Investigation Report Under-Frequency Load Shedding Event on 10 January 2020

June 2020

Important notice

PURPOSE

This report is published in accordance with WEM Rule 3.8.3. This report has been prepared to investigate the Under-Frequency Load Shedding (UFLS) event that occurred in relation to the South West Interconnected System (SWIS) on Friday, 10 January 2020. This report does not contain information that cannot be made public under the Wholesale Electricity Market Rules or which AEMO considers should not be released and AEMO did not engage independent experts to report on the incident.

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VERSION CONTROL

Version	Release date	Changes
1.0	25/6/2020	Initial release

Executive summary

Event summary

At 20:08:31 (AWST) on Friday, 10 January 2020, the NewGen Kwinana (NGK) combined-cycle gas power station tripped while it was ramping down for a planned outage, resulting in a near-instantaneous loss of generation of 250 megawatts (MW). This credible contingency event led to a decline in system frequency that was adequately arrested by the spinning reserve quantities procured by AEMO under the Wholesale Electricity Market Rules (WEM Rules). The system frequency nadir after the initial event was 49.26 hertz (Hz).

However, a confluence of other generator trips, as well as the runback of two wind farms and a material reduction in output from a gas-fired power station, led to the system frequency declining below 48.75 Hz, triggering the partial activation of Stage 1 of the automatic Under-Frequency Load Shedding (UFLS) scheme. As a result of the UFLS activation, 94,578 customers in the South West Interconnected System (SWIS) were disconnected, some for up to four hours.

In total, 495 MW of generation was lost within four minutes – the initial trip (250 MW) and the subsequent generator trips, runbacks and reductions (245 MW additional loss). This comprised 12 generating units that tripped, two wind farms that were run back by the operation of the Generator Interim Access (GIA) system, and two of Alinta's gas-fired generating units that unexpectedly reduced their output. Of the total generation lost, 90% was from three facilities – NGK (the initial trip), the Badgingarra Wind Farm (runback), and Worsley Alumina (four tripped generating units).

The results of the investigation indicate that there was sufficient spinning reserve to cater for the initial single generator contingency trip, but not enough to cover the subsequent generator trips, runbacks and reductions. This is consistent with power system design practice for management of contingencies, as well as AEMO's obligations under the WEM Rules.

Given the cascading contingency, the UFLS scheme worked as designed and supported the stabilisation of the power system. Further, additional stages of UFLS were available, but not activated, to protect the power system in case the event escalated further.

System inertia was relatively high and did not adversely influence this event. As the event occurred at night, rooftop photovoltaic (PV) was also not a factor.

As a result of this event, changes have been made to the GIA scheme to prevent runbacks of GIA generators when system frequency deviates outside of the normal operating band. Preliminary changes have been implemented to Worsley Alumina's operating practices to mitigate against the risk of generating units tripping. Further work is required to design and implement a permanent mitigation. Alinta is also working with its equipment supplier to modify control system behaviour, and AEMO has engaged with other generators that tripped or reduced output to minimise any reoccurrence.

This investigation report provides information on:

- The performance of the power system during the event.
- The causes of the event.
- Corrective and mitigation actions taken by AEMO and other parties to manage power system security.

AEMO has prepared and published this report as part of its obligation under the WEM Rules to investigate significant incidents in the SWIS.

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1. Introduction

On the evening of Friday, 10 January 2020, the NewGen Kwinana (NGK) combined-cycle gas power station tripped while it was ramping down for a planned outage, resulting in a sudden decline in system frequency from 50 hertz (Hz) to 49.26 Hz. In the following minutes, a series of additional generator trips, as well as the reduction in output from other generators, led to a further drop in system frequency below 48.75 Hz, resulting in Under-Frequency Load Shedding (UFLS). As a result of the UFLS activation, 94,578 customers in the South West Interconnected System (SWIS) were disconnected, some for up to 4 hours.

This report describes the sequence of events that led to the UFLS activation, and the findings and outcomes of AEMO's investigation. AEMO has prepared and published this report as part of its obligation under the Wholesale Electricity Market Rules (WEM Rules) to investigate any incidents in the operation of equipment comprising the SWIS that endangers Power System Security or Power System Reliability to a significant extent[1].

This report is structured as follows:

- Chapter 2 explains the principles and characteristics of power system design for management of contingency events.
- Chapter 3 details the sequence of events on the evening of Friday, 10 January 2020.
- Chapter 4 provides AEMO's analysis and findings in relation to the individual contributing events that led to the UFLS activation.
- Chapter 5 describes the corrective actions that AEMO and other parties have taken since the UFLS activation.

Unless otherwise stated, all times in this report are Australian Western Standard Time (AWST). All power outputs in this report are quoted as gross as-generated[2] values based on either real-time SCADA or high-speed fault recorder data.

Facility names in this report relate to registered Facilities as indicated in the following table.

Table 1 Facility names

Report name	Participant Name	Facility Code	Facility Type	Maximum Capacity (MW)
Alinta Pinjarra GT1	Alinta Sales Pty Ltd	ALINTA_PNJ_U1	Scheduled Generator	143
Alinta Pinjarra GT2	Alinta Sales Pty Ltd	ALINTA_PNJ_U2	Scheduled Generator	143
Badgingarra Wind Farm	Alinta Sales Pty Ltd	BADGINGARRA_WF1	Intermittent Non-Scheduled Generator	130
Beros Rd Wind Farm	Blair Fox Pty Ltd AFT The Blair Fox Trust	BLAIRFOX_BEROSRD_WF1	Intermittent Non-Scheduled Generator	9.252
Karakin Wind Farm	Blair Fox Pty Ltd AFT The Blair Fox Trust	BLAIRFOX_KARAKIN_WF1	Intermittent Non-Scheduled Generator	5

1 Section 3.8 of the WEM Rules.

2 As-generated outputs are four-second instantaneous values measured at the generator terminals. Market demand values are lower because behind-the-meter generation and consumption is netted off.

Report name	Participant Name	Facility Code	Facility Type	Maximum Capacity (MW)
West Hills Wind Farm	Blair Fox Pty Ltd AFT The Blair Fox Trust	BLAIRFOX_WESTHILLS_WF3	Intermittent Non-Scheduled Generator	5
Richgro Bioenergy plant	CleanTech Energy Pty Ltd	BIOGAS01	Intermittent Non-Scheduled Generator	2
Red Hill	Landfill Gas and Power Pty Ltd	RED_HILL	Intermittent Non-Scheduled Generator	3.64
Tamala Park	Landfill Gas and Power Pty Ltd	TAMALA_PARK	Intermittent Non-Scheduled Generator	4.8
Newgen Kwinana (NGK) GT and ST	NewGen Power Kwinana Pty Ltd	NEWGEN_KWINANA_CCG1	Scheduled Generator	335
NewGen Neerabup GT11 and GT12	NewGen Neerabup Partnership	NEWGEN_NEERABUP_GT1	Scheduled Generator	342
Rockingham landfill gas plant	Perth Energy Pty Ltd	ROCKINGHAM	Intermittent Non-Scheduled Generator	4
South32 Worsley Alumina Pty Ltd (WAPL)	Perth Energy Pty Ltd	WAPL_WORSLEY_IL1	Non-Dispatchable Load	N/A
Henderson waste gas plant	Waste Gas Resources Pty Ltd	HENDERSON_RENEWABLE_IG1	Intermittent Non-Scheduled Generator	3
Kemerton GT11	Synergy	KEMERTON_GT11	Scheduled Generator	154.7
Kemerton GT12	Synergy	KEMERTON_GT12	Scheduled Generator	154.7
Muja G5	Synergy	MUJA_G5	Scheduled Generator	195.8
Muja G6	Synergy	MUJA_G6	Scheduled Generator	193.6
Kwinana Power Partnership (KPP)	Synergy	PPP_KCP_EG1	Scheduled Generator	85.7

2. Power system design for contingency

This section describes the protective mechanisms that are designed to manage contingency events in relation to the power system.

The SWIS has been designed, like many energy systems, with several layers of protection to maintain power system security in the event of a contingency, for example, the unplanned disconnection of a large generator (as was the case during this event when NGK tripped) or a transmission line from the network.

