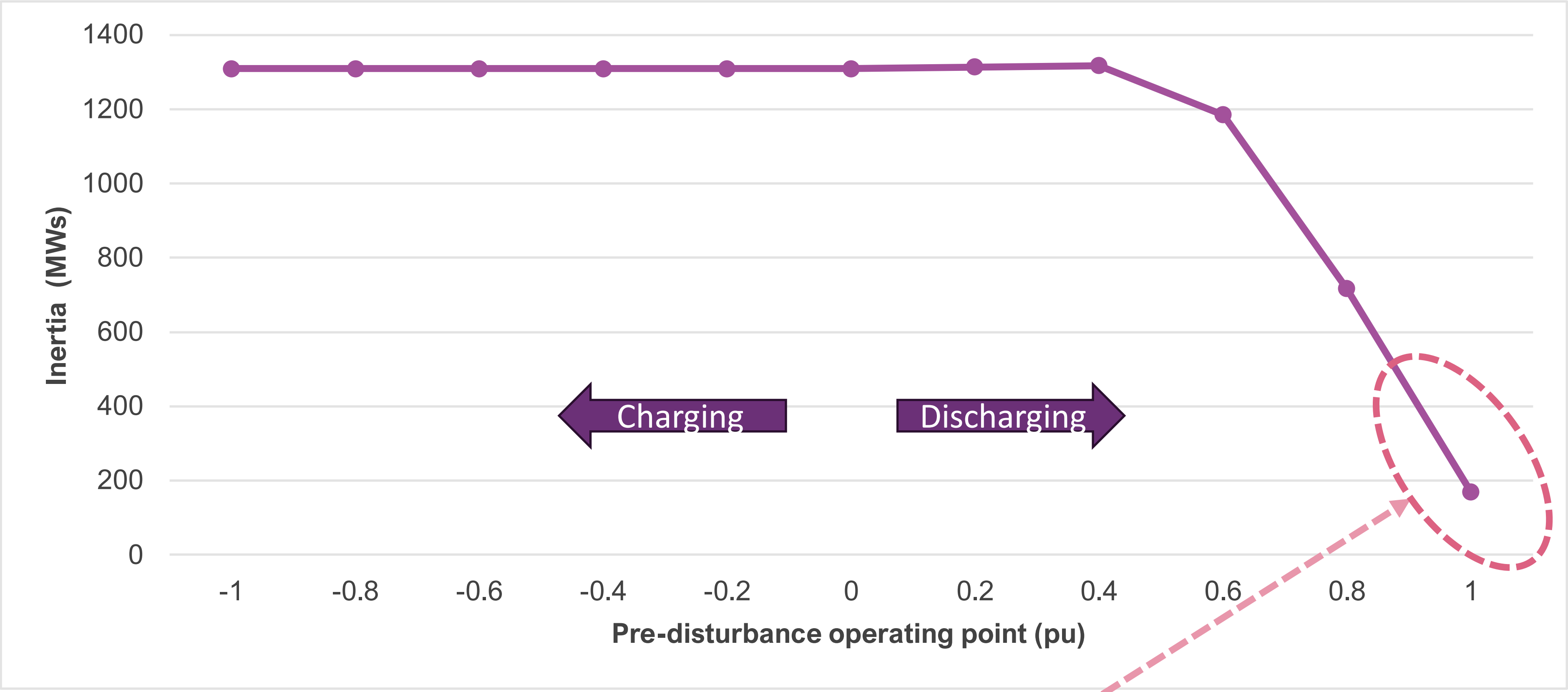
Under-frequency event



with an increase in pre-disturbance operating points in discharging mode, the synthetic inertial contribution of GFM BESS starts to decline

