ElectraNet

Dalrymple Battery Energy Storage Project
API 2020 Summer School

Hugo Klingenberg
Manager Network Development

24 February 2020

In partnership with:

agl

ARENA
Australian Government
Australian Renewable Energy Agency

Advisian
WorleyParsons Group

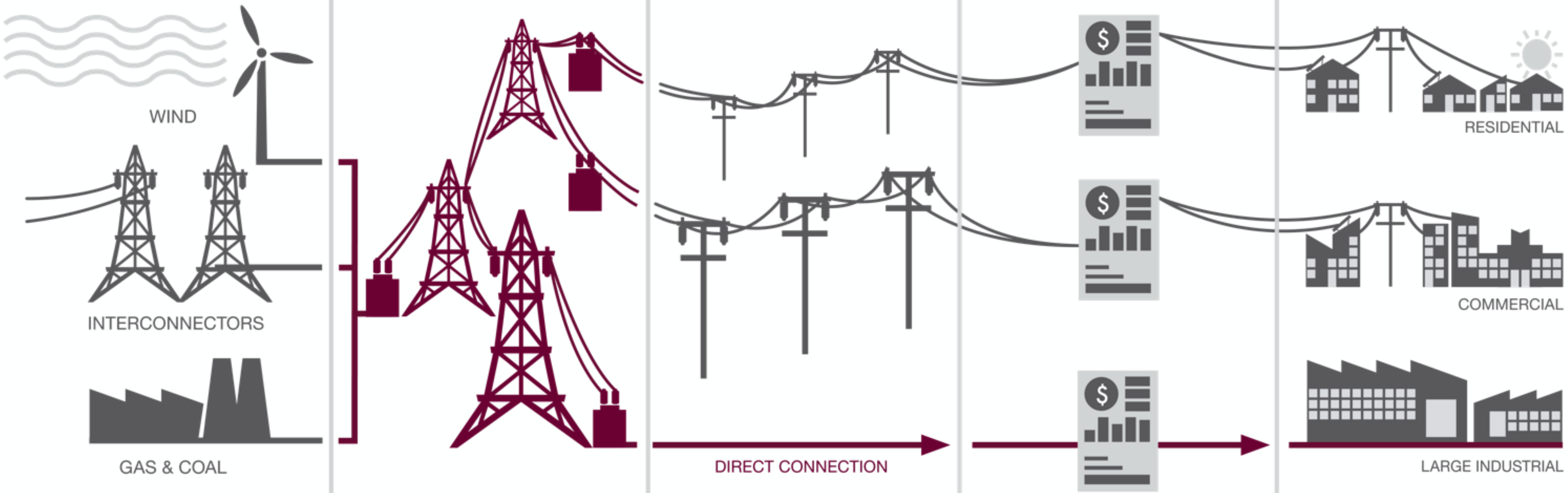
This activity received funding from ARENA as part of ARENA's Advancing Renewables Programme

Presentation outline

- South Australian power system context
- Dalrymple ESCRI-SA Battery Energy Storage System (BESS)
  - Business case & Commercial arrangements
  - Project design, registration & implementation
  - Operational experience
  - Key learnings / challenges
- Looking ahead

South Australian Power System Context

The role of ElectraNet



Generation

Electricity is generated from traditional and renewable energy sources such as wind, solar, gas and coal.

Transmission

Electricity enters ElectraNet's network where it is converted to higher voltages, for efficient long-distance transport to cities and towns around South Australia. The voltage is then lowered so it can enter the distribution network or be supplied directly to some large industrial customers.

Distribution

The distribution network, operated in South Australia by SA Power Networks, transports low-voltage electricity to residential and commercial customers.

Retail

Retailers are the primary point of contact for residential and commercial customers. They coordinate connections and manage billing and payments.

Consumers

The traditional flow of electricity supply is changing. Around one in three South Australian homes now combines the electricity they draw from the network with power generated by rooftop solar panels, and also contributes surplus electricity back to the network.

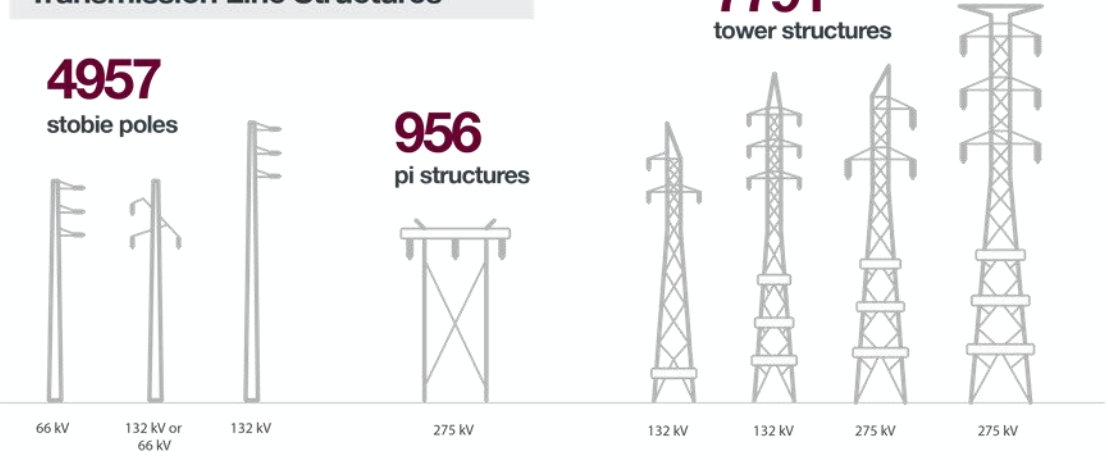
Our Assets

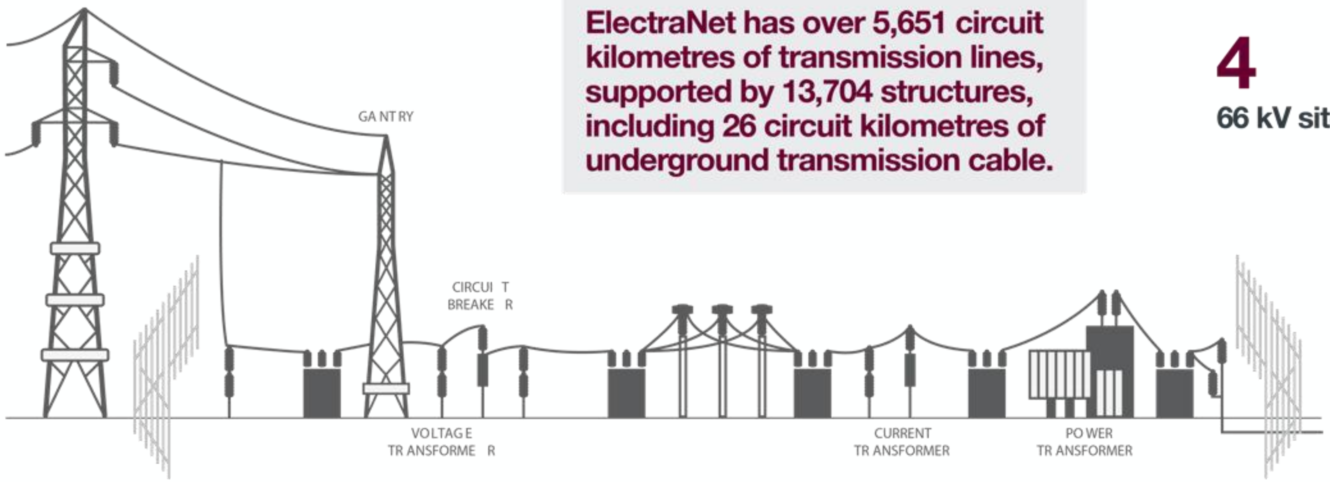
Transmission Line Structures

4957 stobie poles

956 pi structures

7791 tower structures





ElectraNet has over 5,651 circuit kilometres of transmission lines, supported by 13,704 structures, including 26 circuit kilometres of underground transmission cable.

96 substations and switchyards

34 275 kV sites

58 132 kV sites

4 66 kV sites

3524 voltage and current transformers

627 circuit breakers

108 132 kV power transformers

44 275 kV power transformers

131 telecommunications sites including 45 stand-alone towers

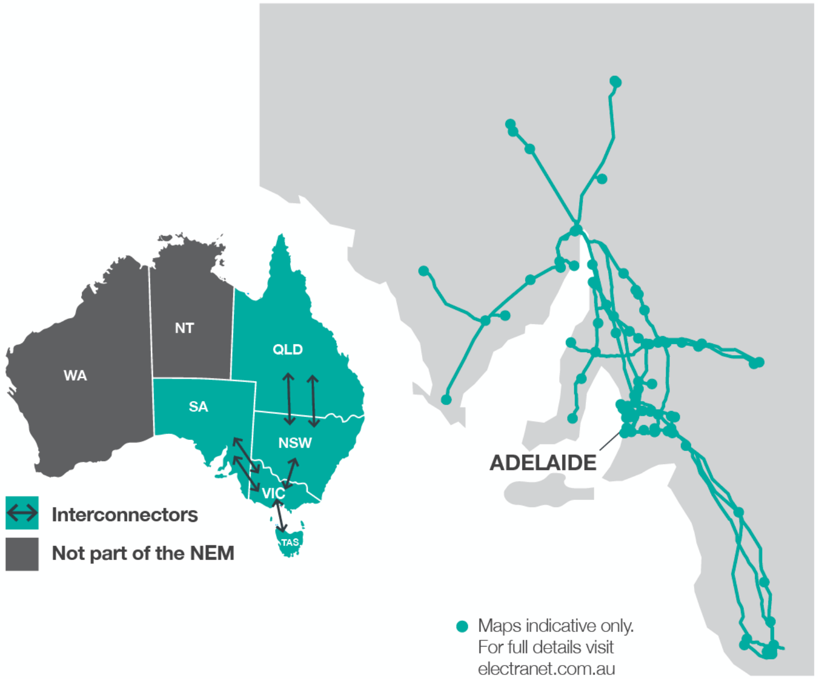
1251 km of optical fibre (approx)

98 weather stations including 57 stand–alone

South Australian System Overview

South Australia (SA) is at the forefront of energy transformation

- Abundant high quality renewable energy resources with leading wind and solar penetration levels compared to demand
- Last coal fired power station closed 2016
- Reliance on gas generation and impact of higher gas prices
- SA separation and load shedding events have led to heightened concerns about power system security
- New measures have been introduced by AEMO and the SA Government to manage power system security
- Ongoing policy drivers to lower carbon emissions, new technology and customer choice are driving energy transformation



Heywood Interconnector (currently 600 MW)

NEM – National Electricity Market
AEMO – Australian Energy Market Operator

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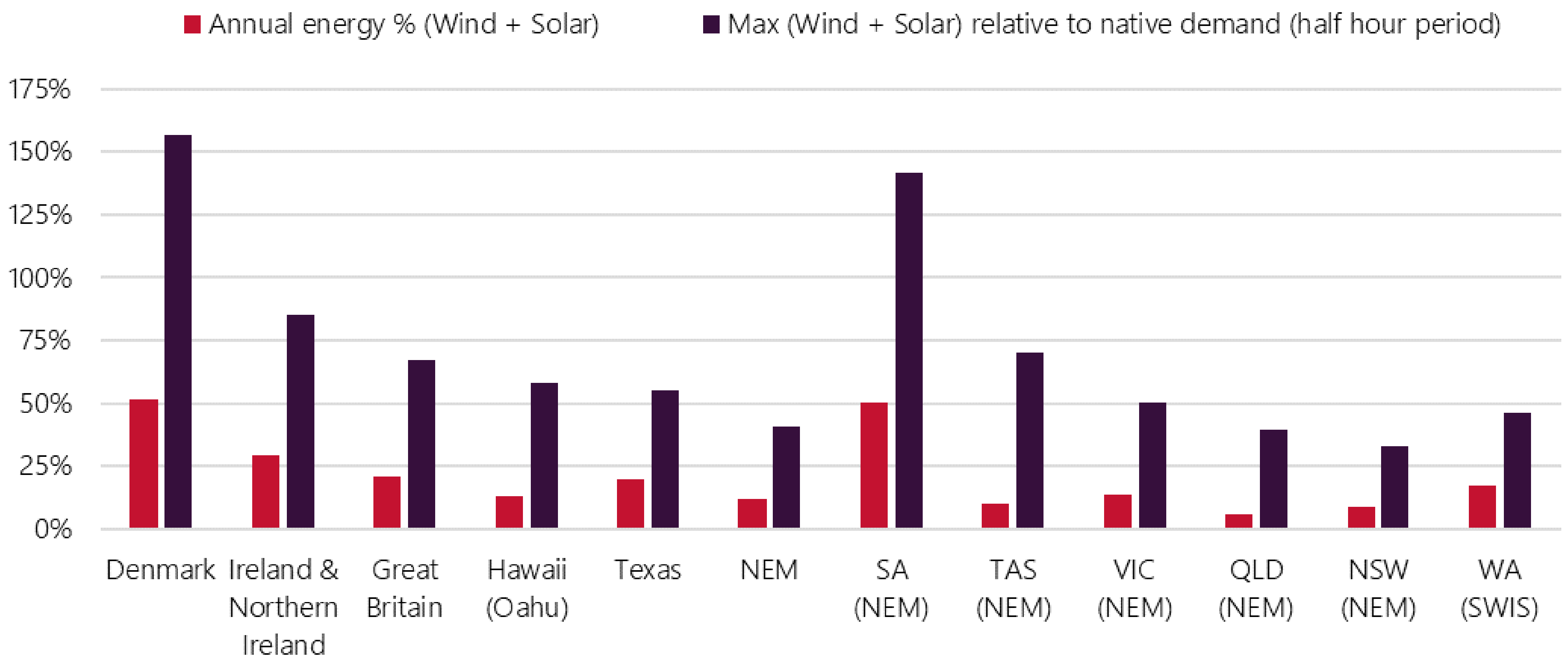
How does Australia compare?

Large international power systems operating with high instantaneous penetrations of wind and solar generation



Source: AEMO, Maintaining Power System Security with High Penetrations of Wind and Solar Generation, October 2019

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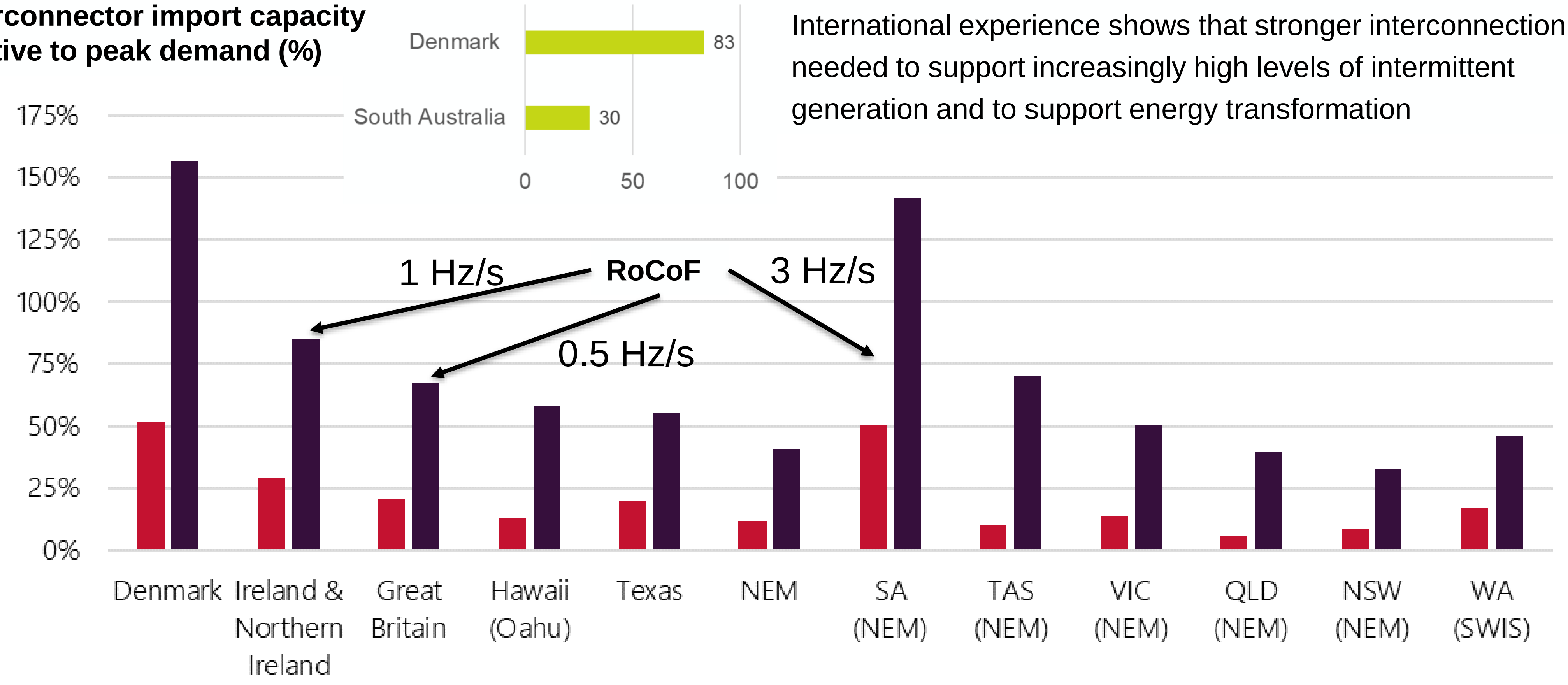
Focus on South Australia

New challenges are emerging from the combination of high levels of intermittent generation and a relatively isolated and weakly interconnected system