A contingency is deemed *credible* when there is a non-negligible probability that it could occur and that it would potentially have a significant impact on the system. Classifying contingencies in this fashion is largely to prevent the excessive provision of costly reserves for rare events that are precipitated via a complex or coincidental chain of failures, e.g. multiple generators or transmission lines unexpectedly fail at the same time.

During a contingency resulting in loss of generation, there is a disruption in the supply and demand balance in the system, that is, a shortage of generation relative to load. This is manifested in a declining system frequency, as energy from the rotating masses connected to the system is used to supply the generation lost, but in doing so causes the speed of rotation to fall[3]. For the system to remain stable after a loss of generation contingency, other generators connected to the system must increase their outputs and/or loads must decrease their demand, with the aggregate change in power being equal to the amount of generation that was lost.

Conversely, a network contingency, such as the tripping of a transmission line, can lead to a sudden loss of load. The excess of generation relative to load leads to an increase in system frequency, as the rotating masses connected to the system will absorb some of the excess electrical energy and will speed up. To maintain the stability of the system, generation must be reduced to rebalance supply and demand.

In the absence of corrective actions, the system frequency can either climb or collapse. This can lead to equipment protection systems activating to disconnect equipment from service to prevent damage in an uncoordinated fashion. In extreme cases, this can result in a system black event.

In the SWIS, there are three main protective mechanisms to protect the power system following a contingency and prevent a system black event.

2.1 Layer 1: Mandatory Primary Frequency Response Requirements

The first layer of protection is the mandatory 'droop response' requirement imposed on generators connecting to the SWIS. As part of their conditions for connection, generators must comply with section 3.3.4.4 of Western Power's Technical Rules, which mandates a short-term primary frequency response (PFR) for all dispatchable generators whenever the system frequency deviates from a narrow band between 49.975 Hz and 50.025 Hz.

With this layer of protection, all dispatchable generators that are online at the time of a contingency are expected to assist (where they can) to prevent the system from becoming unstable and collapsing.

This response is triggered by local measurement of system frequency (at the power station) and can occur due to a relatively small imbalance between supply and demand.

Small quantities of droop response are typically activated several times per day.

[3] Frequency is proportional to the speed of rotation.

2.2 Layer 2: Spinning Reserve and Load Rejection Reserve

While the mandatory PFR requirements ensure that generators each contribute to restoring system security, there are no requirements for ensuring that generators have any headroom[4] to assist. For example, at times of peak load, it is conceivable that all dispatchable generators cleared in the energy market are operating near maximum output and have no further room to increase output to cover the loss of generation.

As a result, the second layer of protection is the explicit provision of headroom up (*Spinning Reserve* for loss of generation contingencies) and headroom down (*Load Rejection Reserve* for loss of load contingencies), and the ability to sustain the increase or decrease in output for several minutes. Under the WEM Rules, AEMO procures Spinning Reserve and Load Rejection Reserve from Synergy's balancing portfolio, and may procure these ancillary services contractually from other Market Participants.

AEMO procures enough Spinning Reserve to cater for the loss of the single largest generation contingency, consistent with its obligations under the WEM Rules[5]. This is typically the largest generating unit connected to the system, but may include multiple generators if deemed credible, for example, if the loss of a single transmission line would also cause the disconnection of two or more generators. This response is also triggered by local measurement of system frequency.

Significant Spinning Reserve events[6] occur approximately 10 to 15 times per year in the SWIS.

2.3 Layer 3: Under-Frequency Load Shedding

For a larger contingency, often as a result of a *non-credible* or *multiple contingency event*, a final layer of protection is the UFLS scheme that operates automatically when the system frequency falls below 48.75 Hz. This scheme prevents the frequency from declining further to such low frequencies that the system is at risk of collapse, leading to a complete system black event. Moreover, if frequency has declined to this level, then the reserves in the first two layers of protection have likely been fully exhausted. With no more reserves to arrest the frequency decline, the UFLS scheme is the final layer of protection to prevent system collapse.

Western Power is responsible for configuring the UFLS scheme in accordance with section 2.4 of its Technical Rules. The UFLS scheme disconnects loads dispersed across the SWIS in order to restore the supply-demand balance. There are five stages in the UFLS scheme, each designed to disconnect approximately 15% of the system load and with staggered frequency activation setpoints: 48.75 Hz, 48.50 Hz, 48.25 Hz, 48.00 Hz, and 47.75 Hz. In practice, each UFLS stage can operate partially or fully in order to disconnect as much load as necessary to stabilise the system frequency[7].

UFLS activations are relatively rare. In the SWIS, UFLS has only activated four times since 2010 (including this event).

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[4] Headroom refers to the circumstance where a generator is operating below its maximum capacity and is able to quickly increase its output, or is operating above its minimum stable generation level and is able to quickly decrease its output.

[5] Sections 3.9 to 3.15 of the WEM Rules set out the definitions, requirements and processes in respect of Ancillary Services.

[6] Generally defined as events where the system frequency deviates below the normal operating range between 49.8 Hz and 50.2 Hz.

[7] Rooftop photovoltaic (PV) generation causes the net load on relevant distribution lines to be lower in the middle of the day than at other times. Consequently, if an UFLS event occurred in the middle of the day (such as 12:00), it is expected that more distribution lines would need to be disconnected than at other times, to shed the same quantity of load.

3. Sequence of events

This section describes the power system conditions prior to the initial generator trip, and the sequence of events from the initial trip until the frequency recovered to the normal operating band. It also outlines post-event actions taken by AEMO to manage power system security.

3.1 Pre-event conditions

This section describes the relevant power system and environmental conditions immediately before the initial trip of NGK.

3.1.1 Weather

The weather in the Perth metropolitan area on the evening of Friday, 10 January 2020 was relatively mild with ambient temperatures around 28.7°C at 20:00 (8.00 pm). The daily minimum and maximum temperatures were 15.8°C and 32.1°C respectively, with no rain recorded in the Perth metropolitan area during that day.

Weather was not a factor in the UFLS event on Friday, 10 January 2020.

3.1.2 Pre-event system conditions

Table 2 provides a summary of the system conditions on the SWIS one minute prior to the trip of the NGK generator. At this time, the SWIS was in a secure Normal Operating State.

Table 2 Pre-event system conditions (20:07 on 10 January 2020)

System Total Load[A] (megawatts [MW])	2,774
Total Generator Inertia [MW.s]	17,390
Total Wind Generation [MW]	438.2
Total Solar PV Generation [MW]	0.0[B]
Total Available Upwards LFAS [MW]	3.5
Total Available Downwards LFAS [MW]	50.0
Total Available Spinning Reserve [MW]	236.5
Total Load Rejection Reserve [MW]	232.2
System Frequency [Hz]	49.98

A. System total load is as-generated at the generator terminals (including generator auxiliary loads) whereas market load is generation sent out to the market.
B. The event occurred at 20:08, which was after the sun had set at 19:25.

The quantity of spinning reserve procured was sufficient for the largest potential single contingency, which was the potential loss of NGK. One minute prior to the onset of the event, NGK was generating

282.9 megawatts (MW), resulting in a spinning reserve requirement of at least 198 MW (representing 70% of the largest contingency[8]). As shown in Table 2, 236.5 MW of spinning reserve was available[9].

The quantity of inertia on the power system prior to the event was reasonably high. Higher levels of inertia will result in a slower rate of change of frequency following a contingency event.

AEMO procures a minimum of 50 MW each of Upwards and Downwards Load Following Ancillary Service (LFAS) between the hours of 19:30 and 05:30[10]. Prior to the trip of the NGK generator, the generators enabled for Upwards LFAS were collectively generating 46.5 MW above their dispatch set points, meaning the majority of the enabled Upwards LFAS had effectively been "consumed" due to system conditions (such as variances from load forecast, fluctuations in non-scheduled generation, and differences in generator ramp).

In addition to the facilities providing LFAS, several Synergy generating units were being operated by the Automatic Generation Control (AGC) system in "Assist" mode, as is normal practice. This ramps unit output up or down in response to under-frequency and over-frequency excursions outside of the normal frequency operating band, respectively.