1.Pre-disturbance operating point

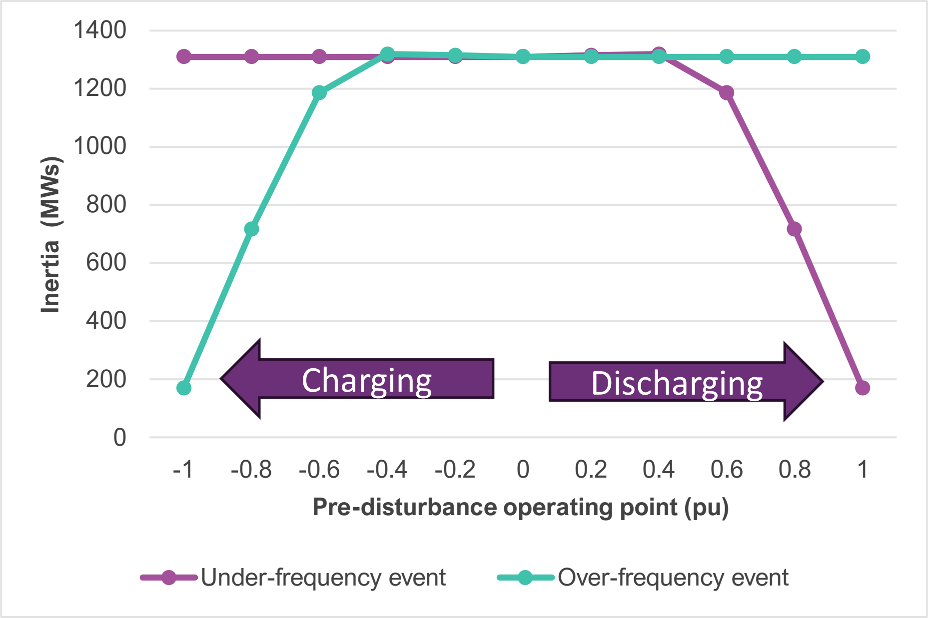
Under-frequency event



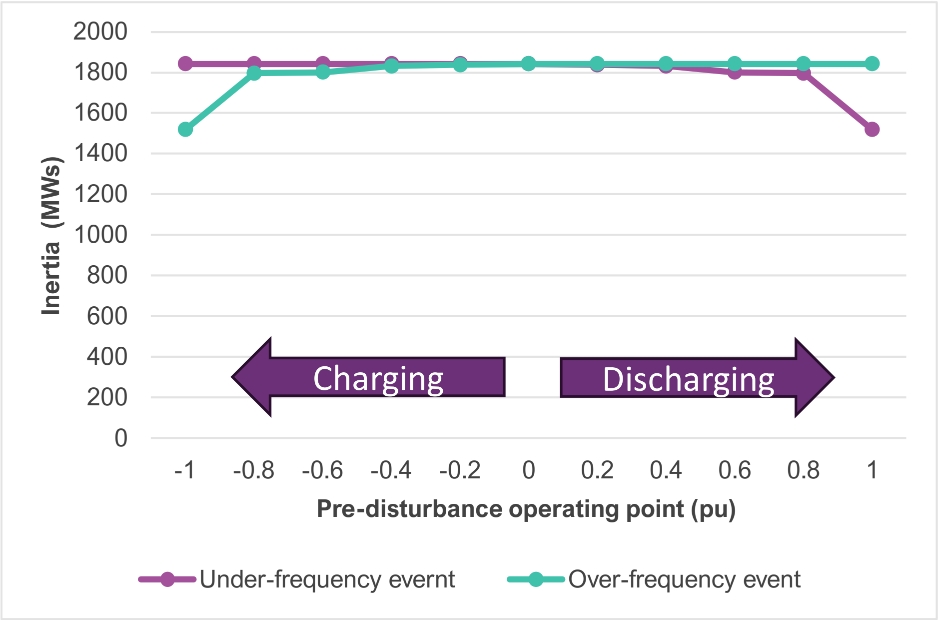
For operating points near the active power limit, synthetic inertia contribution can be substantially limited.

1.Pre-disturbance operating point

Project A



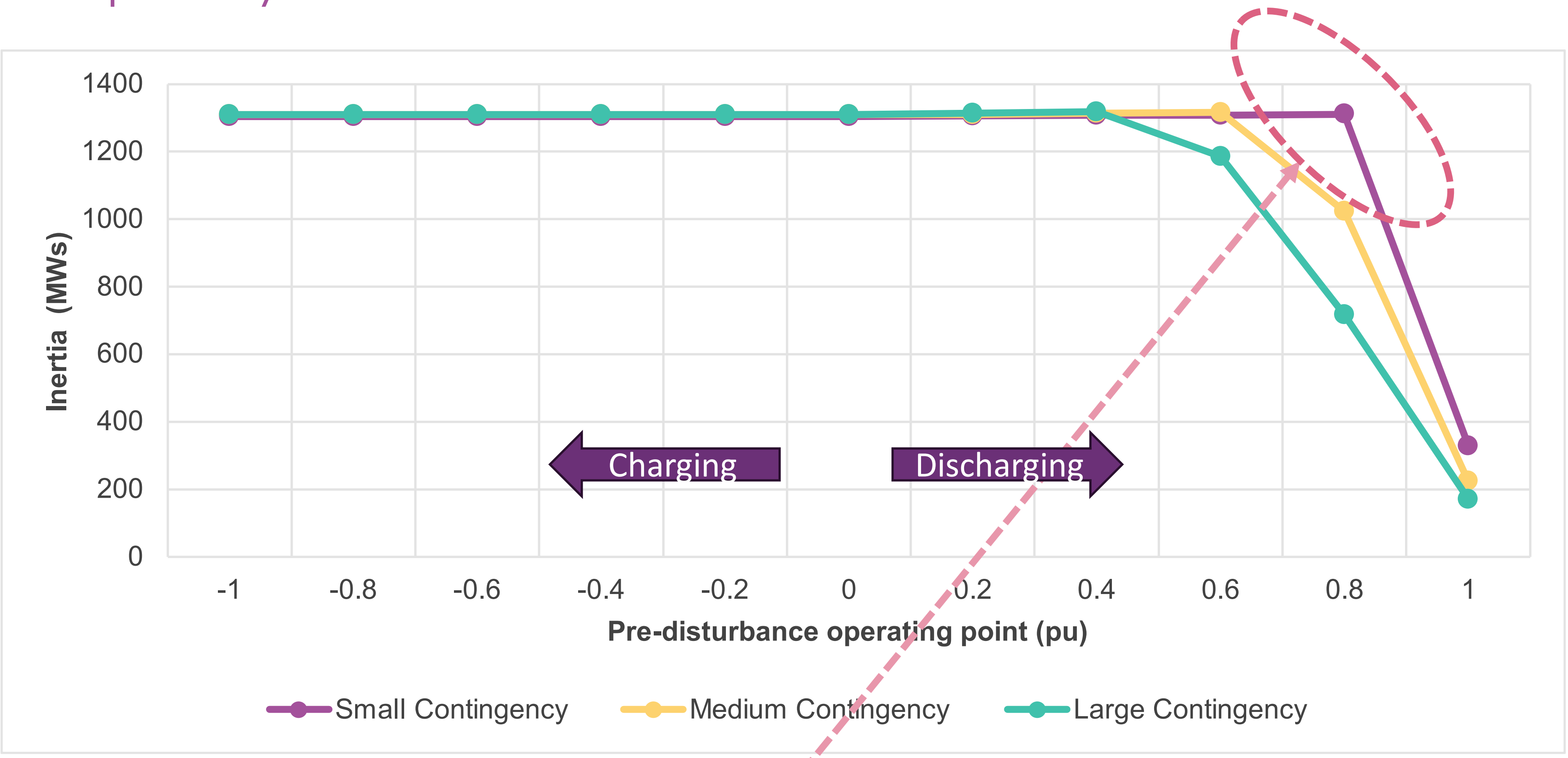
Project B



The extent to which different operating points affects the inertia contribution can vary between different GFM BESS projects.