Interconnector import capacity relative to peak demand (%)



International experience shows that stronger interconnection is needed to support increasingly high levels of intermittent generation and to support energy transformation

Source: AEMO, Maintaining Power System Security with High Penetrations of Wind and Solar Generation, October 2019

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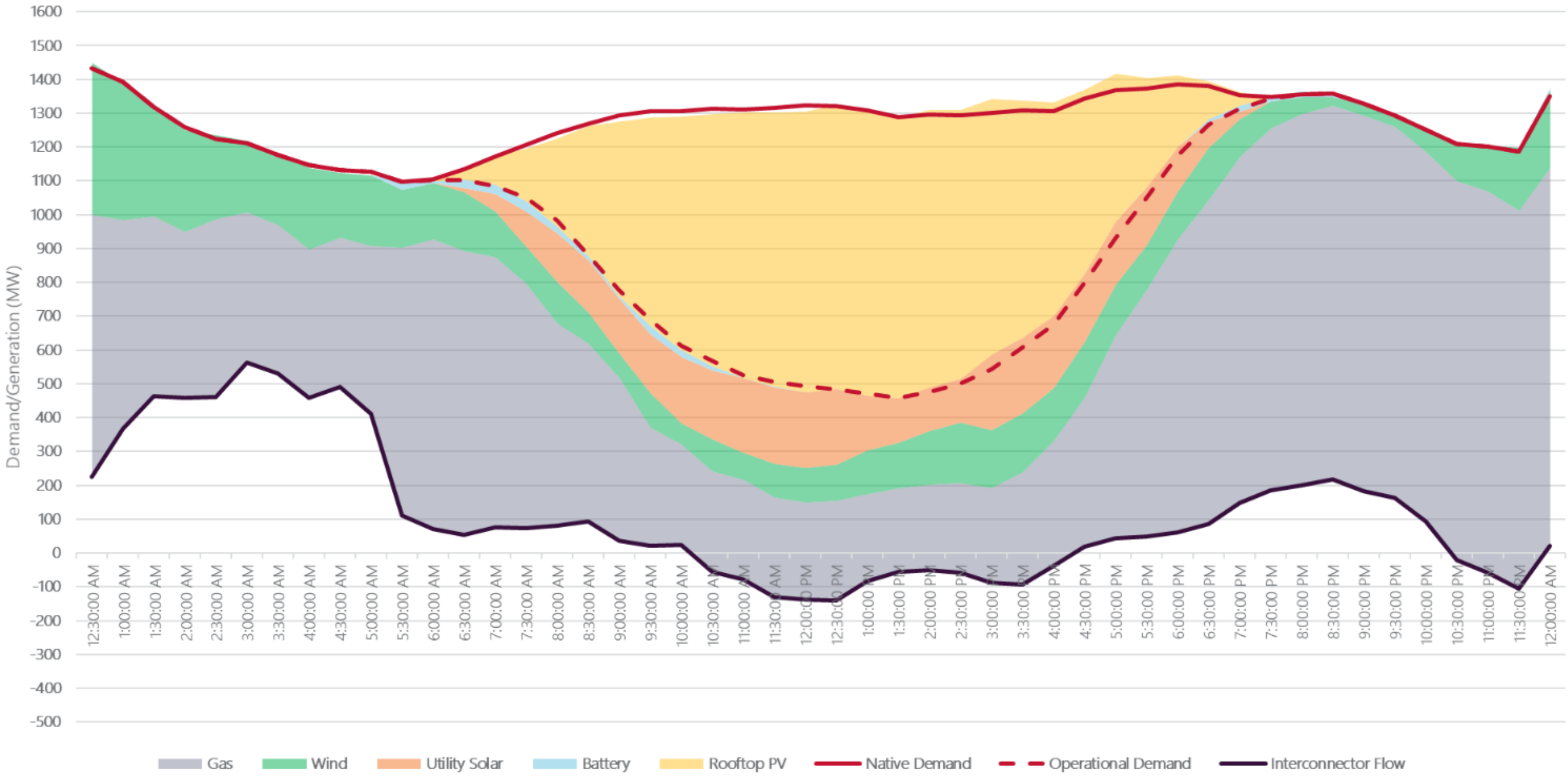
Minimum demand in South Australia decreasing

Record low SA electricity demand set on Sunday, 10 Nov 2019

- Minimum demand has been decreasing between 70-90 MW per annum in recent years
- Distributed solar PV is decreasing minimum demand
  - ☐ Current contribution at minimum demand times is about 800 MW
  - ☐ This generation is non-scheduled (not controllable) and still growing strong

Source: AEMO, Energy Live, 11 November 2019



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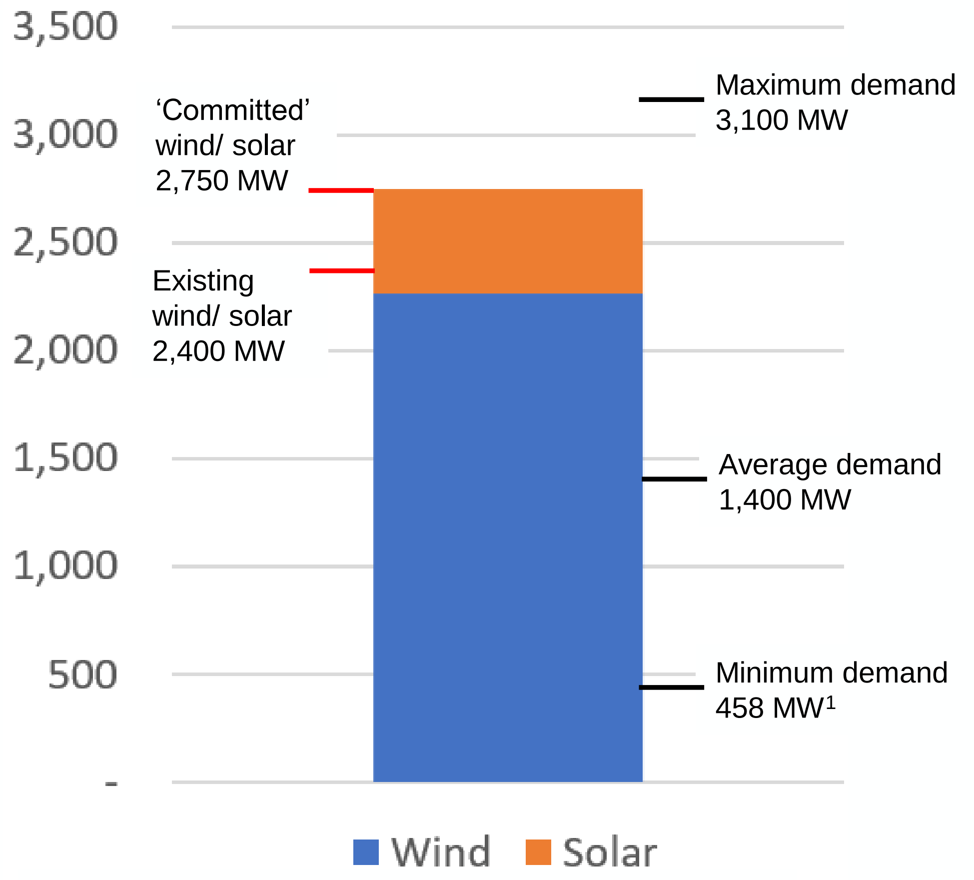
Changing Generation Mix

SA faces the prospect of zero (or even negative) grid demand at times

- The challenges seen in SA in relation to minimum levels of synchronous generation are a first in any large scale power system in the world…
- Current wind/ solar generation capacity is…
  - About 170% of average demand
  - > 500% of minimum demand

Grid connected intermittent generation capacity relative to demand (MW)



1. Minimum demand includes contribution from embedded, distributed solar PV

Source: AEMO, Energy Live, 11 November 2019

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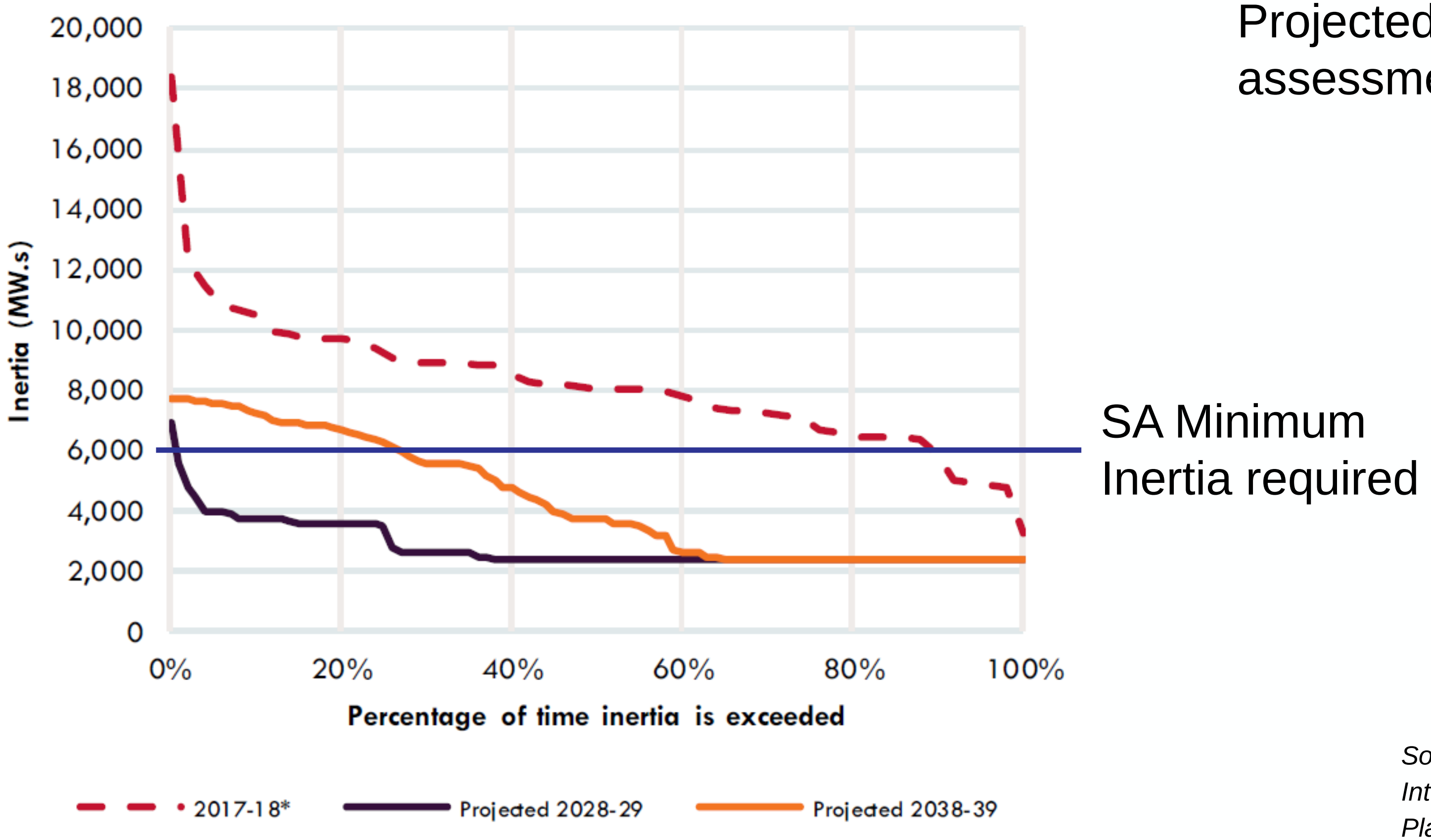
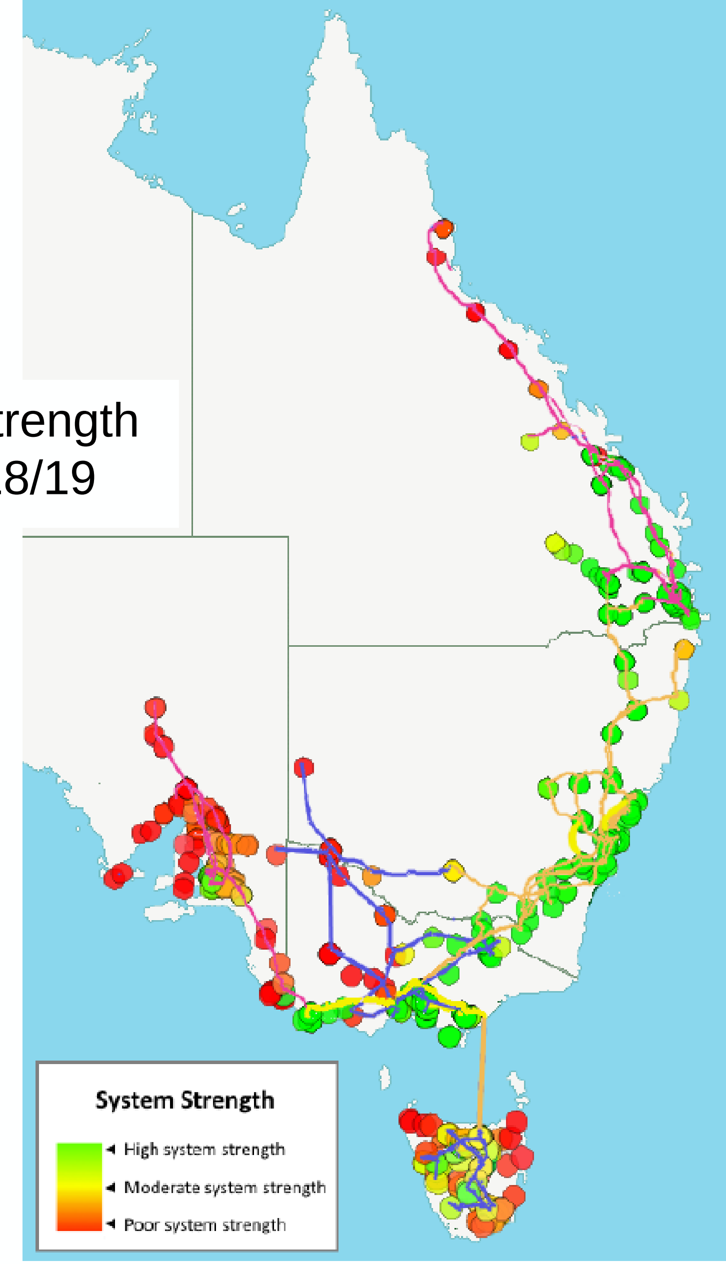
System strength and inertia