NGK was ramping down for an approved planned outage at the time of the event. From correspondence with NGK at the time of the outage approval process (8 January 2020), it was conveyed to AEMO that the gas turbine (GT) had developed a bearing lube oil leak, but NGK had advised that this did not immediately affect the operation of the Facility and the unit was fully available for dispatch prior to the outage.

3.2 Summary of events

A chronological summary of the events leading up to and after the UFLS activation is shown below in Table 3.

Table 3 Chronological summary of events on 10 January 2020

Time	Description of Event
20:00:32	System normal. System is set up to manage NGK ramping down from 318 MW at 5 MW per minute for a complete planned outage due to commence at 22:00.
20:08:12	With NGK operating at 275 MW, the facility's output begins to decline rapidly at approximately 83 MW per minute.
20:08:30	With NGK operating at 250 MW, the GT trips, followed by the steam turbine (ST) at 20:08:34. System frequency drops to a nadir of 49.26 Hz, but 158 MW of spinning reserve response (118 MW provided by generation and 40.2 MW provided by interruptible load) arrests the decline and frequency begins to recover. The AEMO controller issues a command at approximately 20:09 for Kemerton GT11 to start. (Note that this generator takes approximately five to six minutes to synchronise to the grid.)
20:08:52 to 20:17:48	In the nine minutes after the initial NGK trip, Alinta Pinjarra GT1 and GT2 both drift from their pre-event outputs of 130 MW each, at one point reaching a combined 25 MW lower than their pre-event outputs at 20:12:24. (The particular impact of this on system frequency is indiscernible due to its duration.)
20:09:01	Tamala Park landfill gas plant partially trips, resulting in a loss of 2.2 MW.
20:09:10	Thermal constraints in the Generator Interim Access (GIA) tool bind on the Badgingarra Wind Farm and Beros Rd Wind Farm, leading Badgingarra to reduce its output from 114 MW to 102 MW (19.5 MW per minute) and Beros Rd to reduce from 2.8 MW to 0 MW (9.5 MW per minute) over the next 40 seconds. This causes a further system frequency decline from 49.37 Hz to 49.22 Hz.

8 Clause 3.10.2(a) of the WEM Rules requires the Spinning Reserve standard to be a level that is sufficient to cover the greater of: 70% of the total output, including Parasitic Load, of the generation unit synchronised to the SWIS with the highest total output at that time; and the maximum load ramp expected over a period of 15 minutes. With respect to the first component, the remaining 30% of the total output is covered by natural reduction of demand as frequency decreases, and by inertial response from other on-line generation.

9 Available spinning reserve may be higher than that required at specific points in time due to real-time dispatch outcomes.

10 The Ancillary Service Requirements are detailed in the *Ancillary Services Report for the WEM 2019*, June 2019, available at https://www.aemo.com.au/-/media/Files/Electricity/WEM/Data/System-Management-Reports/2019-Ancillary-Services-Report.pdf.

Time	Description of Event
20:10:11	Two embedded generators at South32 Worsley Alumina Pty Ltd (WAPL), WAPL G1 and G3, both trip within 10 seconds of each other, resulting in a further loss of 54 MW. As frequency remains low, spinning reserve generators continue to increase their output by 10 MW. Thermal constraints in the GIA tool bind further, leading Badgingarra Wind Farm to further reduce its output to 42 MW at 19.5 MW per minute. (The particular impact of these events on system frequency are indiscernible from coincident events.)
20:10:23	Red Hill landfill gas plant trips, resulting in a loss of 2.6 MW. System frequency falls below 49.00 Hz, triggering another 21 MW of interruptible load response.
20:10:40 to 20:10:50	The following small power plants trip within 10 seconds, resulting in a total loss of 4 MW: • Rockingham landfill gas plant (loss of 1.2 MW) • Henderson waste gas plant (loss of 1.4 MW) • Karakin Wind Farm (loss of 1.4 MW)
20:11:00 to 20:12:00	The AEMO controller instructs Muja G5 and G6 to provide as much generation as possible and calls the Kemerton power station operator to advise that GT11 was not starting.
20:11:32	Embedded generator WAPL G2 trips, resulting in a loss of 32 MW of generation. (The particular impact of this on system frequency is indiscernible from coincident events.)
20:11:56 to 12:12:06	The following small power plants trip within 10 seconds, resulting in a total loss of 1.4 MW: • West Hills Wind Farm (loss of 1.1 MW) • Richgro Bioenergy plant (loss of 0.3 MW)
20:12:08	UFLS stage 1 partially operates (frequency = 48.748 Hz), resulting in frequency starting to recover.
20:12:12	After Kemerton GT11 fails to respond to the start command, the AEMO controller issues a command for Kemerton GT12 to start.
20:12:27	Embedded generator WAPL G6 trips, resulting in a loss of 49 MW of generation. This causes a further system frequency decline from 49.15 Hz to 48.741 Hz.
20:12:40	UFLS stage 1 partially operates again (frequency = 48.741 Hz).
20:13:30	The AEMO controller instructs Kwinana Power Partnership (KPP) to operate at maximum output.
20:15:00 to 20:49:00	GIA constraints on Badgingarra and Beros Rd are gradually lifted and the wind farms start to increase their output.
20:17:38	Frequency recovers to 49.8 Hz (within normal operating frequency band).
20:18:44	Kemerton GT12 starts ramping up to restore system reserves.
20:25:00	The AEMO controller requests NewGen Neerabup to run two units while being dispatched for 160 MW while the system is being stabilised.
20:27:00	With the system secure, the AEMO controller advises Western Power that it can commence restoration of load that had been disconnected due to UFLS (at an initial rate of 10 MW per minute).

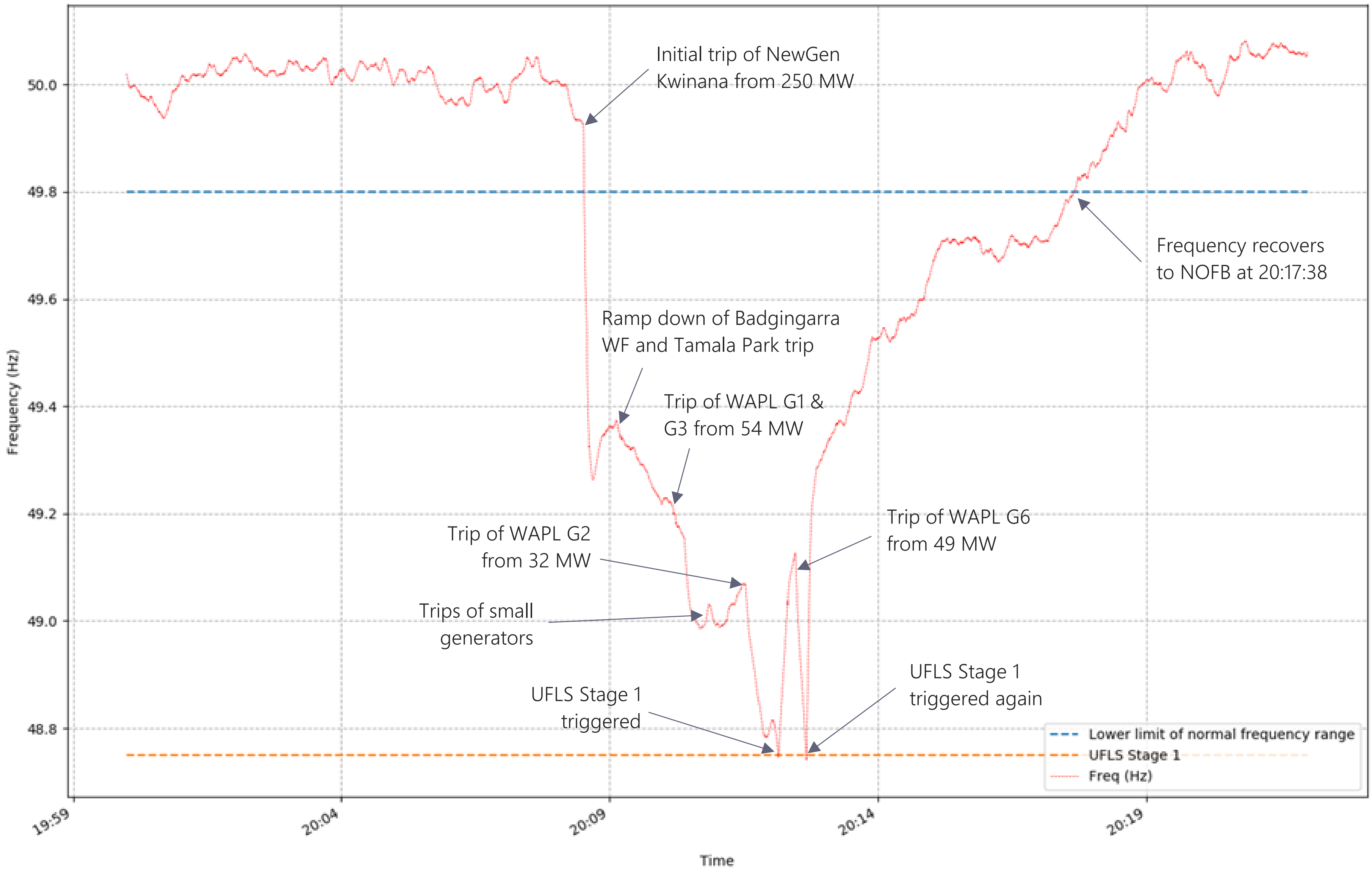
A chronological list of the total amount of generation lost over the entirety of the event is shown below in Table 4.