2.Contingency size/RoCoF

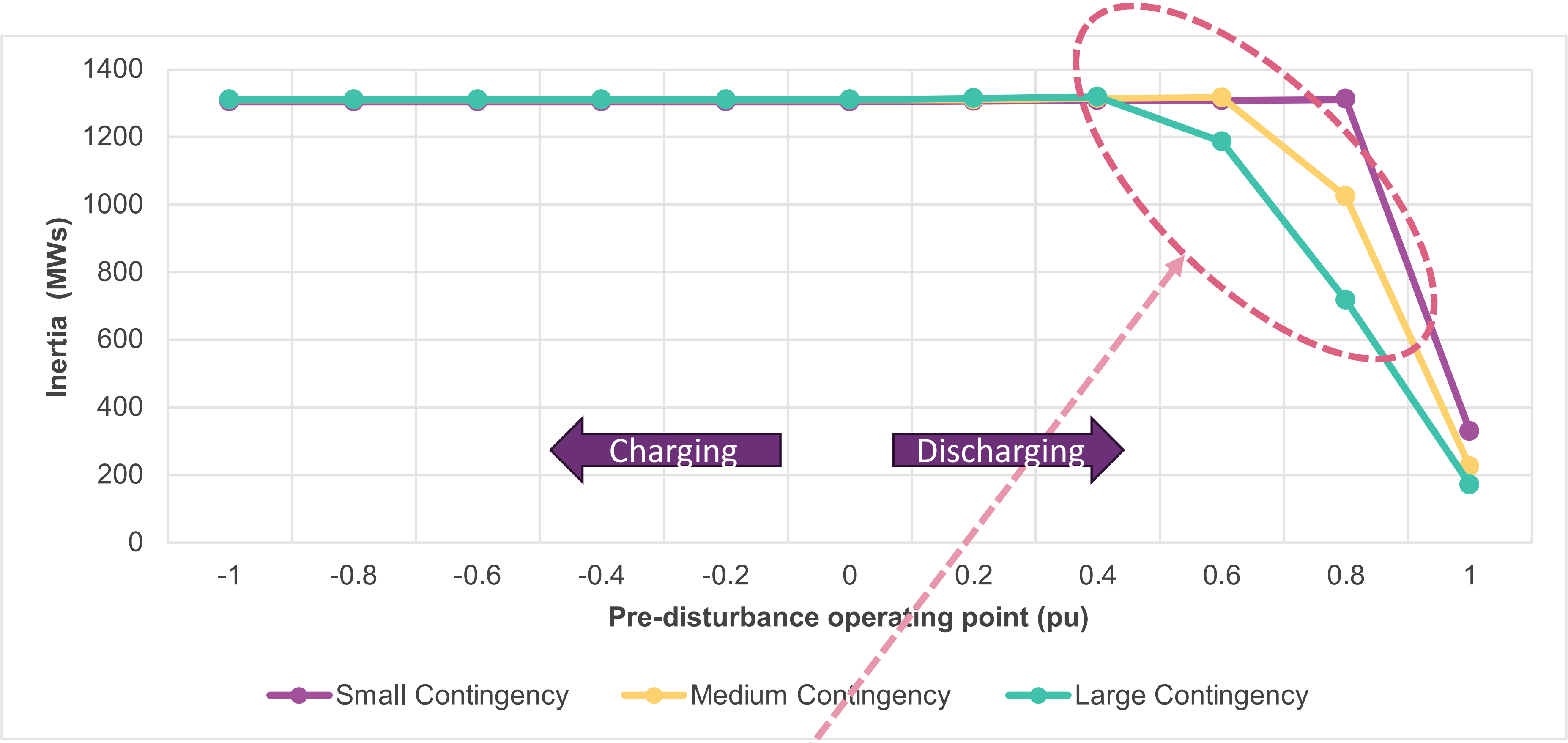
Under-frequency event



In scenario with small contingency/RoCoF, the inertia contribution from GFM BESS starts to decline only for operating points near its active power limit