Low levels of system strength and inertia in SA – 2018 ISP

SA Inertia projections, Neutral scenario



Projected system strength assessment for 2018/19



Source: AEMO, Integrated System Plan, 2018

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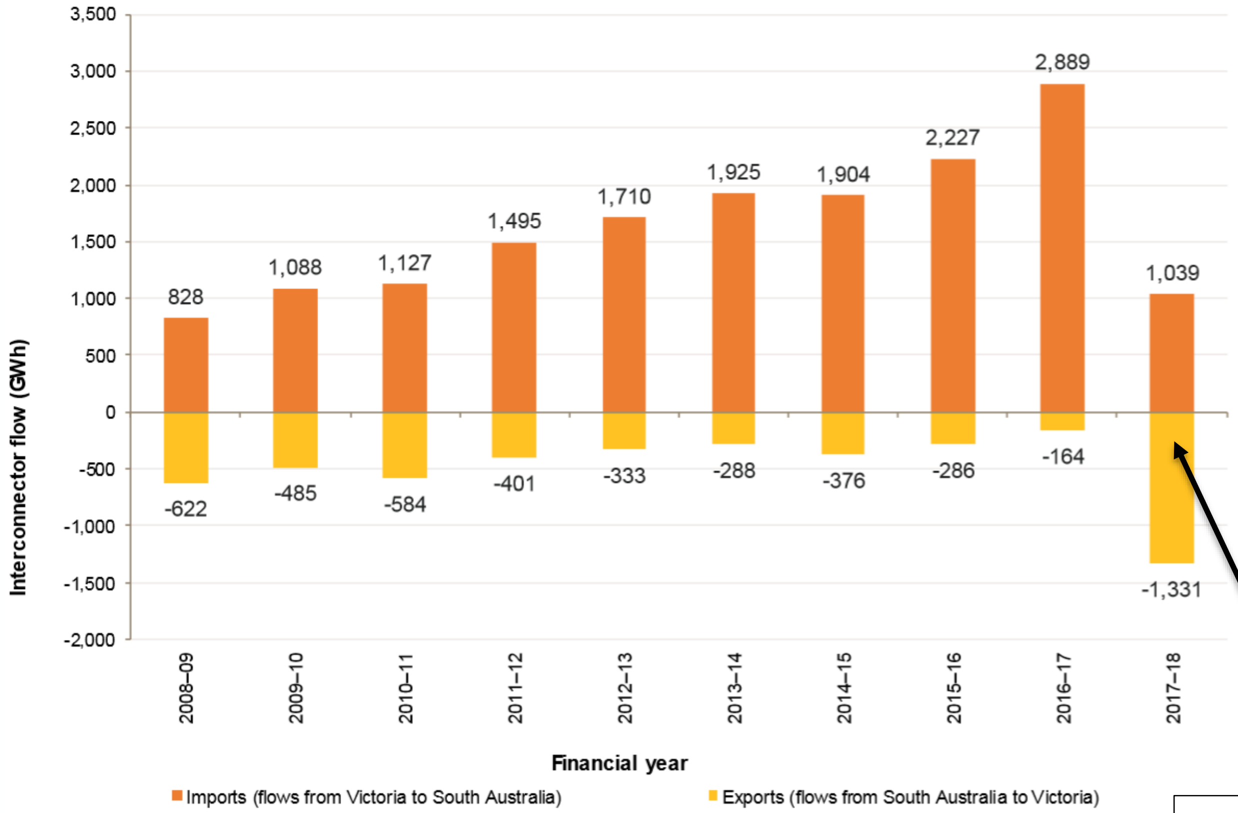
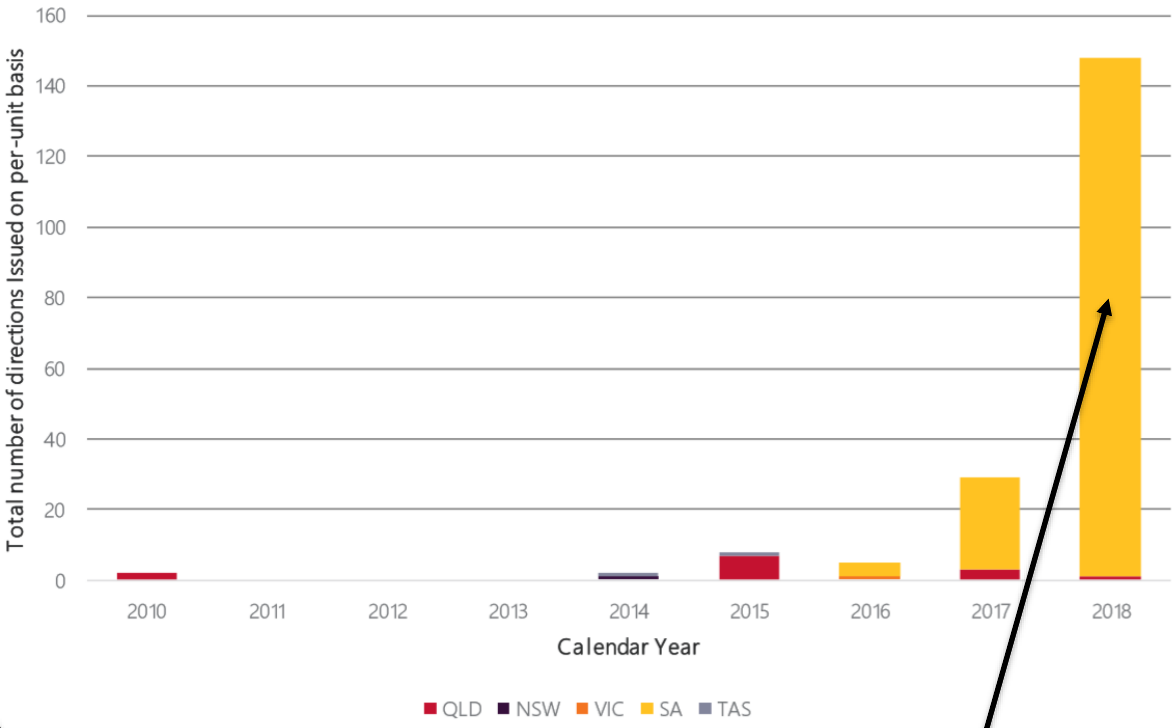
Operational experience

Total Heywood interconnector imports and exports



Source: AEMO, South Australian Electricity Report, 2018

Total number of directions issued by AEMO for the NEM on a per-unit basis (as at 23 September 2018)



- Hazelwood power station closure
- System strength directions for South Australia
- Additional renewable generation in South Australia

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System Strength Solution

- Four synchronous condensers:
  - Two each at Davenport and Robertstown
  - Including high inertia flywheels
- AER approved economic evaluation
- AEMO approved technical solution
- Meets system strength gap
- Meets synchronous inertia shortfall (i.e. 4,400 MWs)
- Lifts system strength limit of the non-synchronous generation in SA to approximately 2000 MW

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Dalrymple ESCRI-SA BESS Business Case & Commercial Arrangements

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Innovation Awards

Energy Networks Australia:
2019 Industry Innovation Award

South Australia Premier's Award:
2019 Energy Sector - Transformational Innovation

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Project development history

ESCRI-SA Phase 1 – Business Case exploration

November 2014 to December 2015	Examined regulatory, commercial, technology and technical issues and publicly reported results – Business case for a 10 MW, 20 MWh battery was poor

ESCRI-SA Phase 2 – Expression of Interest for delivery phase

March to July 2016	30 MW, 8 MWh battery for targeting fast frequency response, but unable to monetise – Benefits included increased Heywood Interconnector import capability, reduced unserved energy, and market price cap trading. Business case improved

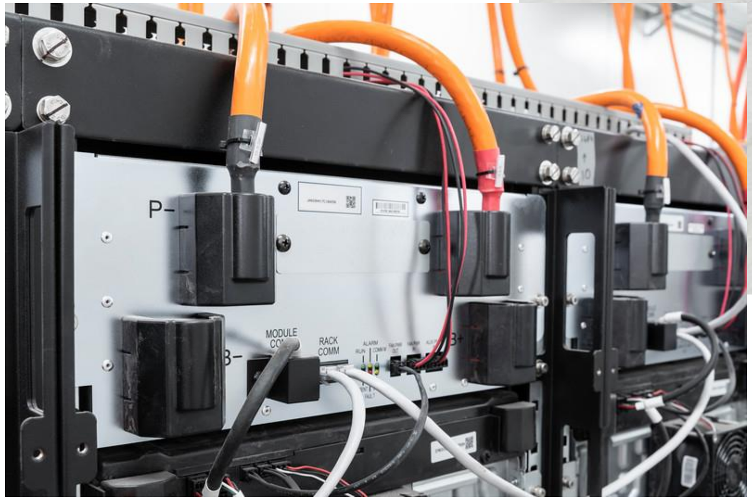
ESCRI-SA Phase 2 – Full Application for delivery phase

January to March 2017	Same 30MW, 8MWh battery but with fast frequency response system security benefit monetised (reducing Heywood Interconnector import constraints) and ancillary services revenue (FCAS) added. ARENA grant funding of up to $12m required.

Project Milestones

Key deliverable	Target date
Financial close and contract award	21 September 2017
Energisation of battery system	30 April 2018
Commissioning and compliance tests of battery system	July – October 2018
Handover for commercial operation to AGL Energy	14 December 2018
ARENA reporting and knowledge sharing period ends (two years)	Q1 2021

Batteries



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Project scope and objectives

Scope: Nominal 30 MW, 8 MWh lithium-ion battery

1. Gain practical experience and learnings from the application of grid connected utility scale battery storage as an enabler of large scale intermittent renewable energy on an interconnected system

2. Demonstrate that utility scale battery storage can effectively provide network reliability and security services alongside market services

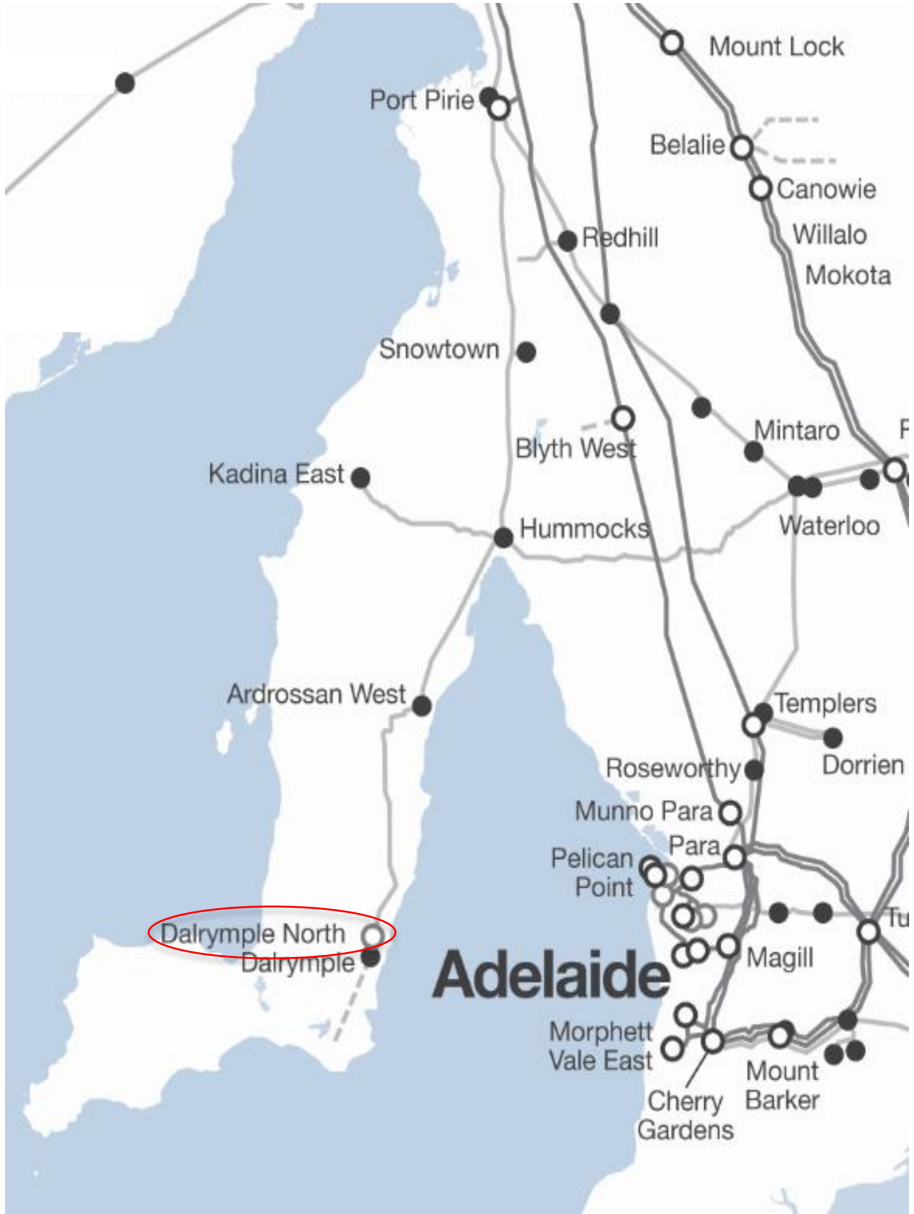
3. Demonstrate network ownership of battery storage and commercial appropriate separation of provision of regulated services and competitive energy market services

4. Demonstrate “seamless” islanded operation with 100% renewable generation following transmission outages

Location

Site selected to maximise value from battery

- Connection at 33 kV at Dalrymple substation on Yorke Peninsula – land available
- Opportunity to reduce expected unserved energy under islanding conditions (max demand is about 8 MW but on average need about 3 MW for 2 hours)
- Site is close to the 91 MW Wattle Point Wind Farm – provides opportunity for battery to support islanded operation with the wind farm and 2 MW of local rooftop solar, following network outages



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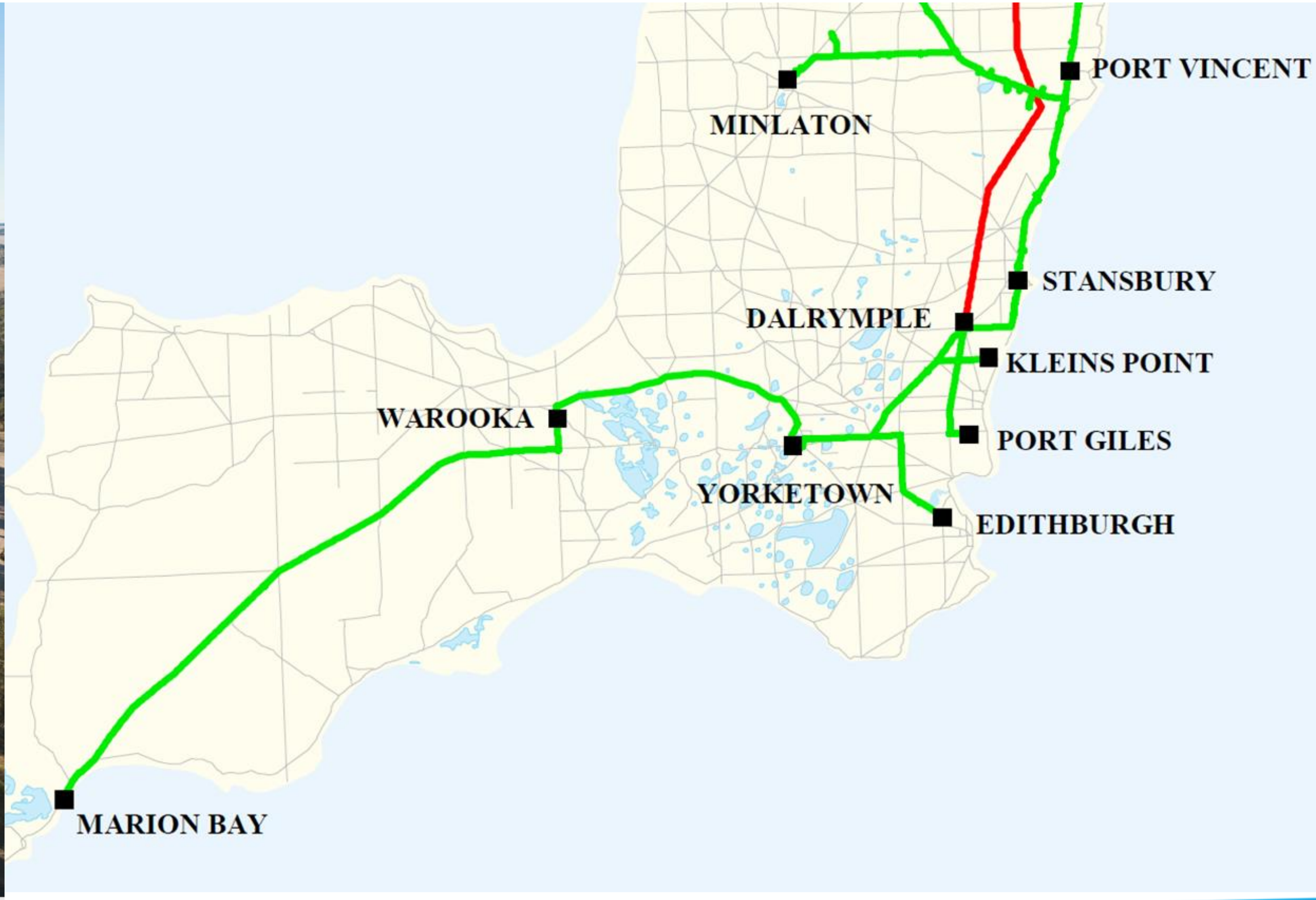
Location


PORT VINCENT
MINLATON
STANSBURY
DALRYMPLE
KLEINS POINT
WAROOKA
PORT GILES
YORKETOWN
EDITHBURGH
MARION BAY

BESS provides a range of services

Benefits used (in bold below) in business case depend on specific application

Component	Service / Benefit	BESS	ESCRI-SA application
Energy	Cap trading	✓	**Market service**
	Energy time shifting	✓	AGL may use
	Energy security	✓	Not applicable
Network reliability / support	USE reduction	✓	**Regulated service**
	Capital deferral	✓	Not applicable
	Voltage & reactive control	✓	Especially in island operation
Frequency control	Short term spinning reserve	✓	Not applicable
	FCAS	✓	**Market service**
	Fast Frequency Response	✓	**Regulated service**
Safety	Fault level	✓	Island operation
	Black start	✓	Island operation

Benefits / Revenue streams

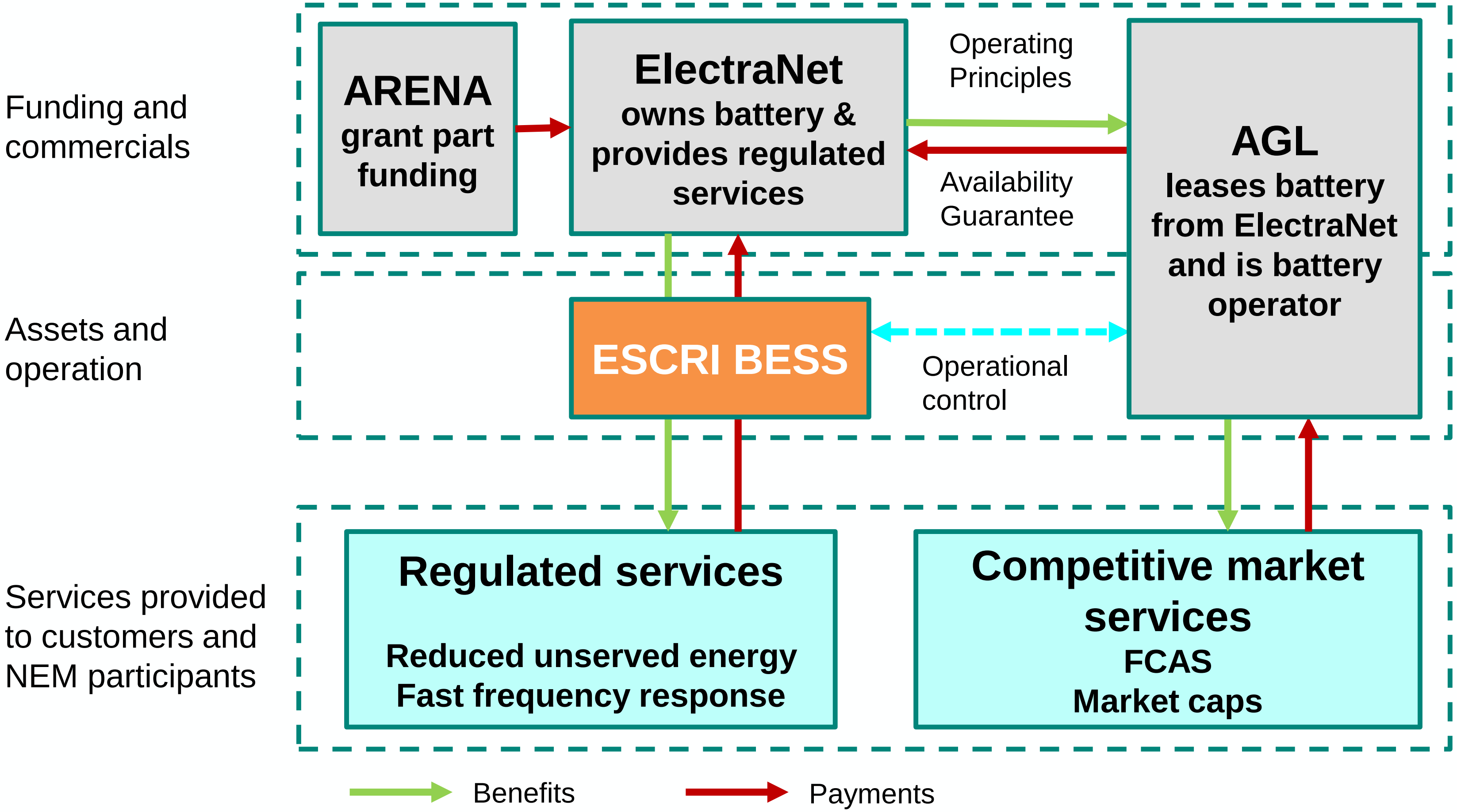
Providing both regulated and competitive market services

Regulated services[1] (ElectraNet)	Competitive market services (AGL Energy)
Fast frequency response Heywood Interconnector benefit	Ancillary services revenue (FCAS)
Reduced unserved energy benefit	Market cap trading

1. During project implementation the BESS was incorporated in the System Integrity Protection Scheme (SIPS), providing additional regulated benefits. The SIPS is an important emergency control scheme that significantly enhances power system security in South Australia (SA) for the non-credible loss of multiple generators in SA.

