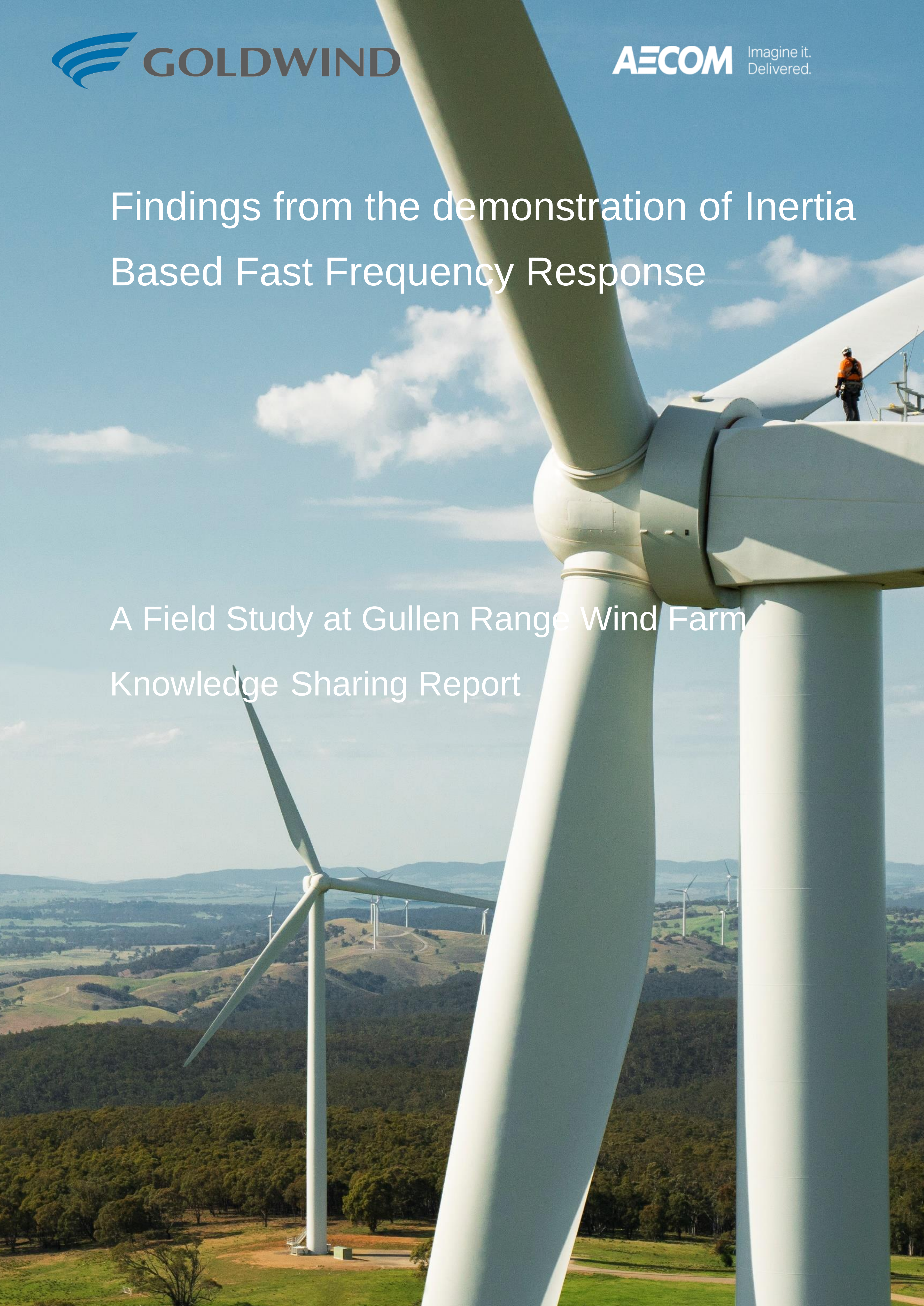
Findings from the demonstration of Inertia Based Fast Frequency Response



A Field Study at Gullen Range Wind Farm

Knowledge Sharing Report

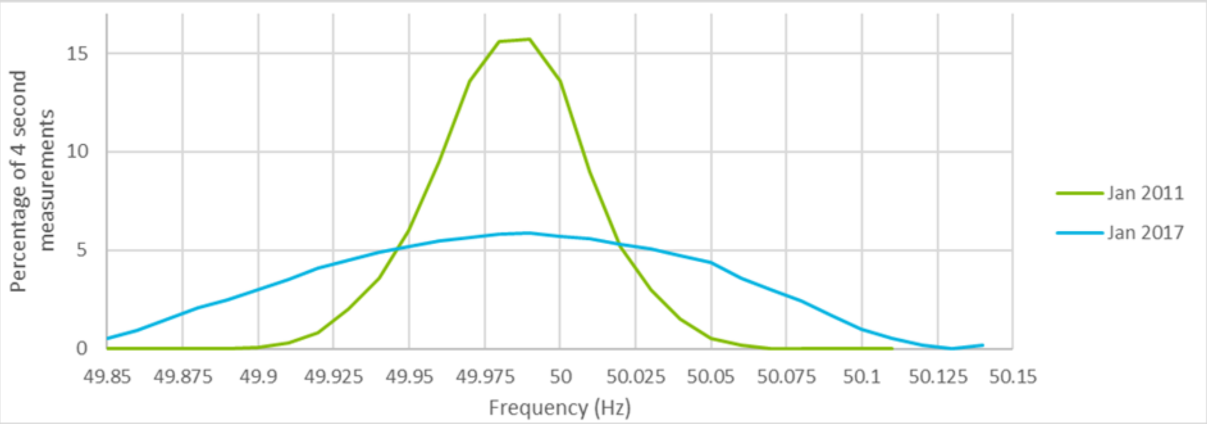
This project received funding from ARENA as part of ARENA's Advancing Renewables Program.

Executive summary

Goldwind's Inertia Based Fast Frequency Response (IBFFR) technology was developed to enable wind farms to mimic the behaviour of traditional synchronous generators to provide voltage and fast frequency regulation to improve the network security. Goldwind's technology uses the rotor kinetic energy (inertia) of the wind turbine blades to boost the power output of wind farm provided in response to a drop in system frequency. A field study of Goldwind's IBFFR technology was undertaken with the support of funding from ARENA as part of ARENA's Advancing Renewables Programme.

The Australian Energy Market Operator (AEMO) has been reporting on an ongoing decline in frequency stability in the National Electricity Market (NEM), as shown in Figure 1. The Australian Energy Market Commission (AEMC) has identified one of the main drivers of the recent degradation of frequency performance as generators decreasing or removing the responsiveness of plant to frequency deviations to avoid actual and perceived dis-incentives associated with operating plant in a frequency responsive mode (1).

Figure 1 NEM mainland frequency distribution: January 2011 vs January 2017 (2)



One service that may assist with maintaining the required frequency balance will be Fast Frequency Response (FFR). FFR generally refers to the delivery of a rapid active power increase or decrease, by generation or load, based on its demonstrated response time of two seconds or less, to correct a supply-demand imbalance and assist in managing power system frequency. Provision of FFR is increasingly being dominated by Battery Energy Storage Systems (BESS).

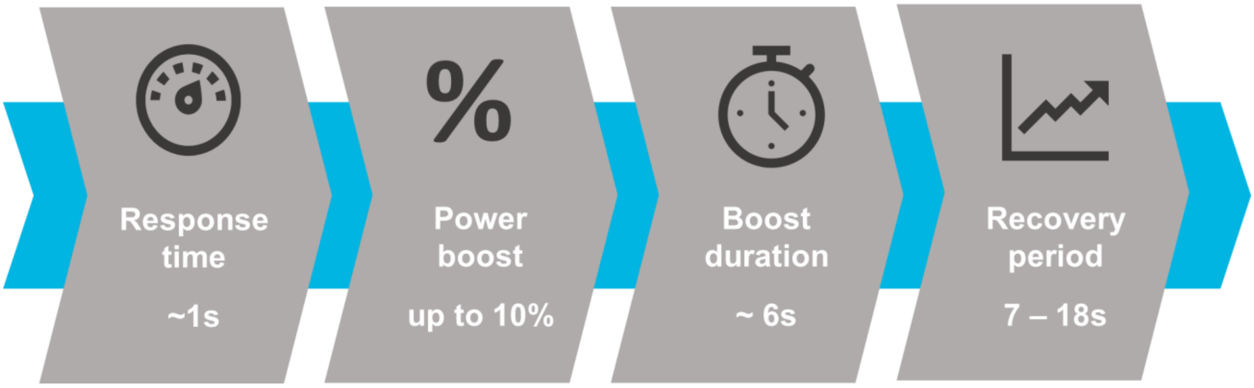
Goldwind has undertaken field trials of IBFFR from Wind Turbines Generators (WTG) at the Gullen Range Wind Farm (GRWF). Testing of this IBFFR capability was conducted across ten WTG, with either a single turbine or multi-turbine/multi-group configuration. There were four main testing objectives, which were to investigate the ability of IBFFR to:

- boost duration capability for single turbines
- boost capacity for single turbines
- characteristics for multiple turbines simultaneously
- characteristics for multiple turbines in a coordinated manner.

The field study components of this initiative were successfully completed in late 2019. The results of this field study are shared as part of the knowledge sharing initiatives under ARENA's Advancing Renewables Programme.

The IBFFR testing provided consistent performance across all tests conducted. A response of up to 10% of nameplate capacity, boost duration of six seconds, a ramp delay of less than two seconds and a time to peak less than two seconds and typically one second were readily achieved across low and high wind speed conditions as shown in Figure 2.

Figure 2 Goldwind's IBFFR technology capability



When this trial commenced, the energy markets did not put a value or specific requirement for this type of FFR; it was theoretically being provided by default by large synchronous generators. However, the AEMC has been investigating the declining frequency stability in the NEM as synchronous generators increasingly avoid operating the plant in a frequency response mode.

This investigation has resulted in recent rule change by the AEMC and offers what could be the most notable opportunity for IBFFR. On 26 March 2020, the AEMC published a rule change to mandate the provision of Primary Frequency Response (PFR) from all synchronous and non-synchronous generators in the NEM (3). Accordingly, IBFFR may provide a low-cost option for WTG operators to meet this requirement for generators to provide PFR.

In this regard, IBFFR compares favourably in response time compared to conventional rapid response generators, as seen in Figure 3. While they are unable to match the millisecond response time offered by BESS, they do provide a potentially scalable and cost-effective option, as summarised in Figure 4. IBFFR complements the synchronous generation responses well, ramping down at approximately the same time as synchronous generation responses become positive after an initial power drop.

It should be noted however that AEMO has not finalised the specific requirements for PFR under the rule change, and as a result the IBFFR field study was not specifically scoped to address these requirements. Accordingly, IBFFR should be considered as a promising option for WTGs that may be a cost-effective option relative to some other technology solutions for the new PFR requirements. Further specific testing should be undertaken once AEMO has finalised the technical requirements.