2.Contingency size/RoCoF

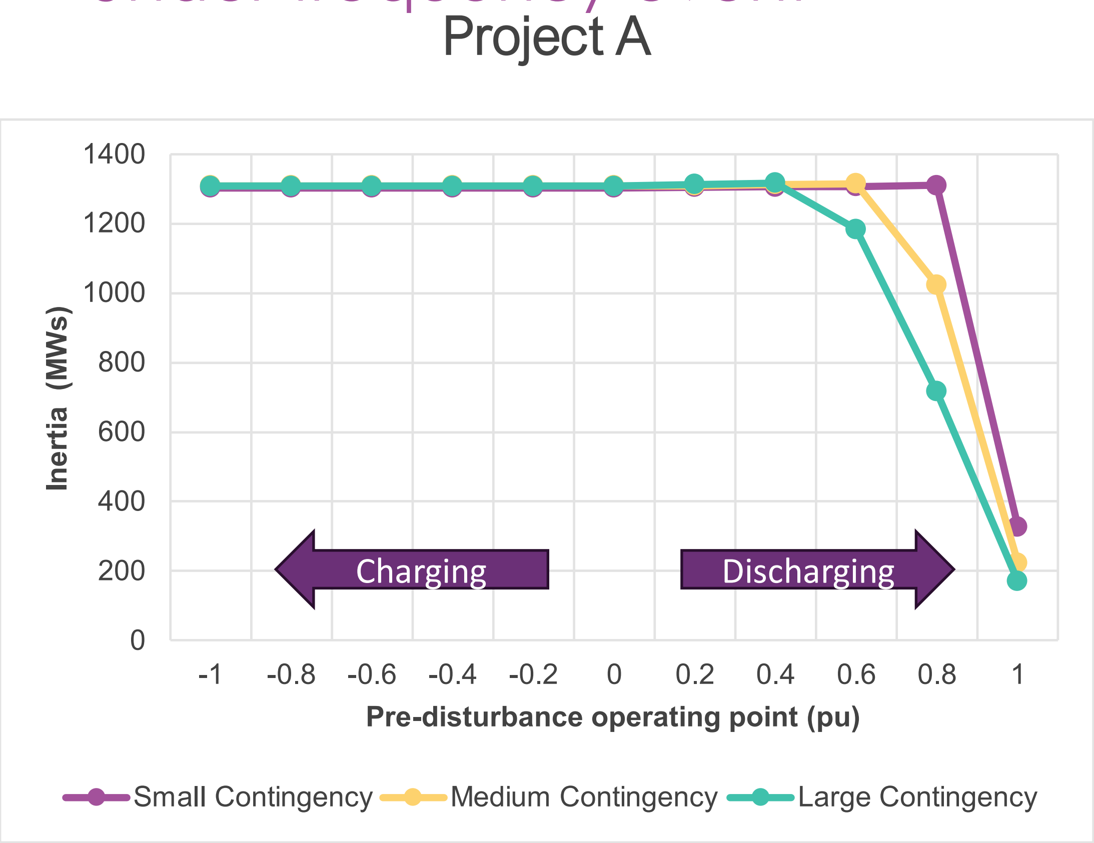
Under-frequency event

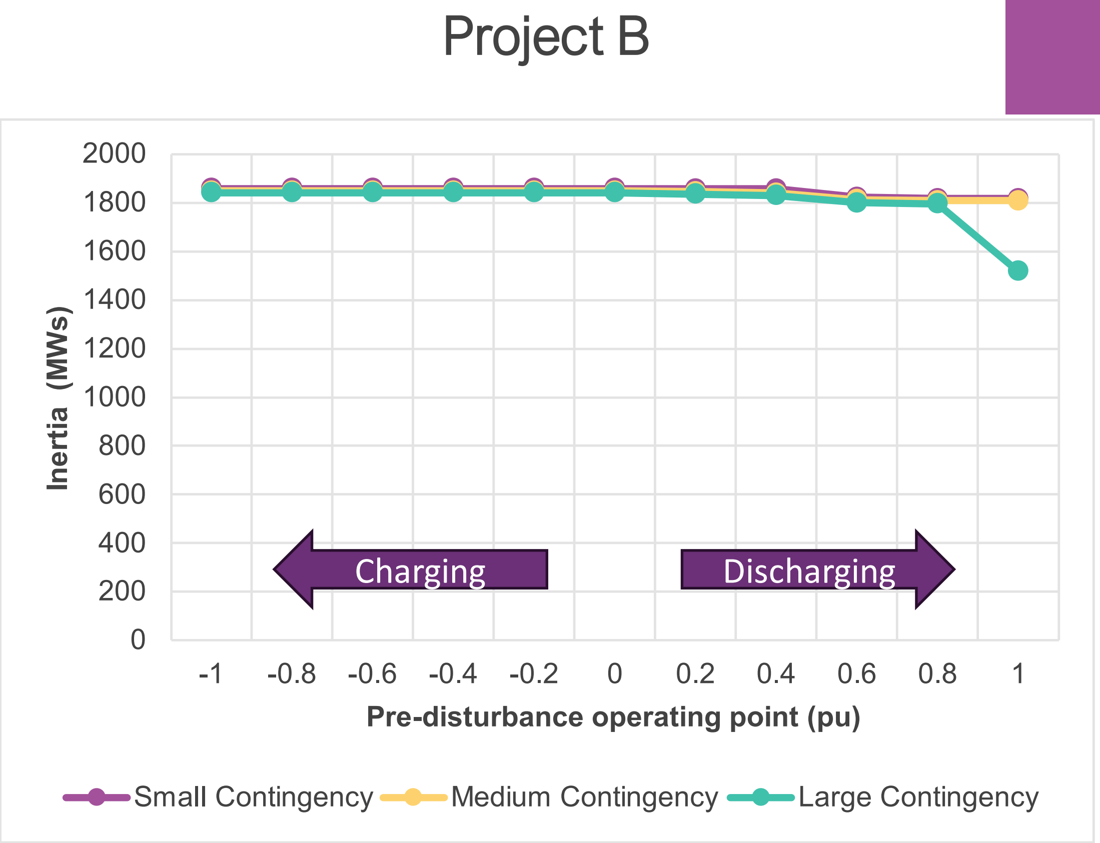


With increase in contingency size/RoCoF, inertia level starts to decline at lower operating points