Table 4 Total generation lost between 20:08 and 20:15, 10 January 2020

Time	Generator	Output lost (MW)
20:08	NewGen Kwinana (GT and ST)	250
20:09 to 20:18	Alinta Pinjarra GT1 and GT2	25
20:09	Tamala Park	2.2
20:09 to 20:13	Badgingarra Wind Farm (runback) Beros Rd Wind Farm (runback)	75
20:10	WAPL G1 WAPL G3	54
20:10	Red Hill Rockingham Henderson waste gas plant Karakin Wind Farm	6.6
20:11	WAPL G2	32
20:12	West Hills Wind Farm Richgro Bioenergy	1.4
20:12	WAPL G6	49
TOTAL		**495.2**

A plot of the system frequency over a 22-minute period from 20:00 to 20:22, covering the entirety of the event, is shown in Figure 1. Key events which significantly and/or quickly impacted the frequency are shown on this plot.

Figure 1 SWIS system frequency between 20:00 and 20:22



3.3 Under-Frequency Load Shedding

At 20:12:08 and then again at 20:12:40, the system frequency declined to below 48.75 Hz. This resulted in the partial activation of Stage 1 UFLS[11], where 94,578 customers were impacted across 76 distribution feeders. A total of 123 MW of load was shed.

At 20:27, with fast-start reserve generator Kemerton GT12 now synchronised and system reserves restored, AEMO advised Western Power that it could begin to restore load at up to 10 MW per minute. As system conditions stabilised, Western Power was advised that it could restore load at up to 20 MW per minute by 20:56 and then up to 30 MW per minute by 21:09[12]. By 23:45, Western Power advised that all load had been restored.

3.4 Dispatch Advisories

The Dispatch Advisories issued to the market during and in the hours after the event are shown in Table 5.

Table 5 Dispatch Advisories issued to the market on the night of the event

ID	Issued Date/Time	Operating State	Details
206603	10 January 2020 20:48:28	High Risk	NEWGEN_KWINANA_CCG1 tripped at 20:08 on 10/01/2020 resulting in a loss of approximately 325MW and a frequency deviation to 48.75 Hz. Frequency returned to a Normal Operating range within 8 minutes of the unit tripping.
206604	11 January 2020 00:12:09	No State Change	Further to Dispatch Advisory 206603, the under frequency load shedding event was caused by a triple contingency involving NEWGEN_KWINANA_CCG1, BADGINGARRA_WF1 and WAPL_WORSLEY_IL resulting in frequency deviation of 48.76Hz. Western Power has enacted network control services and reduced BADGINGARRA_WF1 output to 0MW until further investigations can be completed.

3.5 Immediate actions taken by AEMO

The following actions were taken by the AEMO controllers during the event:

- The start sequence on Kemerton GT11 was initiated immediately after the initial NGK trip at 20:09[13]. After the unit failed to start, the AEMO controller called the power station to advise them of the situation. Kemerton GT12 was then issued a start command several minutes later at 20:12. The unit started up successfully and synchronised to the system at 20:18[14].
- Muja G5 and G6 and KPP were verbally instructed to provide the maximum generation they could provide.
- In the interval of the event (20:00) and the subsequent interval (20:30), the NewGen Neerabup power station was cleared and dispatched for 160 MW (which is near its maximum output). In order to provide additional active power headroom, the AEMO controller requested NewGen Neerabup to run both gas turbines in the facility (denoted GT11 and GT12) at 80 MW each (see Figure 2).

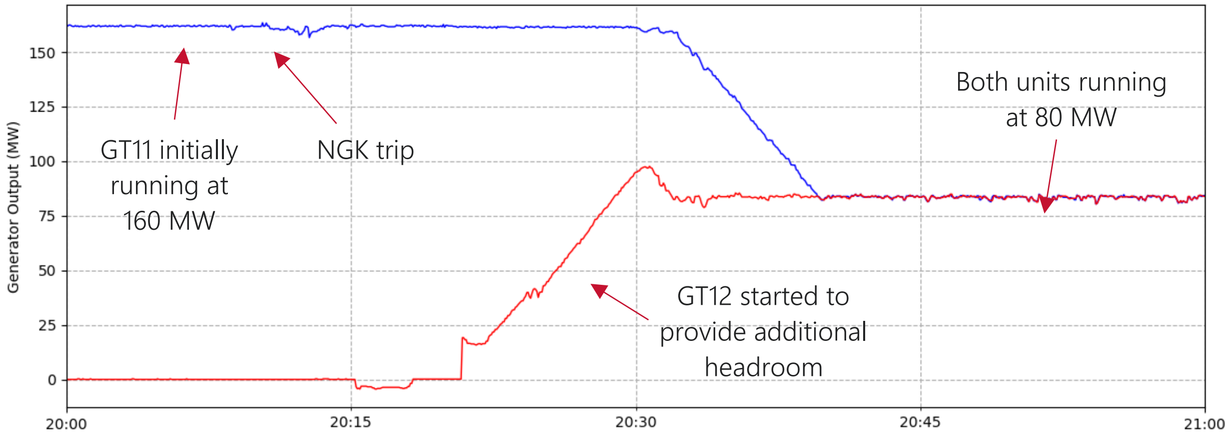
[11] The total requirement for Stage 1 UFLS is the disconnection of 15% of system (market) load or approximately 388 MW at the time of this event.

[12] These are maximum load restoration rates. When restoring load, Western Power must consider practicalities that include safety of people and equipment, the specific mechanisms for reconnecting customers, and the geographical distribution of the affected customers.

[13] It is standard practice for the controller to only start one of the units allocated for Ready Reserve, rather than starting both units simultaneously.

[14] As discussed in Section 4.4, the failure of Kemerton GT11 to start did not impact the UFLS event.

Figure 2 NewGen Neerabup GT11 and GT12 outputs from 20:00 to 21:00



3.6 Post-event actions taken by AEMO

The following actions were taken by AEMO and Western Power after the event to maintain system security:

- Badgingarra Wind Farm was constrained to 0 MW by Western Power after the event while the incident was being investigated. Western Power, with AEMO agreement, then relaxed this to a 50% output constraint with a ramp rate set to a much lower 1 MW per minute after further investigation.
- Additional spinning reserve volumes of 80 MW were temporarily procured by AEMO to cover the possible Worsley Alumina Pty Ltd (WAPL) trip contingency (a repeat of which was deemed to be credible) and possible reductions in wind farm output due to interactions between GIA and Pinjar (when providing a droop response).
- AEMO's Real Time Frequency Stability (RTFS) tool was updated to include the WAPL trip contingency.

Note that these actions were progressively unwound as the underlying issues that caused the event were addressed (refer to section 5.2 for more detail).