Figure 3 Different generation technologies response to frequency drop as a percentage (%) of nameplate capacity (4) (5) (6) (7) (8) (9) (10) (11) (12) (13) (14)

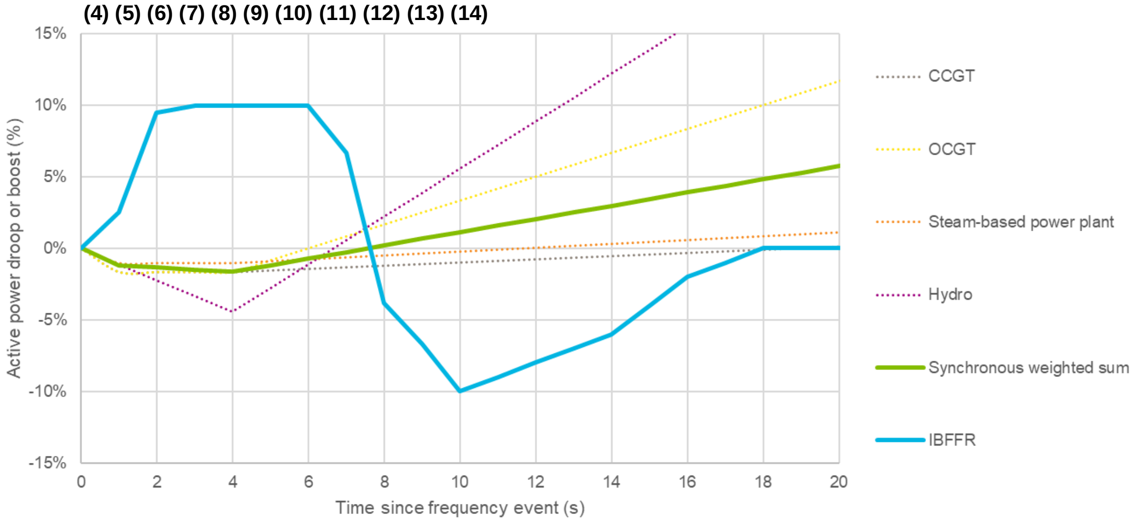
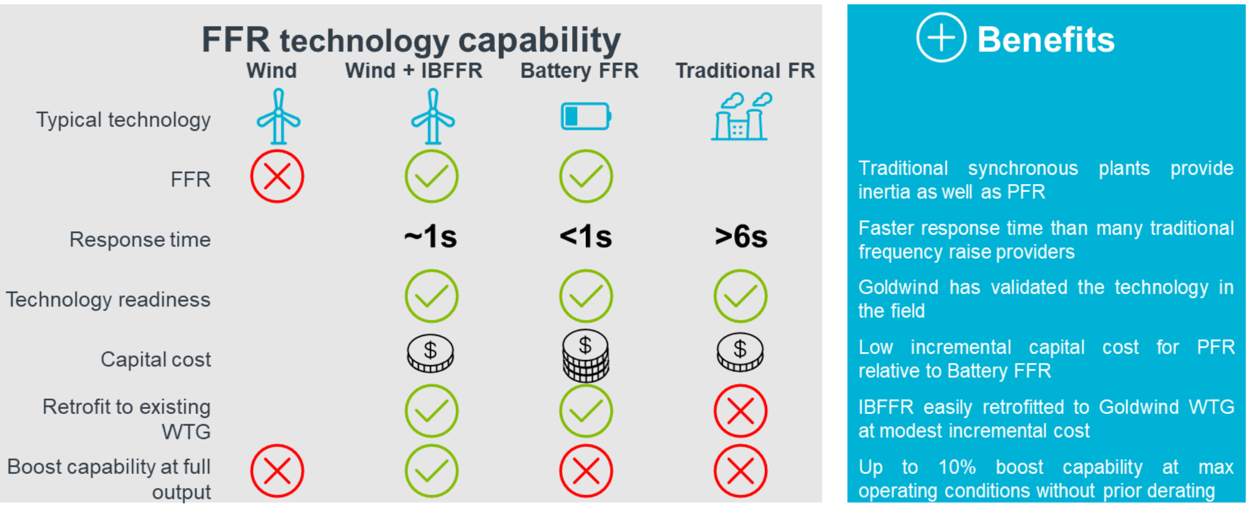
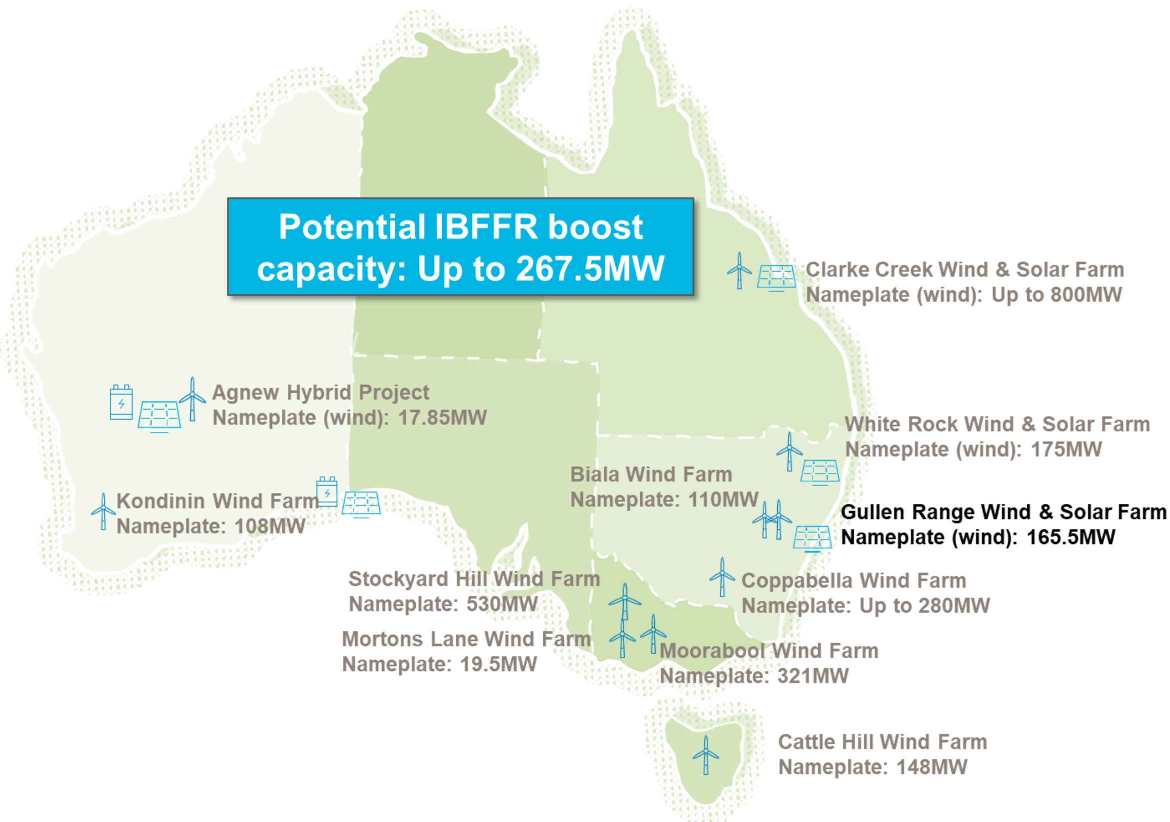


Figure 4 FFR technology capability comparison



Goldwind's IBFFR can potentially provide FFR support for their fleet of already installed WTGs. Theoretically, the potential boost capacity provided by IBFFR on Goldwind's proposed 2.7GW fleet is up to 270 MW across Australian electricity systems, as shown in Figure 5.

Figure 5 Potential IBFFR boost capacity of Goldwind's proposed fleet



The results of this study may be of interest to policy makers and market operators, to inform potential opportunities for frequency restoration. Asset owners, developers and 'gentailers' may leverage IBFFR technology to reduce the cost of any PFR compliance.

Findings from the demonstration of Inertia Based Fast Frequency Response

A Field Study at Gullen Range Wind Farm Knowledge Sharing Report

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			Name/Position	Signature
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Glossary

Term	Definition
AECOM	AECOM Australia Pty Ltd
AEMO	Australian Energy Market Operator
ARENA	Australian Renewable Energy Agency
BESS	Battery Energy Storage System
CCGT	Closed Cycle Gas Turbine
DNSP	Distribution Network Service Provider
FCAS	Frequency Control Ancillary Services
FFR	Fast Frequency Response
GRWF	Gullen Range Wind Farm
Goldwind	Goldwind Australia Pty Ltd
HAS	Harmonised Ancillary Services
Hz	Hertz
IBFFR	Inertia Based Fast Frequency Response
MW	Mega-Watt
NEM	National Electricity Market
NER	National Electricity Rules
NGRWF	New Gullen Range Wind Farm
NOFB	Normal Operating Frequency Band
OCGT	Open Cycle Gas Turbine
POR	Primary Operating Reserve
PFR	Primary Frequency Response
RoCoF	Rate of Change of Frequency
RPM	Revolutions Per Minute
SFR	Secondary Frequency Response
SNSP	System Non-Synchronous Penetration
TFR	Tertiary Frequency Response
TSO	Transmission Service Operator
VAr	Reactive Power
VPN	Virtual Private Network
VRE	Variable Renewable Energy
WTG	Wind Turbine Generator

1.0 Background and scope

Goldwind Australia Pty Ltd (Goldwind) is investigating the capability of Goldwind's IBFFR technology to provide Fast Frequency Response (FFR) and Primary Frequency Response (PFR).

The Field Study of IBFFR at Gullen Range Wind Farm (the Project) involved the installation, commissioning and testing of Goldwind's technology across 10 wind turbine generators (WTGs) at the 165.5 MW Gullen Range Wind Farm (GRWF). The testing provided data across a range of wind speeds to demonstrate the capability of Goldwind's WTGs to provide frequency support without prior de-rating.

This Field Study Report seeks to investigate the following:

- The need for FFR in the National Electricity Market (NEM)
- Review of international Frequency Control Ancillary Services (FCAS) markets and how they incentivise IBFFR
- The approach and methodology of testing IBFFR response
- Challenges and risks of IBFFR response field testing
- The impact and reliability of different IBFFR response parameters and response to different simulated frequency events

AECOM has been commissioned by Goldwind to prepare this Field Study Report.

1.1 Project objectives

This Knowledge Sharing Report aims to investigate both the market context and technical characteristics related to IBFFR to determine the potential applications of this technology within the Australian market context. This report aims to highlight how a wind farm can provide active power boost and frequency support services using IBFFR and to share this information with relevant stakeholders to reduce the risk associated with IBFFR implementation for future wind farms.

1.2 Purpose

This document is a public report issued as part of the Knowledge Sharing commitments of Milestone 2 of the Project, in accordance with the Funding Agreement between Goldwind and the Australian Renewable Energy Agency (ARENA), which has contributed funding support through its Advancing Renewables Program. The purpose of this document is to provide a summary of the trial and its outcomes to date and any lessons learnt throughout.

Box 1 Gullen Range Wind Farm

Gullen Range Wind Farm

Gullen Range Wind Farm (GRWF) is an operational wind farm in the Southern Tablelands of NSW, Australia. It is owned by BJCE Australia [Beijing Jingneng Clean Energy (Australia) Holding Pty Ltd]. The wind farm consists of 73 turbines and produces 165.5MW of renewable power in ideal wind conditions. It also is co-located with 10MW of solar generation. Stretching from north to south, the wind farm measures 22km, approximately centred on the locality of Bannister, 11km South of Crookwell and 32km northwest of Goulburn (15).

Turbine technology

GRWF consists of 73 wind turbines, manufactured by Goldwind Science and Technology. Two different types of turbine are installed on the project: the GRW100-2.5MW (56 turbines) and the GW82-1.5MW (17 turbines). The GW100-2.5MW has a 100m diameter rotor with a hub height of 80m (this is the height of the centre of the rotor). This makes for a height from ground level to the top of the rotor (the tip height) of 130m. At full power these turbines produce 2.5MW of power. The GW82-1.5MW has an 82m diameter rotor on an 85m tower, a tip height of 126m and at full power it produces 1.5MW. Both turbine types produce energy when the wind speed is above approximately 3m/s (11km/h). At 25m/s (90km/h) the turbine is designed to shut down (15).