2.Contingency size/RoCoF

Under-frequency event

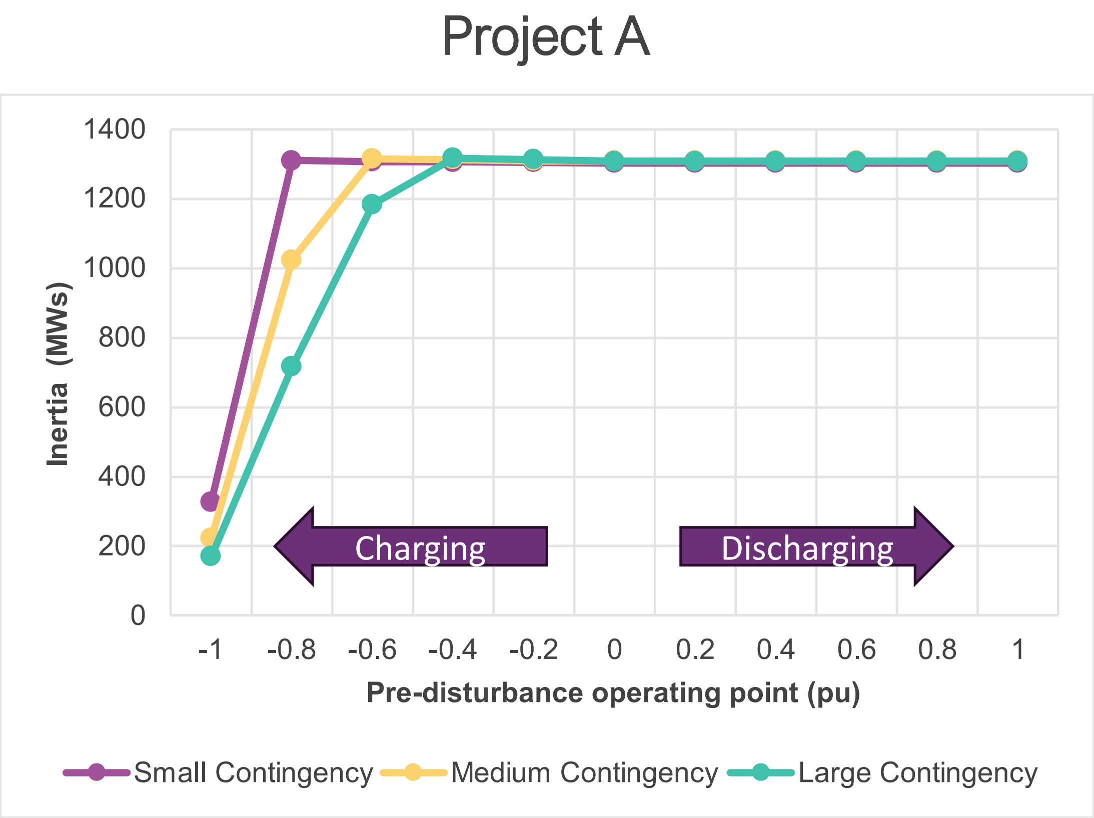


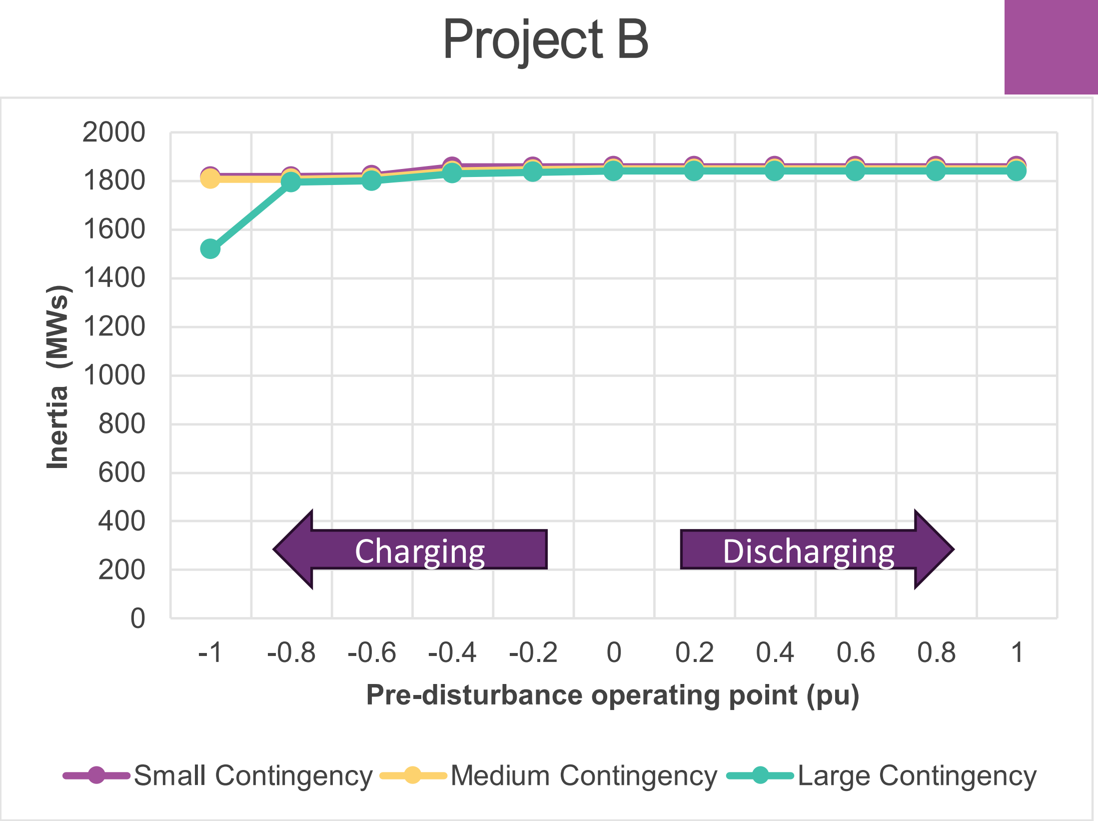


A larger contingency size in conjunction with higher operating points can increase the likelihood of hitting the current limit, and thus reducing the inertial contribution from GFM BESS

