SUBSTATIONS 2019

SOUTH AUSTRALIA - DALRYMPLE BATTERY ENERGY STORAGE SYSTEM

South Australia - Dalrymple Battery Energy Storage System

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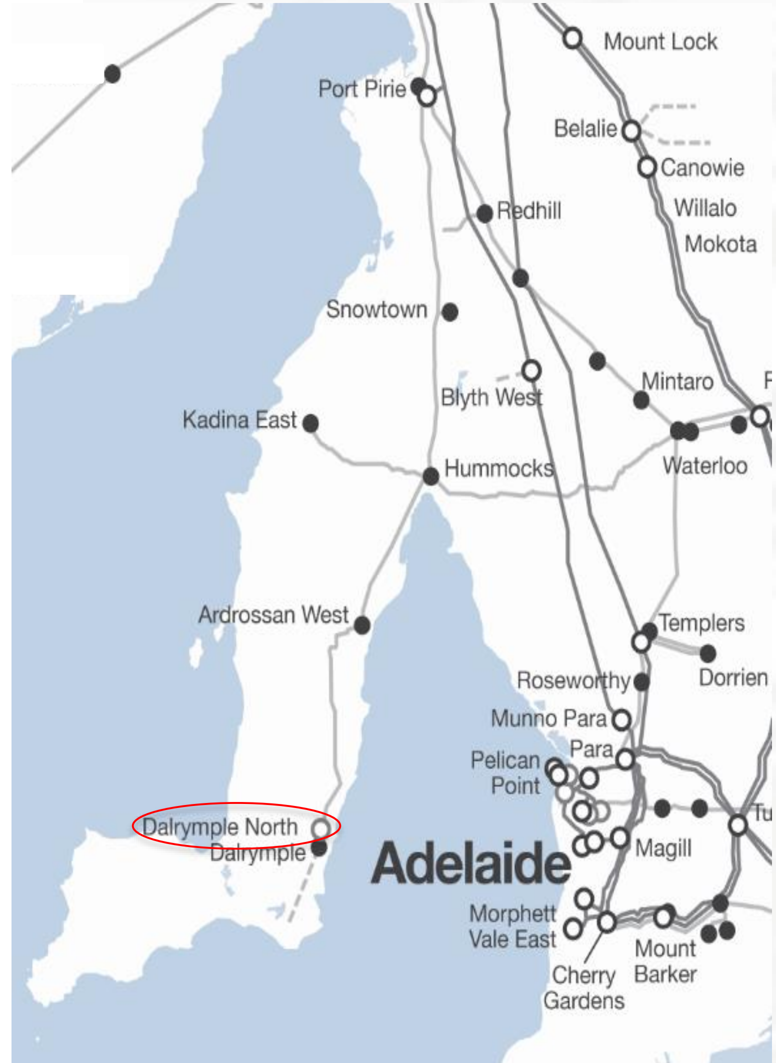
SOUTH AUSTRALIAN NETWORK



CONTEXT

- Substantial increase in renewable generation in SA
- Deployment of:
  - Large scale wind generation;
  - Large scale photovoltaic generation; and
  - Rooftop solar photovoltaic installations.
- Conventional generation:
  - Entire coal based generation fleet retired; and
  - Gas based generators operating at reduced capacity.
- Changing energy supply mix challenges:
  - Affordability;
  - Reliability; and
  - Security of supply.

SA SYSTEM REQUIREMENTS

- Safe, secure and reliable operation of SA system both for:
  - Connected; and
  - Islanded conditions.
- Solutions:
  - Network (conventional); and
  - Non-network / non-conventional.
- System security aspects:
  - Inertia – including provision of synthetic inertia;
  - System strength;
  - Frequency control (both contingent and regulation); and
  - Voltage control.

DALRYMPLE BESS

- Proof-of-concept demonstration project capable of delivering both regulated and non-regulated services
- Dalrymple BESS – option for:
  - Increasing system security; and
  - Integration of renewables.
- 30 MW, 8 MWh ⇔ power BESS
- Connected to ElectraNet's existing Dalrymple substation in the Yorke Peninsula of SA
- Funding:
  - Australian Renewable Energy Agency (ARENA) - grant;
  - ElectraNet (regulated services) – owner;
  - AGL (BESS leasing - non-regulated services) – operator.

DALRYMPLE BESS OBJECTIVES

- Primary - demonstrate that utility scale BESS systems can provide:
  - Network reliability and security services (e.g. FFR);
  - Market services; and
  - "Seamless" islanded operation with 100% renewable generation following transmission outages.
  - evaluate the operation of a local islanded system where:
    - demand is supplied by a local wind farm;
    - with no conventional generation; and
    - with regulation services being provided by the BESS.
- Secondary
  - demonstrate commercial separation and provision of regulated services and energy market services; and
  - build delivery capability for such assets.

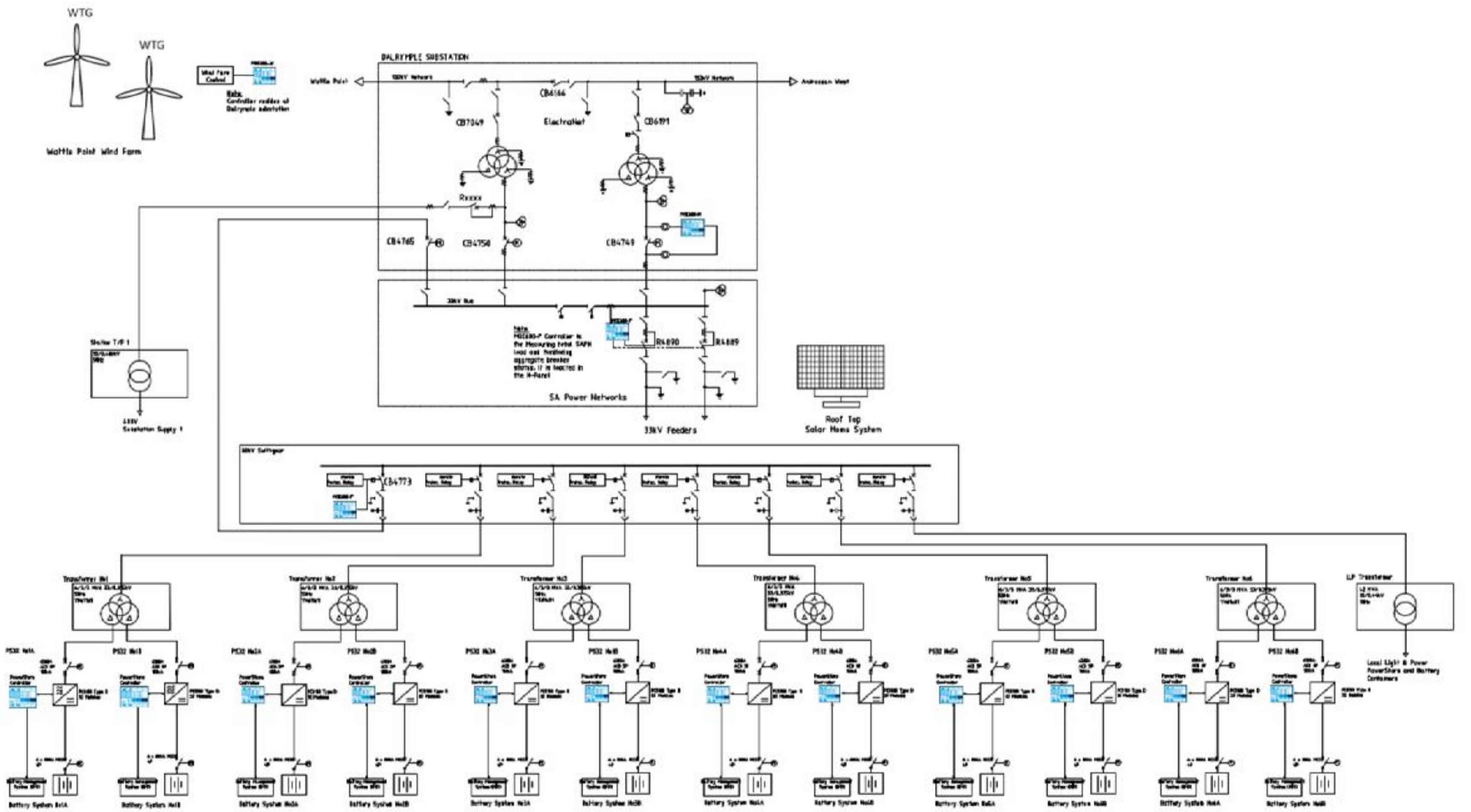
DALRYMPLE BESS SERVICES

- BESS deployment at Dalrymple for provision of services:
  - Non-regulated:
    - Cap trading;
    - FCAS.
  - Regulated:
    - FFR;
    - Reactive / voltage support;
    - Network support – integration in System Integrity Protection Scheme (SIPS);
    - Reduction in unserved energy (islanding support).

CONNECTION AND REGIONAL CONTEXT

- BESS connected to ElectraNet's Dalrymple Substation in the Yorke Peninsula
- Dalrymple substation at the end of radial line
- Local load – rural, light industrial, max 8MW
- Increasing domestic rooftop PV
- Occasionally load can become negative
- 90 MW type 1 Wattle Point Wind Farm (WPWF) connected to the Dalrymple substation
- Local network can be assimilated with a lower scale replica of the SA network – when compared with Australian network

SIMPLIFIED SLD



CONNECTION AND EQUIPMENT

- Connection at 33kV level – secondary side of 25MVA 132 / 33 kV Dalrymple transformer
- 33kV indoor switchgear
- 6 x 6MVA 33kV / 415 V dual secondaries transformers
- 32 ABB inverters PCS-100D – voltage source
- Samsung batteries 12 x 3.117 MVA skid based PowerStore system units with a BoL design capacity of 14.4 MWh

PCS100 BESS MODULES

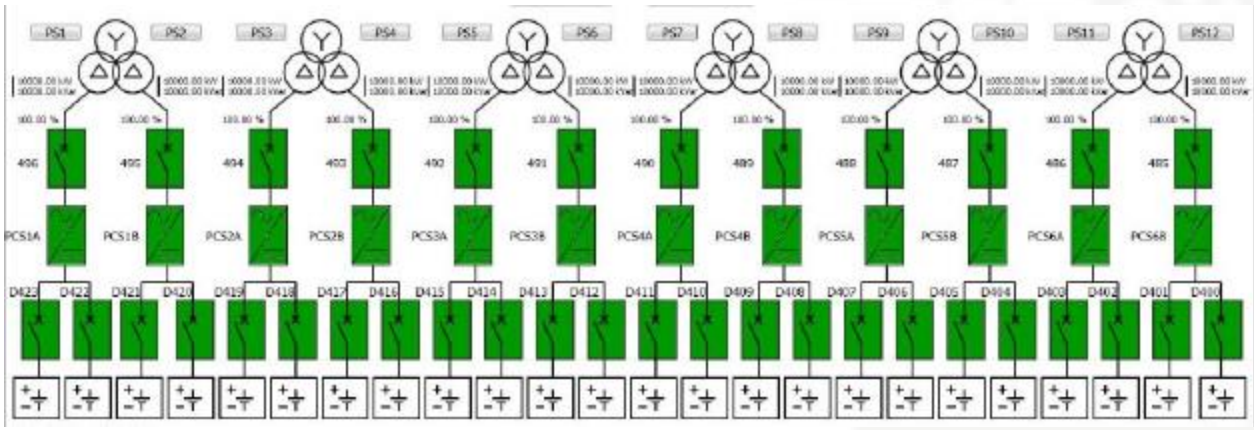
SYSTEM FUNCTIONALITY

- Form of reference frequency and voltage for an isolated or islanded grid segment
- Spinning Reserve functionality (Virtual Generator function)
- Ensure stability for network voltage and frequency
- Provide black start capability in the event of a network blackout
- Provide ancillary grid services with minimal operation intervention.
- Enable a Microgrid to transition from grid-connected to islanded operation and back to grid connected status
- Provide data monitoring and archiving.