The 73 turbines are split into 7 electrical circuits. The generators in the wind turbines produce electricity at approximately 690V, which is stepped up to 33kV by a transformer at the base of the wind turbine. Underground cables transmit this 33kV power from the wind turbine locations to the wind farm switch room near Bannister. The electricity is stepped up to 330kV by two transformers located next to the switch room and then passed on to the national electricity grid via a TransGrid owned switchyard (15).

Development, ownership and construction

Goldwind began construction of the project in 2012. The substation was energised, and the first turbines began operating in 2013. The wind farm was fully operational with all turbines commissioned and exporting electricity on 23 December 2014. The wind farm is now wholly owned by New Gullen Range Wind Farm Pty. Ltd. (NGRWF), whose shareholder is Beijing Jingneng Clean Energy Co., Ltd.

The Gullen Solar Farm is co-located within GRWF, making Gullen Range the first large-scale co-located wind and solar farm in Australia. The Gullen Solar Farm project is an operational solar photovoltaic (PV) power plant with an installed capacity of 10MW, commissioned in 2017. Locating the solar farm adjacent to the wind farm minimises required infrastructure (such as roads, power lines and telecommunications), meaning a reduction in environmental impact and project cost. Construction of the solar farm was supported by a grant from ARENA.

2.0 Frequency control and FFR

Frequency stability is key to ensuring that a power system operates in a secure state. The Australian Energy Market Operator (AEMO) is responsible under the National Electricity Rules (NER) to manage system frequency, which is achieved through balancing demand and supply throughout the electricity network. All components of a power system are designed to operate within a range of frequencies. Imbalances between demand and supply can cause system frequency to deviate beyond this range which may cause system instability, resulting system outages and potential system shutdowns.

Large shifts in demand and supply within the NEM causes system frequency to deviate significantly. Major frequency events, called contingency events, can be caused by the loss of a major generator, a large load or an interconnector.

Frequency Control Ancillary Services (FCAS) are procured in the NEM to correct frequency deviations under normal operation and in response to contingency events, with response times upwards of 6 seconds (16). The provision of FFR, which provides a response within 2 seconds, will become a valuable frequency control service as the NEM shifts towards higher levels of renewable energy, resulting in the decline of frequency stability in the power system.

Although FFR services are currently not incentivised in Australia, there are several international jurisdictions that have defined FFR markets, with specific requirements for WTGs.

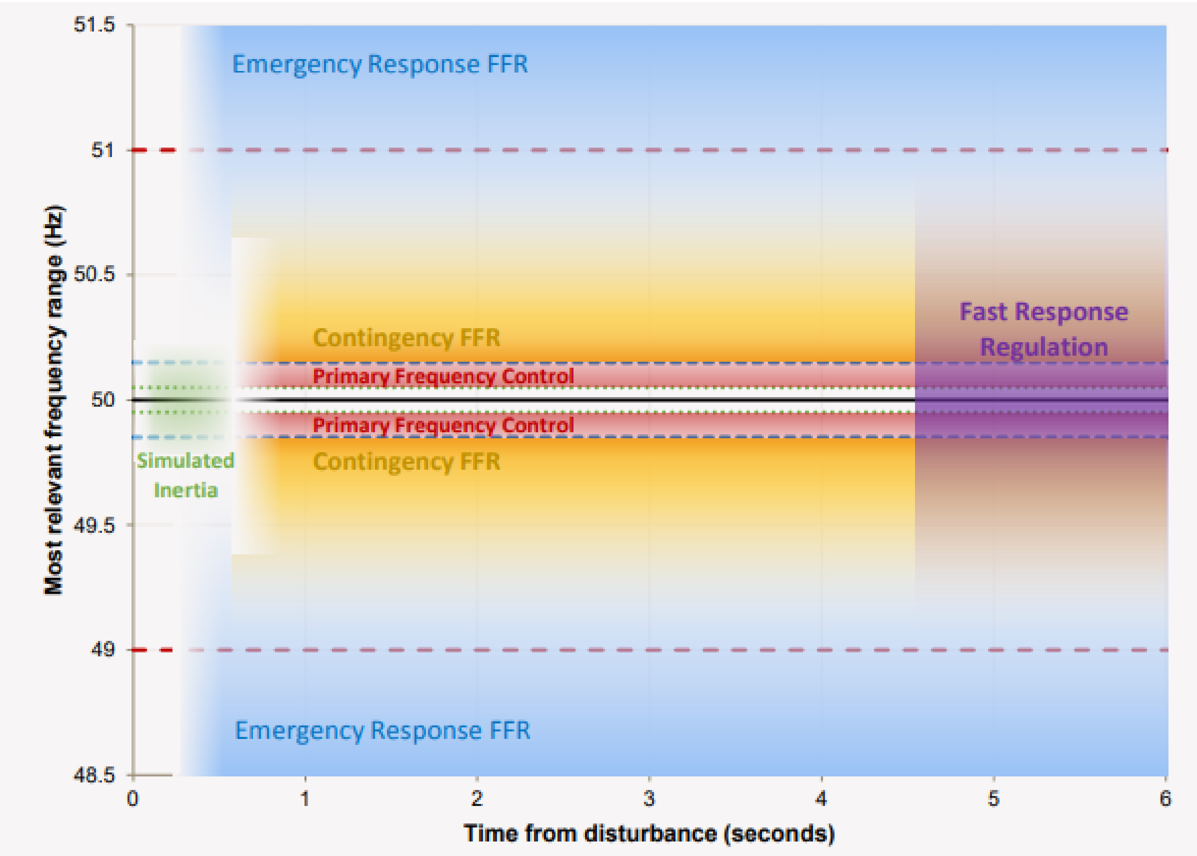
Whilst there is currently no FFR market in the NEM, some FFR providers, specifically Battery Energy Storage Systems (BESS), can participate in the existing FCAS markets. The current market requirements do not place specific value on the faster response provided and may undervalue their impact on ensuring frequency stability in the power system.

2.1 Fast frequency response

FFR generally refers to the provision of a rapid active power increase or decrease, from generation or load, in a timeframe of less than two seconds during a contingency event, to correct supply-demand imbalance in the network and assist in managing power system frequency. FFR offers different benefits to inertia, but because it can be used to restore power system frequency in a similar manner it is sometimes referred to as “synthetic” inertia. During a contingency event, characterised by a sudden change in system frequency, FFR acts to slow frequency decline before other frequency responses kick in to arrest frequency decline, stabilise, and rebalance system frequency.

Whilst specific FFR markets are not currently defined in the NEM, FFR services can supplement current FCAS services because of their faster response speed, as shown in Figure 6. When this trial commenced, the energy markets did not put a value or specific requirement for this type of FFR; it theoretically was being provided by default by large synchronous generators. However on 26 March 2020, the AEMC published a rule change to mandate the provision of Primary Frequency Response (PFR) from all synchronous and non-synchronous generators in the NEM. This rule change by the AEMC, may offer what could be the most notable opportunity for IBFFR.

Figure 6 Map of potential FFR services (17)



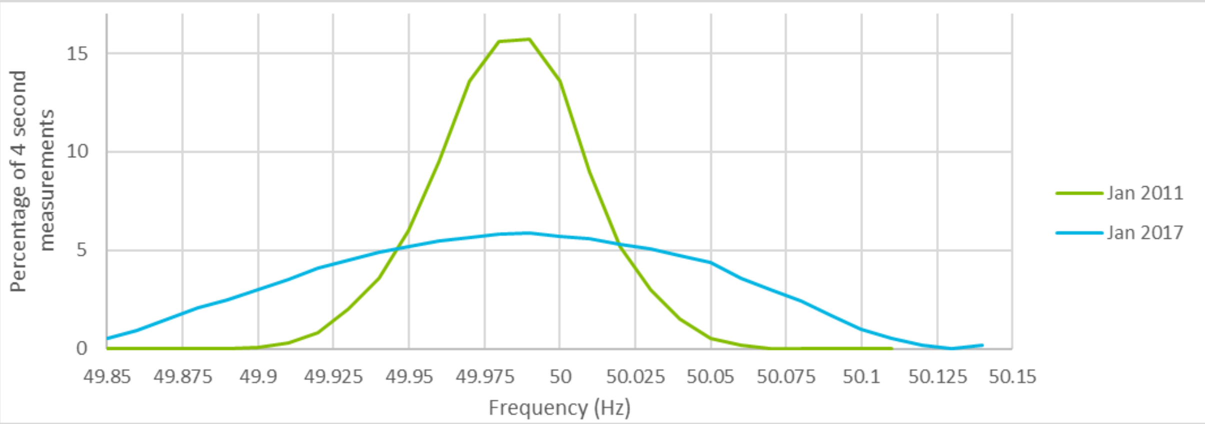
2.2 Frequency in the NEM

A number of frequency support services currently exist in the NEM. Regulation FCAS is the provision frequency control to manage minor frequency deviations following small imbalances between demand and supply in the five-minute dispatch market. Contingency FCAS manages frequency recovery after an under- or over-frequency event. There are currently six contingency FCAS markets with response times of 6 seconds, 60 seconds and 5 minutes. Although some FFR services may be procured through the six-second FCAS market, this may not adequately reflect the value of faster response.

The AEMC and Finkel Review have identified one of the main drivers of the recent degradation of frequency performance is generators decreasing or removing the responsiveness of their plant to frequency deviations to avoid actual and perceived dis-incentives associated with operating their plant in a frequency responsive mode. The AEMC recognises that as some generators reduce or remove their responsiveness to frequency deviations, those that remain experience a greater impact on plant operation, including associated wear and tear costs. This, in turn, strengthens the incentives for generators to further reduce their provision of PFR, continuing the decline in frequency control in the NEM, as shown in Figure 7. (1) , (18)

The structure of the FCAS markets and the associated widening of the governor dead bands have inadvertently caused some perverse frequency outcomes since their introduction by disincentivising primary frequency control (19). New FFR services, including IBFFR, can complement existing FCAS services to address the declining frequency control in the NEM, by acting more quickly than the current available services.

Figure 7 NEM mainland frequency distribution: January 2011 vs January 2017 (2)

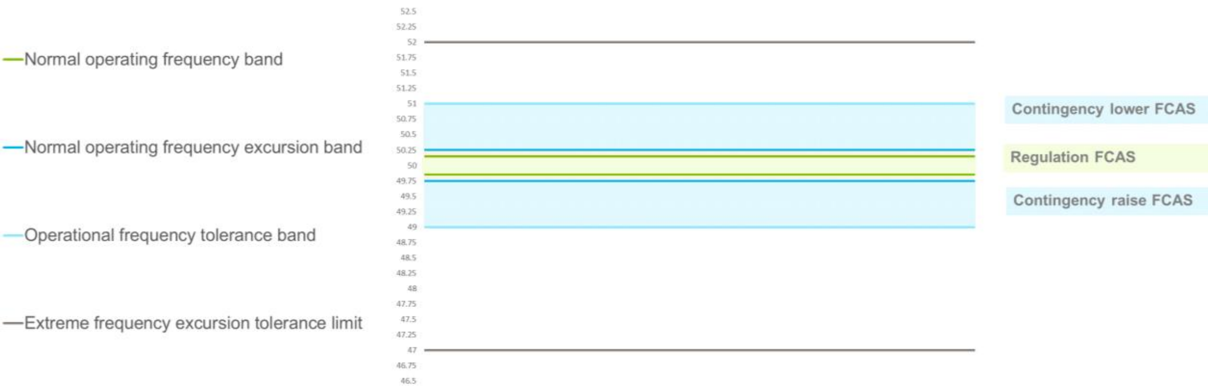


2.2.1 Frequency control in the NEM

Frequency control is key to maintaining power system security. In Australia, AEMO is responsible for maintaining the nominal system frequency of 50 Hz by balancing electrical load and supply in the network. When system frequency deviates from the frequency setpoint, a range of FCAS services are procured by AEMO to slow and arrest frequency changes and restore frequency. This prevents system-wide blackouts and damage to connected generator, network and end-user equipment.

