Musselroe Wind Farm

FCAS Trial

Public Report

January 2022

Table of Contents

This project received funding from ARENA as part of ARENA's Advancing Renewables Program. The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

List of Figures

List of Tables

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Abbreviations

AEMO	Australian Energy Market Operator
AGC	Automatic Generation Control (AEMO)
AP	Active Power
ARENA	Australian Renewable Energy Agency
CapBank	Capacitor Bank
COGATI	Coordination of Generation and Transmission Investment
CPF	Causer Pays Factor
CPP	Consolidated Power Projects Australia Pty Ltd
DI	Dispatch Interval (5 minutes)
ECM	Energy Conversion Model Guidelines (AEMO)
EMS	Energy Management System (AEMO)
FCAS	Frequency Control Ancillary Services
FDS	Functional Design Specification
FSM	Frequency Sensitive Mode (a PPC frequency control mode)
LVRT	Low Voltage Fault Ride Through
MASS	Market Ancillary Services Specification
MLF	Marginal Loss Factor
MRWF	Musselroe Wind Farm
NEM	National Electricity Market
NEMDE	NEM Dispatch Engine
OEM	Original Equipment Manufacturer
PPC	Turbine Power Plant Controller
PSS/E	Power System Simulation for Engineering (Software)
RoCoF	Rate of Change of Frequency
RRCS	Remote Runback Control Scheme
RTAC	Real-Time Automation Controller
SCADA	Supervisory Control and Data Acquisition
SCR	Short Circuit Ratio
SGI	Smart Grid Interface
TI	Trading Interval (30-min up until Oct 20201, then 5 minutes)
TNSP	Transmission Network Service Providers

VCS	Voltage Control Scheme
UIGF	Unconstrained Intermittent Forecast Generation (either from AWEFS, ASEFS or Self-forecasting
WNH	Woolnorth Wind Farm Holdings
WNWF	Woolnorth Wind Farm (the collective site name for the two wind farms, Bluff Point and Studland Bay)
WTG	Individual Wind Turbine Generators on site