LAYOUT

- Light frame building, housing:
  - Control room
  - MV switchgear
  - Inverters
  - Batteries

HMI VIEW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COMPLETED SITE

STANDALONE BUILDING VS CONTAINERS

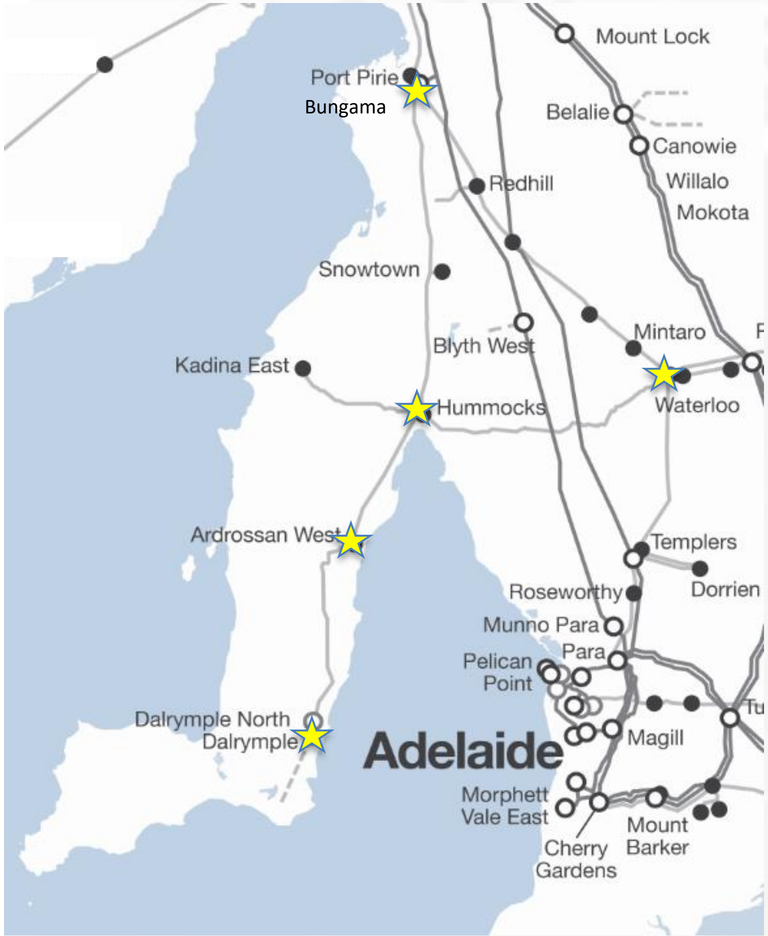
- No perfect solution
- Containerised:
  - Modularity
  - Expandability
- Building:
  - Smaller footprint
  - Faster delivery and installation timeframes
  - Depending on design: lower foundation, trenching and cabling costs
  - Heat management – hence potentially less air-conditioning
  - Potentially Capex / Opex advantages
  - Non-expandable, unless spare capacity designed-in

ISLAND DETECTION SCHEME (IDS)

- Local distribution company requirements:
  - no local customers to be worse-off / no degradation of services reliability – as a result of BESS connection
  - Implementation of BESS anti-islanding capability
- BESS anti-islanding activation for:
  - Insufficient number of batteries / inverters online ⇔ insufficient fault current contribution under islanded condition; or
  - Islanding detection system in-operational
- Topology-based islanding system
  - Monitoring circuit breakers / disconnectors statuses at various substations (via auxiliary contacts) ⇔ planned outages
  - Monitoring 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 systems ⇔ unplanned outages
- Vector shift island system tried – unsuccessfully – due to variety of contingencies and inability to reliably detect / discriminate island vs networked condition

IDS IMPLEMENTATION

- Topology based system extending to 5 substations (Dalrymple, Ardrossan West, Hummocks, Bungama);
  - Respective substations all brownfield, with associated challenges in terms of documentation and accessibility for works;



IDS FUNCTIONS

- Upon detection of island – IDS performs several functions:
  - Signal sent to BESS – for synchronous to isochronous transition;
  - Signal sent to WPWF – offloading of excess generation – avoid overload of ElectraNet transformer from Dalrymple;
  - Relevant CBs at Dalrymple are switched off such that inadvertent reconnection to unsynchronised grid is prevented;
  - Changes Dalrymple AVR behaviour / control in islanded condition;
  - Modifies limits for local special protection scheme;
  - Performs controlled BESS re-synchronisation to the grid once adequate conditions occur.

MODELLING AND NETWORK STUDIES

- Models developed for:
  - Dalrymple local network
    - 132 kV network up to Waterloo and Snowtown
    - Equivalent voltage source models are used to represent the fault contribution from rest of the network
    - Actual tower geometries are used to generate the frequency dependent transmission line model
    - Transformer saturation effect is considered in the design
  - BESS
    - Inverter (detailed model with IGBT switches)
    - Variable DC source as the BESS model
    - Auto grid forming and following transition
  - Distributed PV (average model)
  - Wattle Point WF
    - Type 1 wind farm
    - Two Statcoms
    - One 90MVA transformer
    - Reticulation network

PROTECTION STUDIES

- PowerFactory studies conducted for fault current calculations, protection
- Intention – to ensure protection operation both in networked and islanded conditions
- During islanded condition, criterion used was to rely solely on fault current produced by BESS
- If less than 10 inverters (out of 12) online under islanded condition:
  - insufficient fault current capability; hence
  - BESS would activate anti-islanding facility ⬄ switch itself off when IDS detects an island

STUDIES – REGULATORY REQUIREMENTS

- BESS model developed both in PSSE and PSCAD
- Undertaking of PSSE simulations used for Generator Performance Standards (GPS) determination
- Due-diligence review by AEMO of simulations and assessment of proposed GPS
- Inverter based generating system – fast reacting
- EMTP / PSCAD studies mandated by AEMO for grid-connected condition (including benchmarking between the PSSE / PSCAD models and comparative performance evaluation)
- PSCAD studies undertaken for islanded condition
- Transition between synchronous and isochronous condition modelled extensively

STUDIES – REGULATORY REQUIREMENTS

PSSE studies	PSCAD/EMTDC studies
- Generator performance standard related tests	Grid connected: - Fault studies - Frequency disturbance tests - Voltage and Reactive power control Islanded: - Transition - Fault studies - Compatibility with Windfarm studies - Network event validation

TESTING

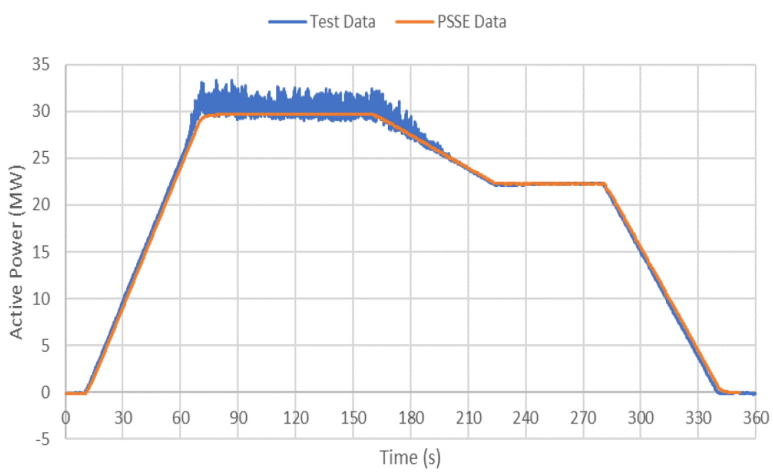
- Purpose:
  - Compliance testing – generation licence
  - Performance testing
- Compliance testing – requirements defined in NER
  - Development of commissioning test plan + review / acceptance by AEMO
  - Undertaking of commissioning tests (R1 testing) – progressively, at increasing import / export power levels
  - Reviewed / further tuned BESS parameters / model
  - Undertaking of model validation tests (R2 testing)
- Performance testing
  - the intent was to validate BESS performance requirements, as stipulated by ElectraNet

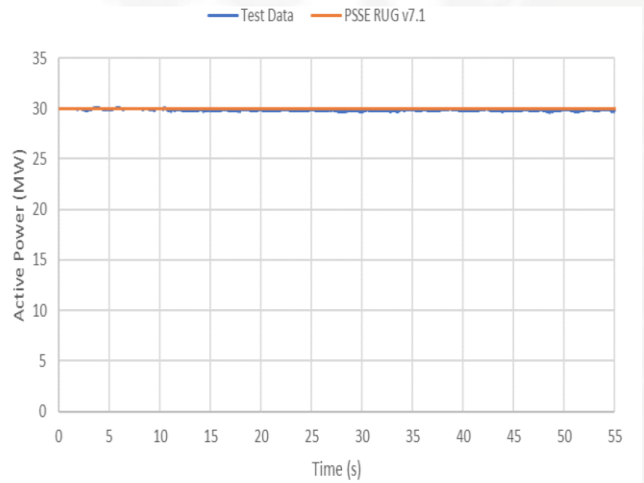
TESTING

- Commissioning tests
  - Hold-point 1 Test at +/-15 MW and +/-12.1 Mvar – Grid connected operations only
  - Hold-point 2 Test at +/-30 MW and +/-12.1 Mvar – Grid connected operations only
  - BESS Isolated Test – simulated islanding, no load, no WF, powerflow in-between inverters
  - BESS Partial Islanding (and re-synchronisation)
    - distribution load, no WF
    - WF, no distribution load
  - BESS Black Start – with distribution load only (no WF participation, limits apply to WF transformer inrush current, POW, etc)
  - BESS islanding with WF and distribution load + re-synchronisation