2.Contingency size/RoCoF

Over-frequency event

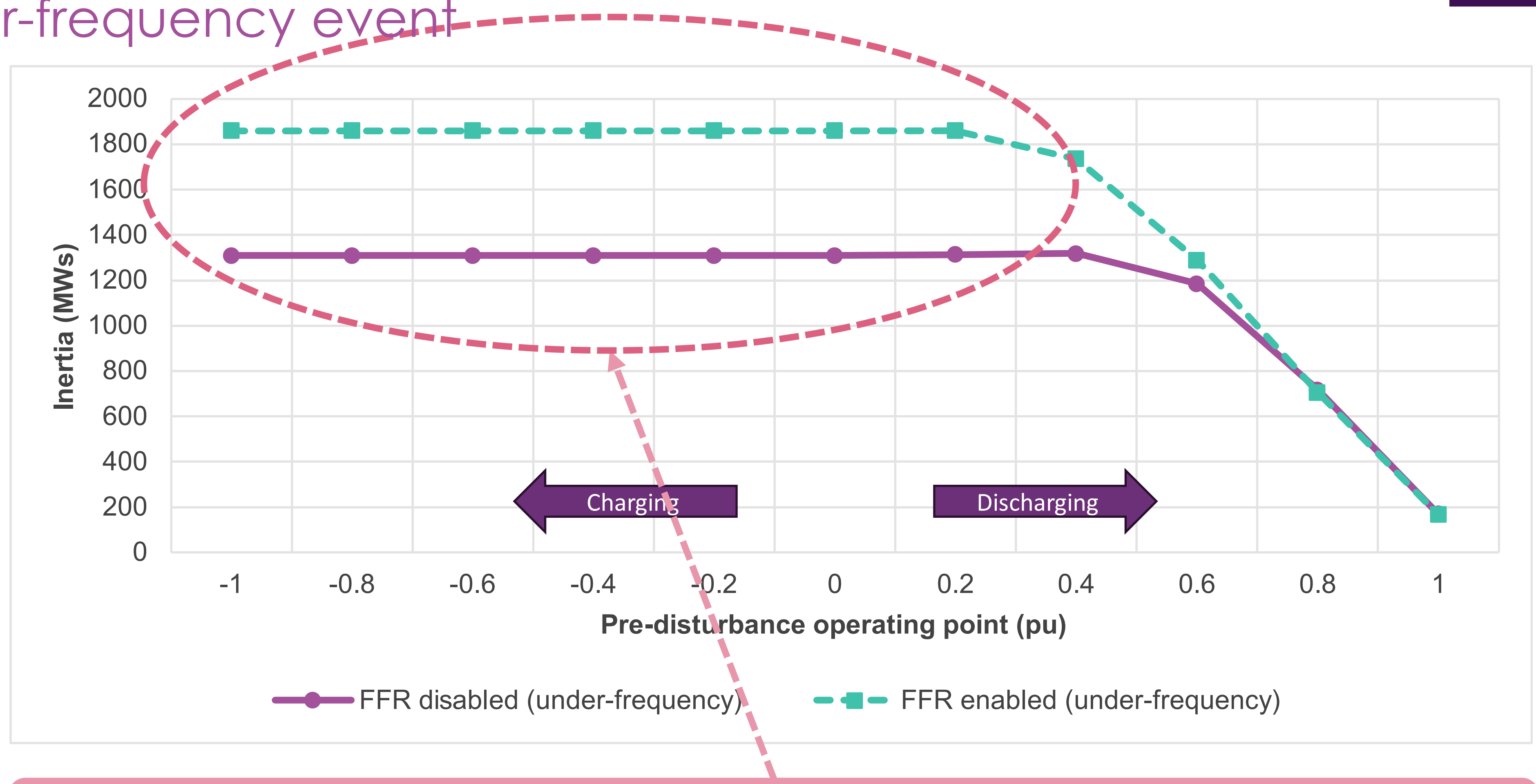




It was also noted that to certain extent, impact of contingency size on synthetic inertia contribution varies between different GFM BESS projects.