1 Introduction

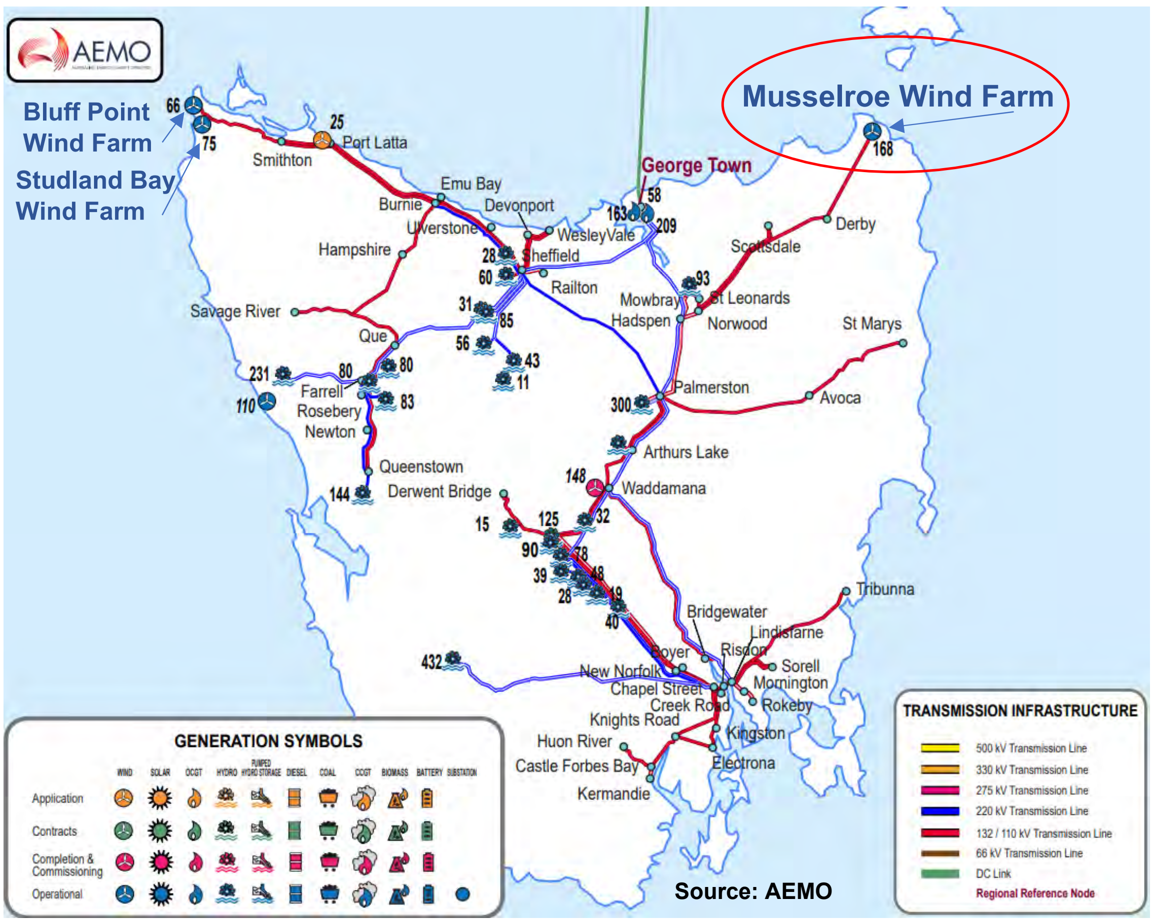
1.1 Background

Musselroe Wind Farm (“**MRWF**”) located at Cape Portland in the Northeast of Tasmania comprises 56 V90 Vestas turbines with an installed capacity of 168 MW (Figure 1)

The facility is owned and operated by Woolnorth Wind Farm Holding Pty Ltd (trading as Woolnorth Renewables ("**WNR**")), who also own and operate the Studland Bay (75 MW capacity) and Bluff Point (65 MW capacity) wind farms located in the Northwest of Tasmania.).

MRWF is connected to the Tasmanian network via a 48km 110 kV single circuit dedicated transmission line from the wind farm to the Tasmanian shared network at Derby. Derby is located approximately 120km from Georgetown the Regional Reference Node (RRN) for Tasmania.

Figure 1 NEM Network Connections – Tasmania Feb 2021

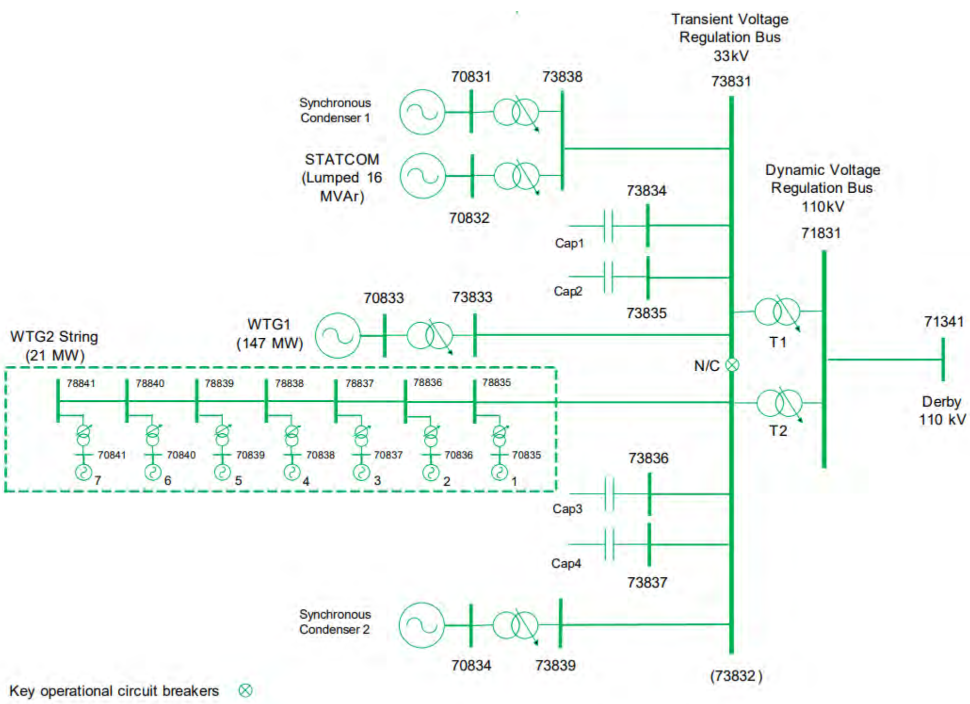


MRWF was commissioned in 2013 with significant network management equipment, due to its size, network connection arrangement and location. The Connection Point at the Derby Substation has a very low fault level (360 MVA) resulting in Short Circuit Ratio (SCR) range at the wind farm of between 1.8 - 2.1.

To meet the performance standards the reactive and generating plant comprises 4 x 4.0 MVar STATCOMs, 4 x 10.0 MVar Capacitor Banks (CapBank) and 2 x 14.0 MVA Synchronous Condensers, together with the 56 V90 3.0 MW double feed induction wind turbines.