R2 TESTING

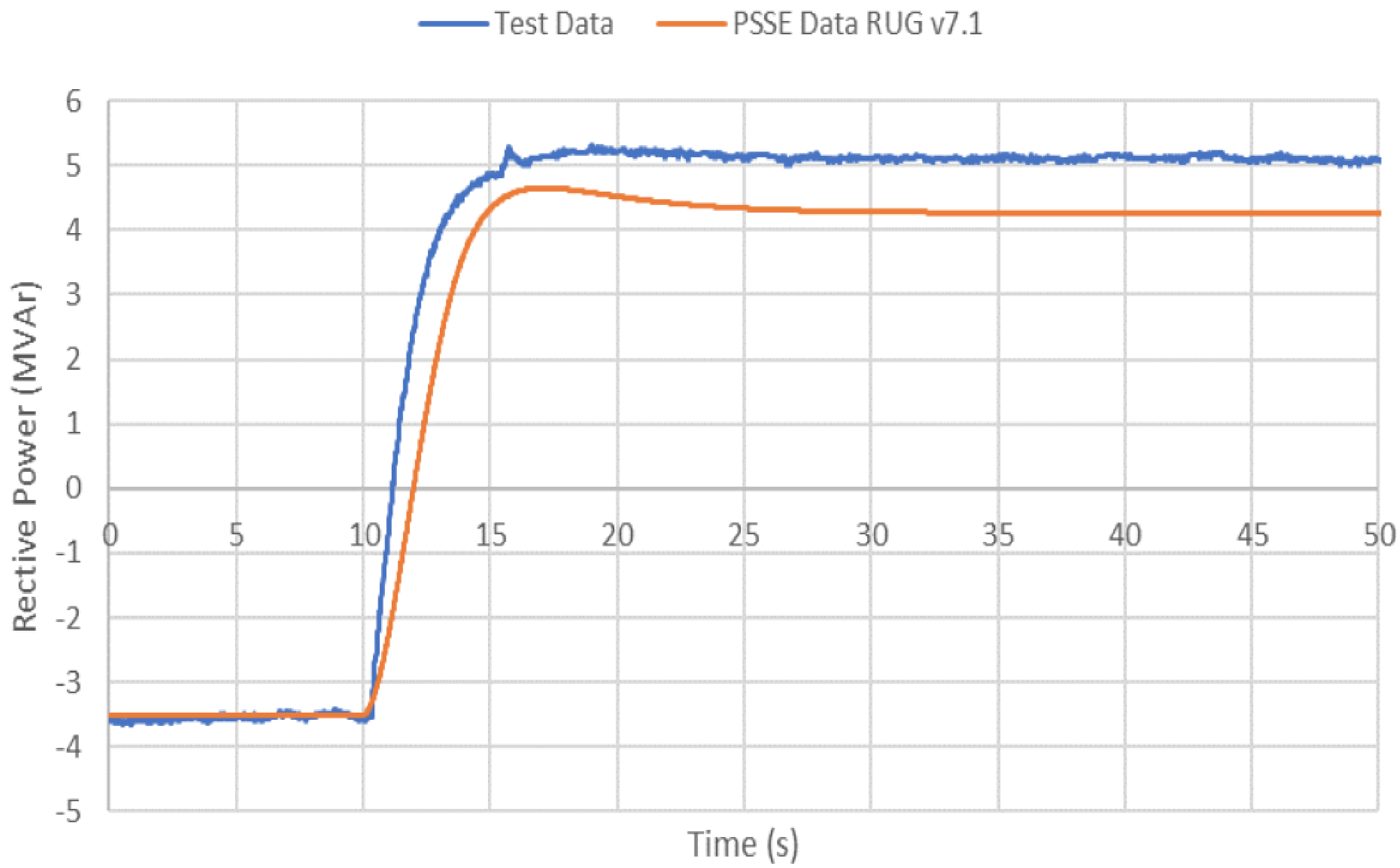
- R2 testing – offline and online tests
  - +5 % Voltage Step Response at +30 MW in voltage control mode
  - Previous oscillation at high discharge resolved
  - No change in MW output at voltage step





