Grid-support Opportunities Provided by GFL and GFM IBR

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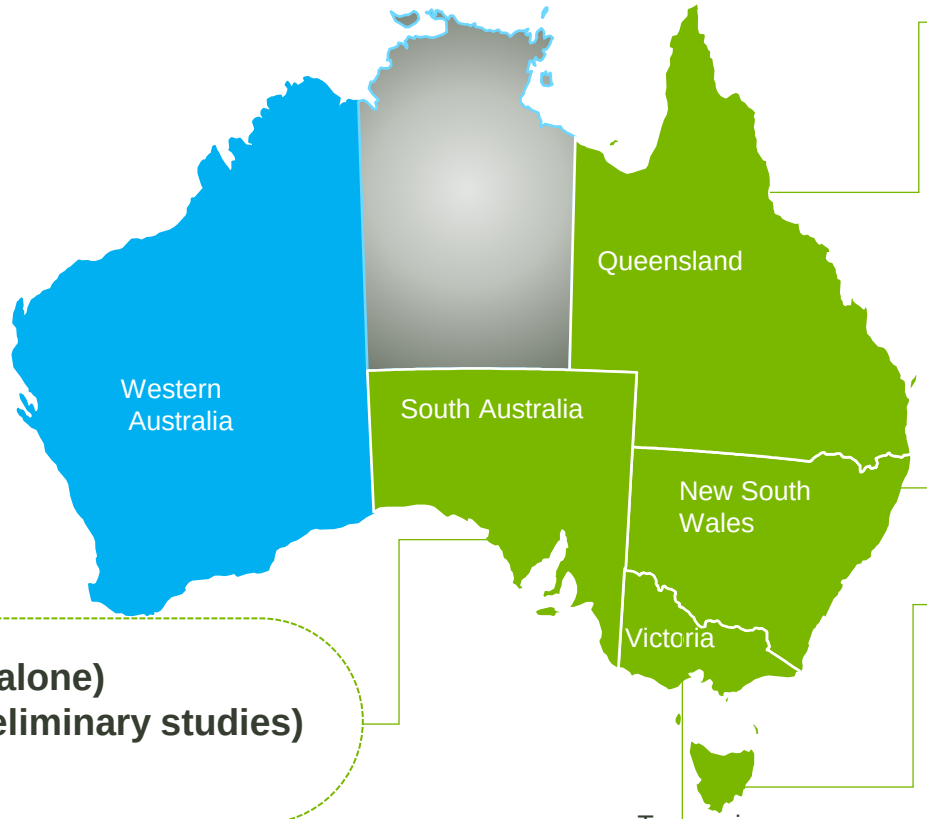
Our current GFL and GFM BESS projects



- 150 MW (GFL-standalone)
- 150 MW (GFL-standalone)
- 350 MW (GFL-hybrid AC)

- 850 MW (GFL-standalone)
- 500 MW (GFL-standalone)
- 350 MW (GFL-hybrid DC)
- 300 MW (GFL-standalone)
- 50 MW (GFM)

- None

- 200 MW (GFL-standalone)
- X MW (GFL/GFM preliminary studies)

- 600 MW (GFL-standalone)
- 600 MW (Potentially GFM-standalone)
- 300 MW (GFL-standalone)
- 280 MW (GFM)
- 100 MW (GFL-standalone)