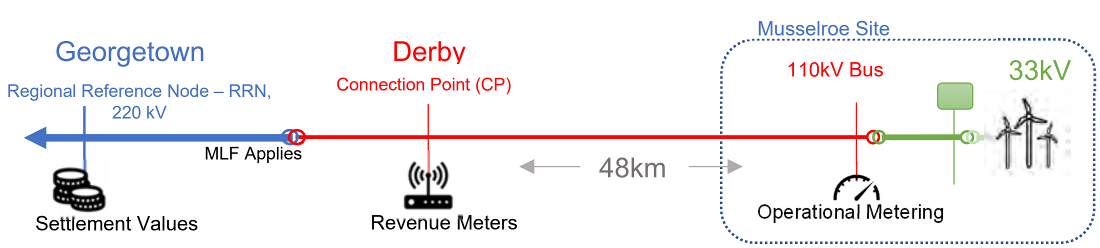
The control system comprises of various components as seen in Figure 2. The wind turbines are managed via a Vestas Power Plant Controller (PPC).

Figure 2 MRWF simplified Single-Line Representation



The plant is connected to a 33kV collector network. This 33kV collector network is connected to a 110kV transmission line via 2 x 33/110kV 90MVA step-up transformers. Indicative locations for both revenue and operational metering are shown for reference as represented in Figure 3.

Figure 3 Overall Connection Schematic



The Balance of Plant configuration for MRWF proved to be a significant issue in the development of the FCAS trapezium used for the Registration approval by AEMO. This configuration limits the potential of the wind farm to provide FCAS services. It is expected that on most occasions, MRWF will be operating at or close to full generation and therefore not likely to be participating in FCAS markets Figure 6 below provides an illustration of the FCAS trapezium.

1.2 Status of Project Activities

The critical outputs of the overall project include:

a) demonstrating the ability of an existing wind farm with Vestas turbines to deliver FCAS and undertake a series of tests in consultation with TasNetworks and AEMO- Completed
b) summarise the commercial and economic assessment of wind farm participation in the FCAS market- Completed
c) the requirements for interfacing with AEMO for the purposes of control, communications, and wind forecasting- Completed
d) the technical impact of enabling FCAS in an existing wind farm rather than a new build wind farm- Completed
e) evaluating the installation of utility-scale battery storage to provide FCAS; and – Milestone 3
f) detailing MRWF's participation in the FCAS market- Milestone 3

Milestone 1, 2A and 2B have already been completed.

1.3 Project Deliverables

As part of the previously reported on Milestone 2B, a public presentation was completed in September 2021 to demonstrate to the industry some of the developments and success that have occurred through the project. Highlights of the presentation included:

- Discussion on the key plant equipment and settings impacting FCAS setup and enablement
- Discussion around the optimisation decisions and participating in the FCAS market

Milestone 3 (FCAS test and implement reporting and optimisation systems) required completion of the following items:

1. Completion of WNH FCAS tests.
2. WNH calculating the optimal MRWF position in the energy and FCAS markets and describing how this is bid into AEMO's physical dispatch process.
3. FCAS bids with AEMO's dispatch and wind forecasting system; and
4. An initial assessment on BESS installation once the FCAS registration had been completed

The final aspect was to consider whether a storage solution may be better fit for the site and how this could be incorporated.

1.4 Significant Activities since Milestone 2B Report (July 2021)

Key activities for this project that have been completed since the end of July 2021 include:

- A public Zoom presentation was hosted by Greenview Strategic Consulting which attracted approximately 80 attendees in September 2021. This presentation provided a progress update on the Milestone 2A/2B works.
    - A link to the recording of the presentation is
    - https://us02web.zoom.us/rec/share/SGzcnOCs2we64Zv58iDJ32STTF9DP0nwbjbyh9SYHAbilfJ05lkYhB85dJxUU40g.JAlUNyRM7qq9DXHc
    - AEMO registration was completed, effective 9 November 2021
- A market test for raise contingency and regulation enablement was conducted successfully on 12 November 2021 and early December 2021.
- Live market bids have been submitted and enabled for short periods of time
- Development and refinement of an FCAS optimisation tool for trading use completed
- The AGC mode activation was tested successfully.
- Development and refinement of a basic Storage model for consideration including the location relative to the connection point.

1.5 Milestone 3 Status

As at the time of writing (17 December 2021), the following items have been completed or are awaiting final outcomes.