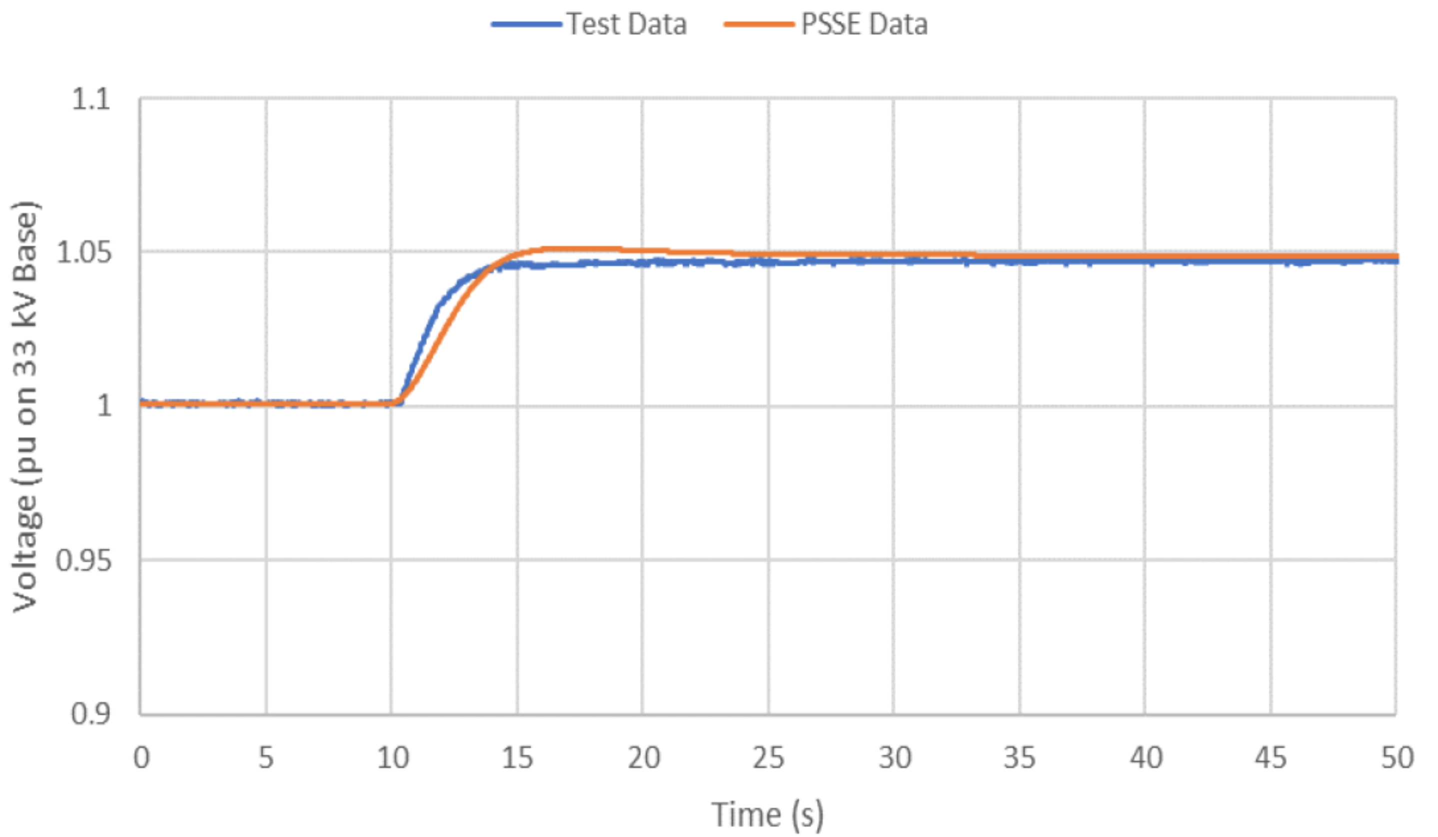
R2 TESTING

- Voltage step response – Reactive Power



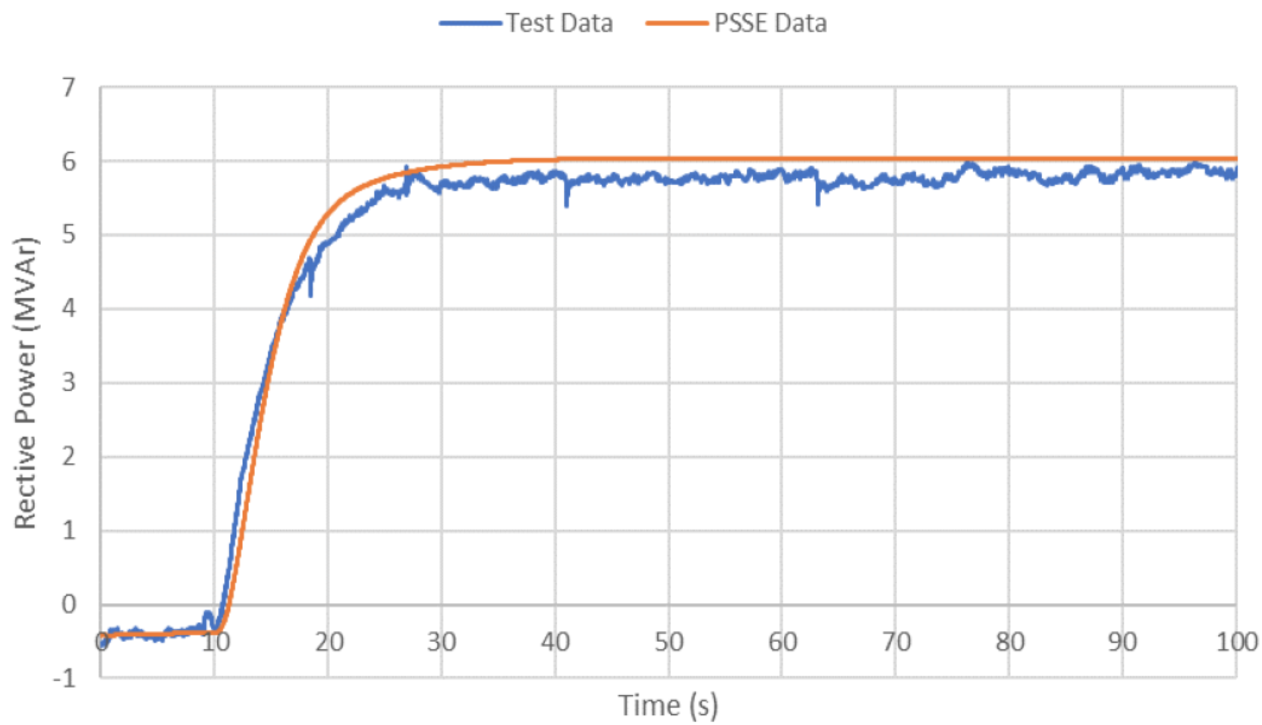
R2 TESTING

- Voltage step response – Voltage



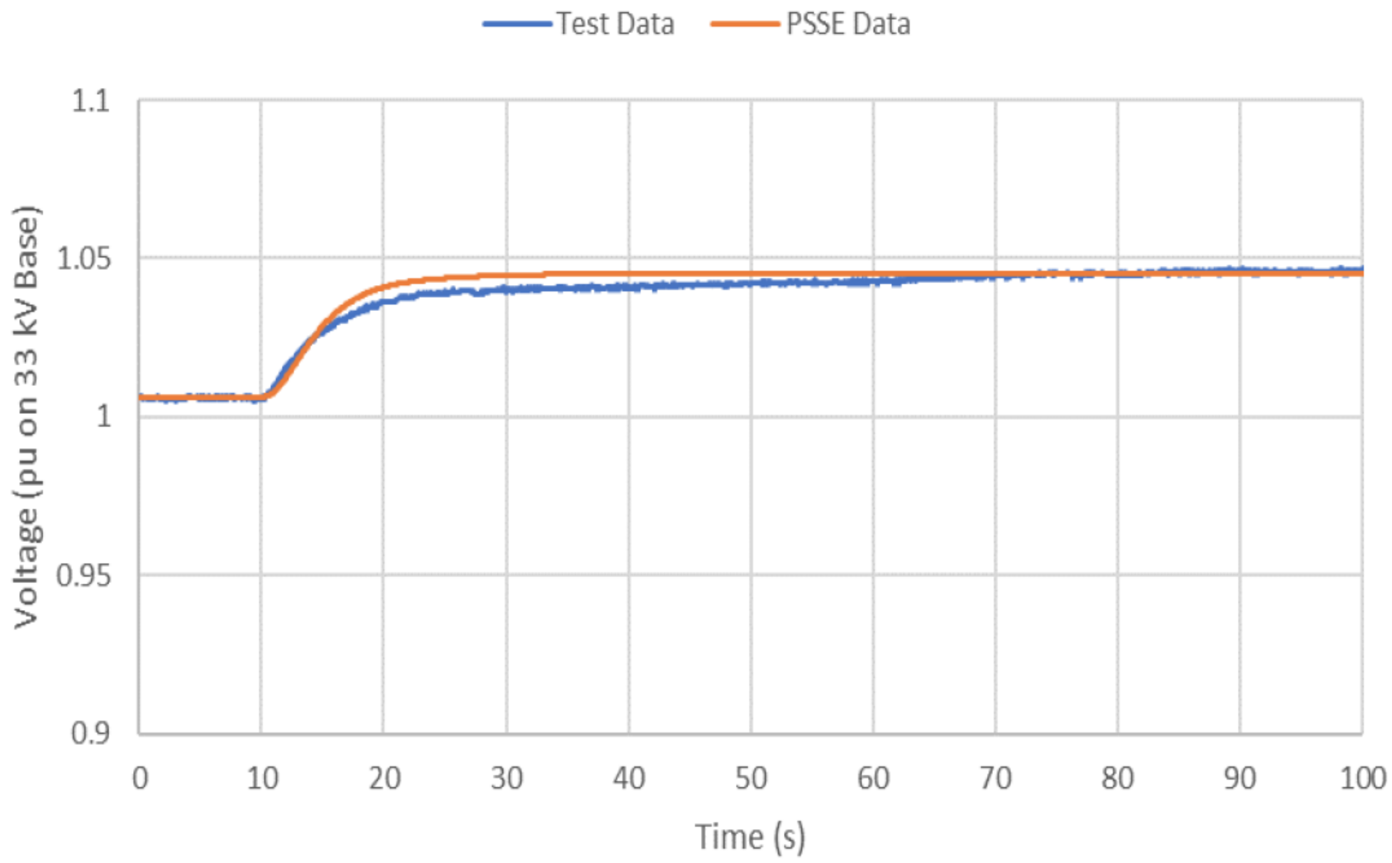
R2 TESTING

- R2 Test Model Response Overlay
  - +0.98 Power factor response in power factor control mode at 30 MW
  - No change in MW output observed



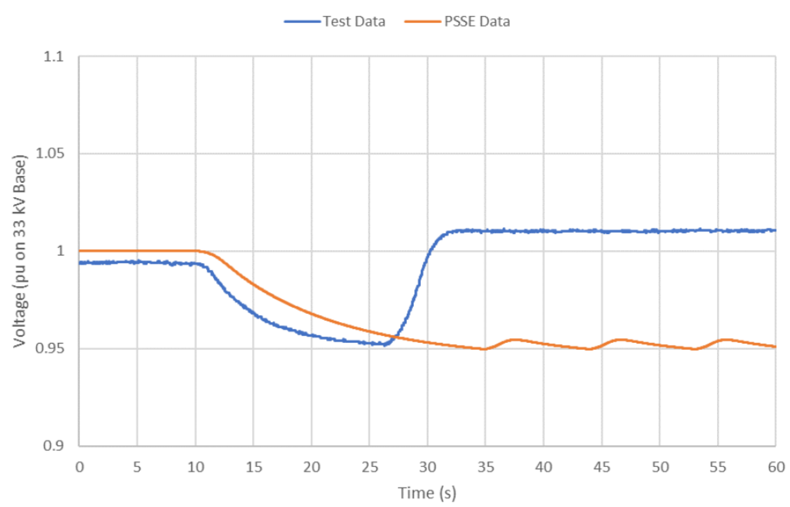
R2 TESTING

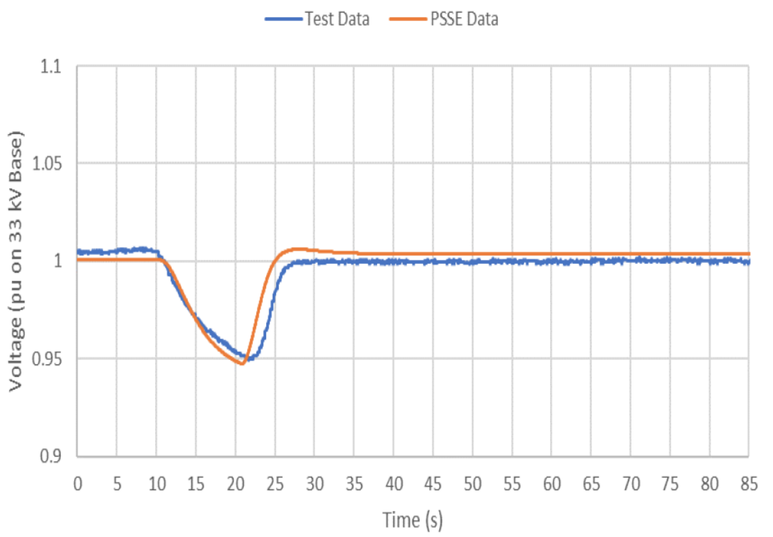
- Power factor step response – Voltage



R2 TESTING

- Automated control change over
  - Forced PF to result in voltage excursion below 0.95 pu
  - As voltage drops below 0.95 pu, control mode switches to voltage control





BESS PERFORMANCE REQUIREMENTS

- Defined operational modes / assigned priorities
  - Unserved Energy / Islanded Operation: priority = 1 ⇔ highest
  - Fast Frequency Response: priority = 2
  - Network Support: priority = 3
  - Contingency FCAS Raise / Lower Services: priority = 4
  - Cap Trading: priority = 5 ⇔ lowest
- Additional performance requirements
  - Fault Level Support in islanded operation
  - Voltage Control / Reactive Power
  - Fault Ride through capability for WPWF/Network Stabilisation Services

UNSERVED ENERGY (USE) - REQUIREMENTS

- Desired outcome
  - Disconnect upstream line (Dalrymple – Ardrossan) and provide grid-forming capabilities
    - Power injection into distribution network
    - Load following
    - Voltage and frequency control
    - Fault level support
- Performance Measurement
  - Power, voltage, frequency measurement at Connection Point
  - Seamless transitions between grid-connected and islanding operating modes
- Detection method / initiating signals
  - on-board or external (IDS, topology-based)
- BESS to provide sufficient fault current contribution for distribution protection system to operate correctly

FFR - REQUIREMENTS

- Desired outcome
  - BESS shall vary its output in response to a high rate of change of frequency to stabilise influence on power frequency.
- Performance Measurement
  - Power, voltage, frequency measurement at Connection Point
- Detection method / initiating signals
  - Internal e.g. local frequency or Phasor measurement; or
  - RoCoF measurements locally or at Connection Point
- Response time: responds nearly instantly (~30 ms), total response time dependant on the disturbance

NETWORK SUPPORT - REQUIREMENTS

- Desired outcome
  - provide BESS controlled charge or discharge in response to an external signal
- Performance Measurement
  - Power, voltage, frequency measurement at Connection Point
- Detection method / initiating signals
  - External signal – e.g. from SIPS / WAMS
- Response time: less than 250 msec