Table 6 summarises the Dispatch Advisories that were issued to the market following the event:

Table 6 Dispatch Advisories issued to the market after the event

ID	Issued Date/Time	Operating State	Details	Withdrawn Date/Time
206607	13 January 2020 17:53:24	No State Change	As part of the investigation into the events that occurred on the night of Friday 10 January 2020 (DA 206603, 206605), AEMO will be increasing the size of the contingency for which we carry Spinning Reserve. This will remain in place until further notice.	7 February 2020 15:37:30
206625	24 January 2020 13:31:01	No State Change	Further investigation into the events that occurred on the night of Friday 10 of January 2020 (DA# 206603, 206605) has resulted in AEMO significantly	7 February 2020 15:37:00

ID	Issued Date/Time	Operating State	Details	Withdrawn Date/Time
			reducing the size of the increased contingency for which we carry Spinning Reserve (DA#: 206607). An increased contingency size will remain in place until further notice.	

4. Analysis of UFLS event

This section provides analysis and describes AEMO's findings on the causes of the generator trips and runbacks and assesses the performance of frequency response services.

4.1 Summary of findings

The activation of UFLS occurred due to the combined effect of a number of second-order contingencies and runbacks that occurred following the initial trip of NGK (250 MW), specifically:

- The GIA runback of the Badgingarra and Beros Rd Wind Farms, which reduced their combined output by 75 MW over four minutes.
- Trips of embedded generators WAPL G1, G2, G3, and G6, with a combined loss of 135 MW over two minutes.
- Downward drift in the output of the Alinta Pinjarra power station over a period of nine minutes, with a maximum reduction of 25 MW occurring four minutes after the initial NGK trip.
- Trips of seven small market generators, with a combined loss of 10.2 MW.

Consistent with standard practice and WEM Rule requirements (described in Section 2), there was sufficient Spinning Reserve available to cater for the initial generator trip (250 MW loss), but not enough to cover the subsequent generator trips and runbacks (245 MW additional loss).

Given the cascading contingency, the UFLS scheme worked as designed and supported the stabilisation of the power system. Further, additional stages of UFLS were available, but not activated, to protect the power system in case the event escalated further.

System inertia was relatively high and did not adversely influence this event. As the event occurred at night, rooftop PV was also not a factor.

4.2 Generator trips and runbacks

The causes of the generator trips and runbacks are described below. These are based on AEMO's analysis and have been confirmed following engagement with the relevant Rule Participants.

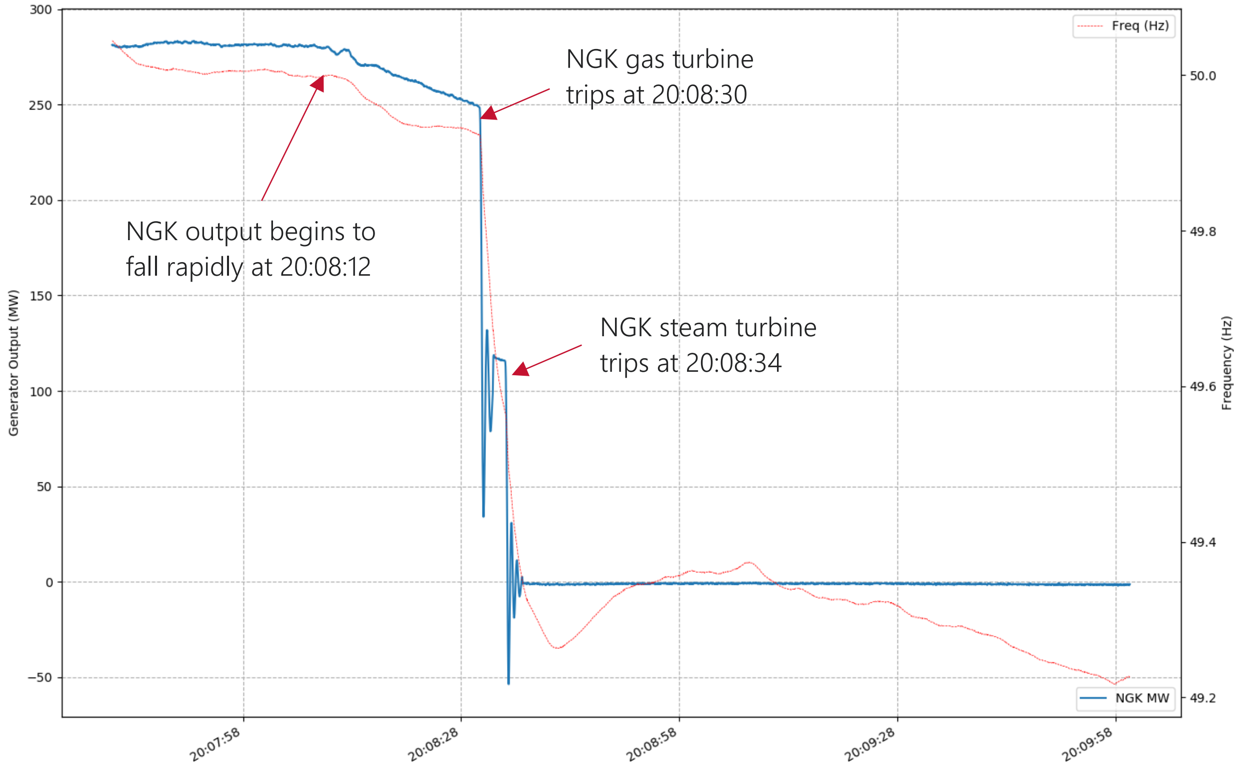
4.2.1 NewGen Kwinana

NGK is a combined cycle gas turbine (CCGT) power station with a maximum capacity of 335 MW[15], which is registered in the WEM by NewGen Power Kwinana Pty Ltd. A CCGT power station produces electricity from two turbines: fuel is burnt in a gas turbine (GT), and the waste heat is recovered and re-routed to a nearby steam turbine (ST), which generates additional power. The ST cannot operate independently, because waste heat from the GT is required to generate the steam.

As explained in Section 3.1.2, NGK was ramping down at the time of the event for an approved planned outage to repair a bearing lube oil leak. During the ramp down, the leaking bearing lube oil ignited and precipitated the unit trip. Typical of a CCGT facility, without the GT online, the ST subsequently tripped (see Figure 3).

[15] Facility maximum capacities are available at http://data.wa.aemo.com.au/#facilities.

Figure 3 High speed recording of the NewGen Kwinana trip



4.2.2 Badgingarra and Beros Rd Wind Farms

The Badgingarra and Beros Rd Wind Farms are located north of Perth, with nameplate capacities of 130 MW and 9.25 MW respectively[16]. At the time of the UFLS event, these were the only two facilities in the SWIS operating under the Generator Interim Access (GIA) tool.

GIA has been developed by Western Power, in consultation with AEMO, to enable the connection of new generators to the SWIS[17] – subject to being constrained down ahead of pre-existing generation where necessary to maintain network operation within technical limits[18].

The Badgingarra and Beros Rd Wind Farms were run back automatically due to two binding thermal constraints in the GIA tool (see Figure 4).

These pre-contingent[19] constraints prevent the JDP-WNO 81 (Joondalup to Wanneroo) and JDP-MUL 81 (Joondalup to Mullaloo) lines from overloading on a trip of the NBT-NT 91 (Neerabup Terminal to Northern Terminal) and TST-NBT 91 (Three Springs Terminal to Neerabup Terminal) lines. Both constraint equations first bound at approximately 20:08:48.

The GIA constraints bound because generating units at the Pinjar power station (which is connected to the same region of Western Power's network) were providing spinning reserve and significantly increased their power outputs in response to the generation trip contingency. This increased output at Pinjar combined with generation from NewGen Neerabup and wind farms to the north of Perth to cause the constraints to bind.