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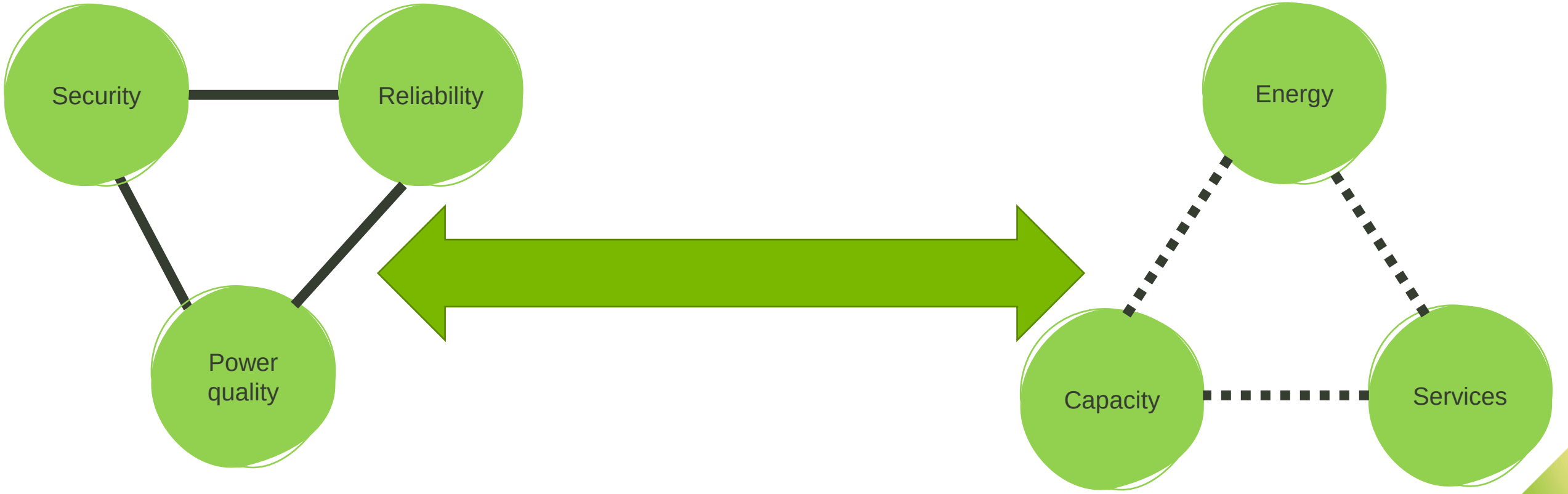
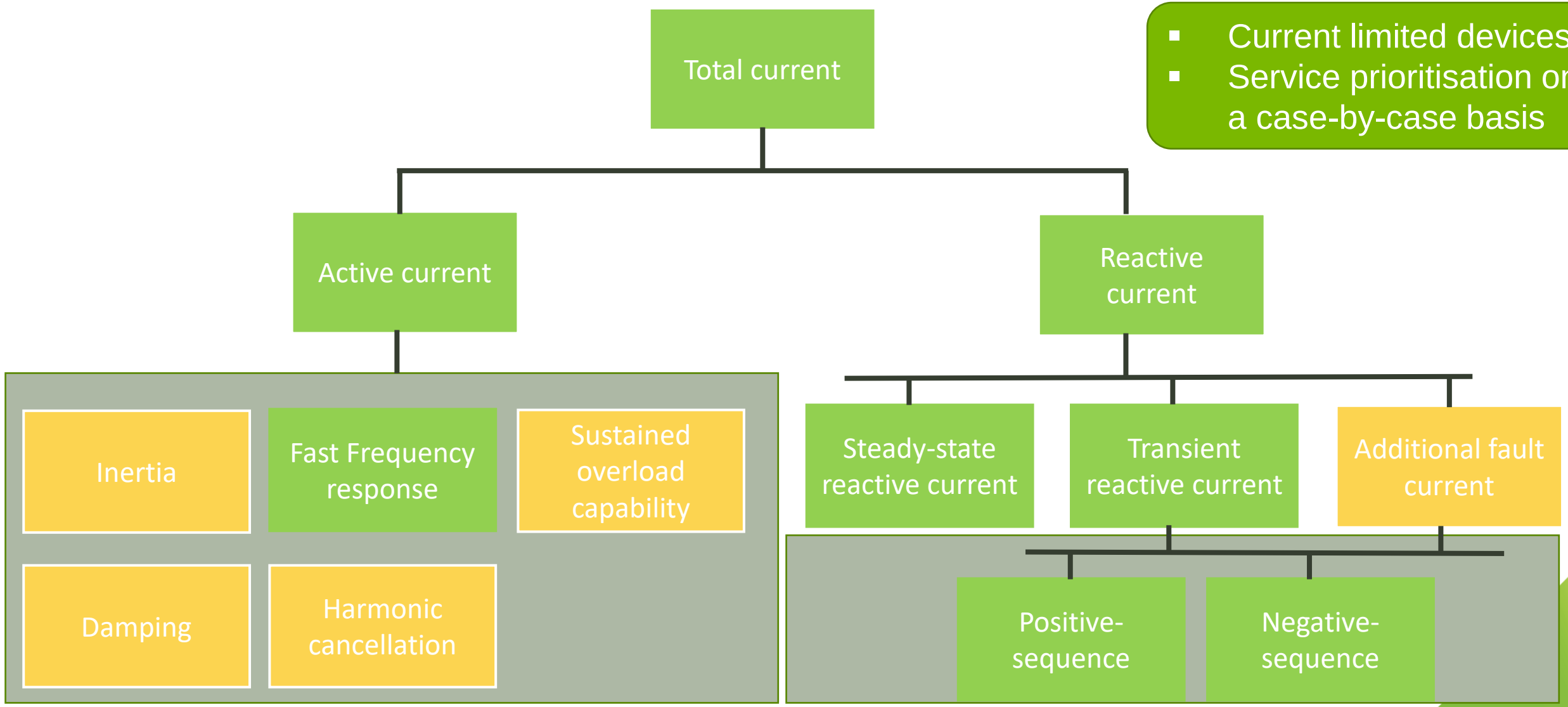
Power system needs