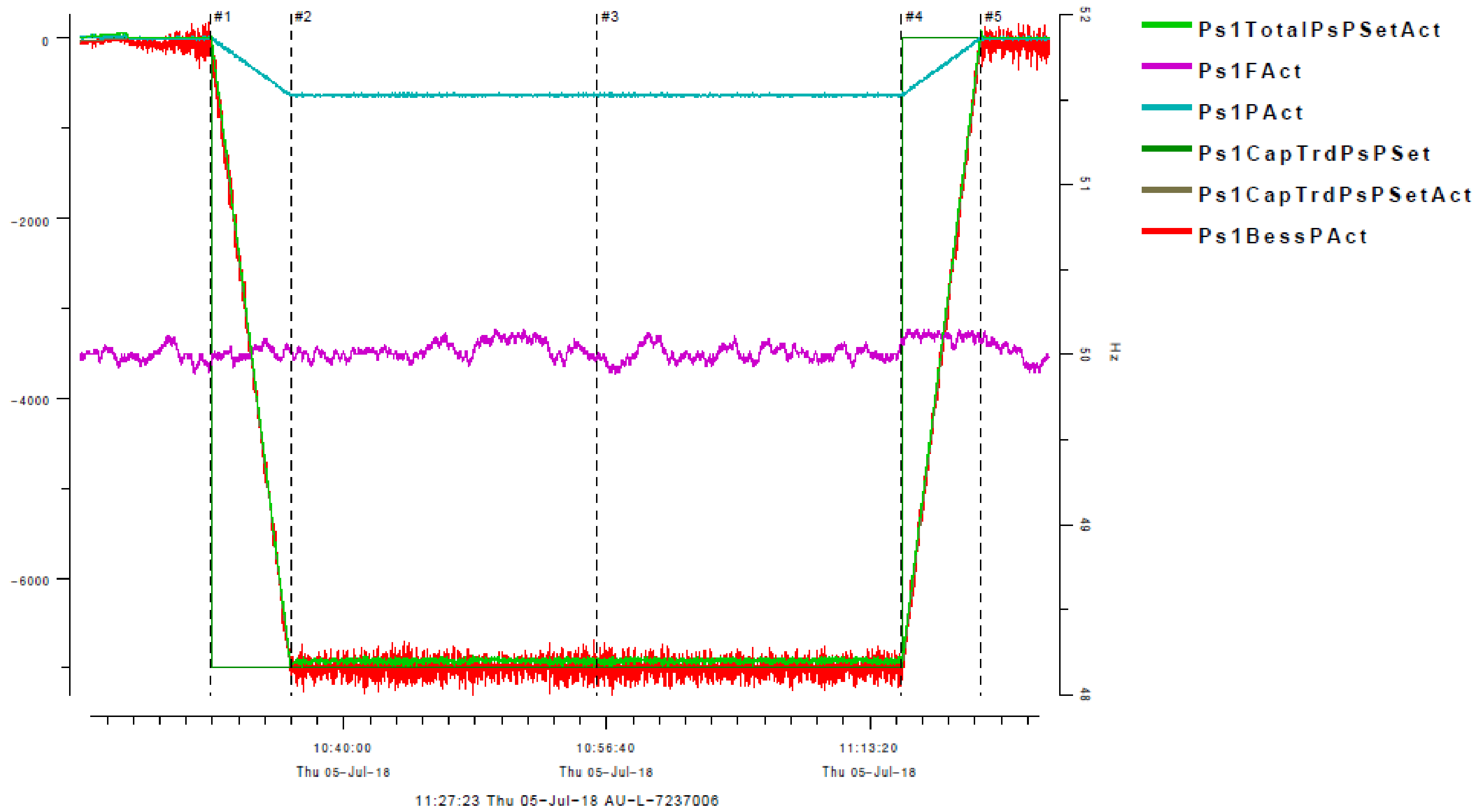
FCAS RAISE / LOWER - REQUIREMENTS

- Desired outcome
  - provide active power injection or absorption to aid system frequency recovery following frequency disturbance
- Performance Measurement
  - Power, voltage, frequency measurement at Connection Point
- Detection method / initiating signals
  - SCADA signals
- Response time: configurable to meet grid requirements (6 sec, 60sec, 300sec).

CAP TRADING - REQUIREMENTS

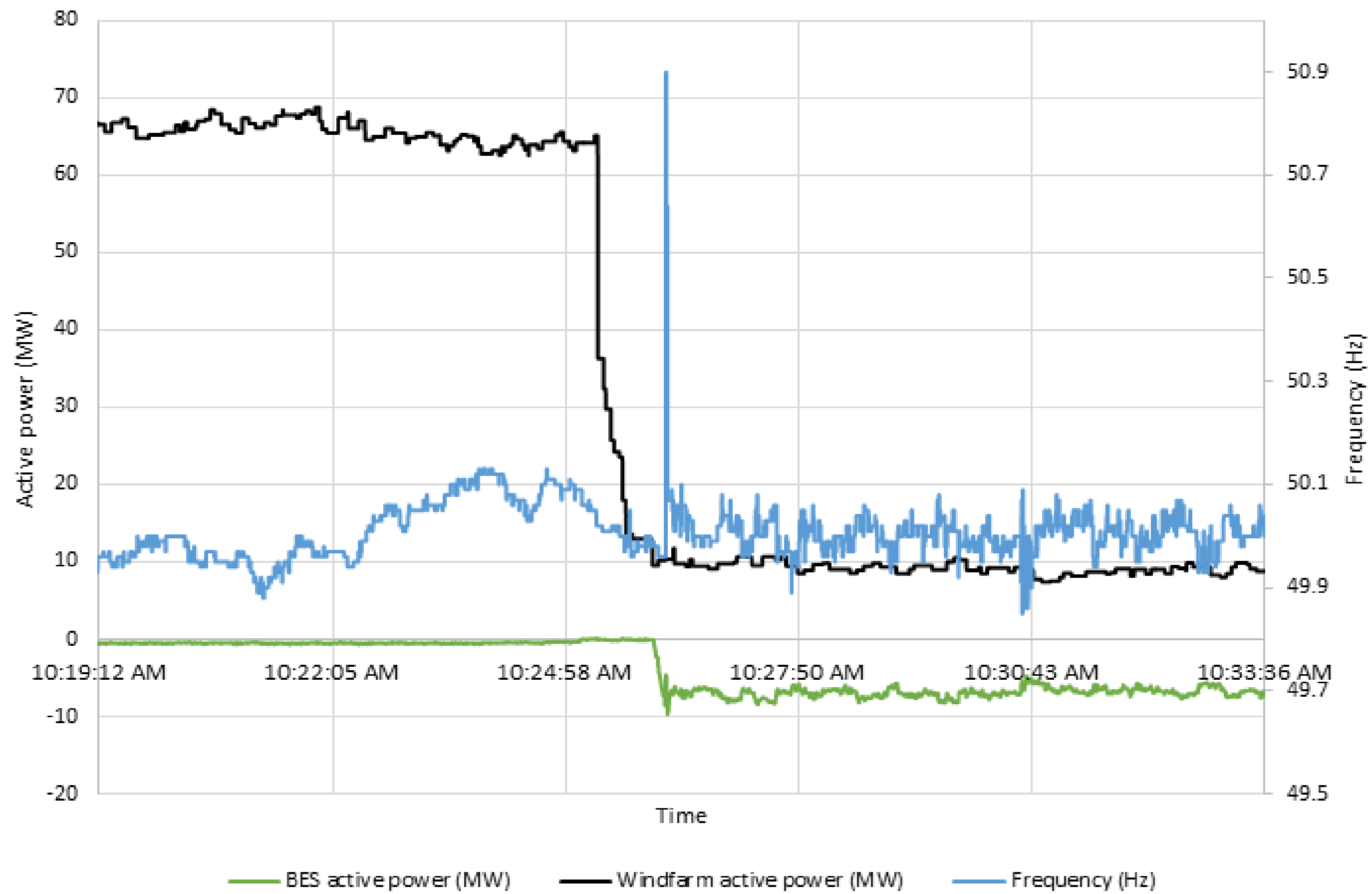
- Desired outcome
  - provide power injection into the network following a dispatch control signal
  - recharging activated via a dedicated control signal
- Performance Measurement
  - Power, voltage, frequency measurement at Connection Point
- Detection method / initiating signals
  - SCADA signals
- Response time: configurable to meet grid operator ramp rate requirements. Currently ~5sec

CAP TRADING - REQUIREMENTS



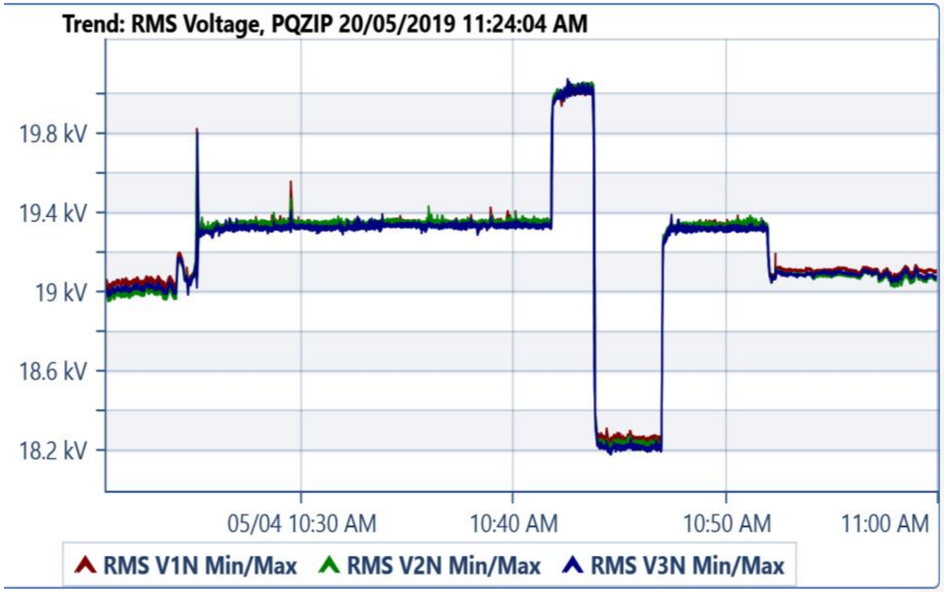
USE - PERFORMANCE

- Planned islanding test with WPWF and distribution load



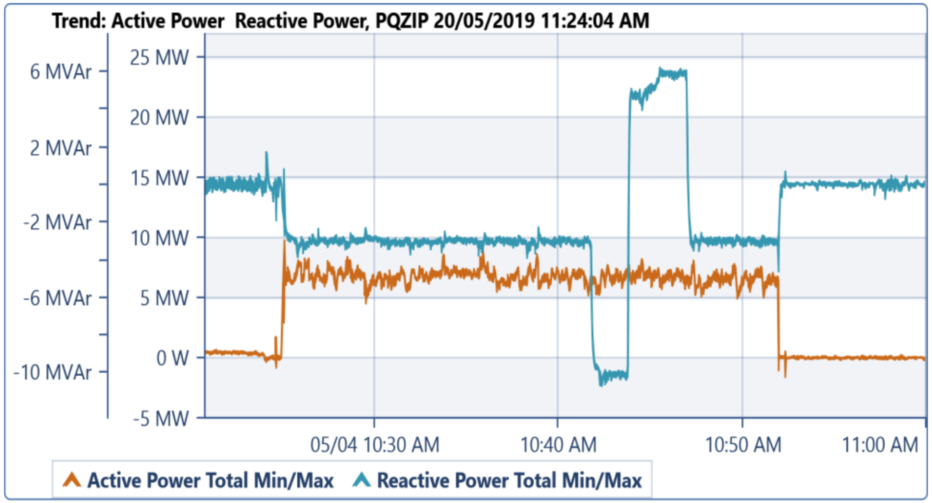
USE - PERFORMANCE

- Voltage step change in islanded network – change from:
  - 1 to 1.05 pu; and
  - 1 to 0.95 pu