Commercial arrangements

Providing both regulated and competitive market services

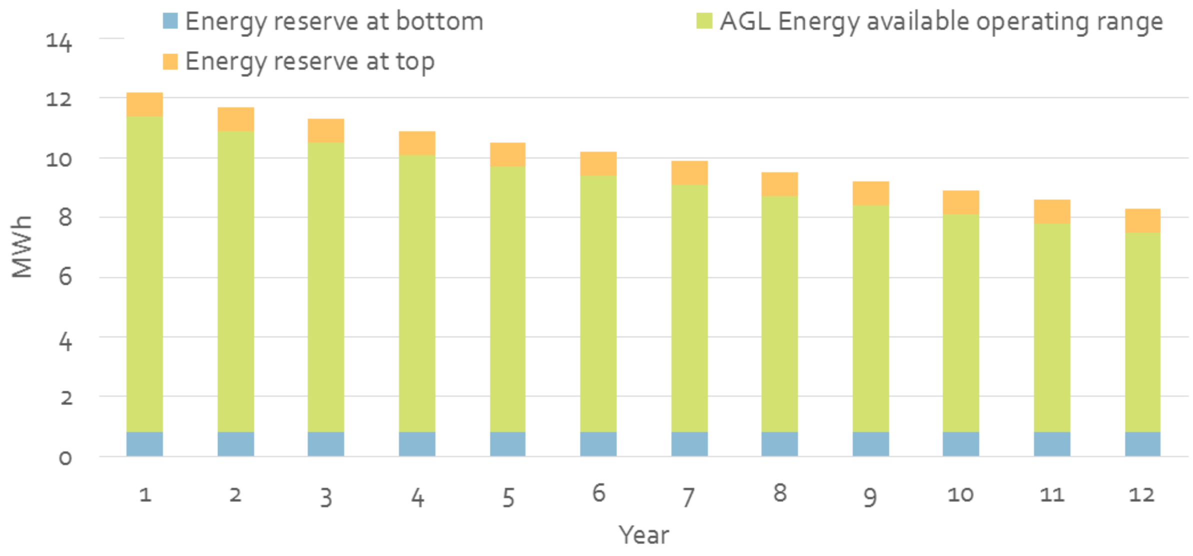


EPC/ D&C contract and 12-year maintenance agreement awarded to Consolidated Power Projects (CPP) following extensive procurement process

Operating principles

Battery Operating Agreement prioritises and protects regulated services

Level of charge at 33kV for non-regulated services	With Windfarm coordination	Without Windfarm coordination
Max allowable level of charge	X – 0.8 MWh	X
Min allowable level of charge	0.8 MWh	4.8 MWh



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Regulatory treatment – for this project at the time

- Acceptance of a service based approach to regulation
- Create a new battery registration category under the National Electricity Rules that picks up relevant generation registration and charging/ discharging requirements so AEMO can manage constraints in market systems
- Current requirement to register as a scheduled load as well as a scheduled generator raises TUOS implications, jurisdictional licensing obligations etc.
- AER approved cost allocation approach, but AER suggested further work is required to develop a more general cost allocation approach for assets providing both regulated and competitive energy market services

Regulated financials[1]

Benefits to regulated customers exceed costs

Estimated cost ands benefits to regulated customers	PV ($m)
Prescribed costs of project (including operating costs)	(6.3)
Benefits of reduced unserved energy	5.3
Benefits of reduced interconnector constraints	8.2
Net benefits to customers	7.2

Capital cost allocation ($m nominal)	Cost allocation[2]
Total capital cost	**30.0**
ARENA grant funding	12.0
Capital cost offsets (in-kind contributions and R&D tax credits)	1.6
Non-regulated component (Battery operator lease)	10.6
Prescribed component	5.8

1. All figures approximate only
2. Direct attribution method applied

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ESCRI-SA BESS – Dalrymple North

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Dalrymple ESCRI-SA BESS Project Design, Registration & Implementation

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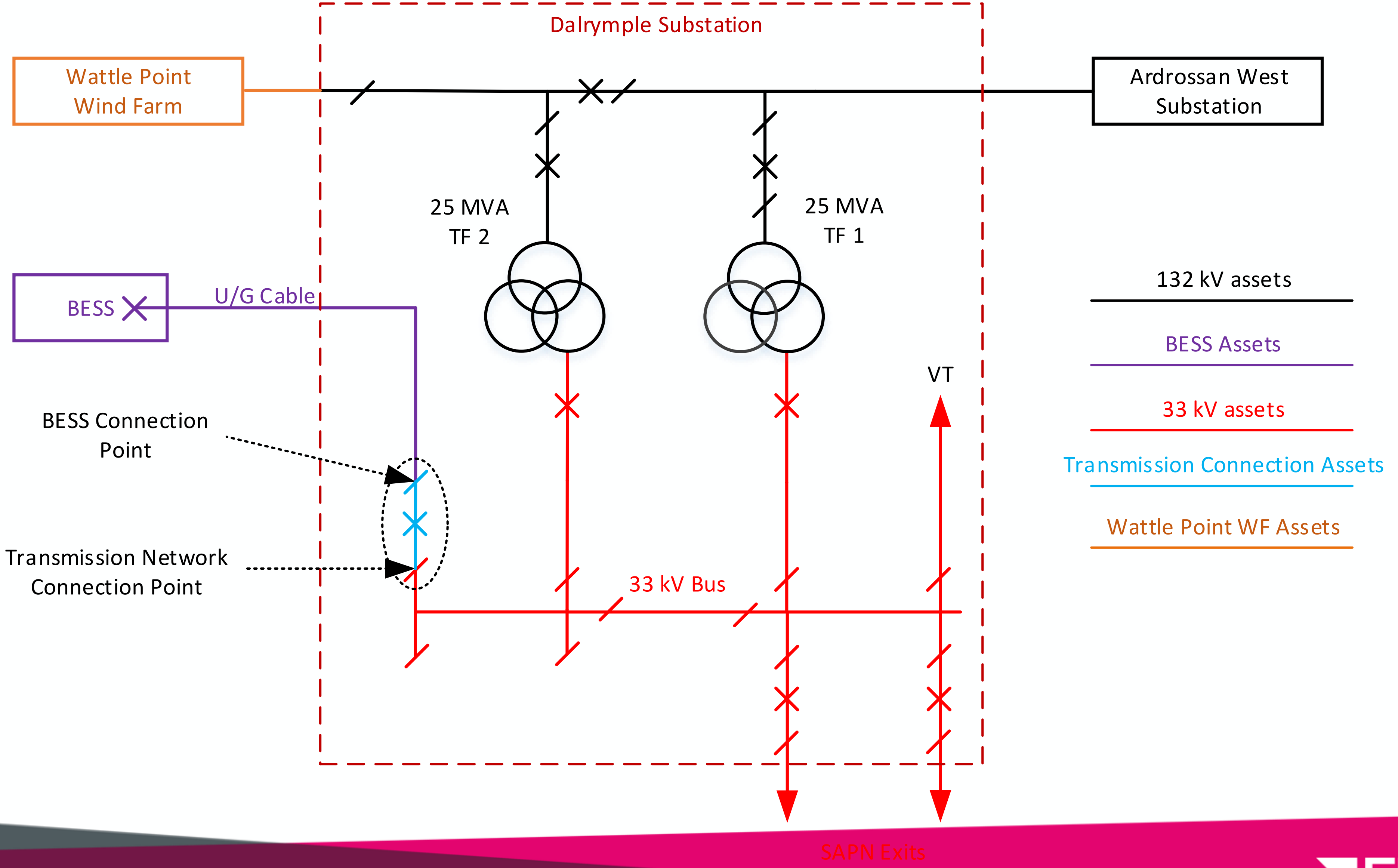
Dalrymple Substation Connection



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Site works – End 2017 to Early 2018

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Modelling and GPS

- Developing compliant models for equipment introduced for the first time in the NEM is complex and time consuming
- Start process early, engage early and regularly with all participants, including AEMO
- The requirements of the grid forming mode (seamless islanding) formed the fundamental basis of development – this in some instances constrained grid connected modes, e.g. speed of response

Licensing and Registration

- Remember jurisdictional requirements (these vary by state)
- National Grid Metering requirements
- Managing around set schedules:
  - ❑ ESCOSA board requires one month to review before granting a license
  - ❑ AEMO registration committee
  - ❑ Review of commissioning test plan
- Early engagement and good collaboration went a long way!

ESCRI-SA

PCS100 BESS Modules

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Performance parameters

- Inconsistent understanding of the FCAS technical functionality and market requirements between the OEM (ABB) and BESS operator (AGL), in particular Contingency FCAS
- Overload capability
- Standby losses
- Battery life and cycle counts:
  - Impact of charging rates
  - Battery rest period requirements
  - Improve definition of a cycle

Islanded operation

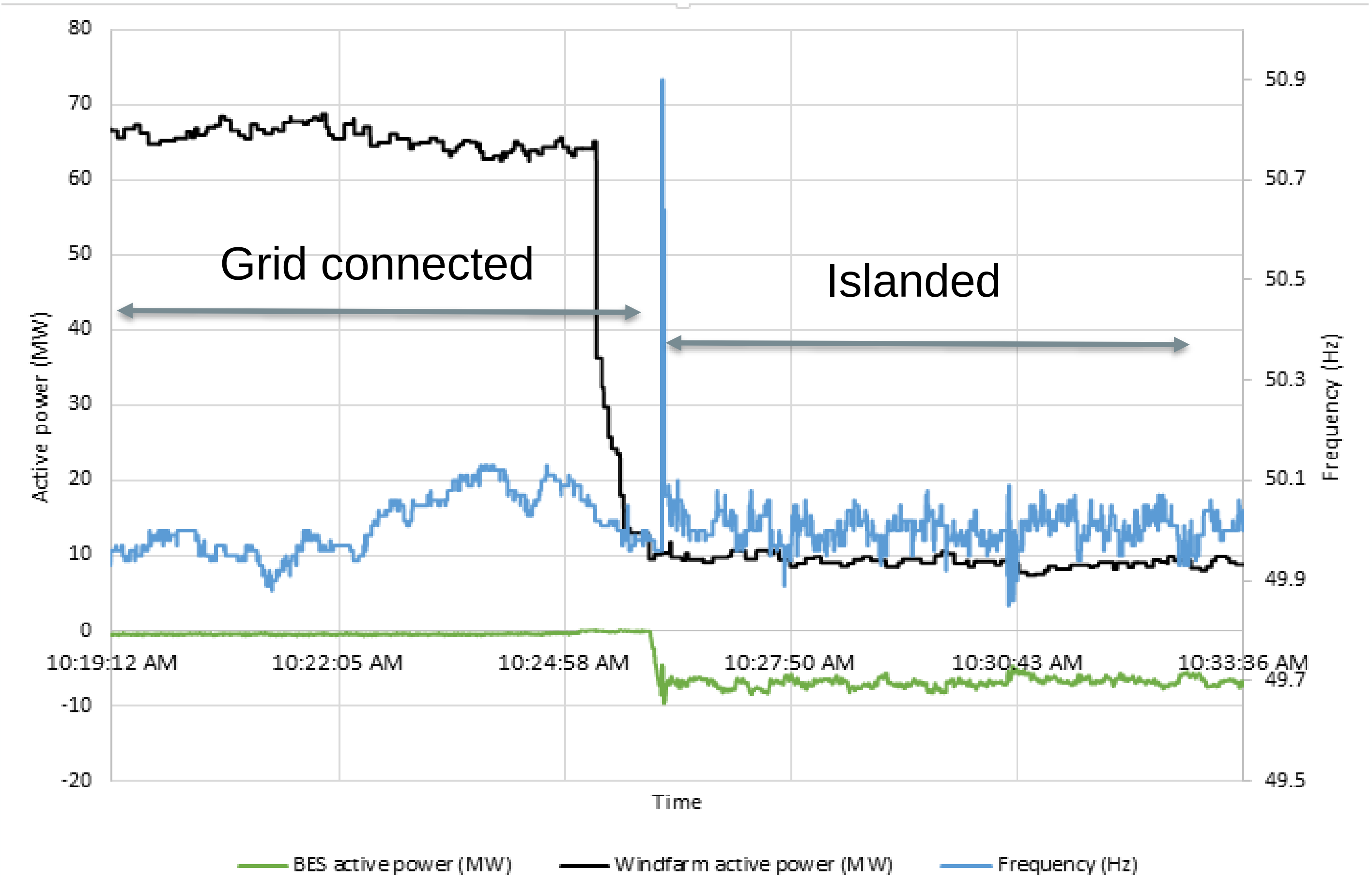
ESCRI-SA BESS manages transition and then controls the island

- Islanding detection
  - ❑ Topology-based Islanding Detection Scheme (IDS)
  - ❑ Anti-islanding protection to disconnect BESS under certain conditions
- Transitioning to an island
  - ❑ Disconnect 80% of Wattle Point wind farm (operated by AGL)
- Islanded operation with BESS as island grid master control:
  - ❑ Voltage and frequency reference
  - ❑ Wind farm generation dispatch – to manage BESS charge level
  - ❑ Fault current provision & distribution protection
  - ❑ Black start (if required)

Performance Tests & R2 Model Validation

- Commissioning tests
- R2 Tests
  - Offline tests
  - Online tests
  - Online Compliance Monitoring Program
- A few example test results follow…

Planned islanding test with windfarm and distribution load



Frequency went up to 50.8 Hz for short amount of time

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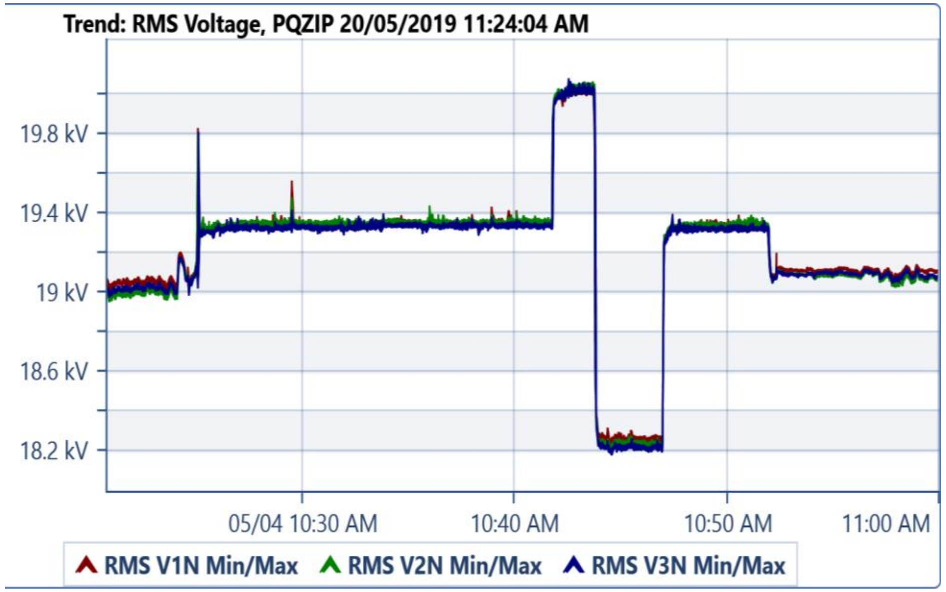
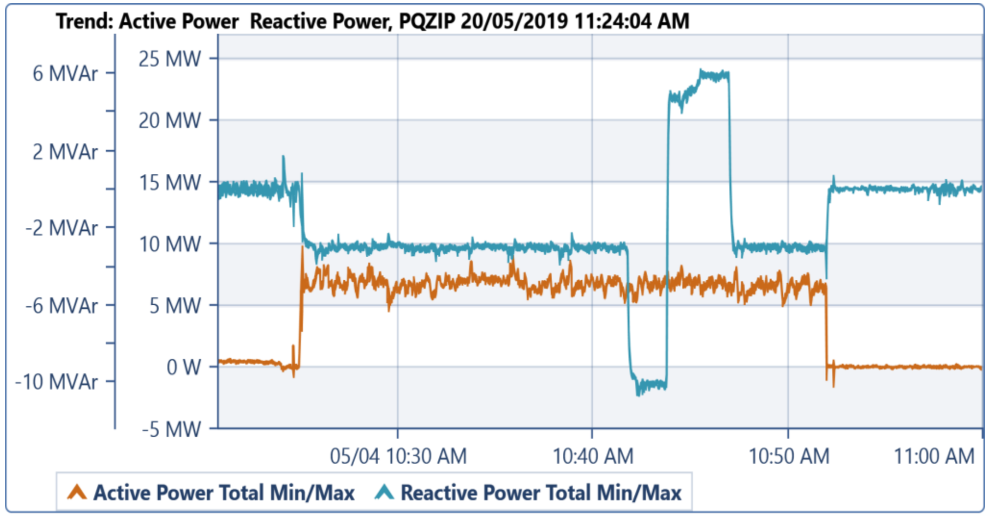
Voltage and reactive control test