Table 1Summary of Status of Tasks

Status	Status	Comment	Next Step
(Carry over) Milestone 2B			
Completion of the FCAS tests	✓	Completed (see Section 2)	-
FCAS bidding registered with AEMO	✓	Completed (See Section 2)	-
Milestone 3			
Finding the optimal position	✓	Optimisation tool completed, including linkage to UIGF	-
Initial assessment of storage elements	✓	Initial Storage model completed	Refine input costs
Discussion on how MRWF could be used to provide FCAS and other grid support from a hybrid wind farm solution	✓	Initial points provided	

2 FCAS Enablement at MRWF

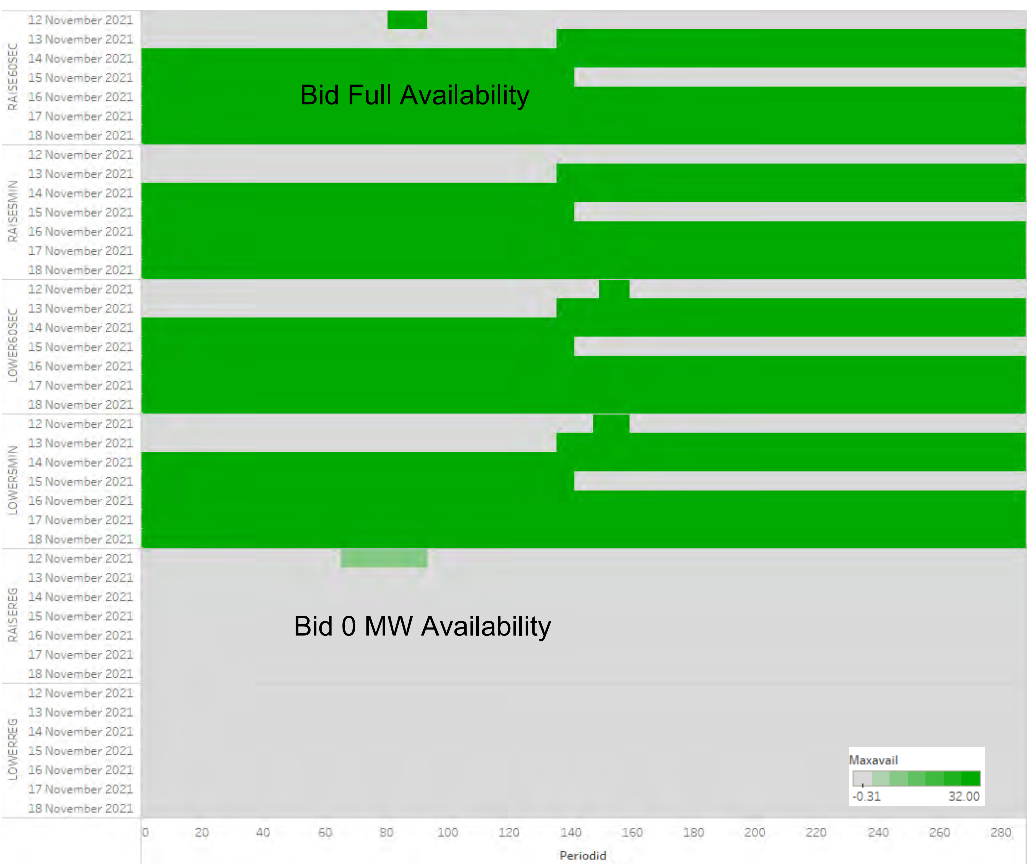
Following registration with AEMO on November 9, 2021, MRWF was able to successfully submit bids to AEMO for contingency raise services during a mid-range wind period, as shown below.

Table 2 FCAS bid initial market test

SETTLEMENTDATE	INITMW	TARGET	SDC	UIGF	R60	R5	L60	L5
2021-11-12 10:30	65.50	65.00	1	78.744	7.45387	0.00	0.00	0.00
2021-11-12 10:35	66.10	65.00	1	83.909	10.25590	0.00	0.00	0.00
2021-11-12 10:40	64.60	65.00	1	84.207	10.41789	0.00	0.00	0.00
2021-11-12 10:45	64.39	65.00	1	80.591	8.45599	0.00	0.00	0.00
2021-11-12 10:50	65.00	65.00	1	83.064	9.79676	0.00	0.00	0.00

For the 7 days between 12 November 2021 and 15 November 2021, MRWF was bid into the R5, R60, L5 and L60 FCAS Markets at full availability, as shown below.

Figure 4: Bid Availability for 7 days commencing 12 November 2021



MRWF is registered for regulation services and completed all testing. AGC was enabled and dispatched by AEMO on the Dec 6 2021 as shown in the figure below.