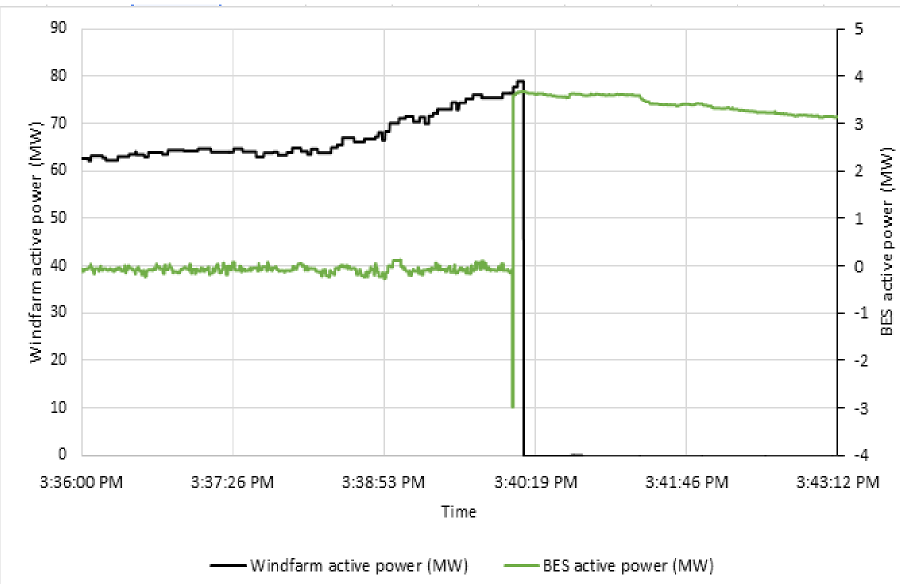
USE - PERFORMANCE

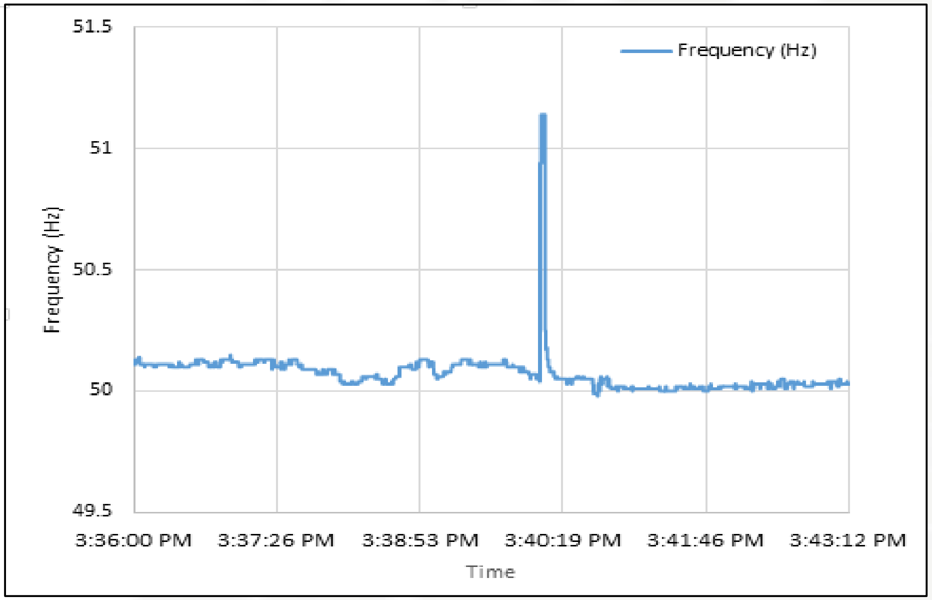
- BESS active and reactive power with voltage step change
- Active and reactive power responses are completely decoupled



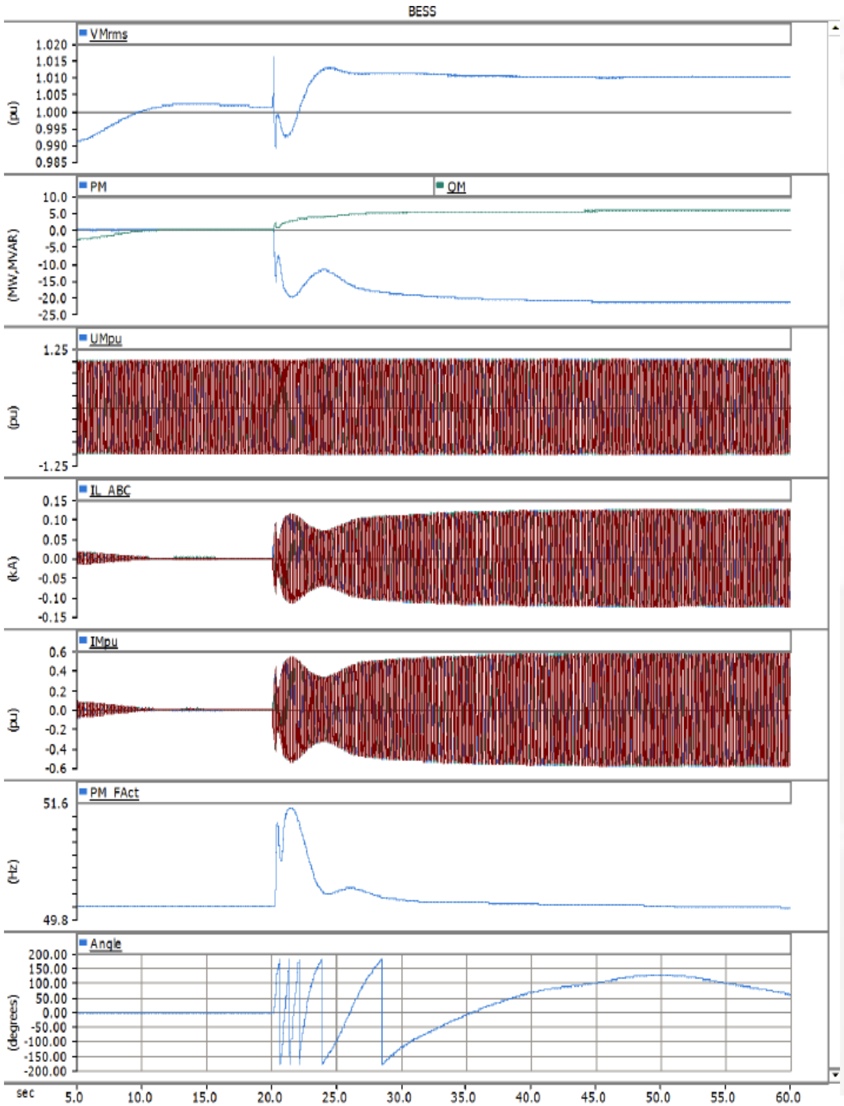
USE - PERFORMANCE

- Islanding test with WPWF output > 60 MW
- Successful unplanned island, but WF trips due to O/F





USE – PSCAD SIMULATIONS

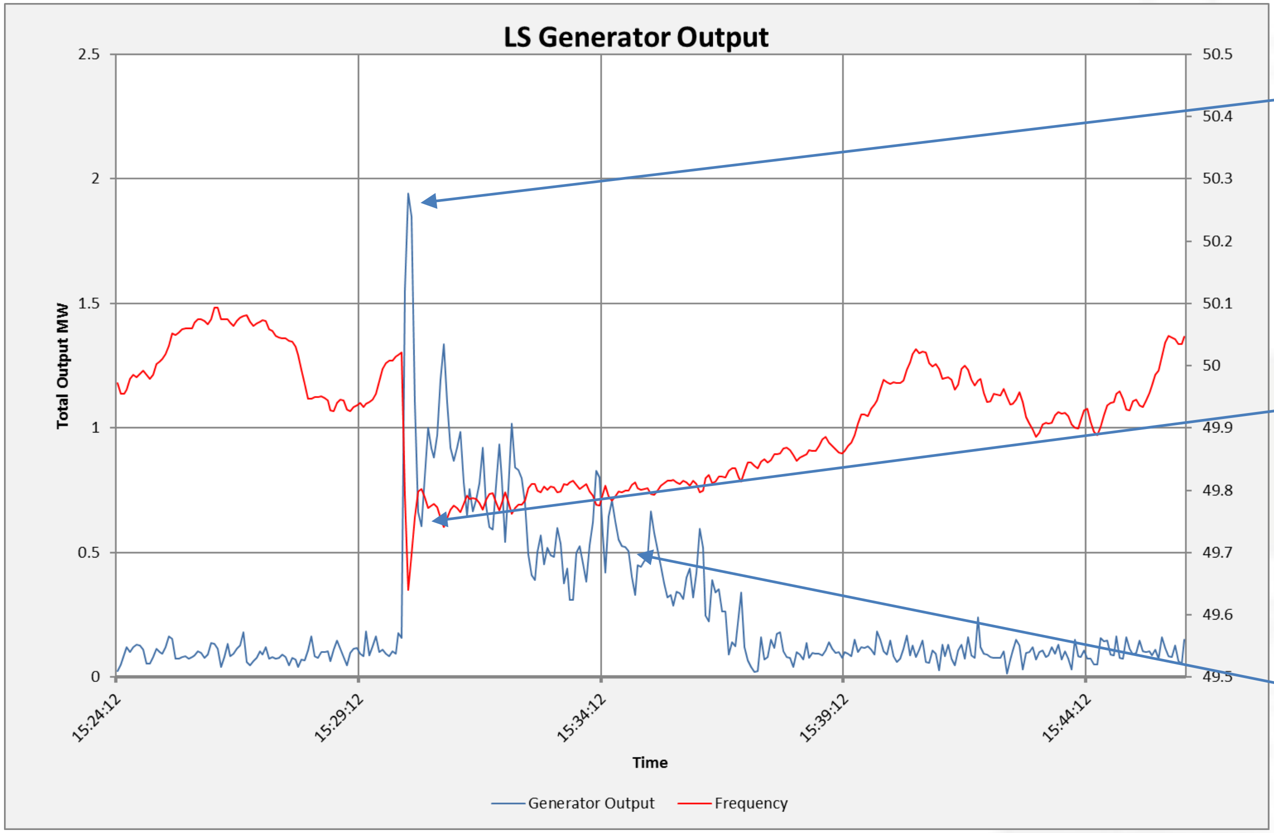


FFR / FCAS - PERFORMANCE

- Generator tripped in NEM – 25.12.2018
- This caused the mainland frequency to rapidly drop to 49.65Hz
- This network frequency drop was outside the bounds of normal frequency control, and triggered an FCAS event
- All registered FCAS units are expected to respond to such an event
- Time to react – 30 msec