3.Fast frequency response

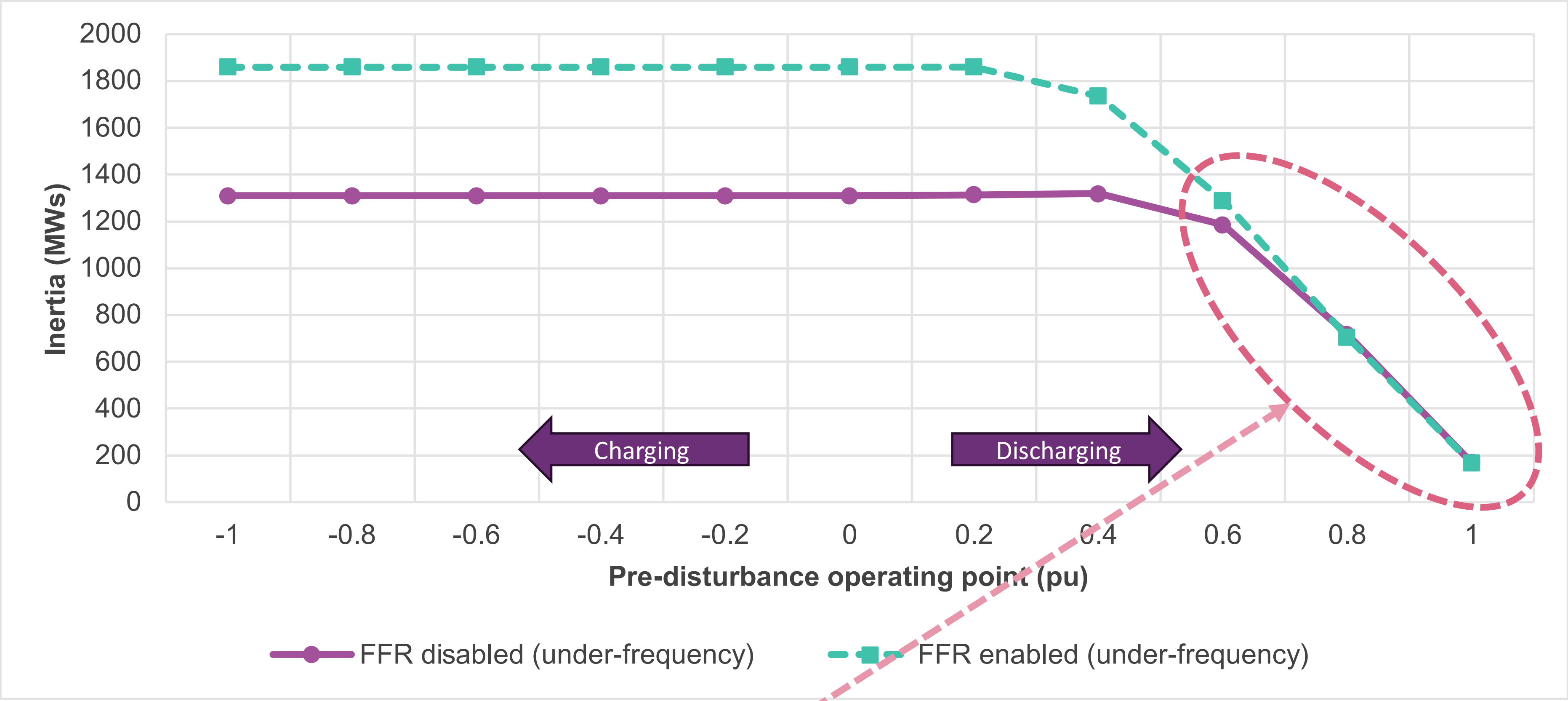
Under-frequency event



The FFR has a confounding impact on the quantification of synthetic inertia provided by a GFM BESS particularly when pre-disturbance operating point is away from its active power limit

3.Fast frequency response

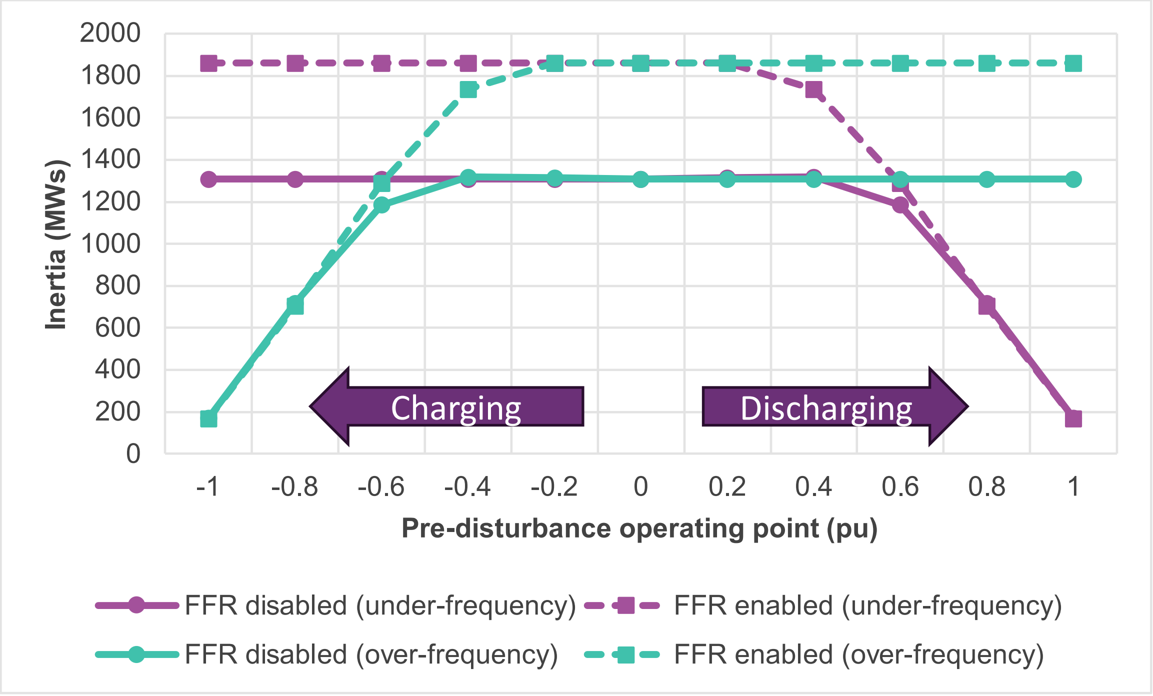
Under-frequency event



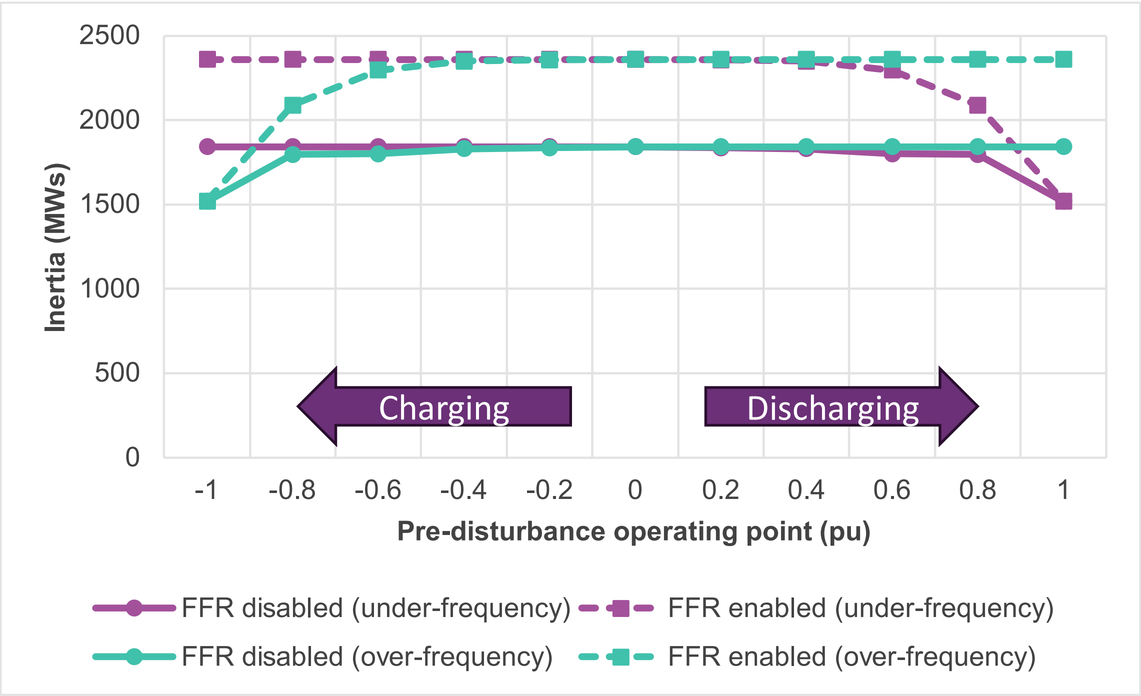
Generally, confounding impact of FFR on the calculated synthetic inertia of GFM BESS appears to be lower and insignificant when GFM BESS is operating at or near its active power limit.