No inherent coupling in an inverter dominated power system

Current allocation and prioritisation in grid forming inverters

- Current limited devices
- Service prioritisation on a case-by-case basis



What grid support opportunities are BESS currently used for?

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Frequency control (inc FFR)

Synchronous generator replacement

System strength support

SIPS

Inertia

Capabilities highlighted in gradient can only be provided by GFM

Black start

Damping of oscillations (PSS like function)

Harmonic cancellation

Virtual transmission lines

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System strength support

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System strength support

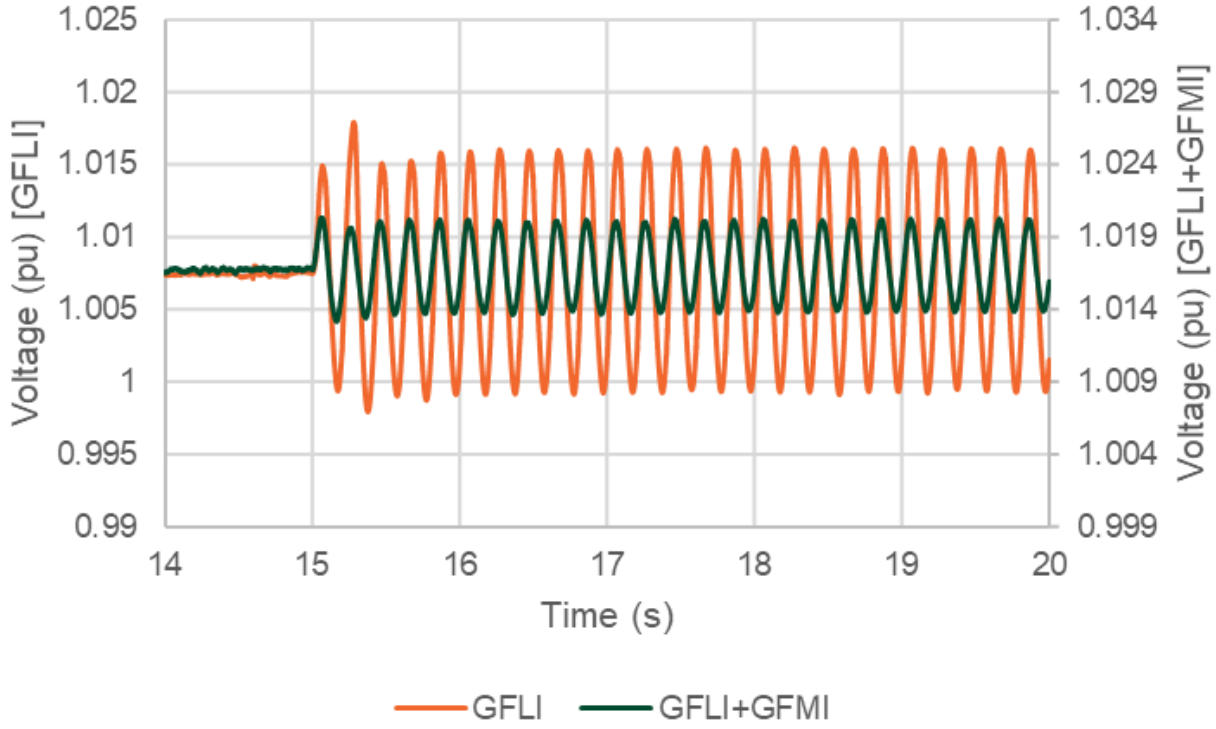
Grid-forming to synchronous condenser MVA effectiveness: 1.0-2.0 pu