FFR / FCAS - PERFORMANCE

- Low speed data (4 sec)



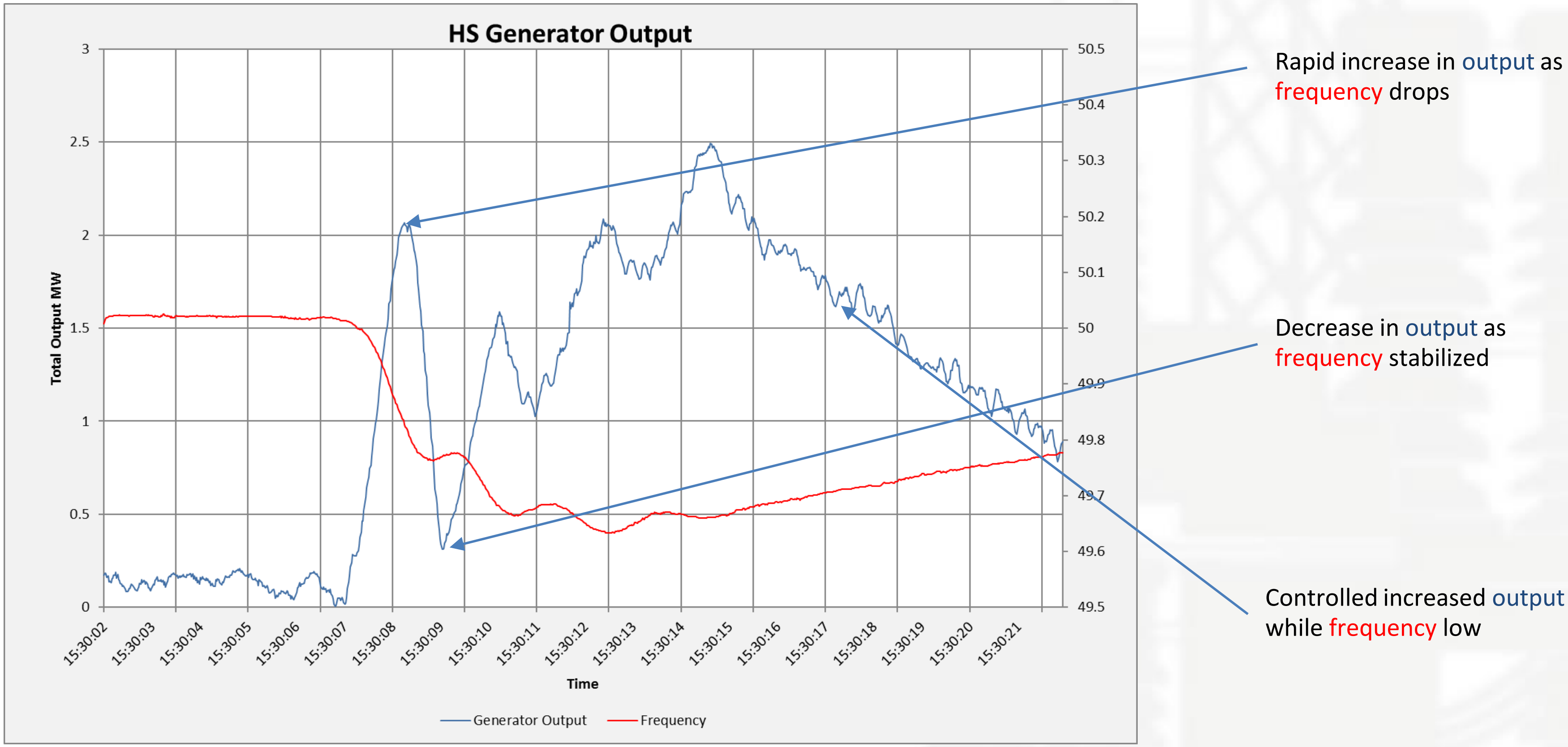
Rapid increase in output as frequency drops

Decrease in output as frequency rebounds

Sustained increased output as frequency recovers

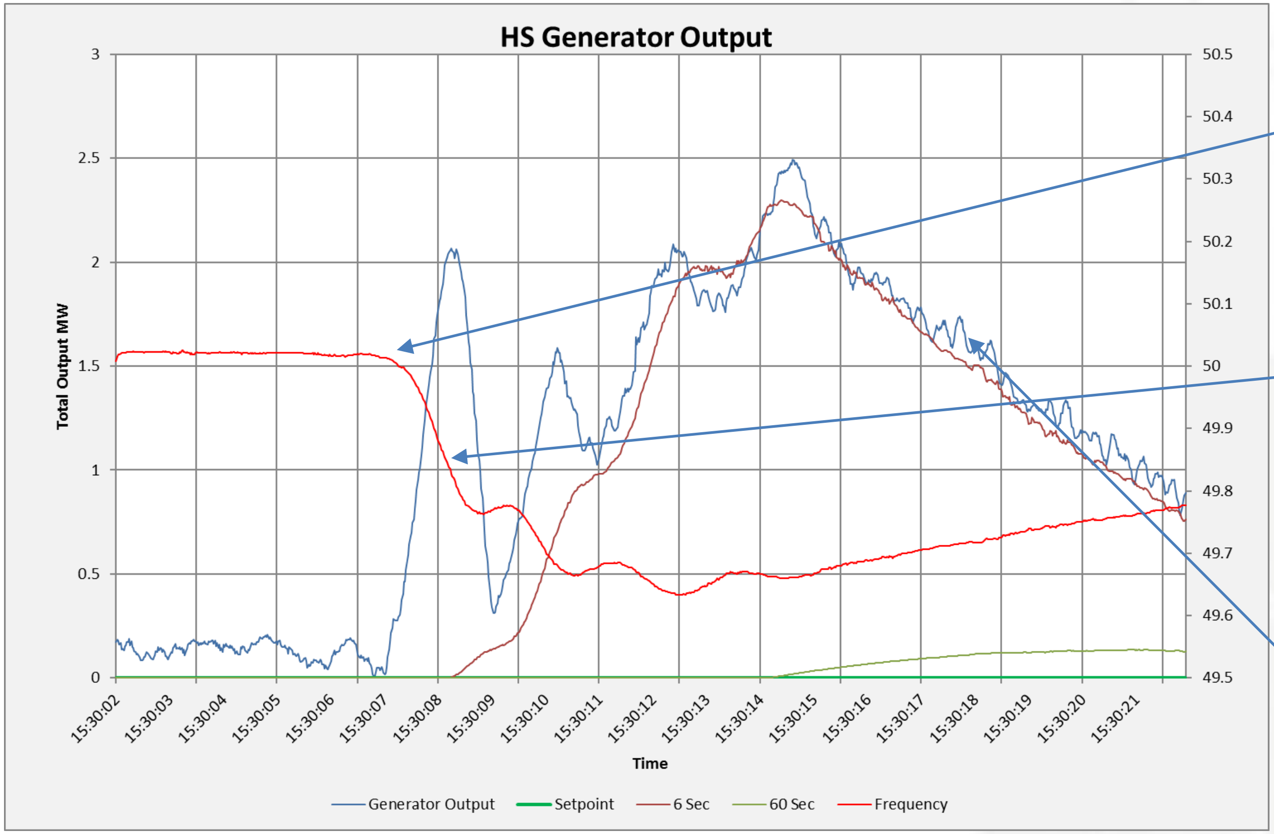
FFR / FCAS - PERFORMANCE

- High speed data (20 msec)



FFR / FCAS - PERFORMANCE

- High speed data – predicted vs actual output



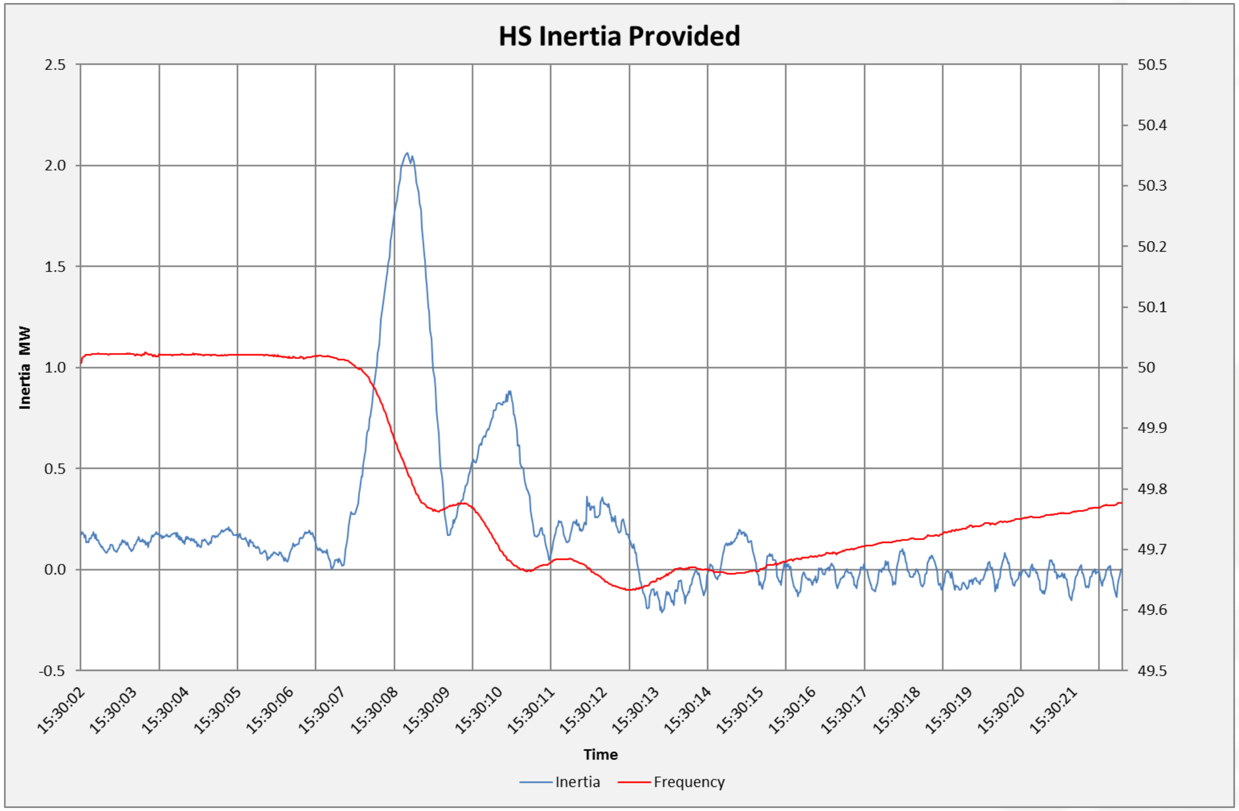
When Rate of Change of frequency increases, inertia control increases output