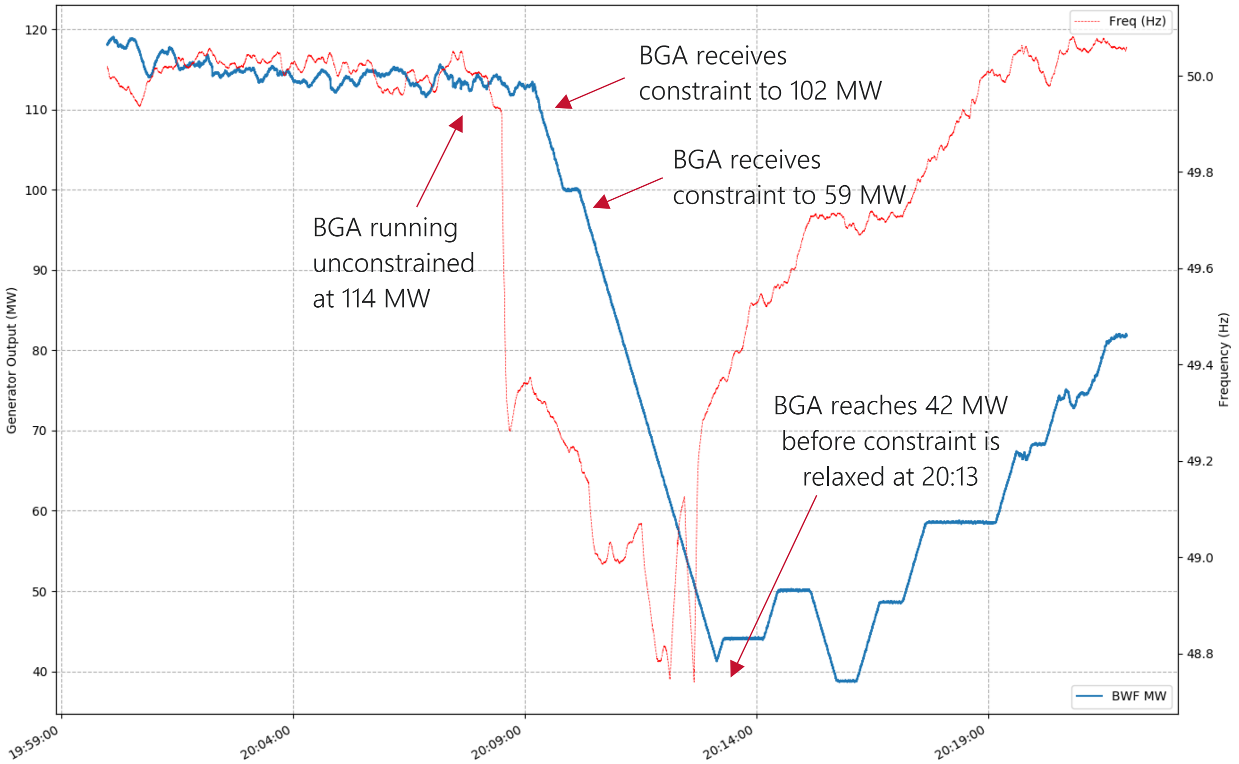
16 Facility maximum capacities are available at http://data.wa.aemo.com.au/#facilities.

17 See https://westernpower.com.au/community/news-opinion/western-power-green-lights-900mw-of-new-green-energy/.

18 See also the Wholesale Electricity Market Rules Amending Rules 2018 (No. 3), which commenced on 29 June 2018, and which related to the participation of GIA generators in the Reserve Capacity Mechanism: https://www.slp.wa.gov.au/gazette/gazette.nsf/lookup/2018-101/$file/gg101.pdf.

19 A pre-contingent constraint ensures that power flows will remain within system limits after a contingency occurs.

Figure 4 High speed recording of Badgingarra Wind Farm active power output



The binding constraints were automatically detected by the GIA tool, which issued a command to the Energy Management System (EMS)[20] to automatically reduce the output of the two wind farms. This automated action occurred while the power system was recovering from the initial NGK trip. Post-event simulations have indicated that it is unlikely that the initial trip of NGK combined only with the GIA runback would have caused an UFLS event.

While the possible interaction of GIA with Ancillary Services, particularly with high North Country generation at Pinjar and Newgen Neerabup, had been identified by AEMO as an issue and discussed with Western Power, the power system modelling studies and operational experience to date had indicated interaction only during planned outages, which was not the case during this incident.

In total, the amount of actual generation run back at Badgingarra and Beros Rd Wind Farms between 20:09 and 20:13 was 75 MW. This runback occurred at a critical time when spinning reserve quantities had nearly been exhausted, preventing the frequency from initially stabilising and then recovering.

Details of remedial actions are described in Section 5.2.

4.2.3 Worsley Alumina

WAPL is an alumina refinery operated by South32 that is registered in the WEM as an Intermittent Load[21]. As such it may export to any level at any time, and import up to a maximum energy limit per interval. There are six embedded generators within the facility.

Prior to the event, the net position was an export (from WAPL into the shared network) of approximately 20 MW. Following the initial frequency decline, the generators provided an initial droop response exporting up to a maximum of 63 MW, in accordance with their Technical Rules obligations[22]. However, due to a trip of

[20] Western Power provides AEMO with use of the XA/21 EMS through a services agreement.

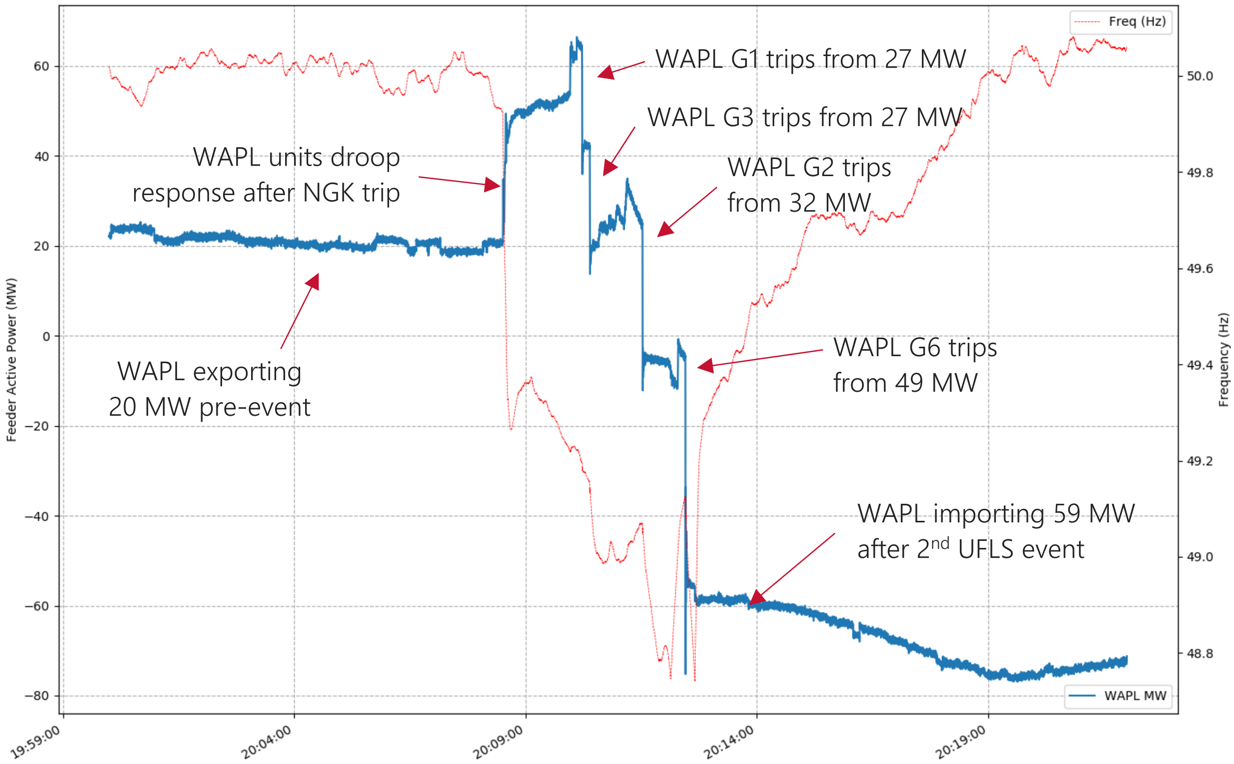
[21] An Intermittent Load is defined in section 2.30B of the WEM Rules and (in summary) relates to a Market Customer with behind-the-meter generation.

[22] Under Clause 3.3.4.4(e)(1)(A) of Western Power's Technical Rules, dispatchable generating units must respond to system frequency excursions at a 4% droop setting.

four generating units within the facility, the direction of power flow ultimately changed to 59 MW importing (see Figure 5).