All components of a power system are designed to operate within a range of frequencies, known as the Normal Operating Frequency Band (NOFB), as shown in Figure 8. Imbalances between demand and supply can cause system frequency to deviate beyond this range which may cause system instability, resulting system outages and potential system shutdowns, known as ‘system black’ events.

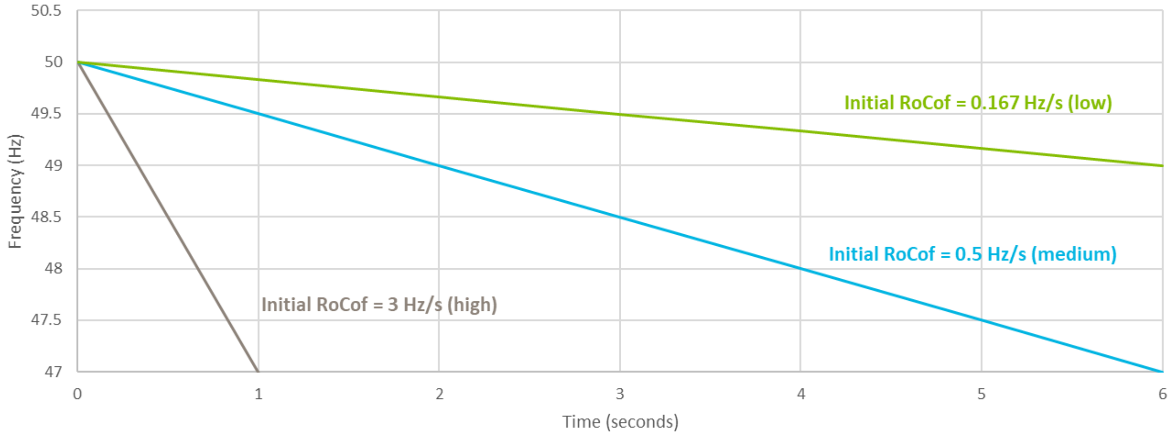
Figure 8 Operating frequency bands diagram (20)



Primary Frequency Response (PFR) refers to the automatic and almost instantaneous change in power output of a generator as a response to locally measured changes in system frequency outside the pre-determined frequency dead band. The frequency dead-band specifies the range of frequency in which governor is unresponsive to changes in frequency and power output is kept steady (20). Synchronous generators provide PFR through their generator governor response when operating in ‘frequency response mode’ by automatically altering power output as a response to frequency deviations (21). Some inverter-based asynchronous generators can also provide a response through programming of its power electronic systems.

The energy mix in the NEM has historically consisted primarily of large synchronous generators providing dispatchable generation, inertia and ancillary services that support grid frequency network stability. Synchronous generators are electromagnetically coupled to the power system and comprise rotating machinery that provides inertia to the power system. This inertia acts to slow the system’s Rate of Change of Frequency (RoCoF) as a result of a disturbance, as the disturbance has to physically slow down or speed up all the rotating equipment. In turn, the initial RoCoF at the time of a disturbance determines the response time that is available to arrest the drop or rise in system frequency before the frequency deviation limit is breached. A lower RoCoF increases the ability of the system to resist changes, as illustrated in Figure 9.

Figure 9 Relationship between RoCoF and response times (22)



In the event of over-frequency, generators can respond by reducing output. In contrast, under-frequency is more difficult to address as increased generation needs to be injected into the grid to arrest the decline in frequency.

There is an increasing need to incentivise additional, faster frequency control services to improve frequency control within the power system. FFR is an emerging frequency response service that acts faster than the current defined FCAS services. With a response time of less than two seconds, FFR from inverter-connected generators is a potential source of synthetic inertial support and can complement existing contingency FCAS services.

2.2.2 Current FCAS requirements in the NEM

Currently in the NEM, FCAS provides a range of frequency control services with different roles work to maintain system frequency within the normal operating range. FCAS services are procured by AEMO with different response times to increase or decrease output when system frequency deviates from the various frequency bands. Under the NEM frequency standard, AEMO must ensure that frequency is maintained between:

- 49.85Hz to 50.15Hz under normal operating conditions, which is managed through regulation FCAS (23).
- 49.5Hz to 50.5Hz following a contingency event and return to the NOFB within 5 minutes, managed through contingency FCAS (23).

Regulation FCAS occurs on a continuous basis to address minor fluctuations in system frequency resulting from minor mismatches between electrical supply and demand. AEMO regulates system frequency within the normal operating band through procuring regulation raise or regulation lower services from generators.

On the other hand, contingency FCAS aims to address large deviations in power system frequency. In the event of a major drop in frequency, contingency FCAS can be provided through rapid injection of active power or rapid load shedding, whilst a major rise in frequency can be addressed through reducing the power output of generators. There are six contingency services required by the NER that are characterised by different response times, which are summarised in Table 1 below.

Table 1 NEM Contingency FCAS markets (16)

Market	Description
Fast Raise	Six-second response to arrest a major drop in frequency following a contingency event.
Fast Lower	Six-second response to arrest a major rise in frequency following a contingency event.
Slow Raise	Sixty-second response to stabilise frequency following a major drop in frequency.

Market	Description
Slow Lower	Sixty-second response to stabilise frequency following a major rise in frequency.
Delayed Raise	Five-minute response to recover frequency to the normal operating band following a major drop or rise in frequency.
Delayed Lower	Five-minute response to recover frequency to the normal operating band following a major rise in frequency.

These timeframes reflect the response characteristics of technologies in the system at the time the FCAS markets were established (i.e. steam, hydro and gas units). Although sustained FFR services, may be procured through the six-second FCAS market, this may not adequately reflect the enhanced value of faster response.

2.2.3 New PFR Rule Changes

On 26 March 2020, the AEMC published a rule change to mandate the provision of Primary Frequency Response (PFR) from all synchronous and non-synchronous generators in the NEM. These changes aim to address the decline of frequency stability, particularly within the NOFB (20).

The AEMC rule change mandates frequency response from generators to frequency deviations outside of narrow frequency dead bands and the removal of disincentives to the provision of PFR, by requiring that:

- All scheduled and semi-scheduled generators, who have received a dispatch instruction to generate to a volume greater than 0 MW, must operate their plant in accordance with the performance parameters set out in the Primary frequency response requirements (PFRR) as applicable to that plant.
- AEMO consult on and publish the PFRR, which will specify the required performance criteria for generator frequency response, which may vary by plant type.

2.2.4 Need for FFR

The introduction of an FFR service may provide a more efficient manner to maintain power system security than mandating minimum inertia levels (22). The primary benefit of FFR is enabling greater flexibility in the allowable RoCoF, which may become increasingly important as the electricity market transitions to a greater proportion of renewables. AEMO has also emphasised the requirement for a series of trials to demonstrate the technical capabilities and potential benefits of FFR (24).

In its System Security Market Frameworks Review (22), the AEMC has raised the possibility of introducing a market for FFR, either through DNSPs procuring FFR as an alternative to inertia to meet system security obligations, or through the introduction of a new FCAS market. Whilst participation in the FCAS market is open to any capable technology, if the current FCAS market does not encourage new participants to provide greater levels of frequency control services, the available FCAS may become insufficient (25).

2.3 International markets

FFR has had limited application internationally to date. Several jurisdictions internationally have introduced frequency control services to incentivise the provision of FFR or have mandated FFR from technically capable WTGs in response to concerns about high RoCoF; the requirements of each of these are detailed in Table 2. Ontario Hydro, requires the provision of IBFFR from WTGs that are equipped with the technical capability. Similarly, Hydro-Quebec has mandated the delivery of FFR following a contingency event from wind generation plants with a capacity greater than 10MW. In Ireland/Northern Ireland, an FFR market, along with a number of other frequency control markets, was introduced in October 2018 to support the transition to higher levels of renewables penetration.

Table 2 FFR requirements internationally (26)

Jurisdiction	Response time (seconds)	Boost	Sustained duration (seconds)	Maximum reduction during recovery
Ontario	1	10% of pre-event levels	10	-
Quebec	1.5	6% of rated power	9	20% of pre-event power levels
Ireland/ Northern Ireland	0.15	N/A	8	Equivalent to energy provided as part of the response

2.3.1 Ontario Hydro (Canada)

Ontario Hydro, the electricity utility in the province of Ontario, has recently required wind turbines that have the technical capability to provide IBFFR. Onshore wind generation facilities with doubly-fed or full converter-interfaced WTGs are expected to have a capability to respond to decreases in system frequency in accordance to the requirements shown in Table 3 below. It is also specified that the rate of change of energy withdrawn from the system during active power recover must in general be less than the rate of energy injected into the system during active power boost (26). wind farms are not obliged to connect with IBFFR control capability if it is not commercially available, however the system operator may request for the installation of this function in the future when it becomes commercially available for the specific turbine type. The maximum subsequent power drop of 5% below pre-disturbance levels shown in Table 3 is referenced in the report titled "International Review of Frequency Control Adaptation" (26).

Table 3 Requirements for wind-based FFR in Ontario

Parameter	Requirement
Minimum duration	10 seconds
Power contribution	At least 10% of pre-trigger active power
Frequency threshold	-0.3 Hz
Maximum response delay	1 second
Minimum output for availability	25%
Maximum subsequent power drop below pre-disturbance	N/A (5% outlined by DGA Consulting and AEMO but not confirmed)

2.3.2 Hydro-Quebec (Canada)

Hydro-Quebec is the electricity utility managing Quebec's electricity system, including generation, transmission and distribution. Hydro-Quebec has mandated the delivery of FFR from WTGs since 2006 and is the first grid operator to connect wind plants with FFR capability. At the time the requirement was introduced, Hydro-Quebec had 1.5 GW of planned wind generation and was preparing for an additional 2 GW capacity. The resultant wind generation capacity was anticipated to serve around 10% of peak load and close to 25% of light load by 2015 (26).

The FFR enabled WTGs have been shown to successfully provide FFR as specified in response to real contingency events. They are reporting a response within 1-2 seconds, with an active power increase of 6-10% of rated capacity, which extends for about 10 seconds. WTGs from a number of different manufacturers have been shown to successfully deliver this response (26).

Hydro-Quebec's frequency control requirements from wind plants with a rated power greater than 10 MW for the frequency control support following a disturbance are described in the 2019 Grid Code and summarised in Table 4. Different requirements apply to under frequency conditions (during which the system relies on the inertial response of wind generators) and over frequency conditions (during which the system relies on continuous frequency regulation) (7).

Learnings from the power system experiences with emulated inertia in Hydro-Quebec indicate that if the NEM elects to introduce an FFR service, design capabilities need to be considered to ensure that products presently on the market will be able to participate (if these response characteristics are optimal for the NEM) (26). Also note that analysis has suggested that the IBFFR recovery period should be carefully modelled to ensure appropriate operational control (26).