FCAS Starts to ramp when frequency crosses 49.85Hz

When Rate of change of frequency stabilizes, FCAS holds increased output

FFR / FCAS - PERFORMANCE

- By removing predicted FCAS response, inertia response is:



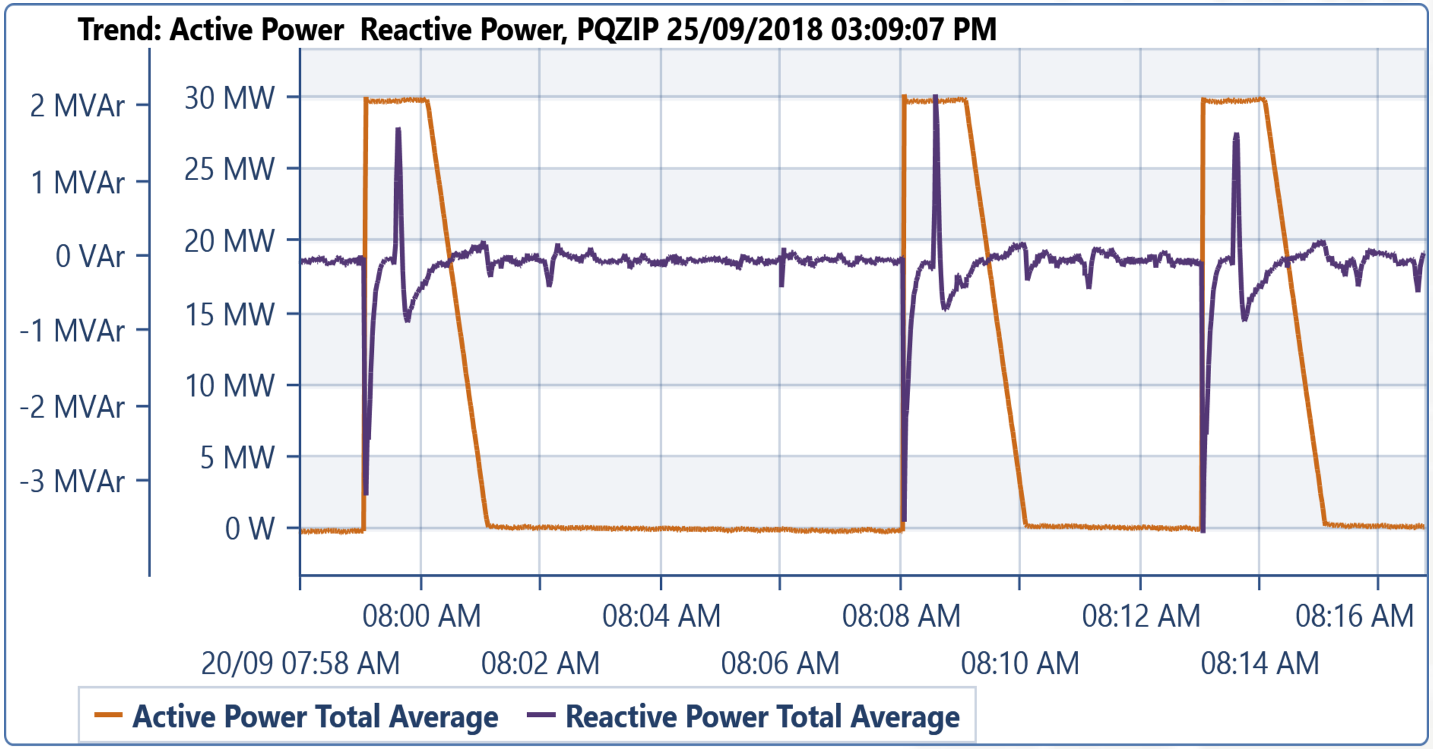
NETWORK SUPPORT - PERFORMANCE

- BESS integrated in SIPS scheme
- SIPS detects major generation loss by monitoring power swings
- Three stage response for SIPS after unstable power swing detected:
  1. Inject rapidly power into network – use BESS (due to rapid response capabilities)
  2. Trip selected loads
  3. Initiate separation from NEM
- Functionality can be transferred to PMU-based WAMS / WAPS system
- Speed of response essential (when U/f protection systems not effective)

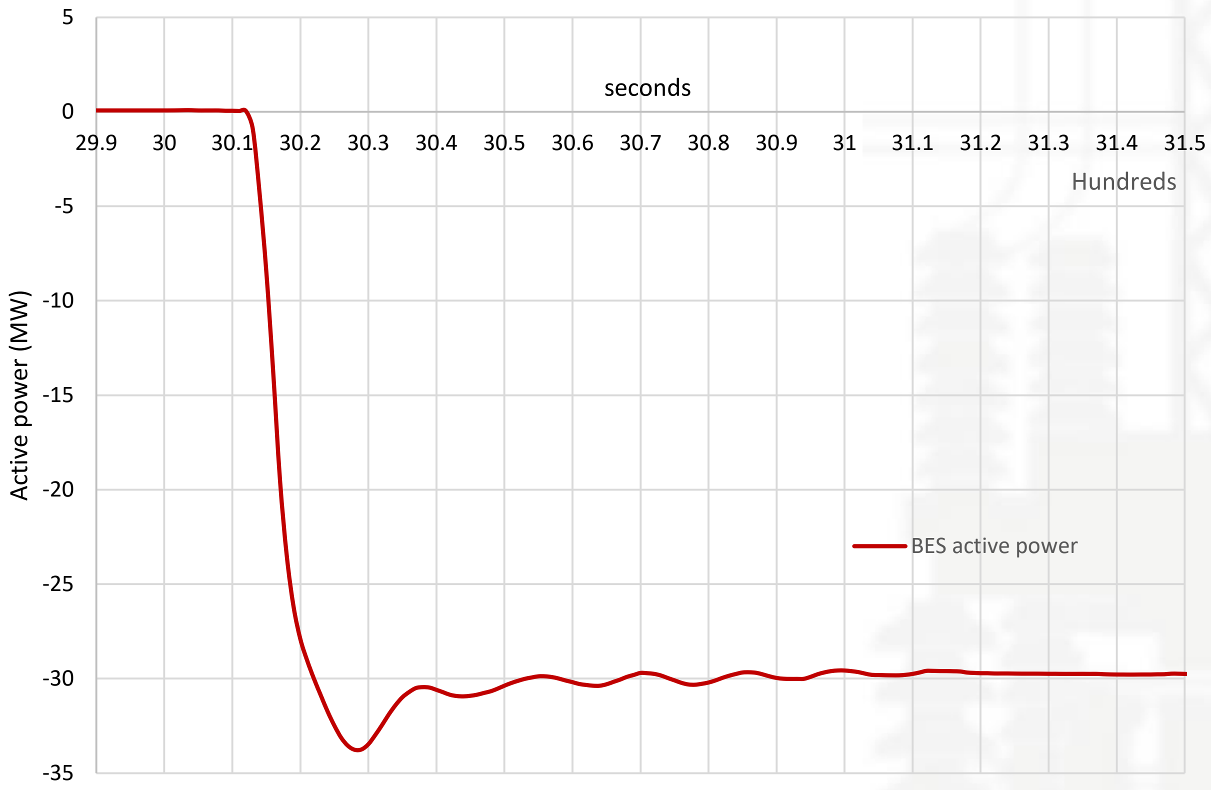
NETWORK SUPPORT - PERFORMANCE

- SIPS scheme simulated loss of generation in SA network
- 30 msec telecommunication signal propagation delay (SIPS detection units installed approx. 400km away from BESS)
- BESS control system response time: 120 msec
- BESS ramp-up time: 100 msec
- Overall response time: approx. 250 msec
- Conclusion – BESS Systems can inject power, assist network effectively following network events and may aid in preventing load-shedding and islanding / black-outs

NETWORK SUPPORT - PERFORMANCE



NETWORK SUPPORT - PERFORMANCE



FAULT CURRENT (USE) - REQUIREMENTS

- Desired outcome
  - BESS shall provide sufficient fault current contribution for distribution protection system to operate correctly
- Performance Measurement
  - Current measurement at Connection Point
- Detection method / initiating signals
  - Voltage measurement at 33 kV bus
- Duration: capable for more than 2 sec

FAULT CURRENT (USE) - PERFORMANCE

- 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 (out of 12) BESS inverters are required to be in service in order to meet fault current requirements
  - WPWF O/F protection settings need to be adjusted
  - Transformer saturation needs to be properly considered for islanding studies

V/Q CONTROL - REQUIREMENTS

- Desired outcome
  - BESS shall dynamically generate or absorb reactive power to support the system voltage at Dalrymple in response to a control signal or set point
- Performance Measurement
  - Reactive Power, voltage measurement at Connection Point
- Detection method / initiating signals
  - SCADA signal; or
  - Voltage measurement at Connection Point
- Response time: less than 1 sec

FAULT RIDE-THROUGH - REQUIREMENTS

- Desired outcome
  - provide 'dynamic reactive support' to system voltage; and
  - dampen power system transients during and after a power system fault to assist the fault ride-through capability of WPWF
- Performance Measurement
  - Dynamic simulation
- Detection method / initiating signals
  - Voltage measurement at 132 kV bus
- Response time: has reactive power rise time, for a 5% voltage disturbance, of less than 2.4 seconds