3.Fast frequency response

Project A

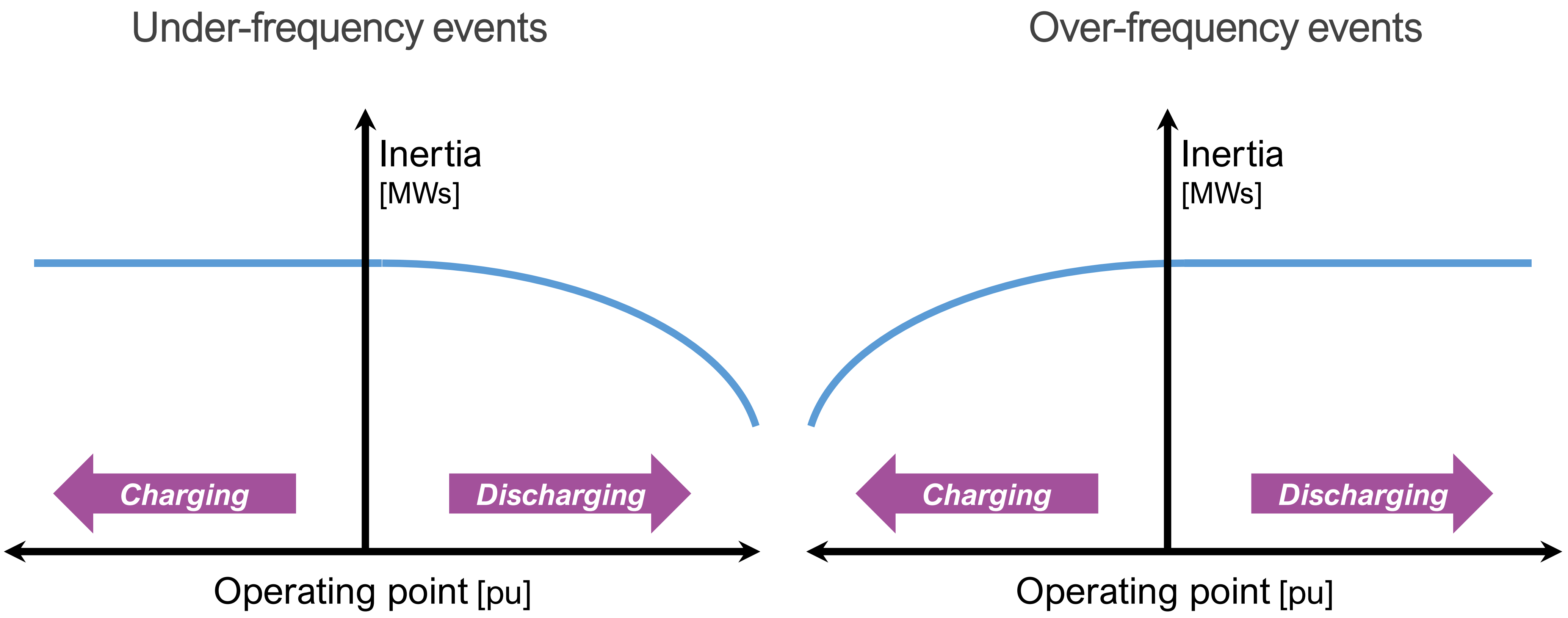


Project B



When quantifying the synthetic inertia of GFM BESS, FFR (or any equivalent frequency support based on frequency measurements) needs to be disabled to calculate the ‘bare-bone’ inertia.

Inertia capability curve



Typical inertia capability curves for a given contingency size (RoCoF).

In reality, there would be a family of three-dimensional curves showing relationship between operating point, synthetic inertia and contingency size (or RoCoF).

Summary

- **Synthetic inertia** of a GFM BESS **is likely to vary** depending on factors such as its operating point and contingency size/RoCoF.

- When GFM BESS is operating at **lower pre-disturbance operating points** (i.e. closer to zero active power), it would have **sufficient headroom** to provide synthetic inertial response.

- **A larger contingency** size or higher RoCoF in conjunction with **higher operating points** can increase the likelihood GFM BESS reaching its current limit, and thus **reducing the inertial contribution** from the GFM BESS.

Summary

- **Frequency control** (in particular FFR) can have **confounding impact** on the quantification of synthetic inertia provided by a GFM BESS.
- This confounding impact would vary based on the operating point of a GFM BESS, size of the contingency and thus RoCoF the GFM BESS is exposed to.
- Therefore, when quantifying the synthetic inertia provided by the GFM BESS, **FFR** (or any frequency support based on frequency measurements) **should be disabled** to calculate the '**bare-bone**' synthetic inertia.

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