Table 4 Hydro-Quebec frequency control requirements (7)

Parameter	Description	Value
Under frequency		
Activation frequency	Frequency deviation which activates FFR	Adjustable between -0.1Hz and-1.0Hz with respect to the nominal frequency of 60Hz
Active power contribution	The minimum amount of additional power output the plant must provide as FFR	At least 6% of rated power of each WTG in service
Duration of active power contribution	The minimum time at which the plant must sustain its active power contribution before going into recovery phase	At least 9 seconds from the start of power ramp up to the start of power ramp down
Activation time	The maximum time to reach full response after an event occurs	1.5s or less
Maximum generation reduction during the recovery phase	The maximum amount of power reduction when the plant goes into recovery phase	20% or less
FFR availability	The operating level at which the FFR capability must be available	At least 25%
FFR recovery time	Time following the end of the recovery phase before FFR capability must be available again	2 minutes
Over frequency		
Activation frequency	Frequency deviation which activates FFR	Adjustable between 0 and +0.5Hz with respect to the nominal frequency of 60Hz

2.3.3 EirGrid/SONI (Ireland/Northern Ireland)

EirGrid/SONI is a collaborative body formed between Ireland (EirGrid) and Northern Ireland's (SONI) Transmission Service Operator (TSOs). In 2011, EirGrid/SONI launched the DS3 programme, a workplan aiming to increase allowable System Non-Synchronous Penetration (SNSP) up to 75% by 2020. The workplan categorises a number of frequency challenges associated with a high penetration of variable non-synchronous wind generation (27). Following extensive modelling and research as part of the programme, a new ancillary services framework was developed. In addition to the existing seven system services under the Harmonised Ancillary Services (HAS), four new services were introduced in 2016 to support a move to higher levels of non-synchronous generation. FFR was subsequently introduced in October 2018, with two further services in the process of being introduced, as summarised in Table 5 (28).

FFR is defined by the TSO as the additional increase in MW output from a unit or reduction in demand following a frequency event that is available within 0.15 seconds from event commencement and is sustained for at least 8 seconds afterwards. The energy provided within the 10-second duration from the start of the event must be greater than any loss of energy in the 10-20 second timeframe afterwards as a result of the FFR. The energy provided and drawn is relative to the pre-event output. FFR providers who maintain or increase their output are also eligible to participate in the Primary Operating Reserve (POR) market (28).

Table 5 Summary of DS3 system services (28)

Service name	Code	Short description
Existing services		
Primary Operating Reserve	POR	MW delivered between 5 and 15 seconds
Secondary Operating Reserve	SOR	MW delivered between 15 to 90 seconds
Tertiary Operating Reserve 1	TOR1	MW delivered between 90 seconds to 5 minutes
Tertiary Operating Reserve 2	TOR2	MW delivered between 5 minutes to 20 minutes
Steady State Reactive power	SSRP	(MVAr capability) *(% of capacity that MVAr capability is achievable)
Replacement Reserve – Synchronised	RRS	MW delivered between 20 minutes to 1 hour
Replacement Reserve – Desynchronised	RRD	MW delivered between 20 minutes to 1 hour
Synchronous Inertial Response	SIR	Instantaneous response for 15-45 seconds
Ramping Margin 1	RM1	The increased MW output that can be delivered with a good degree of certainty for the given time horizon
Ramping Margin 3	RM3	
Ramping Margin 8	RM8	
Fast frequency Response	FFR	MW delivered between 0.15 and 10 seconds
Proposed services		
Dynamic Reactive Response	DRR	MVAr capability during large (>30%) voltage dips
Fast Post Fault Active Power Recovery	FPRAPR	Active power (MW) >90% within 250ms of voltage >90%

3.0 Goldwind's IBFFR technology

Goldwind's IBFFR technology was developed to meet a gap in the market to provide frequency response more rapidly than traditional generation technologies have been able to respond. For example, Hydro power and gas generation can typically respond within 6 seconds, during contingency events (29).

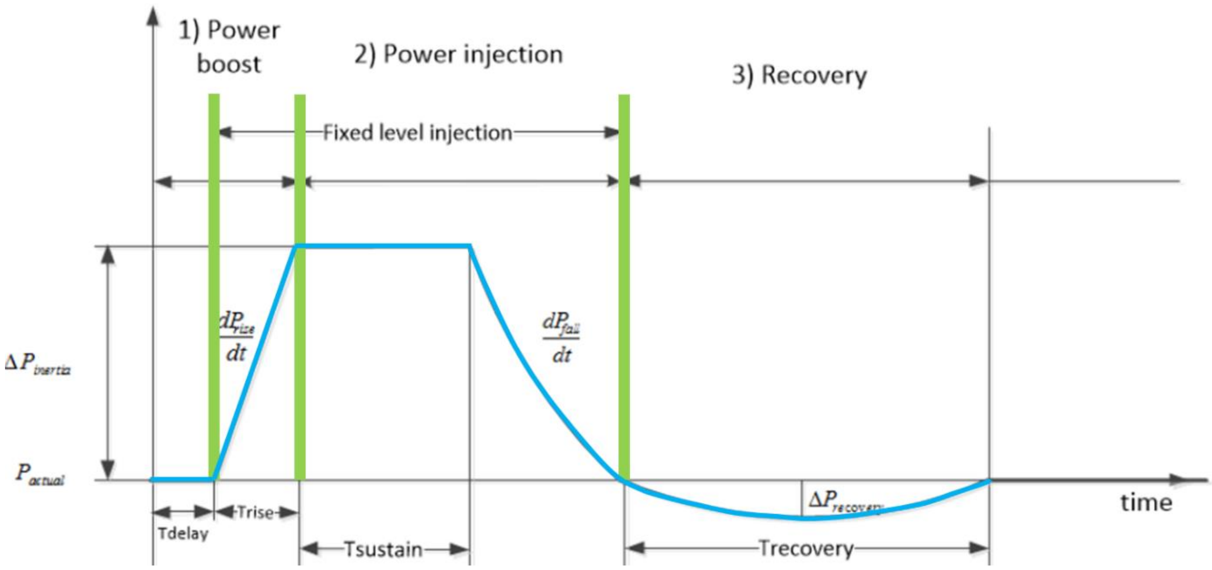
IBFFR adopts the inertial and pitch controls so that the rotor kinetic energy of the wind turbine blades can be fully utilized to boost the power output of Wind farm even at maximum operating condition. Since the FFR is enabled by accessing kinetic energy stored in the inertia of the wind turbine, this capability is named Inertia Based Fast Frequency Response (IBFFR). It is a form of "synthetic inertia", despite utilising the inertial response of the turbine rotor, as the wind turbines are still asynchronous generators.

Goldwind's IBFFR solution is a plant control system that converts additional kinetic energy from the drivetrain of WTGs. The IBFFR control system integrates WTGs and VAr compensation equipment to provide both voltage control and frequency control capabilities at the individual WTG level. IBFFR is able to detect frequency disturbances in the network and instruct WTGs to enter into an FFR control mode, which comprises three main steps, as illustrated in Figure 10 (30):

1. Power boost: provide a short burst of active power by extracting the kinetic energy stored in the rotor and generator.
2. Power injection: as the speed of rotation is momentarily slowed, the rapid injection of additional active power is sustained for up to approximately 10 seconds.
3. Recovery: a recovery period generally follows the power boost, during which active power is reduced as the blades reaccelerate to pre-event levels.

Unlike other methods of providing contingency FFR, IBFFR does not require prior de-rating or "headroom", meaning that IBFFR can be provided by wind farms without significant income impact of prior de-rated operation.

Figure 10 IBFFR response (31)



4.0 Approach to IBFFR field testing

The purpose of the IBFFR testing was to gain a better understanding of the output capacity and duration that could confidently be achieved under normal operating conditions. Field testing was conducted at the GRWF. A number of frequency events were simulated across the WTGs and the IBFFR provided was analysed to gain confidence in its capability.

The power output over time in response to a frequency deviation was recorded from a select number of turbines at GRWF that were used for this test. The testing and analysis were focused on the consistency and characteristics of the response. Tests were carried out with single turbines with different boost duration and capacity targets as well as two groups of turbines and one large group of turbines, to see if the aggregate response was different from the single turbines. Sensitivity to smaller frequency deviation bands was also tested. All data was recorded at a millisecond resolution.

4.1 Field Data Collection

The field data was created by Goldwind through a series of simulated tests at the existing GRWF. Each of the WTGs is subject to a simulated frequency event, where the network frequency that the WTG “sees” is artificially dropped, triggering the IBFFR functionality of the WTG. A target boost output, duration and post-boost power drop are selected. The output data for the time-varying power output, control signals and WTG operational parameters was captured before, during and after the boost occurred. The test data falls under two categories defined by the target parameter being tested for:

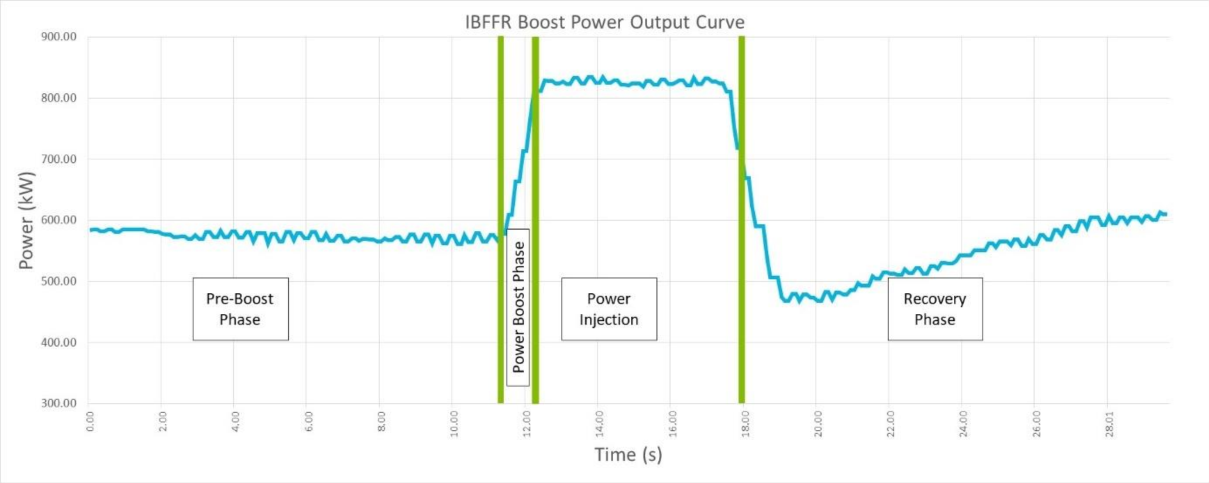
- *Time target tests:* The WTGs were set to boost with one of three target durations (6s, 8s or 10s) at whatever boost capacity they could achieve. Within these tests, the boost duration was the primary metric being analysed and compared.
    - *Ten turbine, one group tests:* A group of ten turbines was configured to boost for the selected boost duration of 6s simultaneously
    - *Ten turbine, two group tests:* two groups of five turbines had their IBFFR boost coordinated so that one would boost after the other, attempting to create an extended boost duration
    - *Ten turbine, narrow frequency test:* A group of ten turbines were set to boost for 6s simultaneously, but the observed change in frequency was made progressively narrower
- *Power target tests:* The WTGs were set to boost, but the maximum allowable power drop magnitude in the recovery phase was fixed at 10%, 15% or 20% of the nameplate capacity and the resulting change in the recovery phase duration observed

4.2 Field Data Analysis

For analysis, each data set was broken down into four time-varying categories with a group of characteristics, illustrated in Figure 11:

- *Pre-boost phase:* the period of time prior to the commencement of the power boost phase
- *Power boost phase:* the period of time while the WTG increases its output until it produces a meaningful increase
- *Power injection phase:* the period of time in which the WTG produces a meaningful increase in power output. This is determined by looking at times in which the WTG power output exceeds the pre-frequency event average power, with the difference being the boost duration.
- *Recovery phase:* the period of time in which the WTG power out stabilises from the boost event.