Hosting capacity release of grid-following inverters: 2.0-4.0 pu

Lesson 1: System strength support provided by grid-forming inverters is comparable or sometimes better than that provided by synchronous condensers.

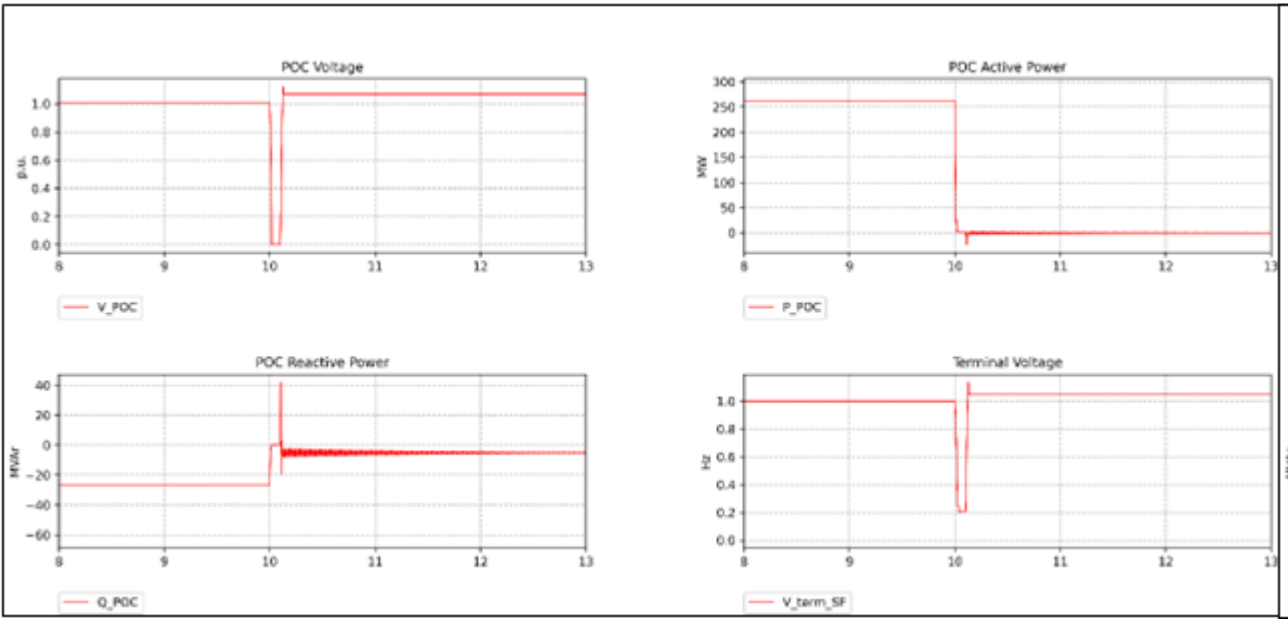
Lesson 2: Provision of additional fault current has not been always identified as a key factor from a system strength support perspective.