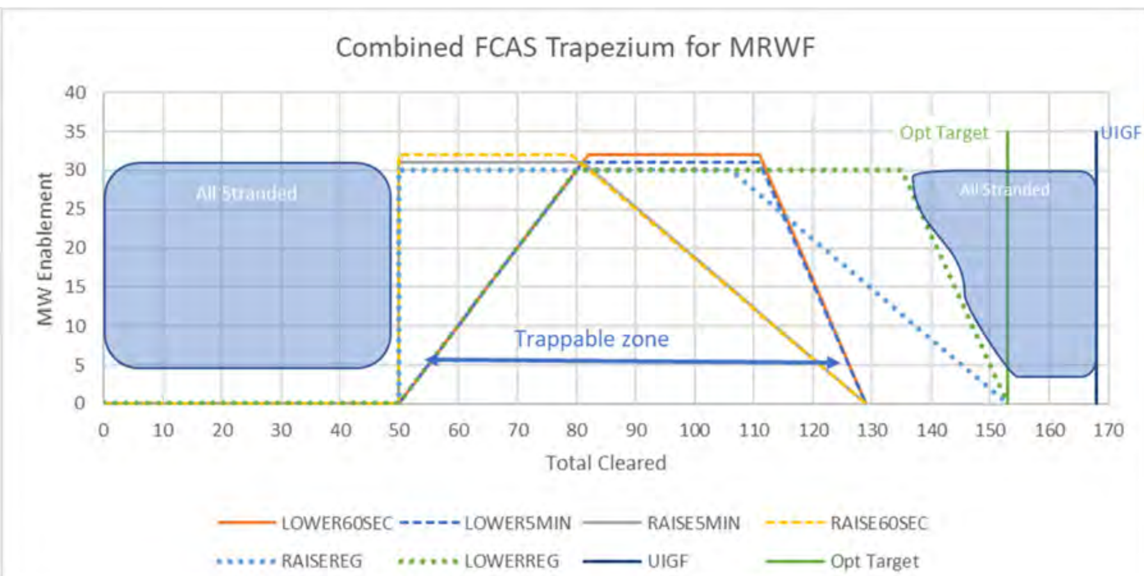
Figure 5: AGC Enablement 6 Dec 2021

Musselroe/Woolnorth Dispatch

DATETIME	INT	STATUS	SETTPRICE	INITMW	TARGET	UIGF	SDC	AGC	FCAS ENABLED	MWERROR	FC ORIGIN	UP/DN	RREG$	LREG$	UL/LL	RR	LR
06-Dec-21 16:45	0		$28.94	117.80	119.80	119.80	0	1	0		AWEFS	150/168	$12.64	$11.03	117.4/50	0.0	0.0
06-Dec-21 16:40	0	NORMAL	$28.94	118.20	122.01	133.81	1	1	0	-4.2	AWEFS	150/168	$12.50	$14.03	122/50	0.0	0.0
06-Dec-21 16:35	0	NORMAL	$28.92	106.30	132.72	132.72	0	1	0	-14.5	AWEFS	150/168	$12.50	$13.76	131.8/50	0.0	0.0
06-Dec-21 16:30	0	NORMAL	$28.94	105.30	105.30	136.28	1	1	1	0.0	AWEFS	0/168	$17.81	$13.50	127.9/50	7.2	15.0
06-Dec-21 16:25	0	NORMAL	$28.92	105.10	105.10	136.02	1	1	1	0.0	AWEFS	0/168	$12.51	$7.53	130.4/50	8.1	15.0
06-Dec-21 16:20	0	NORMAL	$28.94	105.40	105.40	133.19	1	1	1	0.0	AWEFS	0/168	$18.73	$8.33	131.1/50	8.2	15.0
06-Dec-21 16:15	0	NORMAL	$28.92	105.40	105.40	132.81	1	1	1	0.0	AWEFS	0/168	$12.52	$10.49	128.2/50	7.3	15.0
06-Dec-21 16:10	0	NORMAL	$51.92	105.30	105.30	119.35	1	1	1	0.0	AWEFS	0/168	$12.64	$10.49	119.3/50	4.5	11.7
06-Dec-21 16:05	0	NORMAL	$51.92	105.40	105.40	119.24	1	1	1	0.0	AWEFS	0/168	$15.56	$10.79	111.1/50	1.8	4.8
06-Dec-21 16:00	0	NORMAL	$62.93	104.90	104.90	124.92	1	1	1	0.0	AWEFS	0/168	$20.09	$3.86	119.5/50	4.6	12.1
06-Dec-21 15:55	0	NORMAL	$61.79	105.80	105.80	120.08	1	1	1	0.0	AWEFS	0/168	$12.64	$3.86	119.5/50	0.0	11.4
06-Dec-21 15:50	0	NORMAL	$67.25	106.10	106.10	117.18	1	1	1	0.0	AWEFS	0/168	$12.64	$3.94	111.9/50	0.0	4.8
06-Dec-21 15:45	0	NORMAL	$57.04	110.60	110.60	122.49	1	1	1	-1.6	AWEFS	0/168	$20.09	$4.17	114.1/50	0.0	2.9
06-Dec-21 15:40	0	NORMAL	$65.05	116.40	116.40	118.17	1	1	0	-5.8	AWEFS	0/168	$12.64	$4.17	116.3/50	0.0	0.0

Perhaps the most critical aspect to FCAS delivery from any plant, but especially renewable plant, is the FCAS Trapezium. So, while it was excellent that the project was able to finally be enabled, the complexities associated with FCAS enablement became clearer as the month of bidding continued.