Figure 11 Illustration of pre-boost, power boost, power injection and recovery phases



Within these time categories, there are a series of characteristics that are studied to gain a better understanding of the behaviour of the WTG within each data set. These characteristics are outlined in Table 6.

Table 6 Time categorisation characteristics summary used for field data analysis.

Phase	Characteristics
Pre-boost phase	Response time: timing characteristics of the WTG before and at the beginning of the power boost
Power boost phase	Ramp characteristics: power ramping characteristics of the max boost output.
Power injection phase	Boost duration and capacity: duration and capacity, relative to nameplate capacity, of the boost output.
Recovery phase	Recovery characteristics: power output behaviour of the WTG after the boost output stops.

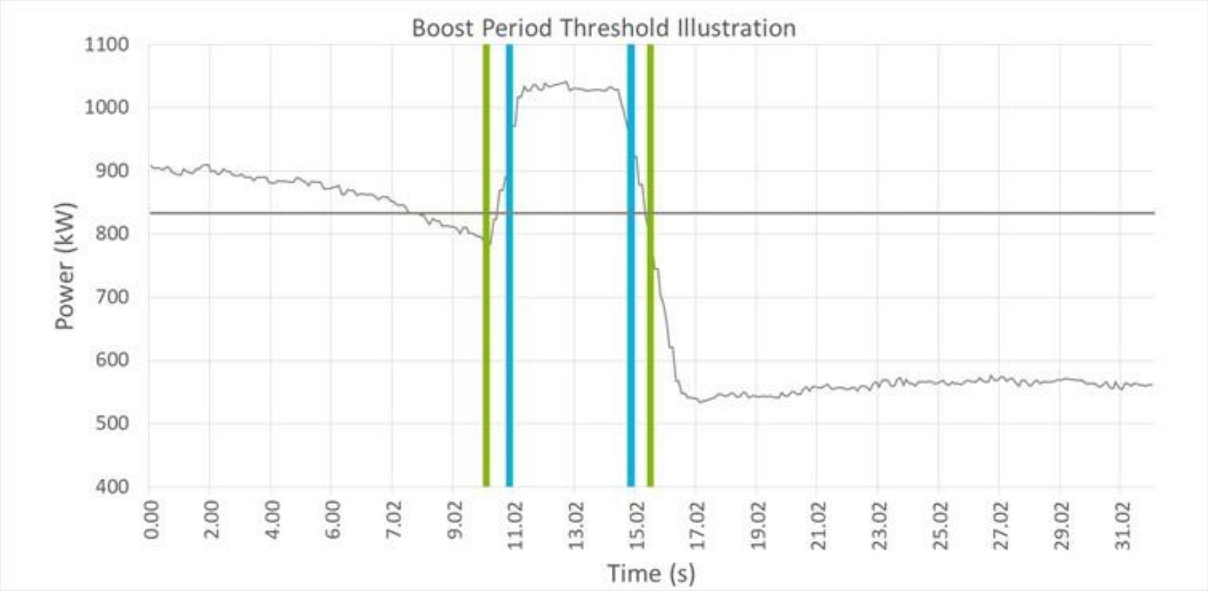
4.3 Data Analysis Observations

During the data analysis, it was observed that different approaches to carrying out the analysis would produce differences in the calculated performance. This was most prominently identified in the analysis of the power boost phase, where the threshold chosen for determining when the turbine is “boosting” has notable effects on the turbine’s response performance.

Numerous approaches could be used, including defining the start of the boost phase at the event signal or a static threshold. In this analysis, the threshold selected for determining when the boost output occurs uses the average power output of the turbine from the beginning of the dataset to when the simulated frequency event occurs, represented by the horizontal blue line in Figure 12. The average is used as it is more representative of the turbine’s power contribution to the network and will provide a threshold identifying when the turbine has increased its useful power output over the general power contribution.

This approach tends to produce a more conservative estimate of IBFFR performance. In instances where the turbine power output curve is decreasing before the IBFFR engages, the calculated threshold will be higher than the instantaneous power of the turbine, resulting in a smaller recorded increase in boost power as well as a slower response time (see the area encompassed by blue lines in Figure 12). In the event that the turbine power output is increasing prior to the IBFFR engaging, the calculated threshold and instantaneous power at the point of the IBFFR engaging will be more aligned.

Figure 12 Example of difference in results based on selected threshold for determining boost period.



4.4 Field Testing Challenges and Risks

A number of challenges that could have material impact on the project, were identified at the commencement of the project. A project risk analysis highlighted a number of risks unique to the implementation of this novel technology and have been summarised in Table 7. Further details of lessons learned from undertaking the project are outlined in section 6.4. A comprehensive risk register can be found in Appendix B.

Table 7 Field testing challenges

Risk/issue	Description	Risk management / mitigation
Stakeholders	Testing of IBFFR technology requires coordination with and support from AEMO, TransGrid, ARENA and BJCE.	Open and consistent communication was required between Goldwind and each relevant stakeholder.
Network impact	Testing did not assess impacts to network frequency at the connection point.	Forward notification to TransGrid was required when scheduling testing.
Coordination	Coordination with multiple internal teams, internally and externally, was required to conduct the project.	Assistance from the Goldwing R&D team in China was required to develop the IBFFR software. Coordination with the operations team was required for the testing to occur in order to carry out the simulated frequency events Permission from TransGrid was required to ensure that engaging IBFFR would not impact the network.
Unexpected wind events	Delays in data collection were experienced due to sub-optimal wind conditions on testing days.	Constant monitoring of wind conditions in order to reschedule testing as early as possible.
Market changes	A number of proposed changes to PFR requirements of generators were released to the public for consultation during the testing phase of the project. This resulted in	Open discussion about the rule changes and their relevance was carried out to determine if extra testing was required.

Risk/issue	Description	Risk management / mitigation
	changes to testing parameters and additional analysis.	
Grouping of datasets	Creating a coordinated boost with extended capacity or duration with multiple turbines in multiple groups was challenging due to the inherent variability in wind speeds across the array.	Ensure comprehensive testing is carried out in order to best characterise the turbine boost performance.
Design risk	The IBFFR equipment is essentially a piece of control equipment mounted in a cabinet, retrofitted to an existing wind farm. The largest design risk is failure to comply with Australian Standards or relevant codes.	Goldwind has installed a similar cabinet (VMP - a voltage management control hardware) at the White Rock Wind Farm and did not experience any compliance issues during installation Goldwind is aware of required Australian standards in relation to hardware and control through works on 3 previous wind farms in Australia."
Construction and commissioning	Coordination of planned turbine outages with IBFFR installation and commissioning was required.	Ensure that planned outages are not in the commissioning schedule.

5.0 Results of analysis

The IBFFR testing provided a consistent response of up to 10% of nameplate capacity for the target of six seconds reliably across all tests conducted. It had a very reliable response time across all tests for low and high wind speed test conditions; the ramp delay was less than one second and time to peak was less than two seconds.

Coordination between the two groups in the two group tests was challenging because of the variation in wind speed. However, these tests showed that a coordinated response could minimise the impact of the recovery phase and minimise power loss from the first responding group.

The frequency deviation tests show that boost response was still easily attainable under tighter frequency response bands, such as those outlined in the original PFR rule change proposals submitted to AEMC.

Tests found that IBFFR performance is reasonably consistent, however power loss and recovery phase duration are sensitive to the wind conditions post-boost, as shown in the average results of the single and multi-turbine tests summarised in Table 8. The power boost characteristics were found to be consistent across all tests, as shown in Table 9.

The one to two second response rate is not able to match utility-scale battery storage systems, which can provide a response in less than a second. However it is more rapid than the FCAS capabilities of conventional generation technologies shown in Figure 14. Coal and nuclear energy in particular have slower ramp rates ranging 2-8% of rated capacity per minute (32).

Table 8 Summary of averaged findings for key parameters.

Time category	Pre-boost phase			Power injection phase			Recovery phase	
Parameter	Ramp delay (s)	Ramp rate (kW/s per turbine)	Time to peak (s)	Boost duration (s)	Avg. ΔP_{MAX} (kW per turbine)	Avg. max boost percentage (%) Compared to nameplate power	Power loss (kW per turbine)	Recovery phase duration (s)
Time target tests	0.5	240	1.4	5.5	115 (150kW target) 170 (250kW target)	7	470	14
Power target tests	0.7	325	1.5	4.8	190	8	490	18.3
10 turbines, 1 group tests	0.56	277	1.37	4.7	142	5.7	287	10.7
10 turbines, 2 group tests	0.85	170	1.43	5	78.5	3	267.5	9.5
Variable frequency deviation tests	0.7	197	2.25	4.5	139	5.6	320	7

Table 9 Summary of findings for each time category for each test.