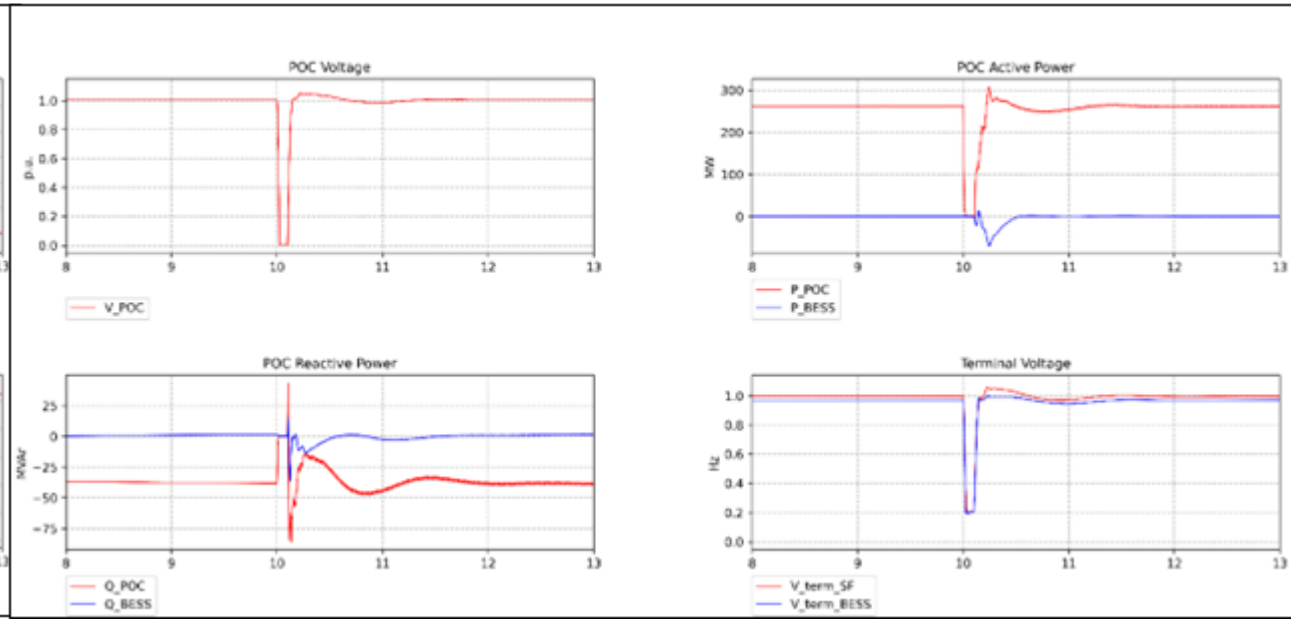
GFM stabilising impact (example 1)



- Oscillation injection test on vendor-specific site-specific EMT models
- GFL experienced sustained oscillations
- GFM did not exhibit any oscillations
- GFL+GFM reduces the oscillations to more than half of that seen with GFL alone

GFM stabilising impact (example 2)





Failed ride-through without grid-forming inverters

Successful ride-through with grid-forming inverters

The use of grid-forming and grid-following inverters for system restoration

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Black start candidates studied for Australia's Global Power System Transformation (G-PST) research

Synchronous generator

- Inherent inertia and damping
- Higher fault current capability
- Requires a minimum stable load