Voltage changed in islanded network from:
- 1 to 1.05 pu
- 1 to 0.95 pu

Active and reactive power responses are completely decoupled

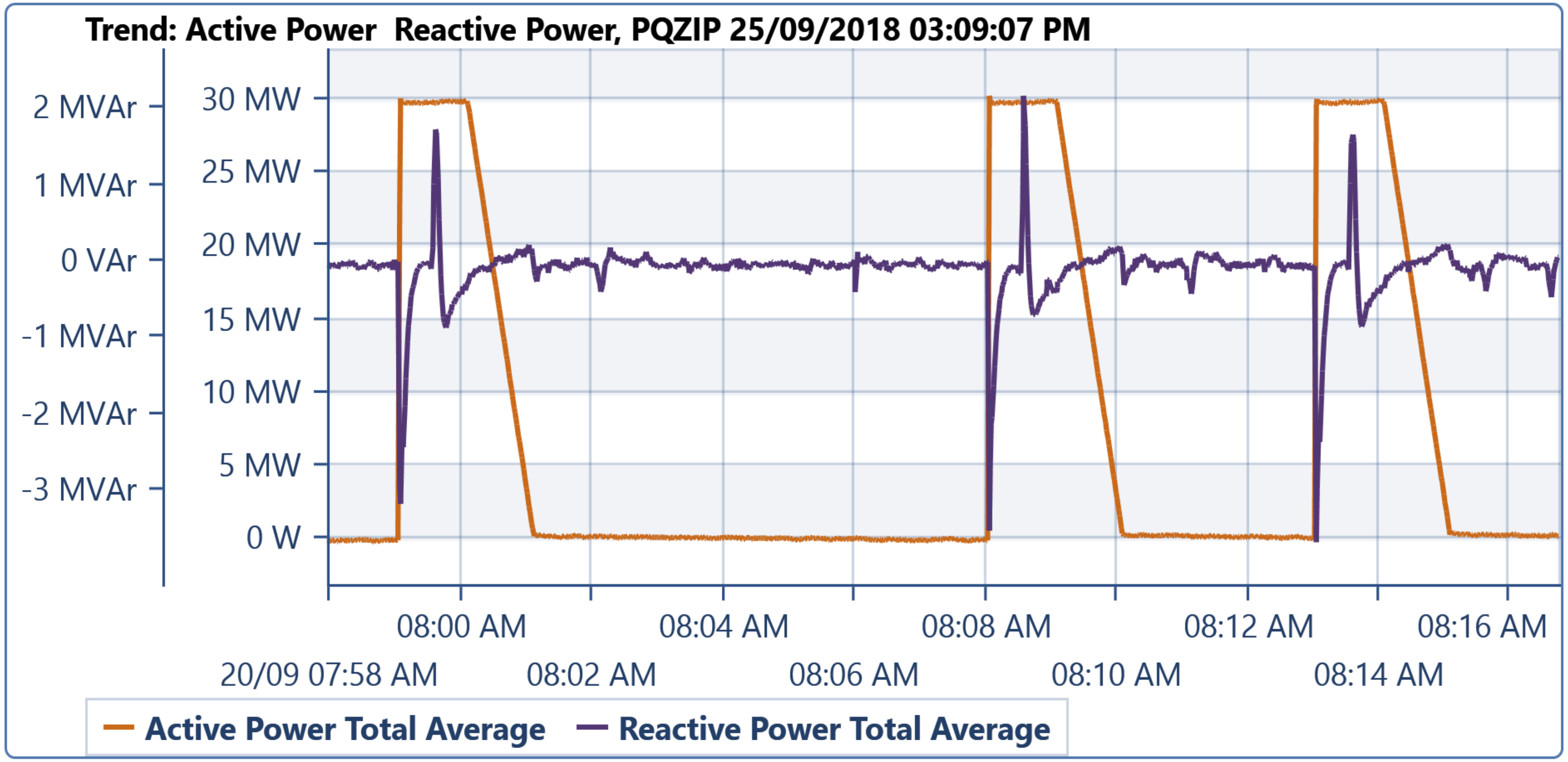


Voltage step change in an islanded network



BESS active and reactive power with voltage step change

Responses from SIPS test



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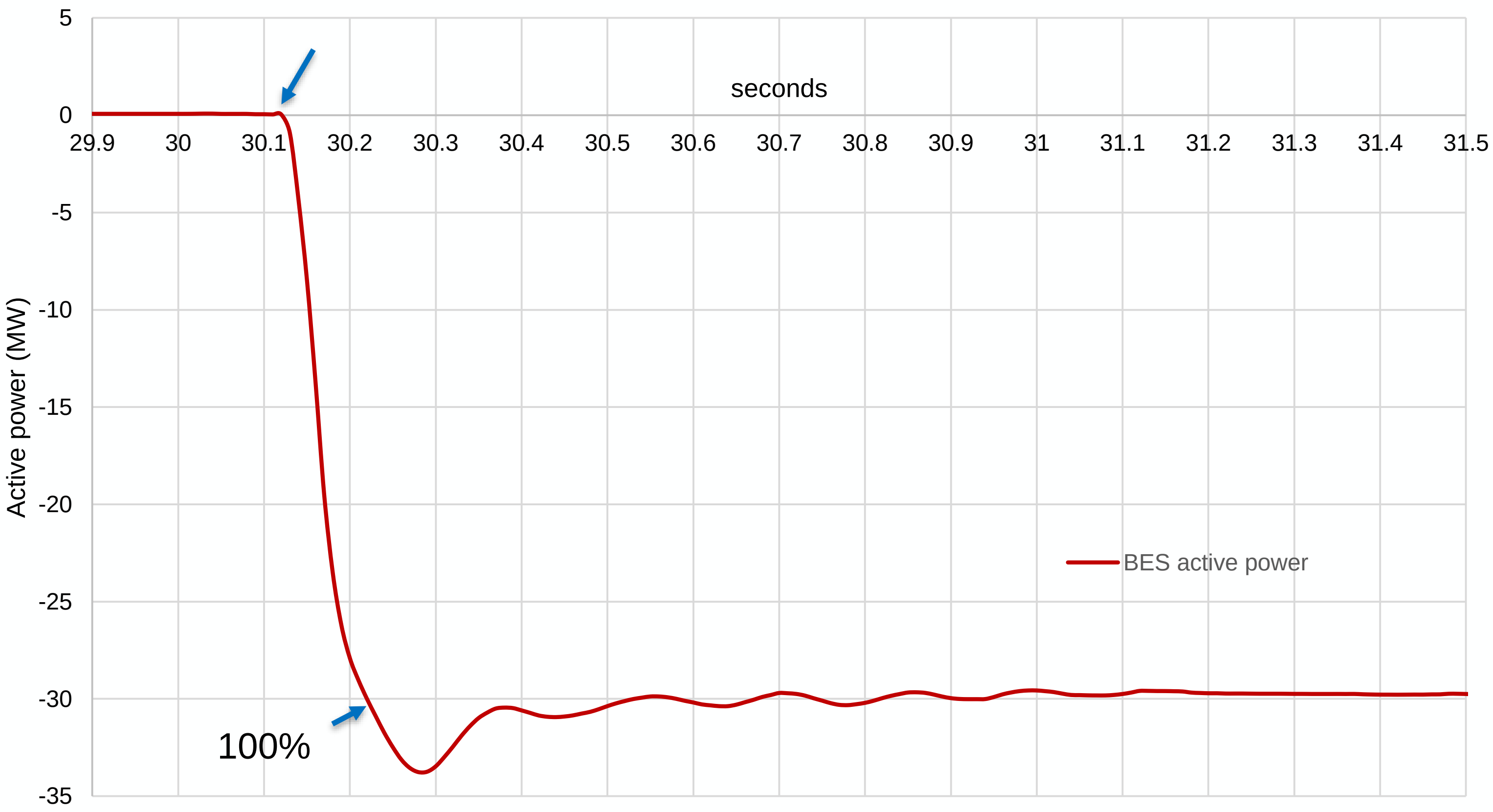
Detailed SIPS response



- Signal propagation delay from SEAS – 30 ms
- BESS control action – 120ms
- BESS response from 0 to 100% (discharge) - 100 ms

R2 Test Model Response Overlay

- +0.98 Power factor response in power factor control mode at 30 MW
- No change in MW output observed

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Dalrymple ESCRI-SA BESS Operational Experience

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Benefits / Revenue streams

Providing both regulated and competitive market services

Regulated services[1] (ElectraNet)	Competitive market services (AGL Energy)
Fast frequency response Heywood Interconnector benefit	Ancillary services revenue (FCAS)
Reduced unserved energy benefit	Market cap trading

1. During project implementation the BESS was incorporated in the System Integrity Protection Scheme (SIPS), providing additional regulated benefits. The SIPS is an important emergency control scheme that significantly enhances power system security in South Australia (SA) for the non-credible loss of multiple generators in SA.

Key Metrics – First 12 months of operation

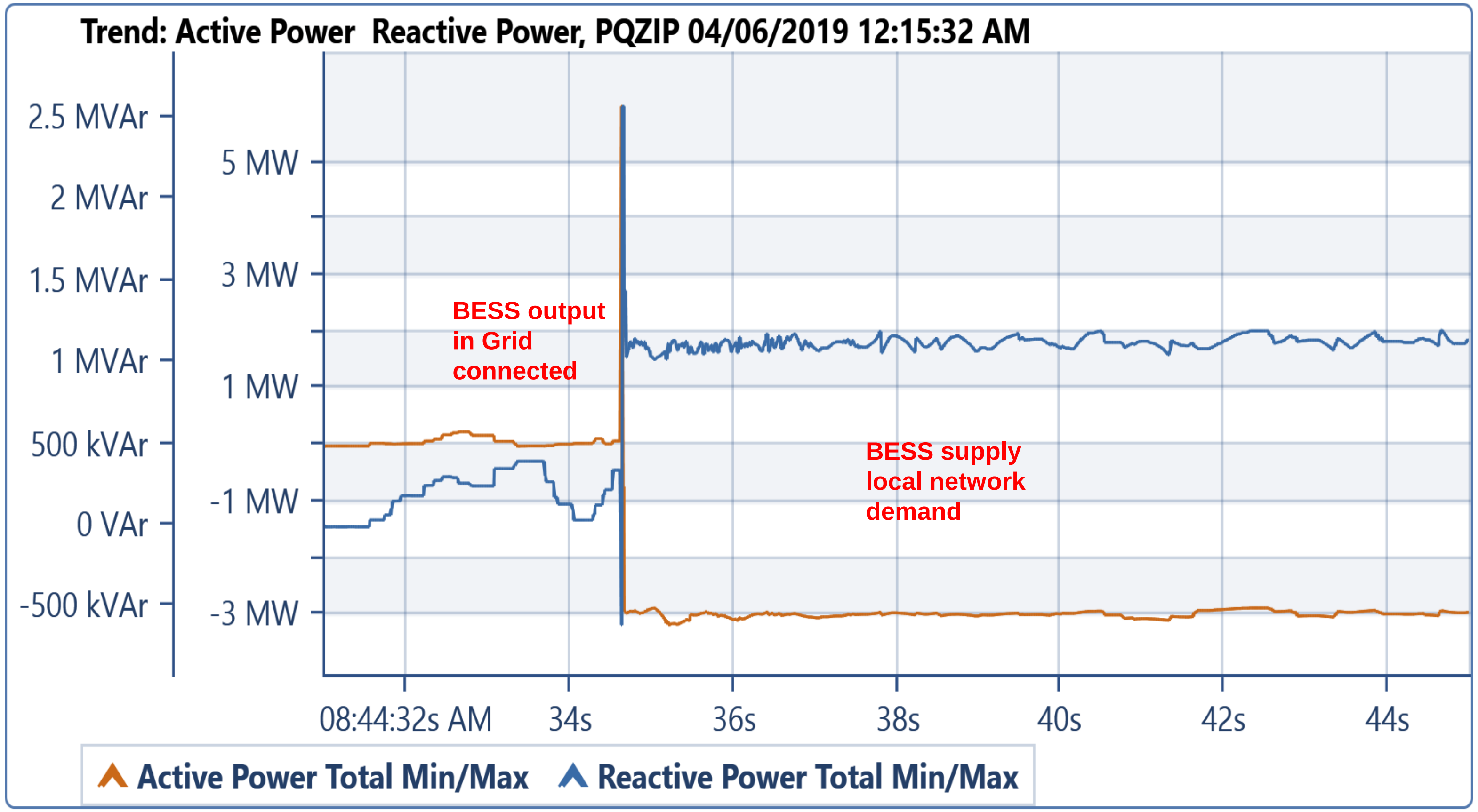
Key Performance Metric	Value for Reporting Period (14-12-2018 to 14-06-2019)	Value for reporting period (14-06-2019 to 14-12-2019)
Average BESS Availability	98.01%	97.35%
Total Energy Consumed	1,370 MWh	2,006 MWh
Total Energy Exported	160 MWh	768 MWh
Average auxiliary load and losses (% of 30 MW rated capacity)	2.19%	2.25%
Number of Charge and Discharge Cycles (per BOA definition)	2	4
BESS Charging Cost	$120,000	$101,000
BESS Discharge Revenue	$116,000	$97,000
FCAS Revenue	$1.33m	$3.73m

Reduction in Unserved Energy

- 29 March 2019 – Islanding Detection System (IDS) failure, incorrect detection and creation of island – No load lost
- 7 April 2019 - Planned outage for maintenance work to the line protection and isolators in the Ardrossan West and Hummocks substations.
- Dalrymple BESS was able to provide approximately seven hours of the required supply during a seven and a half hour outage.

Unplanned Islanding

- 29 March 2019 Incident
- BESS PQ load



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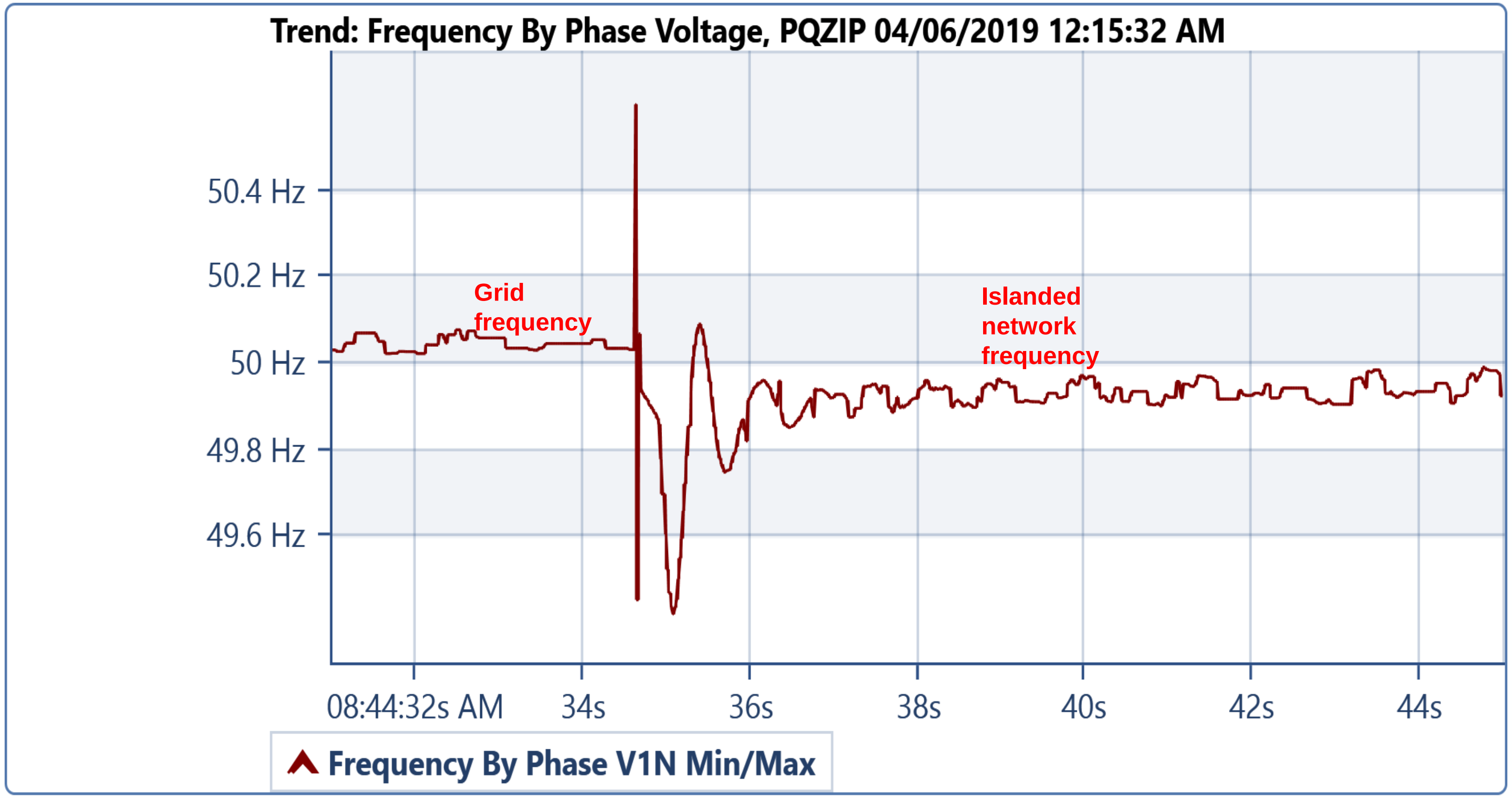
Unplanned Islanding