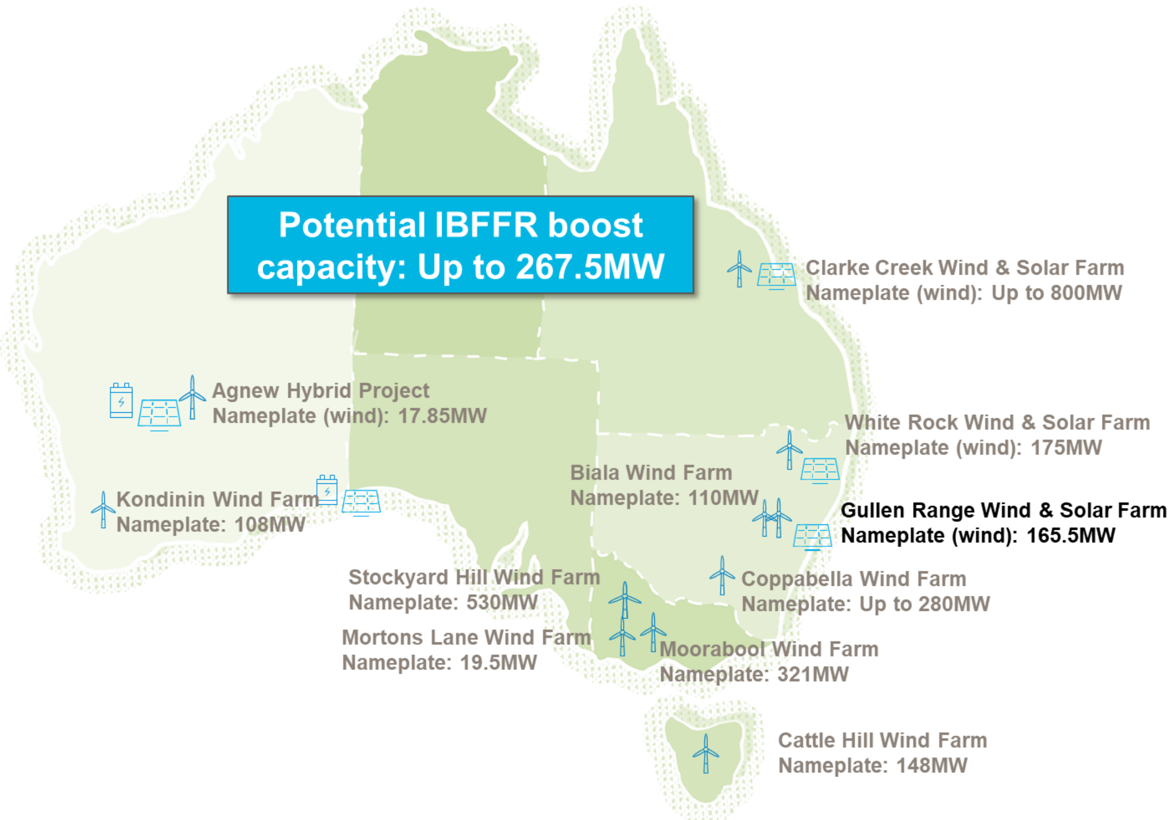
Test	Power boost phase	Power injection phase	Recovery phase
Single turbine Time target test	The power boost characteristics of the time target tests were consistent between the different target boost durations. This is to be expected, as the target ramp duration shouldn't impact how the turbine commences the boost.	The power injection duration of the time target tests were found to vary and not always reach the maximum intended duration under all wind condition. The 6s time target tests however were found to consistently come close to the 6s boost duration target.	The recovery phase characteristics varied greatly between tests and did not always correlate precisely with the target boost duration, but more with the variability in wind speed during the recovery phase.
Single turbine Power target test	The power boost characteristics of the power target tests were consistent between the different target boost durations. This is to be expected, as the target ramp duration shouldn't impact how the turbine commences the boost.	The power injection characteristics of the power target tests differed from the perfect theoretical case due to real world wind conditions. On average, a boost of 10% from nameplate capacity is achievable, however within the 10% boost tests there were some cases where this was not obtained due to unfavourable wind conditions.	The power loss observed did correlate with the power target test in question, with a larger targeted boost output resulting in a greater power loss post-boost. However, the recovery phase duration did not always show the same correlation, as it is more dependent on the variability in wind speed during the recovery phase.
Ten turbines One group	The power boost characteristics of the ten turbine, two group tests were fairly similar to the other single turbine tests that were carried out, but with a larger magnitude of boost output. This is to be expected, as there has been no change in the initial ramp behaviour by having multiple turbines.	The ten turbine, one group tests behaved in a similar fashion to the single turbine tests, but with the power output scaled to ten turbines. The group of turbines behaved as anticipated, with similar boost duration and magnitude to what was observed in the single turbine tests.	The ten turbine, one group tests had better recovery phase performance than other single turbine test in both power loss as well as recovery phase duration
Ten turbines Two groups	The power boost characteristics of the ten turbine, two group tests were fairly similar to the other single turbine and multi turbine tests that were carried out. This is to be expected, as there has been no change in the initial ramp behaviour by having multiple turbines.	The ten turbine, two group tests did not facilitate a seamless extended boost duration of around 10-12s. This was likely due to the difference in wind speed characteristics between each turbine within the array as well as optimisation required in coordinating the primary and secondary boosts.	The ten turbine, two group tests had better recovery phase performance than other single and multi-turbine tests, in both power loss as well as recovery phase duration. The difference in wind speeds across the turbines worked in favour of the ten turbine, two group test. Some turbines experienced favourable post-boost wind conditions resulting in less power loss and shorter recovery times, others have poor post-boost conditions resulting in larger power losses and longer recovery phases. When averaged put, the aggregate curve experienced less power loss and shorter recovery phase duration than the ten turbine, one group tests.

6.0 IBFFR capability and opportunities

Goldwind's IBFFR capability was found to be reliable for its chosen field trial configuration of boosts of six seconds long and approximately 10% of the turbine's nameplate capacity, even when operating in conjunction with other turbines. Increasing the boost duration or capacity above these levels was achieved under some wind conditions. Turbine performance in the recovery phase reduced in performance as boost durations and capacities were increased, unless extremely favourable wind speeds were being experienced.

The technology can potentially provide IBFFR as a retrofit for the fleet of already installed Goldwind WTGs. Theoretically, the potential boost capacity provided through IBFFR by Goldwind's proposed 2.7GW fleet is up to 267.5MW across Australian electricity systems. This capacity compares favourably against the 350MW to 450MW base quantity of raise 5 second FCAS volumes in the NEM (33). Goldwind's IBFFR technology provides a genuine opportunity for renewables to support system strength in the network.

Figure 13 Potential IBFFR boost capacity of Goldwind's proposed fleet

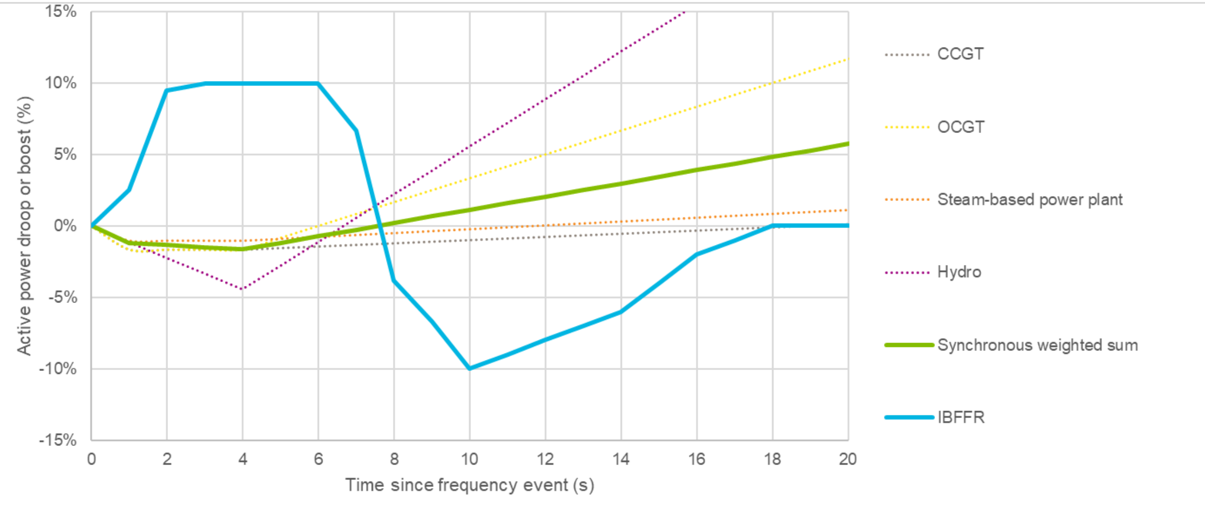


6.1 Usefulness of IBFFR technology within the NEM

There are multiple technologies which can operate within the existing FCAS markets for extended periods of time, at large capacities and with great reliability. The advantage that IBFFR is the notably faster response time that that is readily achievable by conventional generation technologies, as shown in Figure 14. This is under regular operating conditions, with no additional pre-curtailing or pre-warming measures.

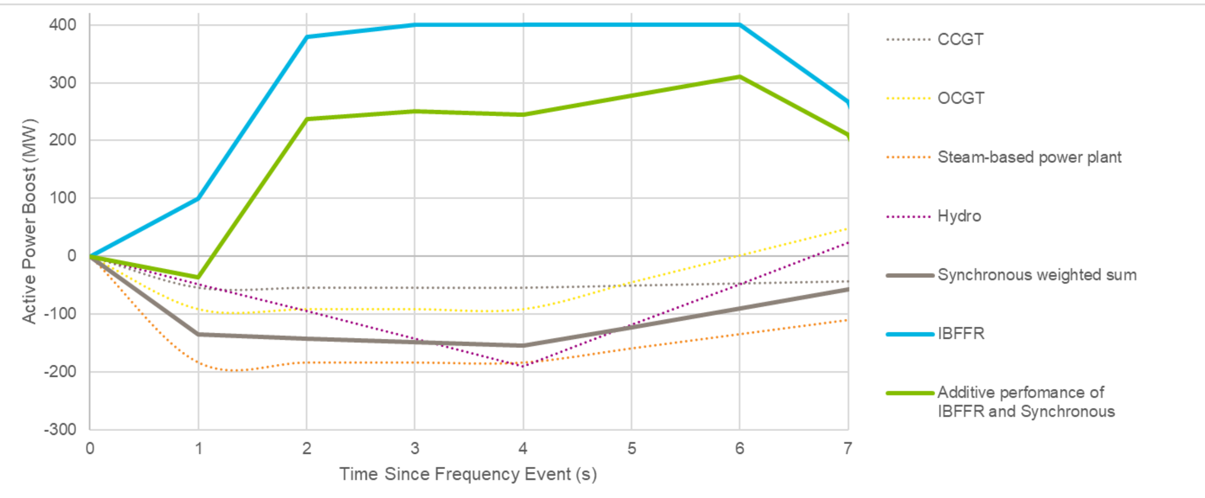
This positions IBFFR as a technology which can, at a sufficient scale, fill the demand gap seen in the immediate seconds after a frequency event. IBFFR complements the synchronous generation responses well, ramping down at approximately the same time as their responses become positive after an initial power drop. This is particularly true for hydro which experiences a significant power drop and is likely to play a significant role in a decarbonised future (34).

Figure 14 Different generation technologies response to frequency drop as a percentage (%) of nameplate capacity (4) (5) (6) (7) (8) (9) (10) (11) (12) (13) (14)



The expected response curves for each technology were applied to the known nameplate installed capacity of each generation type that provides FCAS services, displayed in Figure 15. It is estimated that approximately 5000MW of IBFFR enabled wind generation could ensure a near zero reduction in instantaneous generation output in the immediate seconds after a frequency event as other generation power output drops. With further optimisation, multiple turbines can be coordinated together to increase the magnitude or duration of the boost, which could further increase the value of IBFFR.

Figure 15 Generation profile of different technologies in response to a frequency drop in MW (4) (5) (6) (7) (8) (9) (10) (11) (12) (13) (14)



Some international energy markets have either introduced market incentives or have mandated IBFFR capability from WTGs to manage power systems with increasing penetration of renewables, as outlined in section 2.3. As renewables penetration increases in the NEM, there may be an increasing need to provide similar incentives to encourage faster frequency response (3).

The testing parameters applied to Goldwind's technology for these Gullen Range field tests showed results that meet most of the existing FFR requirements in international markets under the test targets and conditions analysed in this report, as shown in Table 10. It is important to note that this testing was not aimed at demonstrating the ability to meet these international requirements, and targeted testing for these conditions may yield even more favourable results. Further, the analysis shows that IBFFR was sensitive across all three frequency deviation thresholds outlined in the original rule change request to the AEMC, as summarised in Table 11

Table 10 Capability of IBFFR to meet international FFR requirements (26)

Jurisdiction	Response time (s)	Boost	Sustained duration (s)	Maximum reduction during recovery
IBFFR	0.5 - 0.7	3 - 8%	4.5 - 5.5	2% - 31%[1]
Ontario	✓ 1	~ 10% of pre-event levels	~ 10	✓ N/A
Quebec	✓ 1.5	✓ 6% of rated power	~ 9	✓ 20% of pre-event power levels
Ireland/ Northern Ireland	✗ 0.15	✓ N/A	~ 8	~ Equivalent to energy provided as part of the response

✓ Requirement met on average ~ Requirement met in some cases ✗ Requirement not met

Table 11 Capability of IBFFR to meet PFR rule change requests (20)

Proponent	Rule change	Details	IBFFR
Dr Peter Sokolowski	PFR requirement	Inclusion in the NER of a mandatory requirement for registered generators to provide PFR to frequency deviations outside of 50.00 +/- 0.025Hz.	✓
AEMO	Removal of disincentives to PFR	Removal of disincentives in the NER to the voluntary provision of PFR to deviations in excess of 50.00 +/- 0.05Hz.	✓
AEMO	Mandatory PFR	Mandate the provision of PFR from registered and technically capable generators outside of a narrow frequency response dead band of 50.00 Hz +/- 0.015Hz.	✓

6.2 Incentivising the FCAS market to encourage the use of IBFFR

The distinct benefit of IBFFR is the sub-two second response time that is regularly achieved under normal operating conditions. This has the potential to rapidly address frequency events by slowing the RoCoF faster than most other generation technology types, with the exception of battery energy storage systems.