This net change of approximately 135 MW within 2.5 minutes (79 MW net change from the original position at the time of the NGK trip) contributed to a further reduction in system frequency. The frequency drop that followed the trip of WAPL G6, to 48.741 Hz, triggered the second UFLS event.

Figure 5 High speed recording of the combined net active power from the WAPL feeders



Based on discussions with South32, which has conducted a preliminary investigation of the event, the causes of the WAPL generator trips were:

- WAPL G1, G2, and G3 all tripped due to high condenser pressure after increasing generation levels through droop response.
- WAPL G6 tripped due to high steam pressure following the WAPL G1 to G3 trips.

Details of remedial actions are described in Section 5.3.

4.2.4 Alinta Pinjarra

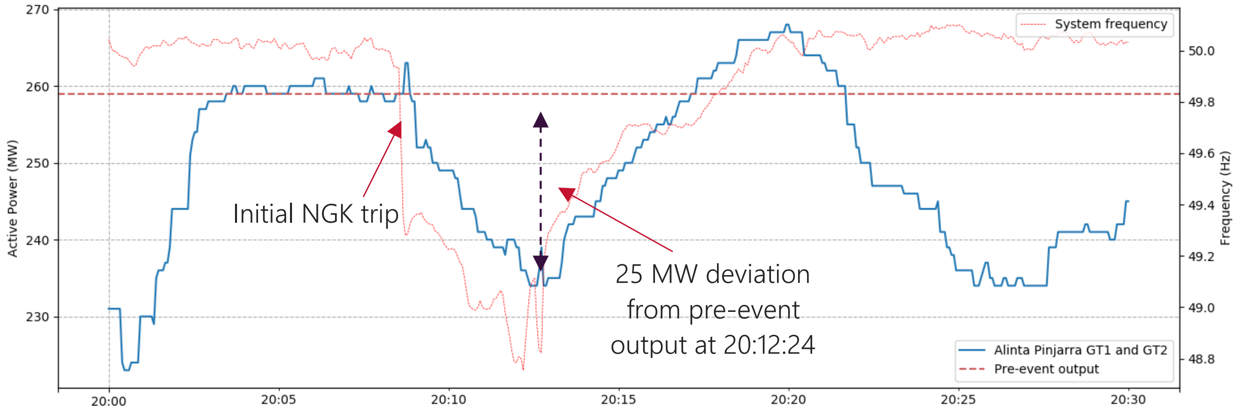
The Alinta Pinjarra power station is a gas-fuelled cogeneration plant consisting of two turbines (GT1 and GT2), each of which provides up to 143 MW of electricity to the SWIS[23] and steam to Alcoa's Pinjarra refinery.

The reduction of output from the Alinta Pinjarra facilities was not expected, as the dispatched basepoints for both units remained at 130 MW or above. In the crucial three minutes after the initial NGK trip (but before the first UFLS activation), the outputs of the Alinta Pinjarra units drifted lower, with a maximum combined deviation from the pre-event output of 25 MW at 20:12:24 (see Figure 6).

This reduction had the effect of exacerbating the frequency deviation, as additional reserves had to be used to counter the reduced output from Alinta Pinjarra.

[23] Facility maximum capacities are available at http://data.wa.aemo.com.au/#facilities.

Figure 6 Combined output of Alinta Pinjarra GT1 and GT2 during the event



Alinta has supplied an investigation report to AEMO, which identifies elements of the control systems that acted to reduce the output of both generating units. Details of remedial actions are described in Section 5.4.

4.2.5 Small market generators

Seven small market generators, each with nameplate capacities less than 10 MW, tripped (partially or fully) in the 3.5 minutes between the initial NGK trip at 20:08:30 and the first UFLS activation at 20:12:08. The generators that tripped are shown below in Table 7. The total generation lost from the small generator trips was 10.2 MW.

Table 7 Small market generators that tripped during the event

Generator	Type	Participant	Pre-event output (MW)	Output lost (MW)
Henderson	Waste gas plant	Waste Gas Resources	1.4	1.4
Karakin	Wind farm	Blair Fox	1.6	1.4
Red Hill	Landfill gas plant	Landfill Gas and Power	3.64	2.6
Richgro Bioenergy	Bioenergy plant	Cleantech Energy	0.3	0.3
Rockingham	Landfill gas plant	Perth Energy	1.2	1.2
Tamala Park	Landfill gas plant	Landfill Gas and Power	4.0	2.2
West Hills	Wind farm	Blair Fox	1.3	1.1

Despite their small size, and their minimal impact in this event, AEMO has engaged with each of the Market Participants responsible for the small market generators that tripped during the event. At the time of publishing this report, these Market Participants have provided details of specific faults that have been recorded by their generation controller systems and, if necessary, any remedial measures that are to be undertaken.

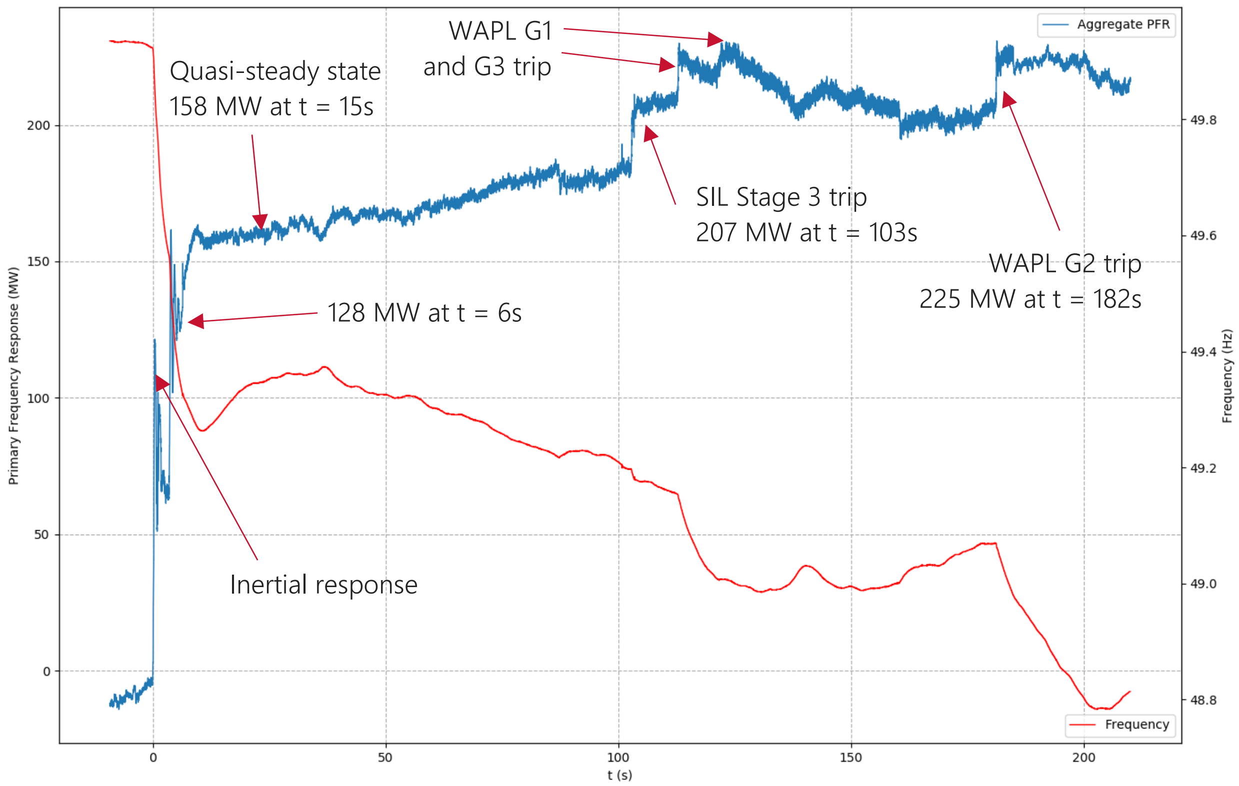
4.3 Primary Frequency Response

Figure 7 shows the aggregate system PFR[24] from all scheduled generators and System Interruptible Loads (SILs) in the SWIS for the first 3.5 minutes after the initial NGK trip[25]. As was explained in Section 2, PFR comprises short-duration droop response and longer-duration spinning reserve provision.