- 29 March 2019 Incident
- Islanded Network Frequency



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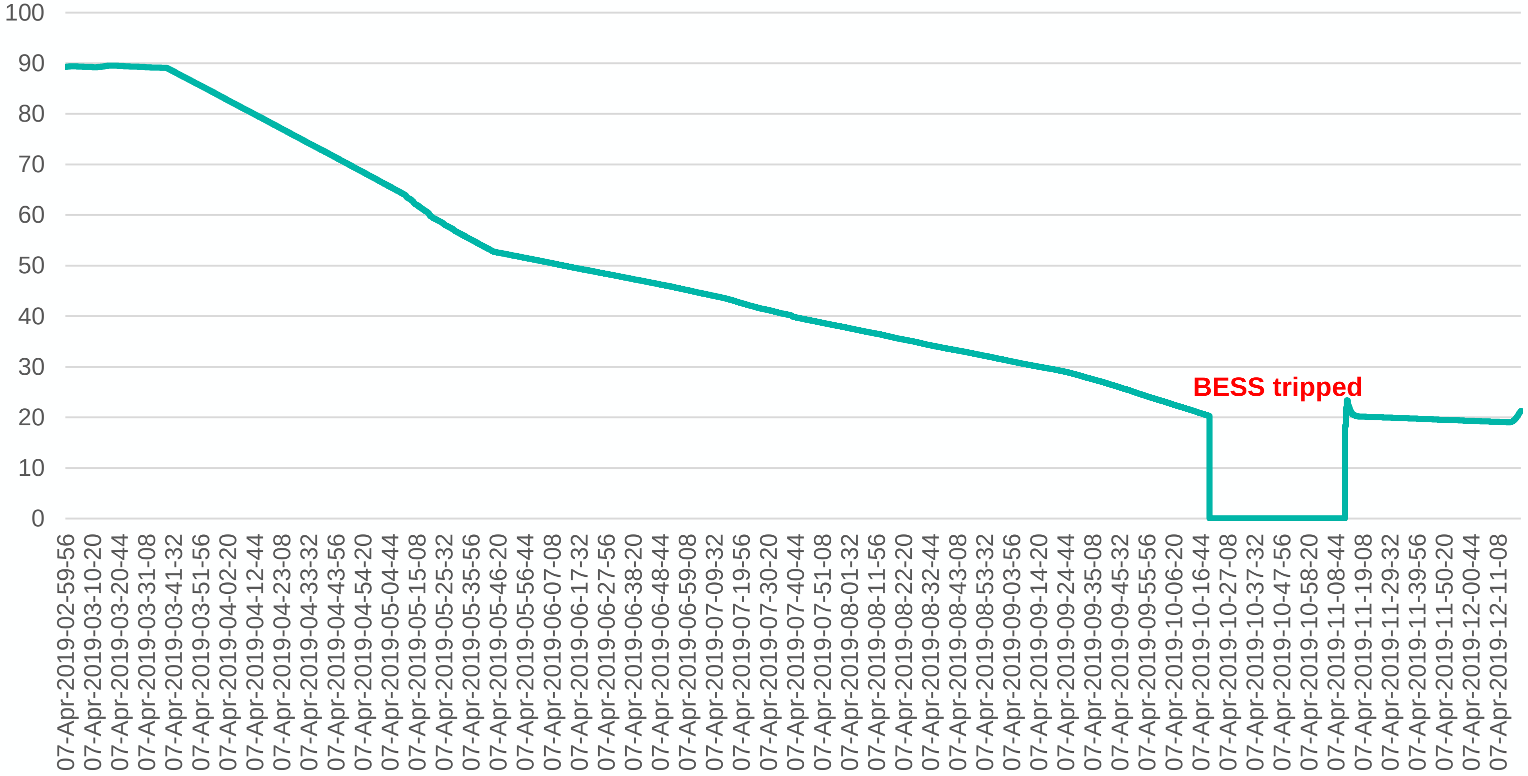
Planned Outage & Islanding

- 7 April 2019 Event
- BESS State of Charge (SOC)
- Note: SCADA reading zero when BESS tripped offline



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Transformers

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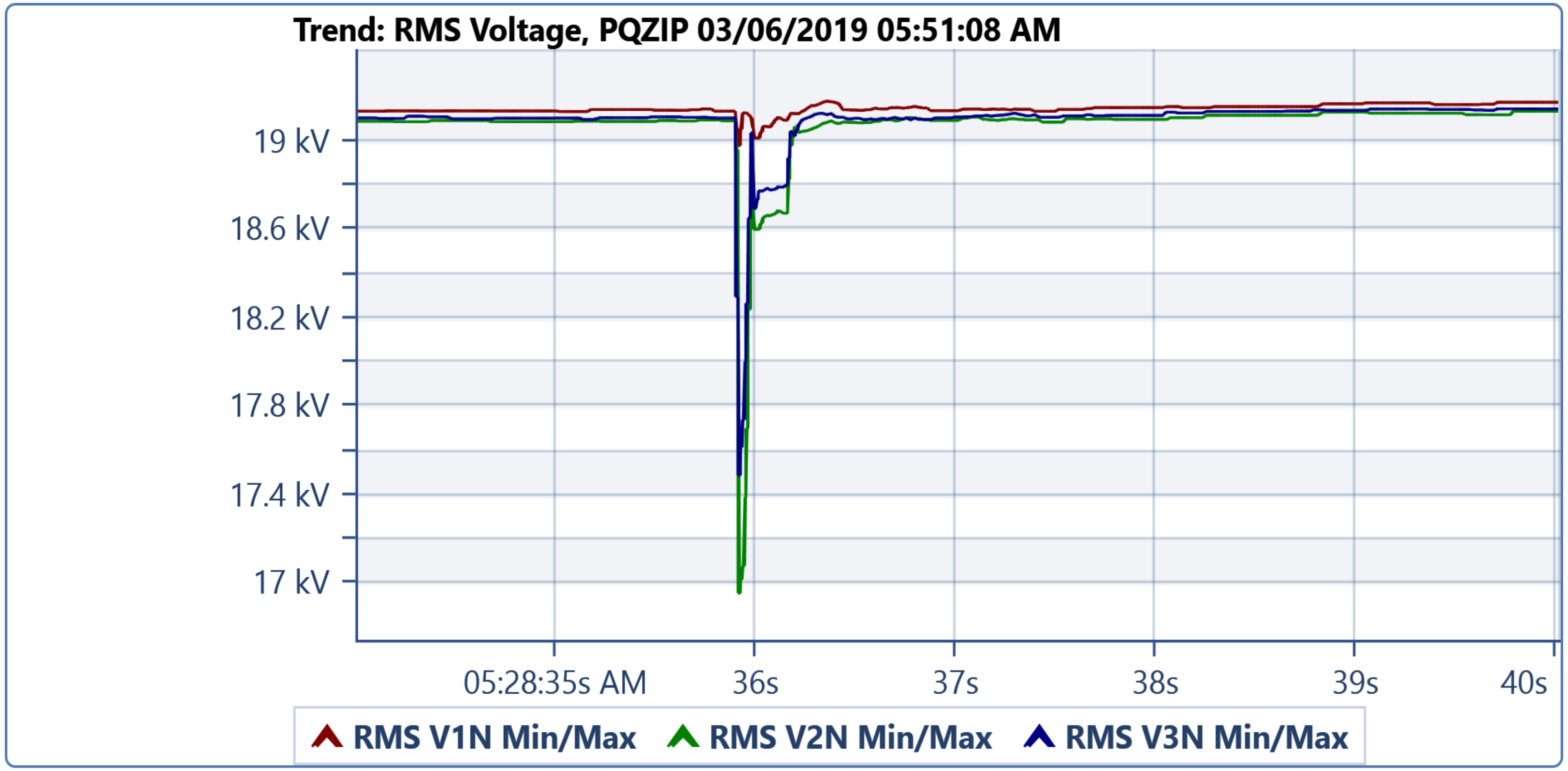
System Events – First 12 months

- 14 operational system events:
  - Eleven of these events were single-line trips or a frequency event
  - The other three events were more significant and led to the BESS supplying load to prevent or reduce the duration of an unserved energy event
- High-speed data recordings from Power System Performance Monitor (PSPM) confirmed the BESS successfully rode through the fault or responded as required

Fault ride through capability

- 2 Phase fault on the Mintaro – Waterloo 132 kV line at 5:29 on 4/3/2019
- Dalrymple BESS RMS Voltage



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Fault ride through capability

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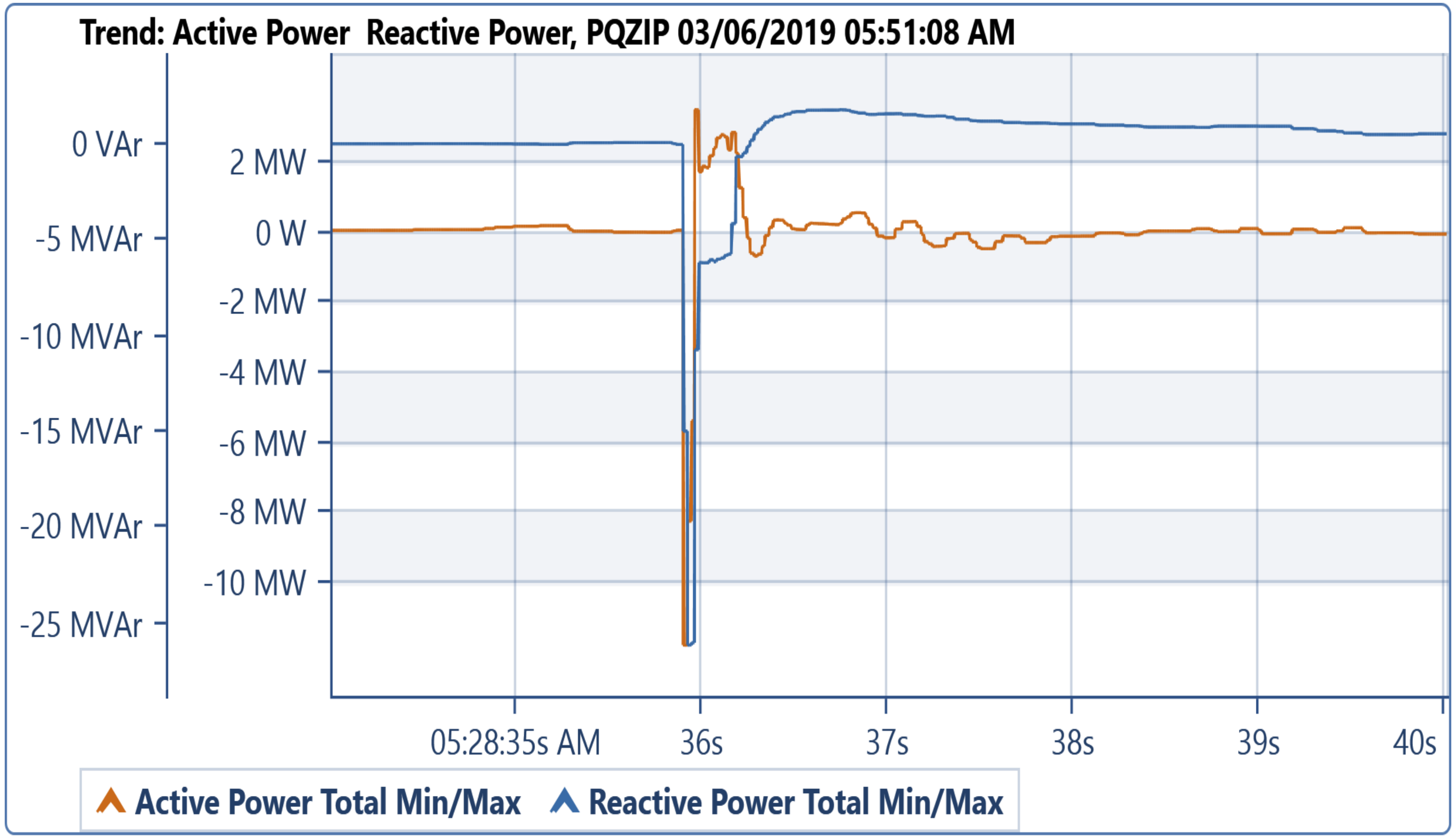

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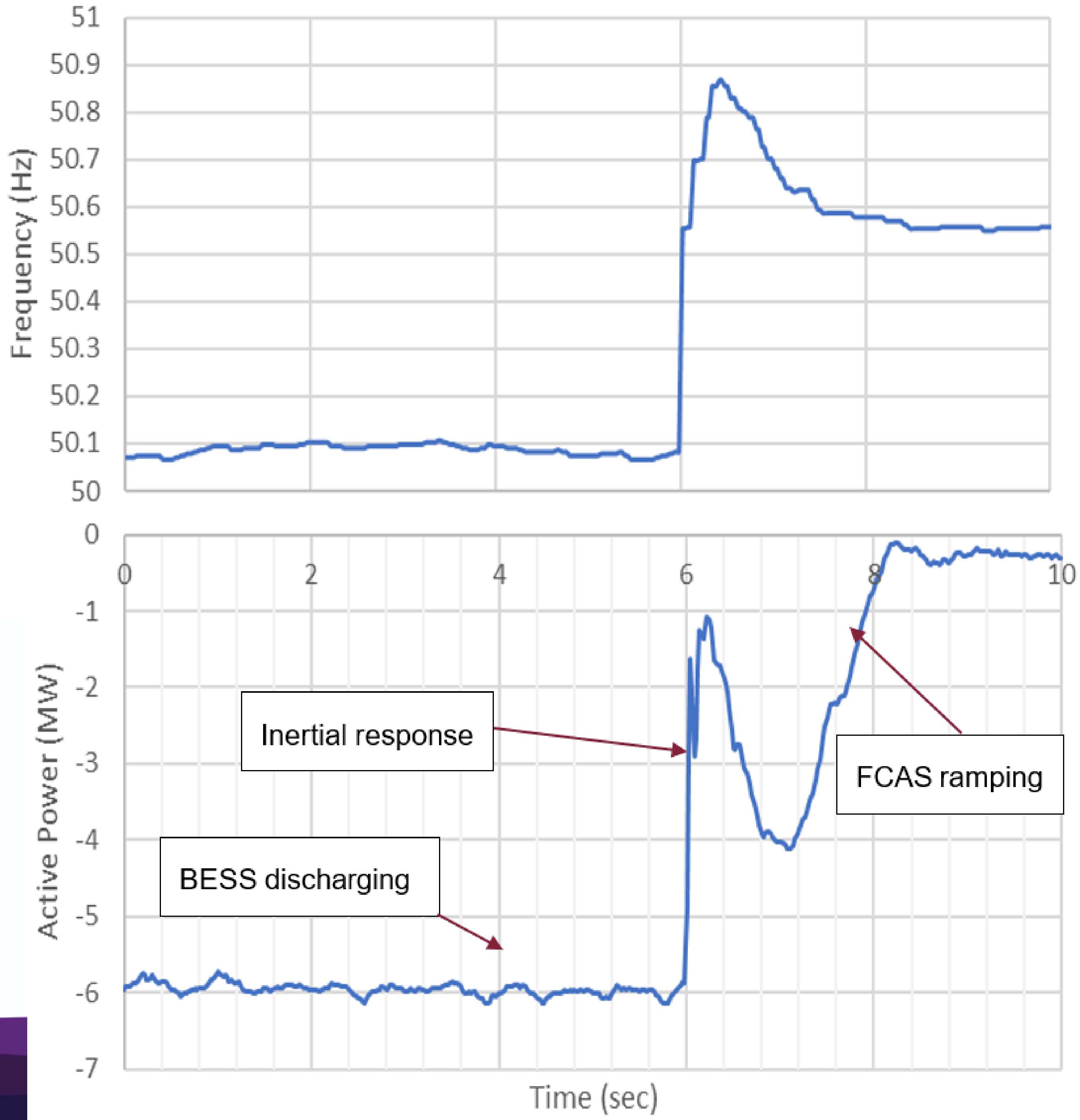
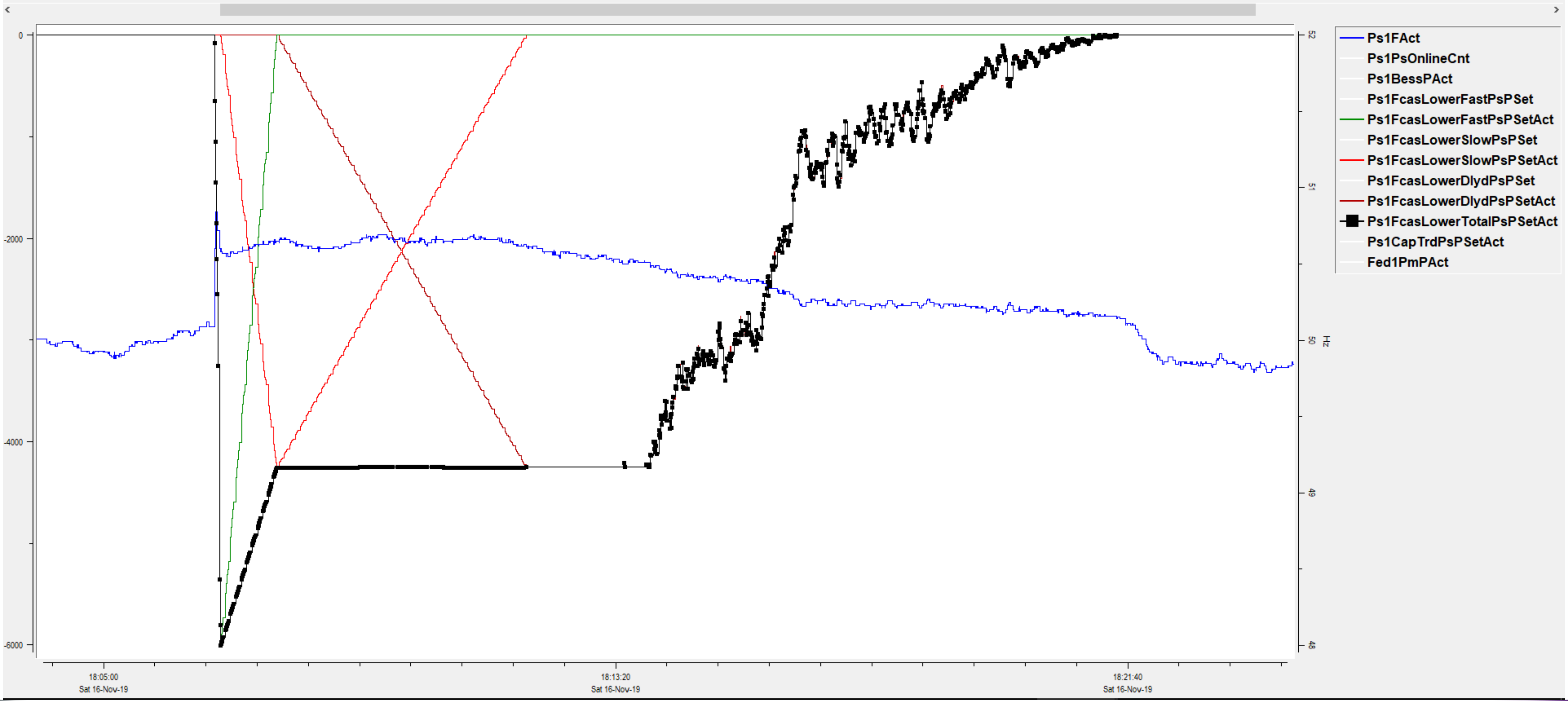
SA Islanding from NEM