[1] Recovery period depends on operational strategy of the IBFFR

6.3 Benefits and limitations of the technology

The response to network frequency events that was identified in this investigation highlighted future possibilities that will require further investigation in order to determine the full operational capability of IBFFR. This includes the potential to improve the FFR time to consistently below 1 second by delegating the IBFFR trigger to the WTG Converter.

From the testing conducted, it was found that there is a reduction to turbine performance after the boost output, with power loss per turbine ranging between 260 – 600kW of pre-boost power output levels, which is higher than the boost output obtained, for up to 19s. In many instances, the turbine did not return to the pre-boost power output in the collected data. This presents an opportunity cost for the turbines as there is a material amount of energy that is lost from engaging IBFFR

IBFFR enables increased and diversified utilisation of a single asset, as the wind farm can participate within the future FFR and wholesale markets simultaneously. By being able to participate in multiple markets, the wind farm operator may maximise revenue return by optimising dispatch in either market. This may allow for improved returns on investment.

However, there are some limitations to the implementation of IBFFR, which means it may form only part of the solution. . From this investigation, it was found that variability in wind speed played a significant role in determining the boost capacity, duration and recovery phase characteristics, with small differences producing material differences in performance. In particular, further testing under a variety of test conditions is warranted to better understand the boost output capability that can be offered.

6.4 Lessons Learned

Implementation of IBFFR technology at the Gullen Range Wind Farm posed some unique challenges given the novelty of the technology. There were a number of technical and operational challenges that had to be overcome from installation through to data analysis. With the implementation of an appropriate risk management process, these challenges were addressed with minimal impact to project scope, budget and schedule.

Software design and implementation posed a unique challenge during the IBFFR development. The customisation of certain elements of the IBFFR programming, specifically for the field study, required remote work with Goldwind R&D in China.. Additionally, some minor software modifications to the WTG software itself was required to achieve the desired turbine behaviour. The time associated with each software development step was not considered in the original project timeline. For future developments of novel technologies, additional contingency should be allocated for software development from the initiation of the project.

In order to gain a comprehensive understanding of the behaviour of the IBFFR technology, testing needed to be carried out under a range of wind conditions. Due to the variable nature of wind, it is hard to predict in advance when a certain wind speed will occur. There were a few instances of testing rescheduling because the desired wind speed was not available at the original time. To avoid project delays, additional time should be reserved for testing to accommodate for wind speed variability.

As this field study was an Australian first study, there were no precedents for conducting this type of field study at an operating wind farm. Coordination with TransGrid was key to carrying out the live testing. The field study was undertaken with the knowledge and cooperation of TransGrid and an arrangement was agreed in which Goldwind would give TransGrid several days' notice in advance of testing. Due to the limitations in long term wind forecasting, this was a source of scheduling uncertainty and delays for the completion of the field study testing.

Goldwind originally considered testing a version of the staggered group test that consisted of 4 staggered groups of turbines. It was found that the wind speed (and fluctuation of wind speed) has a significate influence on IBFFR output profile, particularly the recovery period. During a staggered test, the impact of wind speed changes on WTs was much greater than other use cases. In the 24 second period, the output power can change by more than 10% of rated power. In this regard, meaningful conclusions on IBFFR performance were not reliable enough, because the test results were not primarily influenced by the IBFFR behaviour. The staggered group test was changed to 2- groups, and this provided more reliable results.

In terms of information and communication management, Goldwind found this project to be successful, with effective information flow between Goldwind departments and other stakeholders resulting in successful implementation of the study.

6.5 Next steps

To facilitate greater predictability of IBFFR capabilities, continued analysis into specific performance of different wind turbine types under different wind conditions is appropriate in order to better understand the capabilities of IBFFR. This study has shown that short term wind speed characteristics can notably influence boost magnitude and duration, which introduces some uncertainty into predicting IBFFR boost capability in real time. This may place limitations on the contribution that IBFFR can make in response to frequency events. In contrast, Goldwind has high confidence that the response time for IBFFR can be reduced with modest configuration changes.

Appendix A

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Appendix A References

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Appendix B

Risk Register

Appendix B Risk Register

Table 12 Risk register

Potential Risks	Resulting In: Risks/Unplanned/Unwanted Event/Potential Impact	Risk Category	Current Risk with existing controls				Post mitigation			End of Project Outcome
			Severity (1-5)	Likelihood (1-5)	Risk Rating	Additional Controls required to manage the risk	Severity (1-5)	Likelihood (1-5)	Risk Rating	
Technical problems prohibit data from being collected from all 10 WTGs Required data collection requirements for Project purposes including Knowledge Sharing not considered in advance of implementation.	The benefits ARENA expects from the project cannot be assessed either partially or fully.	People, Brand & Reputation	5	4	Critical	Ensure that the data collection requirements of the Knowledge Sharing Plan are a required deliverable from GWA and any consultant. Ensure during commissioning and early testing phase that the correct data is being recorded. IBFFR product is required to collect test data from all controllable WTGs	2	2	Medium	After communications with Goldwind R&D and commissioning tests, the IBFFR was confirmed to have all test recording functions, which can collect all required field study data
The knowledge that is shared is not of benefit to either project participants, ARENA or Industry Analysis of the data and production of knowledge sharing products of low quality and pattern are not explicit	The benefits of the project may not be fully or partially realised.	People, Brand & Reputation	3	3	High	The knowledge sharing requirements the Knowledge sharing plan have been defined as per contents of knowledge sharing plan. The testing plan is being created in collaboration with ARENA. Goldwind has invite AECOM to analysis data together and write knowledge sharing report	3	2	Medium	Goldwind has engaged AECOM to to assist with field study analysis and reporting. In Goldwind's view the report highlights the benefits and potential of IBFFR technology.
Stakeholder management is not effective Wind Farm owner may withdraw support for field study	Interruption of works and field study operation	Financial Impact (EBIT) / Return on Investment $AUD	5	2	Critical	GWA has a close working relationship with BJCE and the parties have discussed the field study prior to grant application submission. JNCEC has provided letter of support for the field study.	3	2	Medium	Goldwind has communicated successfully with stakeholders well BJCE are satisfied with how the field study was conducted
Failure to secure AEMO/Transgrid support on time AEMO require additional connection studies or are slow respond to Goldwind's communications in order to proceed with the trial	Installation and field trial are delayed or not able to be conducted	Financial Impact (EBIT) / Return on Investment $AUD	5	3	Critical	Goldwind has provided the test simulation study to Transgrid. AEMO and Transgrid have confirmed that they do not need detailed modelling for this field study Goldwind provides test schedules before each test and noticed Transgrid before and after each test	3	2	Medium	communication protocol with TransGrid was agreed: Goldwind provided test schedules before each test and noticed TransGrid before and after each test
Failure to meet agreed AEMO obligations due to: ▪ Ineffective technical DD ▪ Poor quality design and installation ▪ Force majeure event ▪ Equipment failure	▪ Reduced revenue of Gullen Range Wind Farm ▪ Unplanned outages ▪ Breach of AEMO market rules	Financial Impact (EBIT) / Return on Investment $AUD	4	5	Critical	Goldwind grid connection expertise and wind farm compliance buffering AEMO risk. The IBFFR feature can be disabled if causing any non-compliance. Goldwind started the test from one wind turbine to reduce the impact to grid and wind farm. The wind farm operation would then revert back to its normal (compliant) mode of operation	3	1	Medium	The IBFFR did not interfere with the regular operation of Gullen Range Wind Farm. The IBFFR capabilities were only activated for those short periods of times in which data was being collected for a field test.

Potential Risks	Resulting In: Risks/Unplanned/Unwanted Event/Potential Impact	Risk Category	Current Risk with existing controls: Severity (1-5)	Likelihood (1-5)	Risk Rating	Additional Controls required to manage the risk	Post mitigation: Severity (1-5)	Likelihood (1-5)	Risk Rating	End of Project Outcome
OHS incident during installation A serious incident occurs harming an employee, contractor or third party due to: ▪ Poor quality or lack of induction ▪ Inadequate contractual requirements or lack of compliance ▪ Inadequate planning and/or supervision, or negligent behaviours ▪ Unsafe work environment	▪ Personal and family impacts from loss of life/personal injuries ▪ Additional Work Safe imposts ▪ Increased workers' compensation and public liability insurance premiums ▪ Reputation damages ▪ Fines and /or penalties	Injury	5	2	Critical	Use of experienced contractors with proven track record, Goldwind in-house expertise. Goldwind's current on-site personnell shall be involved in the work. Goldwind HSE management systems that comply with AS4801 & ISO18001. Undertake a Hazard and risk assessment. Regular safety inspections by Goldwind Project Manager or HSEQ Manager Licenced and trained operators and technicians CM3 prequalification Any Contractors certified under the FSA Commissioner Site induction and sign-in procedures applied	4	1	Medium	No injuries or OHS incidents occurred
Unfavourable grid conditions The frequency change events experienced at the grid connection point do not allow for a range of IBFFR capability and scenarios to be tested	extension of field study duration	Project Schedule (NTP-PC)	3	4	High	Frequency step changes are able to be simulated during the field study and thus the field study is not reliant on external conditions During the test, Goldwind use inject input signal to simulate the frequency step changes	1	2	Low	The tests were conducted using simulated injection testing (and not from actual frequency measurements)
Driving Skills International employees' driving skills are unknown. Steep terrain driving skills unknown for all. Driver behaviour: speed, overtaking, fog, wet.	Fatality.	Injury	5	2	Critical	International employees were able to work remotely. No driving was required	1	1	Low	All Goldwind TSD staff have driving license and attend the driving safety courses. No injury or accident occurred during the field study.
Wind Inaccurate wind prediction means it is hard to meet three-day notice to Transgrid	Lost time & project delay	Financial Impact (EBIT) / Return on Investment $AUD	3	5	Critical	A wind forcast check was performed every day and more than 3 months during the testing period.	2	5	High	Goldwind Staff monitors wind forcasting everyday during the testing period. Wind speed are not very high in some of the testing months, this resulted in a project delay of appoximately three months.
Travel Long hours - fatigue. Travel before/after a full day at work. Wildlife collisions. Local events add to road traffic.	Very Serious – Fatality or other injury	Injury	5	2	Critical	Mitigated by restricted work hours. Advice re public events. Controls travel/work itineraries so meet national guidelines. HSEQ management by EPC Contractor.	5	1	Critical	No injuries or OHS incidents occurred
Isolated/Remote Worker Lone worker. Pair of workers become lone worker if one has to leave	Casualty treatment. Serious Injury. Lost time injury/illness.	Injury	4	3	High	See statutory standards (electrical). Create protocols (buddy system, communication/reporting, planning the trip/work, cease work if your buddy is not there).	3	1	Medium	No injuries or OHS incidents occurred