Figure 6: Final FCAS Trapezium for MRWF



As Figure 6 includes, a trapped and stranded zone exists for all FCAS providers in all individual services (identified in blue in Figure 4), as well as an enablement zone (the area under all curves). These technical parameters mathematically describe to AEMO's Dispatch Engine the limitations of the plant across all fuel types and operating conditions. Through the adjustment of the Total_Cleared value as part of the optimisation process, an optimal energy/FCAS balance can be calculated (Appendix 1 of Milestone 2B report has additional information).

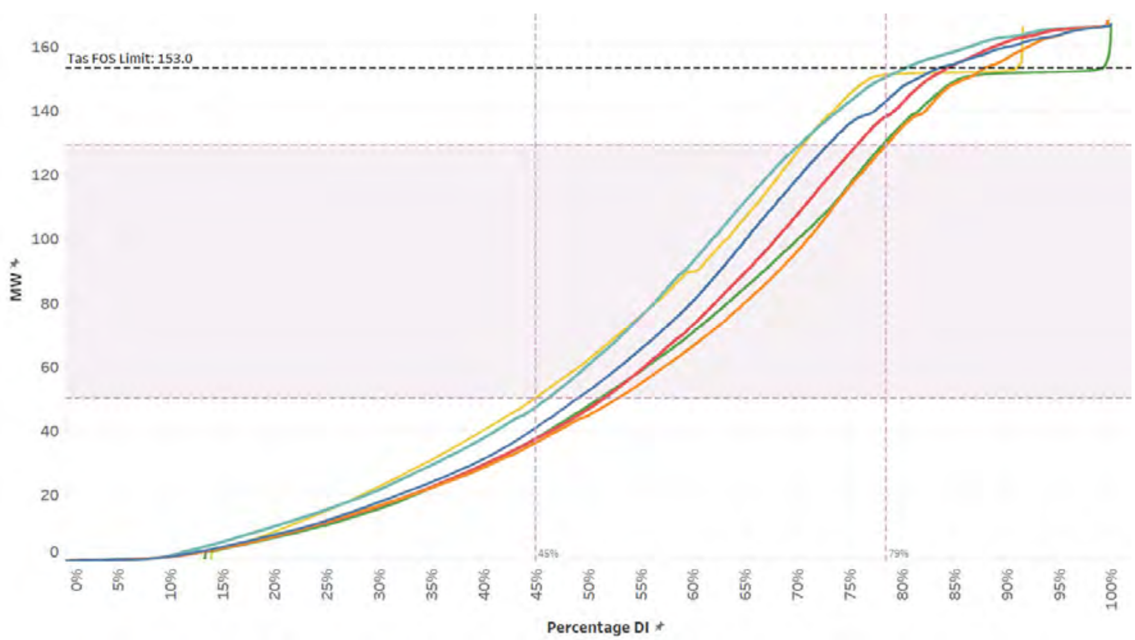
FCAS Optimisation Challenges

The above information highlights several key factors:

- The FCAS trapezium for MRWF limits the potential time for MRWF to be enabled with MRWF only spending 25-30% of its time within that theoretical generating boundary (see Figure 7).
- Despite being bid available, the actual enablement of MRWF is based on the price of the FCAS services, which through much of November 2021 was stable and low.

The critical question to answer for FCAS co-optimisation, 'Is it economic?' is a complex calculation that must consider many factors. Given there is no automated bidding solution to solve this issue at present, and to assist with the optimisation process, we developed a small Excel Solver that can help determine the most optimal FCAS/Energy position.

Figure 7: Yearly Generation overlayed with the Ideal FCAS Trapezium



In MRWF's case, the additional complications include:

- The fuel source is variable resulting in the standard FCAS trapezium being shifted lower as the wind potential decreases (observable via Availability decreasing)
- To meet site setpoints below ~45MW, the plant controller will pause turbines out of service, thereby prohibiting FCAS control below this level (thus creating the 50MW minimum enablement level)