- On 16 November 2019 at 18:06, the 500 kV double circuits between Heywood and Moorabool tripped
- The Heywood interconnection between South Australia and Victoria was lost and the SA transmission network transitioned to an islanded condition with SA exporting approximately 300 MW at the time of the event



FFR, FCAS & GPS



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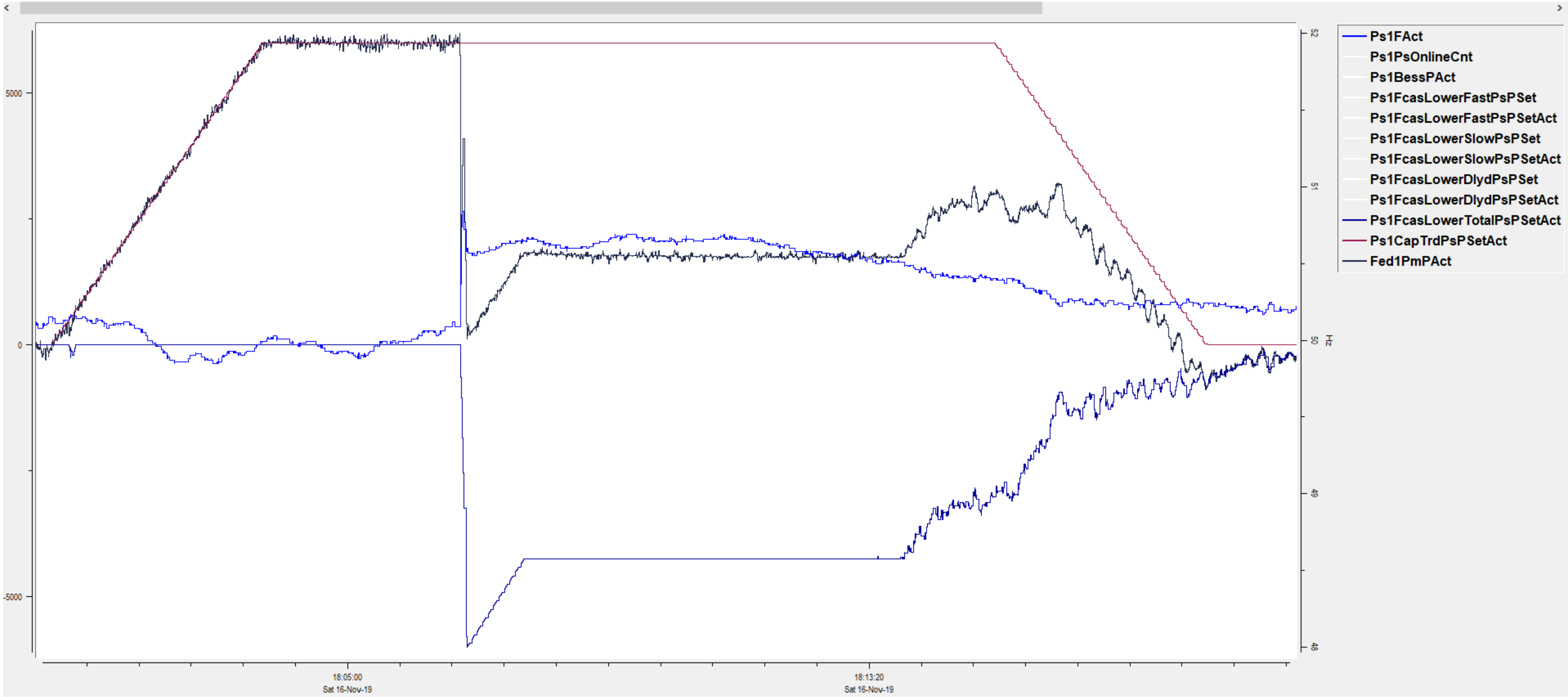
What would be the best use of the BESS be?



General Operational Issues to manage

- Availability
- Air conditioning
- Energy losses
- Inverters & batteries
- Communications
- SCADA alarms

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Dalrymple ESCRI-SA BESS
Key learnings / challenges

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Knowledge Sharing Portal

- ARENA knowledge sharing commitments
  - ☐ Project delivering substantial knowledge sharing benefits to stakeholders
- Real-time data
- Data downloads
- Reports
- Presentations
- Knowledge Sharing Reference Group
  - ☐ Agendas
  - ☐ Minutes

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Key learnings / challenges

- Each battery project appears to have its own set of unique challenges and some learnings are quite project specific
- Learnings/ challenges have included…
  - ❑ demonstration project with an aggressive timeline - pushing technical boundaries, e.g. wind farm islanding, vector shift
  - ❑ regulatory treatment
  - ❑ obtaining equipment models and evaluation of Generator Performance Standards (GPS)
  - ❑ clarifying AEMO registration and metering requirements
  - ❑ improving understanding of performance parameters - obtaining / refining equipment models for evaluation of Generator Performance Standards, exacerbated by optimising control for grid-connected and islanded operation
  - ❑ islanding challenges
  - ❑ managing commercial contract signed before design was completed

Islanding challenges

- Islanding detection and anti-islanding protection
- Wattle Point wind farm integration (AGL as operator)
- Transformer inrush currents
- Rooftop PV resulting in minimum demand
- Distribution network protection
- Distribution network Voltage Change Over scheme

Future challenges and next steps

- Manage promised 96% availability
- Energy losses
- Manage BESS capacity – 8 MWh – after 12 years!!

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Looking Ahead -
Energy Security and System Security

Energy batteries and power batteries

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Batteries and energy security

Many batteries required to provide energy security with intermittent generation

- Assumptions
  - Wind still night (12 hours)
  - No synchronous generation
  - Average state demand (1,500 MW)
  - Imports from Victoria at 650 MW
- Battery assumptions
  - Batteries charged at 50% at start
  - Hornsdale battery – 129 MWh (Grid Scale)
  - Residential battery – 10 kWh
- How many batteries do we need?

Type of battery	Grid Scale	Residential
Scenario 1 (Grid Scale only)	> 150	None
Scenario 2 (Grid & Residential)	> 110	500,000

Energy security and system security

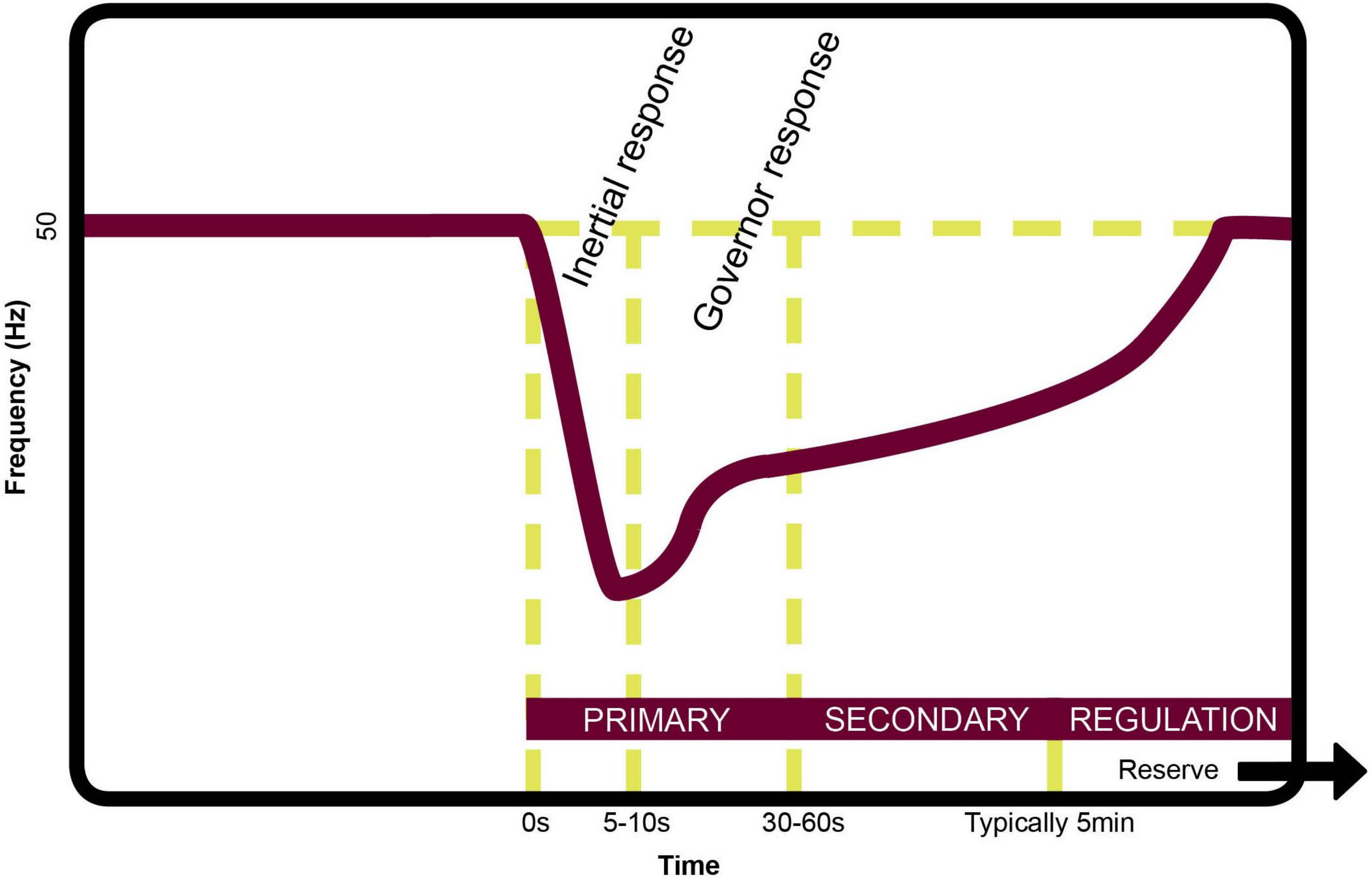
Batteries alone unlikely to provide required energy security

- Energy providers for energy security:
  - ☐ Energy batteries (limited)
  - ☐ Fast start synchronous generators (in combination with sufficient fuel source)
  - ☐ Solar thermal energy storage
  - ☐ Pumped hydro energy storage
  - ☐ Transmission interconnectors

- Grid scale batteries are well suited to assist with system security:
  - ☐ Fast Frequency Response
  - ☐ Part of a Special Protection Scheme (SPS)
  - ☐ Frequency Control Ancillary Services (FCAS)
  - ☐ Voltage control

Frequency - separation event

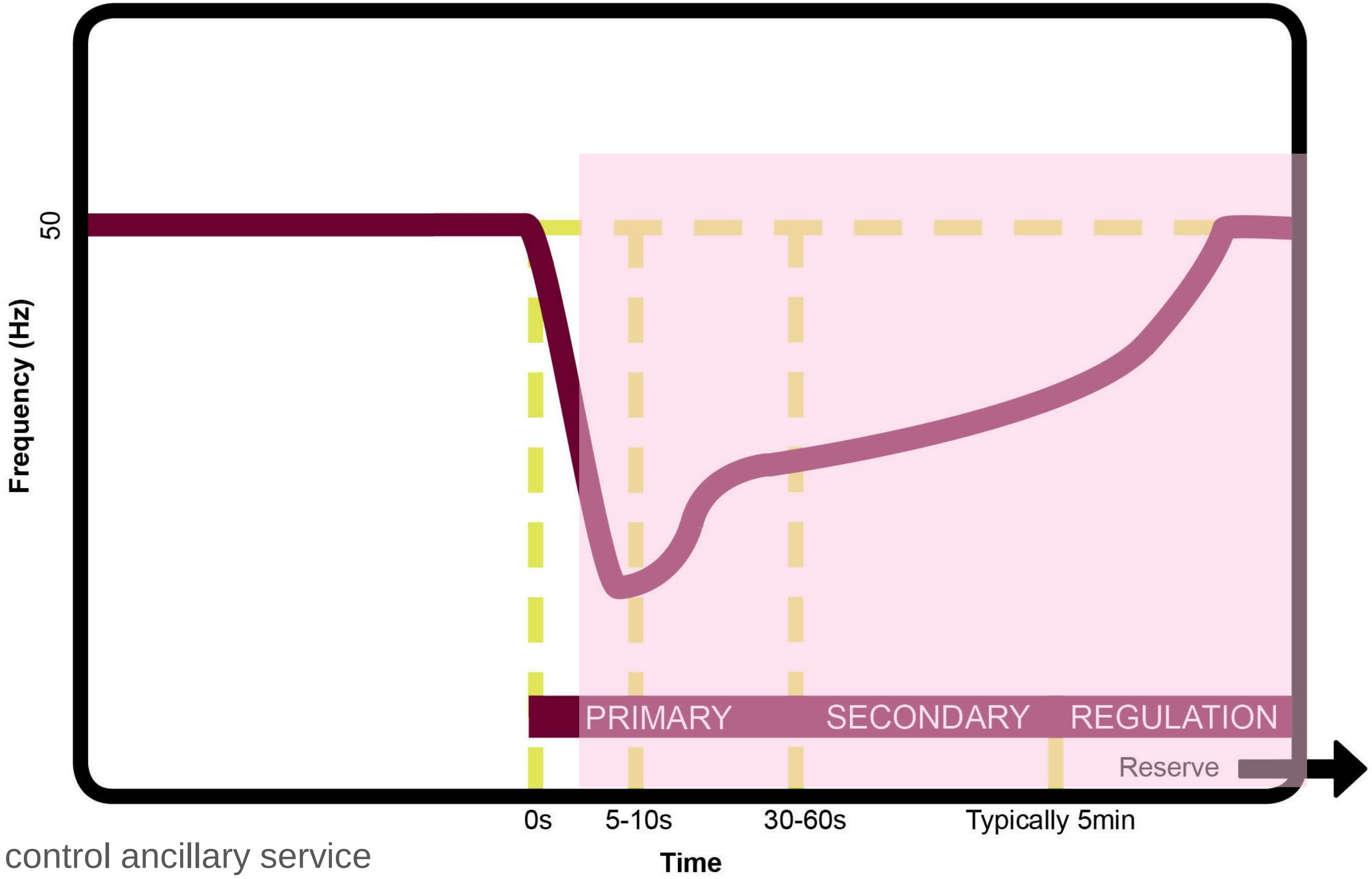
Typical frequency response: Arresting, stabilisation and recovery



Stabilisation and recovery

Existing arrangements (governor action and FCAS) can cater for most events

- Governor action
- Contingency FCAS
- Regulation FCAS
- Aggregated distributed energy resources (DER)