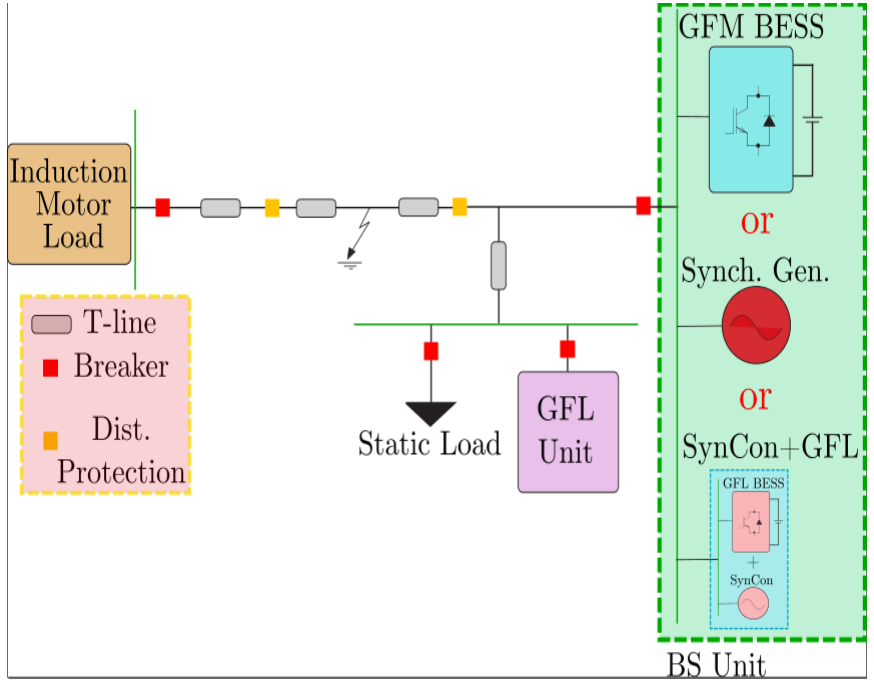
Grid-forming BESS

- Emulates most capabilities of a black start synchronous generator
- Faster speed of response
- Comparable or better performance

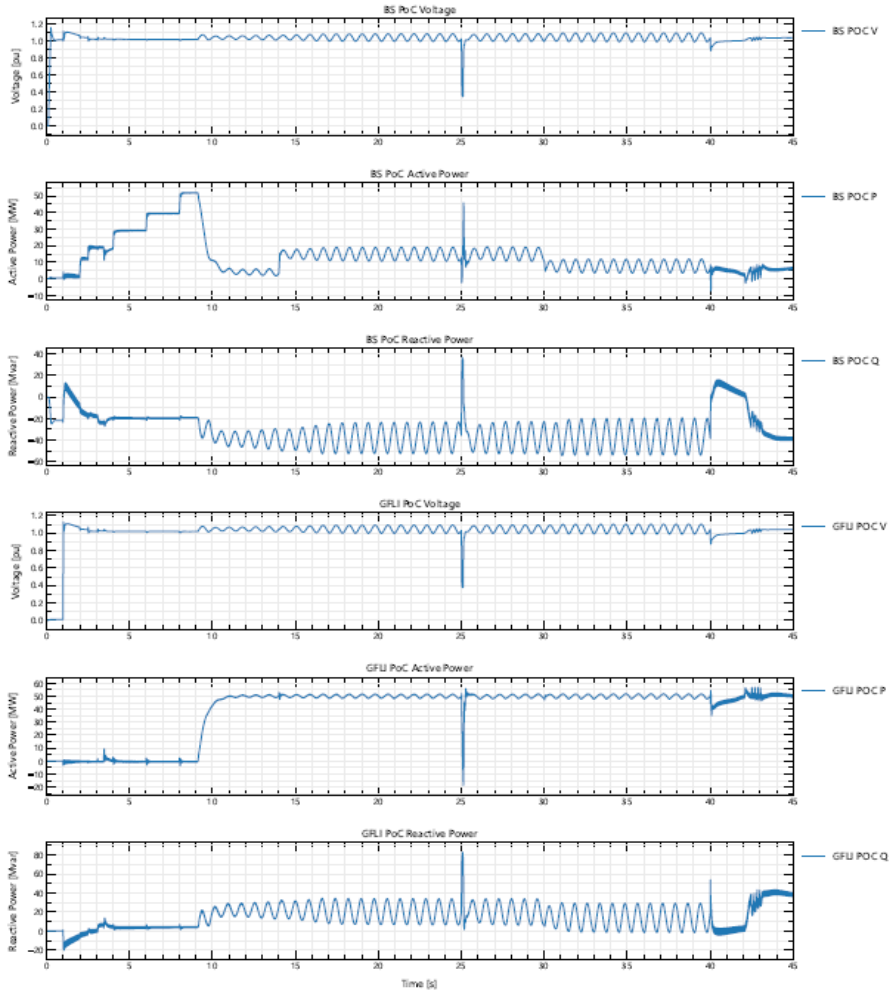
Synchronous condenser + Grid-following BESS

- Synchronous condenser to form the voltage
- Grid-following BESS to control the frequency
- Lower capability than the other two options

Vendor-specific EMT modelling



Factors influencing the response of grid-forming blackstart BESS



Factors with insignificant impact

Fault current

Inertia

Damping

Charge or discharge

Factors with significant impact

Grid-forming to grid-following inverter MVA

Grid-following inverter SCR withstand capability

Grid-forming inverters with better SCR withstand capability further improve the performance of the black starter grid-forming BESS.