It can be seen that the system response was satisfactory for the NGK trip, with 158 MW of PFR provided (from a total of 236 MW of spinning reserve provisioned compared to a minimum spinning reserve requirement of 198 MW) and the system frequency reaching a quasi-steady-state value of 49.35 Hz.

It can be seen that subsequent generator trips and runbacks put pressure on the system's PFR reserves in the minutes following the initial trip of NGK – the time during which AEMO is working to dispatch additional generation so that spinning reserves can be restored. By the time WAPL G2 tripped, the amount of PFR used had reached 95% of the amount of spinning reserve that had been provisioned pre-event (before the initial NGK trip), although the amount of PFR provided was more than the minimum required.

Figure 7 Aggregate system primary frequency response



4.4 Kemerton start command issue

Prior to the event, Kemerton power station was withheld from operation to meet the Ready Reserve Standard[26]. Immediately after the initial trip of NGK, the AEMO controller issued a "Start to 75%" command to

[24] Primary frequency response refers to the initial response from generators and loads immediately after a contingency to arrest the frequency deviation and stabilise the frequency. A distinction is made between PFR and spinning reserve, as the latter term is defined in the WEM Rules to include longer-term responses (up to 15 minutes after the event) that are for frequency restoration to 50 Hz, i.e. secondary frequency response.

[25] Note that the amount of PFR delivered is proportional to the frequency deviation. As a result, not all of the provisioned spinning reserve was required to be used after the initial NGK trip.

[26] The Ready Reserve Standard is described in clause 3.18.11A of the WEM Rules, where sufficient generating and/or demand side management capacity is maintained in reserve to be deployed within 15 minutes in the event of a contingency.

Kemerton GT11, but this unit did not respond to the instruction and the controller was forced to issue a "Start to max" command to Kemerton GT12 several minutes later. This unit subsequently started successfully.

It should be noted that despite Kemerton GT11 not starting, it was not material to the eventual outcome, because the unit would not have been synchronised in time to prevent UFLS Stage 1 activation. The Kemerton units take approximately five to six minutes to synchronise to the grid.

After the system had stabilised, the AEMO controller called the operator at Kemerton power station for an explanation. The operator advised that a start command had not been received by Kemerton GT11. Further investigations with Synergy post-event indicated that there was an historical agreement to not commission the "Start to 75%" command although the command still exists in the EMS[27].

4.5 Market impacts

The design of the Balancing Market in the WEM includes the forecasting of Balancing Prices ahead of a Trading Interval, whereas the final Balancing Price is determined ex-post based on the observed system demand[28]. Where a generating unit was dispatched, but its generation was priced above the final Balancing Price, it may be eligible for Constrained On Compensation. Similarly, a generating unit may be eligible for Constrained Off Compensation if it was unable to provide all of its available generation that was priced below the final Balancing Price, due to power system security requirements.

During the 20:00 Trading Interval[29] on Friday, 10 January 2020, the final Balancing Price dropped by 49% compared to the latest forecast (from $78.00 per megawatt hour [MWh] to $38.45/MWh). This was a direct result of the 182 MW decrease in End of Interval Relevant Dispatch Quantity compared to the latest forecast, which was driven by the UFLS action.

AEMO has identified that two Market Participants may receive Constrained On Compensation as a result of this event.

[27] Work is currently underway to remove this command.

[28] As power system operation requires that supply and demand must match, total system demand is determined from measurements of generator outputs, which implicitly include the effect of network losses.

[29] The 20:00 Trading Interval is the half-hour period from 20:00 to 20:30.

5. Remedial actions

This section describes the mitigation measures that have been taken since the event to address the issues that led to UFLS activation.

5.1 NewGen Kwinana

The planned outage at NGK went ahead to allow the lube oil leak to be repaired, and the facility returned to operation on 21 January 2020. (While the facility tripped again on 10 February 2020, this was unrelated to the trip on Friday, 10 January 2020 and did not activate UFLS.)

5.2 Generator Interim Access

To prevent future adverse interactions between GIA facilities and spinning reserve facilities, AEMO and Western Power have jointly developed a solution comprising two elements:

a) As an interim measure, a table of manual constraints that prevents potential network overloads while allowing for the headroom of specific generating units providing spinning reserve.

b) A system monitor function that will avoid constraining GIA generator outputs when the system frequency is out of the normal operating range (49.8-50.2 Hz), requiring a manual reset by AEMO when the system is stable and back to normal.

The system monitor function is consistent with the GIA tool's behaviour under network contingencies, where the output levels of GIA generators are capped at their pre-event outputs.

After the implementation of a) and b) above, the 50% constraint on the Badgingarra Wind Farm was lifted on 7 February 2020. Constraints on Badgingarra continue to be applied according to the existing GIA arrangements.

With the frequency monitor in place, the spinning reserve response of generators will not result in GIA constraints binding; however, manual constraints may still be required under certain conditions to manage the interaction with other Ancillary Services.

Significant ongoing work is also being undertaken by Western Power, with input from AEMO, to improve the GIA mechanism, noting the limitations of this interim tool until security-constrained economic dispatch is introduced as part of the Western Australian Government's Energy Transformation Strategy.

AEMO notes that, in the longer term, reforms to market and power system operation, including the introduction of systems and processes for security-constrained economic dispatch, will supersede the GIA tool.

5.3 Worsley Alumina

In discussions with AEMO, WAPL has provided assurances that it has made temporary changes to the operation of its units, such that condenser/steam pressures should remain within safe operating ranges if a similar event occurred. The proposed temporary operating practices are similar to a previous operating configuration that was in use at the time of a previous UFLS event on 22 September 2016, with no loss of generation at WAPL.

These new operating practices were implemented by WAPL on 22 January 2020, and will continue until otherwise advised in advance by WAPL. The additional spinning reserve that was carried by AEMO for the tripping of the WAPL units was removed on 24 January 2020 (see Dispatch Advisory 206625 in Section 3.6).

In the longer term, WAPL has committed to developing a permanent proposal for mitigating the risk of the WAPL units tripping during an under-frequency event. This proposal will be provided to Western Power for review.

5.4 Alinta Pinjarra

Alinta has advised AEMO that it is working with the GT equipment manufacturer to review the current control system settings and implement appropriate changes to improve GT performance during under-frequency events. This will be investigated further with the manufacturer to see if the control modifications can be made safely without damaging the turbine. AEMO is continuing to engage with Alinta.

5.5 Changes to Market Rules and Market Procedures

Clause 3.8.3(b) of the WEM Rules requires that this report include a description of any changes to the WEM Rules or Market Procedures that AEMO considers are necessary to prevent the future occurrence of similar incidents.

AEMO does not consider that specific changes are required.

However, this report highlights the complexity of operating the power system and the importance of power system Ancillary Services, contingency event frameworks and generators fulfilling their performance standard obligations under the Technical Rules to keep the power system secure.

AEMO is supporting the Western Australian Government's Energy Transformation Strategy and working with industry to examine these interdependent issues to make extensive changes to governing artefacts to facilitate the power system transition from centralised, firm, synchronous generation to decentralised, variable, non-synchronous generation.

Glossary

Terms and abbreviations used in this document are listed below.

Term	Definition
AGC	Automatic generation control
AWST	Australian Western Standard Time
CCGT	Combined cycle gas turbine
DA	Dispatch Advisory
EMS	Energy Management System
GIA	Generator interim access (constrained access scheme for new generator connections)
GT	Gas turbine
Hz	Hertz
KPP	Kwinana Power Partnership
LFAS	Load Following Ancillary Service
MW	Megawatt
MW.s	Megawatt-second
NGK	NewGen Kwinana
PFR	Primary Frequency Response
PV	Photovoltaic
RTFS	Real-time frequency stability tool
SCADA	Supervisory control and data acquisition
SIL	System interruptible load (a load that has been contracted by AEMO to provide Spinning Reserve by disconnecting during system under-frequency events)
ST	Steam turbine
SWIS	South West Interconnected System
UFLS	Under-frequency load shedding
WAPL	South32 Worsley Alumina Pty Ltd
WEM	Wholesale Electricity Market
WF	Wind Farm