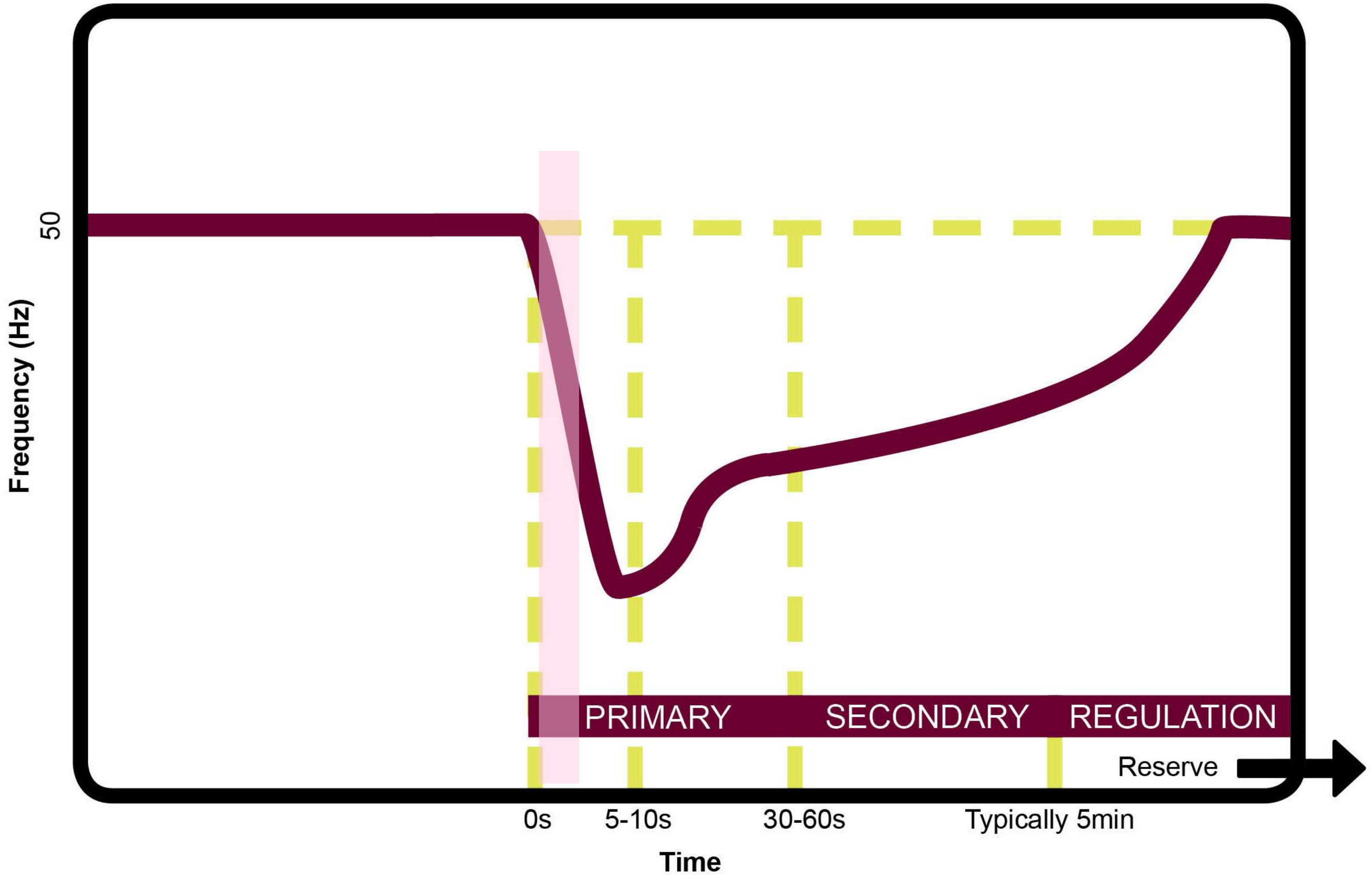
FCAS: Frequency control ancillary service

Arresting frequency

A combination of inertia and FFR providers will be required in future

Fast Frequency Response (FFR)

- Inertial response
  - Synchronous generators
  - Synchronous condensers
- Grid-scale battery storage, Murraylink, new wind farm controls
- SPS / Demand response
- Under frequency load shedding



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Various battery applications

Batteries can help over various time frames

Service provided by:	Pre-emptive emergency response	Fast frequency response	Very fast contingency FCAS	Contingency FCAS
	External signal triggers SIPS	Local measure-ment of either RoCoF or frequency	Within 1-2 seconds	Normal 6 second market
Grid-scale BESS	✓	✓	✓	✓
Virtual Power Plant		✓	?	✓
Distributed Energy Resource		✓		
		Co-ordination?		

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Questions

Thank You

For more information contact:

Hugo Klingenberg
Manager Network Development

Phone: +61 8 8404 7991

Email: Klingenberg.Hugo@electranet.com.au

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Largest autonomous regional micro-grid

Outline

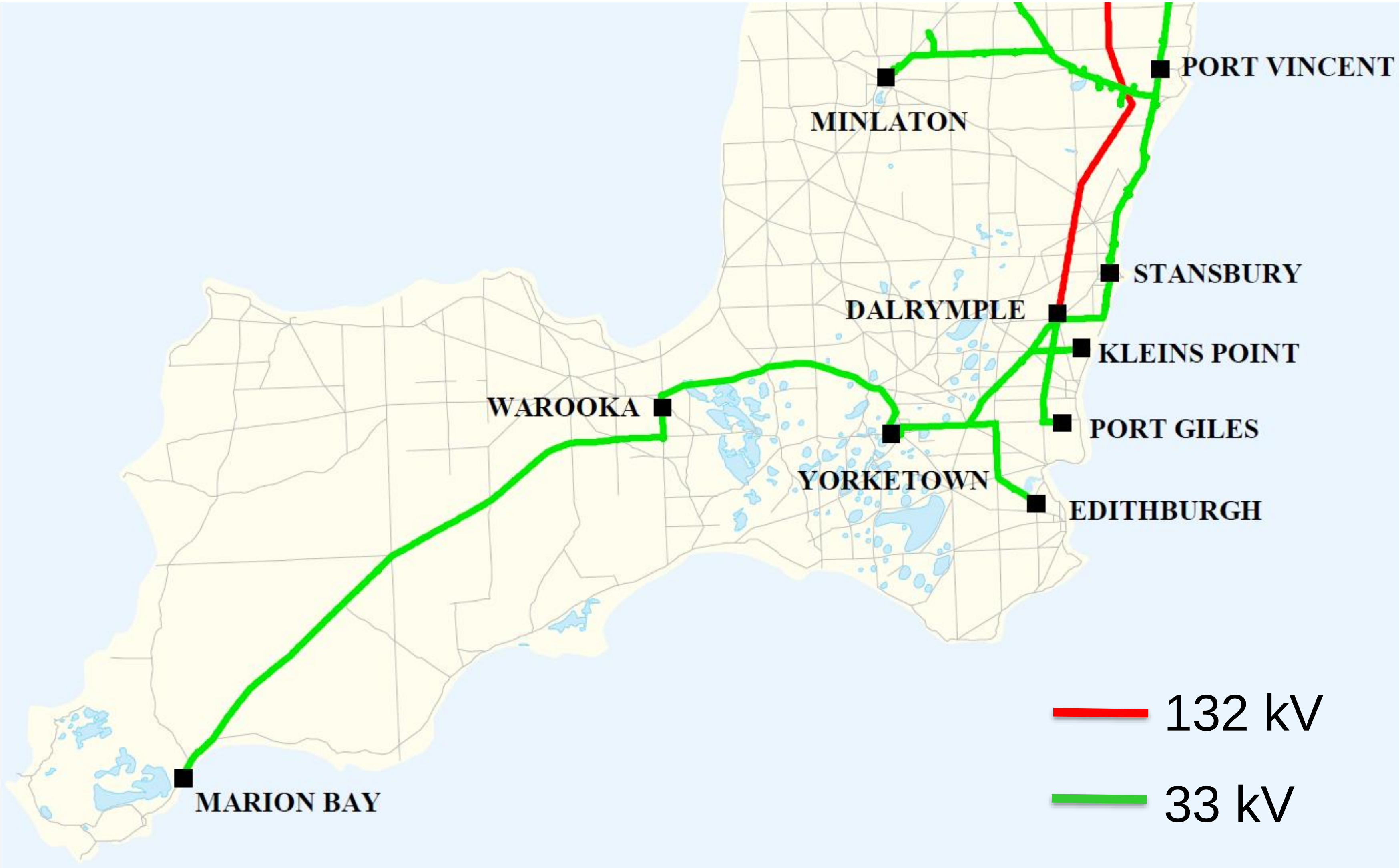
- Industry innovation
- 33 kV distribution network
- Islanding detection
- Transitioning to an island
- Islanded operation
- Challenges

Industry innovation

A number of firsts

- Largest (30 MW BESS) indoor and climate-controlled BESS installation in Australia
- Largest autonomous regional micro-grid development to-date. All-in-one control design co-optimised for both grid-connect and islanded operation, allowing seamless transition between the two operating modes
- Grid-forming capability implies ability to operate conceptually at very low Short Circuit Ratios (<<1.5)
- Islanded grid master control including WF generation MW dispatch / curtailment
- Black-start capability for 8 MW island
- Topology-based Islanding Detection Scheme (IDS)

Geographical supply area



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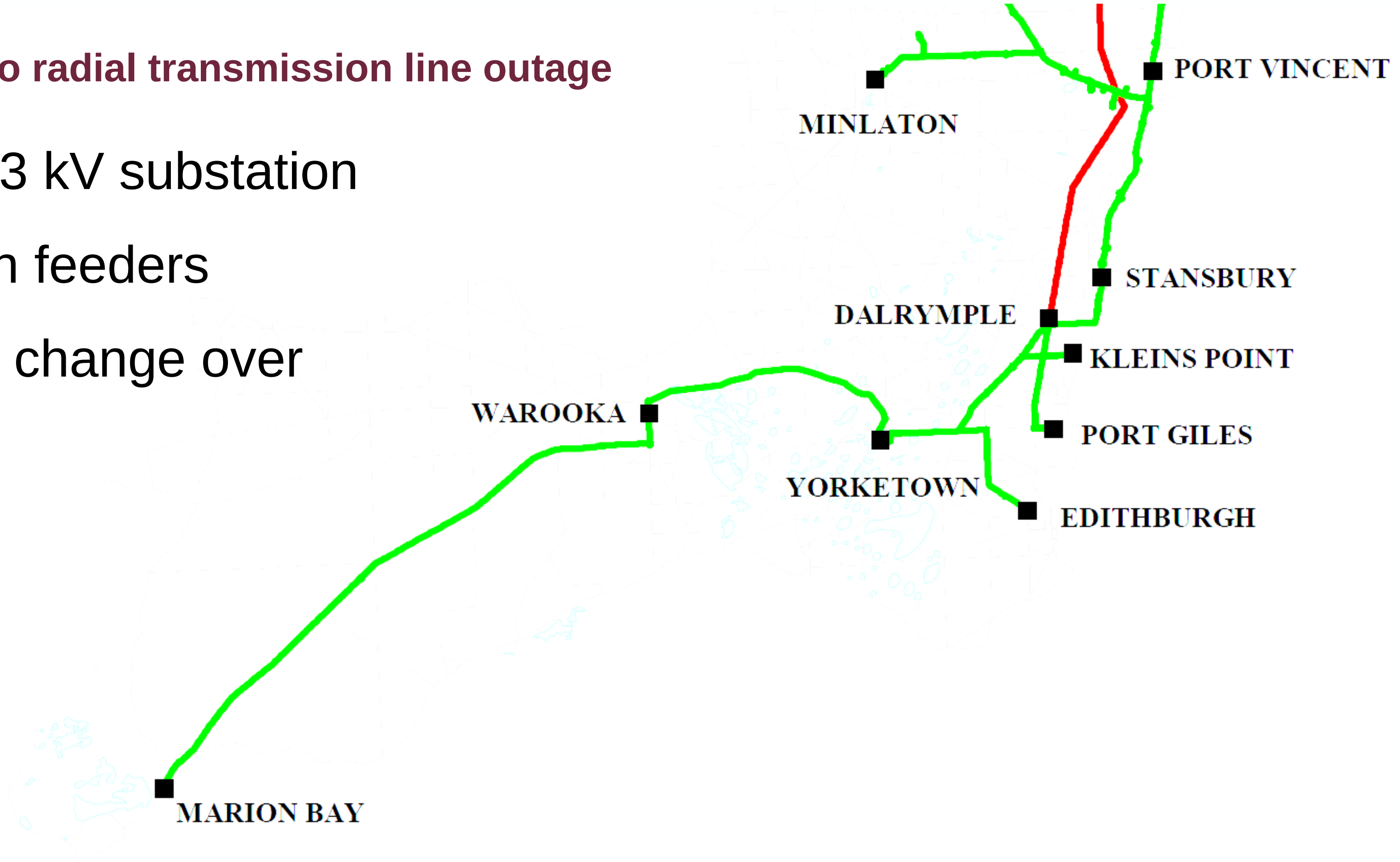
Distribution Network

Customers are exposed to radial transmission line outage

- Dalrymple 132/33 kV substation
- 33 kV distribution feeders
- Minlaton voltage change over
- SWER networks



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Key requirements for islanding

No local customer to be worse off

- No degradation of SA Power Networks service reliability and quality
- Dependable distribution protection
- BESS anti-islanding protection to disconnect BESS under certain conditions

Islanding detection

Important that an islanding condition is reliably detected

- Topology-based islanding system:
  - Monitor status of circuit breakers (CBs) / disconnectors at various substations (via auxiliary contacts) ⬄ planned outages
  - Monitor protection relays - i.e. CB imminent tripping under fault conditions detected via protection relays (even before the CBs would open) and transmitting trip signals via telecommunication system ⬄ unplanned outages
- BESS anti-islanding activation for:
  - Insufficient number of batteries / inverters online (insufficient fault current contribution under islanded condition)
  - Islanding detection system in-operational

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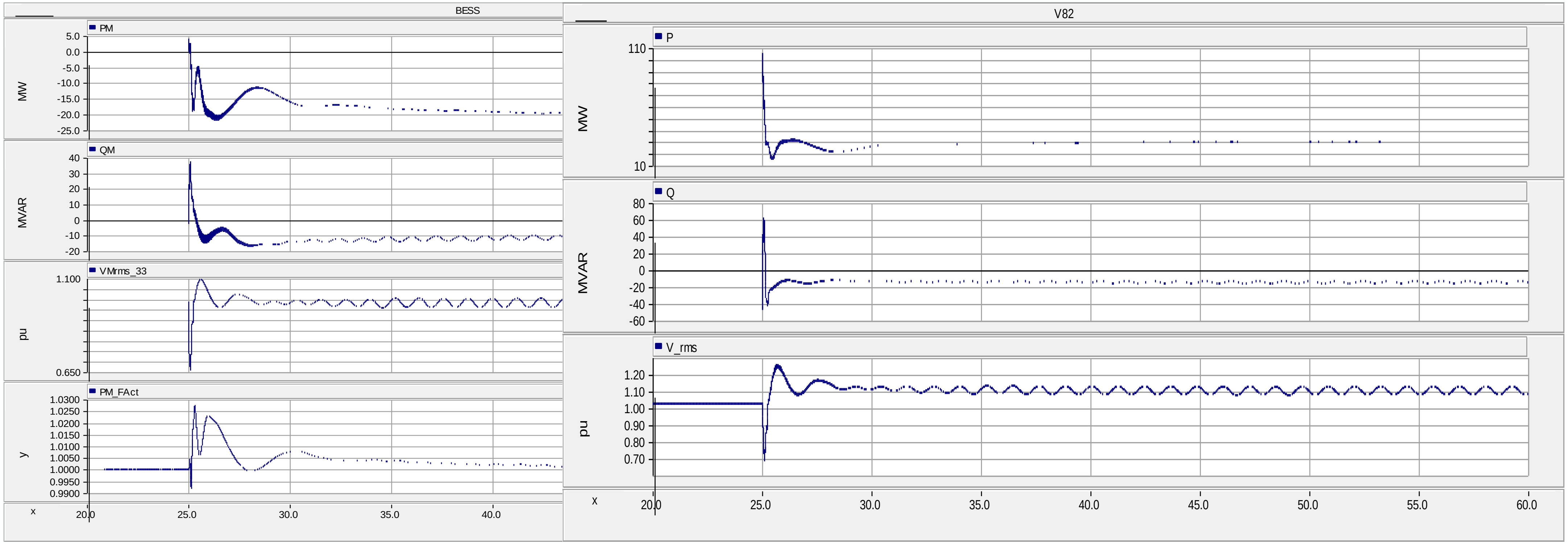
Transitioning to an island

Results from transient studies

- > Disconnect 80% of wind farm
- > BESS grid master control transitions to islanded mode



Islanded operation

ESCRI-SA BESS controls the island

- BESS as island grid master control:
  - Voltage and frequency reference
  - Wind farm generation MW dispatch – to manage BESS charge level
  - Fault current provision
- Distribution protection
- Black start (if required)

Islanding Summary

- Detailed simulations using PSCAD by Electranix and ElectraNet have been conducted using the same parameters as those used in the hardware and island test

- These simulations have been successful in replicating the test results

- Results of the simulation have concluded that:

  - In full island mode a minimum of 10 BESS modules in-service is required to meet fault current requirements
  - Wattle point windfarm needs to fix their frequency protection settings
  - Transformer saturation needs to be properly considered for islanding studies