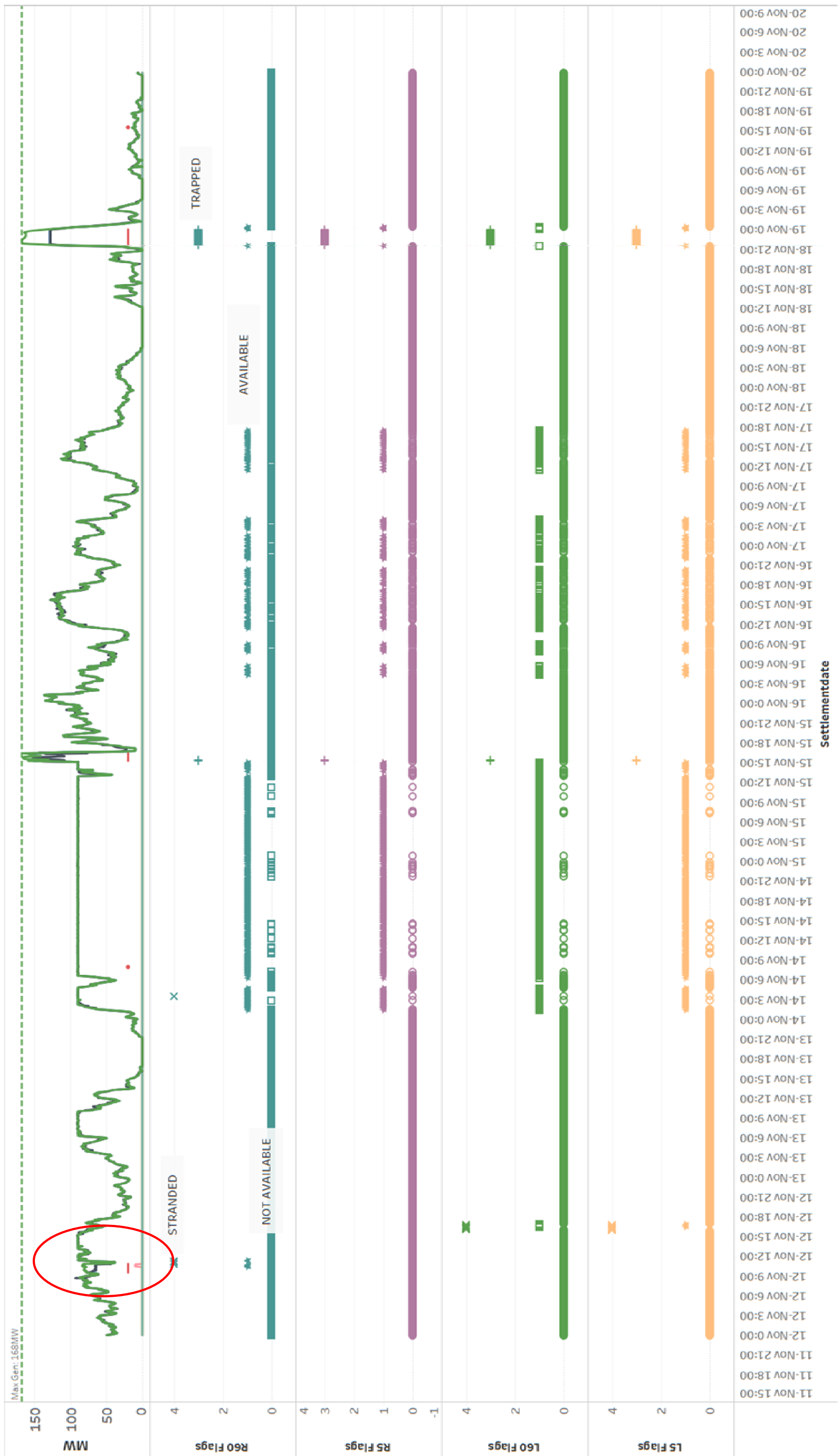
- The CapBank limit, which results in a 130MW site limit being invoked under some ramp down conditions, would result in an inconsistent FCAS performance when operating above 130MW (thus creating the 129MW limit)
- The AGC upper and lower limits are dynamically calculated, often resulting in wind changes resulting in much higher or lower limits
- Given the large site, the variability of the wind to change by 5-10% resulted in AEMO allowing for a 18MW wind change when considering the upper angles. This is in turn results in the slightly bemusing situation with Lower Reg MW where MRWF would have to bid the plant lower to provide lower service

The summation of the FCAS Trapezium complexities noted above and as shown in Figure 8, is that for most of the week, MRWF was either unavailable due to low wind or outside the FCAS parameters.

Finally, on the evening 18 November, a strong front came through site, lifting generation from near 0MW to full output in 30 minutes. As the wind increased above 129MW, MRWF began to receive trapped signals from AEMO, an outcome that was expected under these conditions. This can also clearly be observed in Figure 8.

All these factors must be considered carefully in any FCAS enablement consideration for renewables into the future.

Figure 8: Week of FCAS Bidding



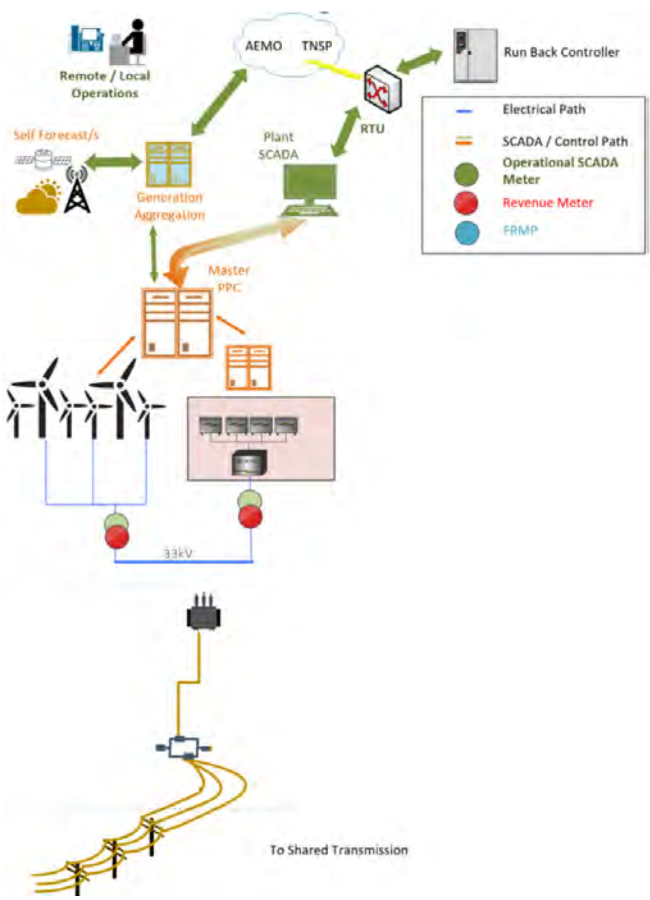
3 Storage Configuration

The following items were considered when assessing the integration of a BESS on site:

- There are no genuine wind/battery hybrid units registered in the NEM as of 30 November 2021.
- The addition of a battery would greatly assist CPF mitigation for MRWF as well as power, reactive and frequency control on the area. If FCAS Regulation services were to be supplied by an on-site BESS, all the control logic is largely in place (including the run-back controller).
- The provision of FCAS Contingency will be easier to implement than AGC control for Regulation, as the BESS frequency controller will simply start to provide MW's when the frequency is outside the normal operating frequency band. Once this trigger is reached, the CPF calculation is suspended, and the battery should be moving the generating system in the right direction for a response.

A design concept for the BESS, integrated at the wind farm is shown below

Figure 9: Nominal Hybrid BESS Layout



3.1 Storage Integration Model

A business model was developed to be able to allow assessment of all options that could be determined for both onsite and off-site purposes. Similarly, given the integration of the wind farm for 'filling' purposes, an accurate configuration was required that matched MRWF's prevailing financial PPA conditions.

The custom, excel based model included the following key attributes:

- Multiple locations for the storage, including within the wind farm, near the connection point and the regional references node. With each of these options, the following key factors changed:
    - Energy from the wind farm into the storage device?
    - MLF impacts?
    - CPF impact?
    - Likely Voltage (hence equipment required)?
- Multiple Vendors and their storage characteristics:
    - MW/MWh
    - Parasitic load
    - FCAS MW capability
    - Likely FCAS throughout

Using the above information, the outputs from the model were able to assist determine:

- Likely FCAS Contingency and Regulation revenue
- Energy Revenue and MWh
- Storage cycling and efficiency
- Value from 'spilled wind' capture

4 Key Conclusions

The following is a list of key information associated with this Milestone.

a) FCAS capability has been successfully enabled on MRWF.
b) The modifications required to the control system were significant and time consuming, involving many different stakeholders.
c) A basic FCAS optimisation model (in lieu of existing auto bidding solutions) can assist WNR and its trading team to optimise FCAS/Energy outcomes as required
d) The complexities associated with the FCAS Trapezium for MRWF, given the prevailing plant conditions, severely limit the time and MW's that will be available for possible FCAS services, which can further limit (through trapping), the time in which MRWF can be simply enabled and await FCAS enablement
e) Given some of the existing wind curtailment issues on site at MRWF, 'filling' a storage device (and providing FCAS capability) is a technically plausible and economically viable option.
f) In the preliminary business case model runs, several configurations' options have been considered and appear economically feasible.

Woolnorth Wind Farm Holdings thanks ARENA for their support for this project.