AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Phase 1 UFLS Review: New South Wales

December 2021

Analysis of Under Frequency Load Shedding Data

A report for the National Electricity Market

Important notice

PURPOSE

This report presents analysis on the Under Frequency Load Shedding (UFLS) scheme in New South Wales, based on data provided by Network Service Providers (NSPs). Analysis of this data is the first phase in AEMO's review of UFLS adequacy. This report is prepared to share these preliminary findings with NSPs and Jurisdictional System Security Coordinators (JSSCs) to inform collaboration on next steps.

This publication has been prepared by AEMO using information available at March 2021. Information made available after this date may have been included in this publication where practical.

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VERSION CONTROL

Version	Release date	Changes
1	21/12/2021	Delivered to Network Service Providers
1	May 2022	Published on AEMO website

Executive summary

AEMO is currently undertaking a review of the NEM Under Frequency Load Shedding (UFLS) schemes, in accordance with its responsibilities under the National Electricity Rules (NER). This review aims to assess the adequacy of the existing scheme. The review is phased as follows:

- **Phase 1 – Data analysis:** Gather the required data from Network Service Providers (NSPs), and analyse to identify preliminary insights, including possibly commencing investigation on any initial actions that may be warranted.
- **Phase 2 – Frequency studies:** Frequency studies examining the behaviour of the power system in response to non-credible contingencies that trigger the UFLS scheme. This aims to determine whether the existing UFLS scheme is adequate across the NEM.
- **Phase 3 – Possible further work (as required):** Other work may follow depending on findings in Phase 2. This may include UFLS scheme retuning (changes to frequency settings) for some or all regions.

This report presents the findings of the analysis in Phase 1, for the New South Wales region. The report is prepared to share these preliminary findings and inform collaboration on possible next steps. Given the rapid uptake in distributed PV in the NEM, and the likely impact on the effectiveness of under frequency load shedding, AEMO is sharing these findings as early as possible, so that investigation on next steps can proceed in parallel with AEMO's analysis in Phase 2 of the UFLS review.

Key findings

- In 2019-20, minimum net load[1] in the New South Wales UFLS scheme was 3,463 MW, occurring at 4:30am on 12 April 2020.
- With continuing growth in distributed PV, the projected minimum net UFLS load is predicted to occur in the middle of the day from 2021 onwards, and projected to reach 2,711 MW by mid-2022 and 2,387 by mid-2023 based on expected distributed PV growth and underlying load in the 2021 ESOO Net Zero scenario.
- AEMO assessed the total net load in the New South Wales UFLS scheme as a percentage of the total underlying load in New South Wales, for the historical 2019-20.
  - The NER indicate that the amount of UFLS capability should be adequate to arrest the impacts of a range of significant multiple contingency events, affecting up to 60% of the 'total power system load' (NER clause 4.3.1(k)).
  - In a power system with large quantities of DPV, the operational demand (defined as total underlying customer load, net of DPV) in some periods will differ very significantly from the total underlying demand. In some periods, operational demand will soon reach zero and become negative in some NEM regions. While operational demand may reach zero, the largest plausible non-credible contingency in a region may not be zero, meaning that determining UFLS requirements as a proportion of a metric that is zero or negative cannot provide a meaningful measure of power system needs.

Under Frequency Load Shedding (UFLS) involves the automatic disconnection of customer loads during a severe under-frequency event. Frequency relays are installed at load circuits, with varying trip settings, designed to progressively disconnect loads in a controlled manner to arrest the frequency decline.

[1] Net load in the UFLS refers to the aggregate total load measured on UFLS circuits at the location of UFLS relays, which is typically net of distributed generation operating on those circuits.

- For this analysis, AEMO has used total underlying load[2] (calculated as operational demand + DPV generation[3]) as a measure of the actual amount of customer load in the power system at a particular time (regardless of whether it is supplied by scheduled generating units or distributed generation). The net load in the UFLS (being the amount of load available to provide an effective UFLS response to arrest a frequency decline) can then be calculated as a percentage of total underlying customer load, for comparison with the 60% value indicated in the NER.
  - AEMO is in the process of developing an approach for estimating the amount of emergency under-frequency response required to produce acceptable frequency outcomes for plausible non-credible contingency events. This analysis may indicate that the amount of response required may be less than 60% of underlying load in some periods. If so, it may be acceptable for NSPs to target a value lower than 60% in some periods.
- This analysis indicates that net load in the New South Wales UFLS scheme is often below 60% of underlying load during periods with high DPV generation:
  - For the 2019-20, in periods with no DPV generating, net UFLS load remained above 60% of underlying load in New South Wales most of the time.
  - However, in 2019-20, net UFLS load was below 60% of underlying load over 41% of the time overall, and in some periods has been observed as low as 44% of underlying load. In periods with high levels of DPV operating (>1200 MW), net UFLS load was below 60% of underlying load during all time periods.
  - By 2022-23, this percentage is projected to fall below 60% more than 45% of the time, and in some periods could be as low as 29%.
- AEMO investigated whether some UFLS circuits may be demonstrating reverse flows in some periods. Reverse flows on UFLS circuits are undesirable; in the absence of intervention, the normal operation of UFLS relays to trip circuits in reverse flows will act to exacerbate an under-frequency disturbance, rather than helping to correct it. However, the data provided by NSPs was not of sufficient granularity for a thorough assessment of the incidence of reverse flows. This requires further investigation by NSPs.

Next steps

This analysis demonstrates that net load in the New South Wales UFLS scheme is decreasing due to continuing growth in DPV.

Each NSP must ensure that sufficient load is under the control of under-frequency relays or other facilities to minimise or reduce the risk of frequency falling below the extreme tolerance limits[4] in response to simultaneous multiple contingency events (NER clause S5.1.10.1). This analysis indicates that the amount of load under the control of under-frequency relays is now below the levels anticipated in the NER (clause 4.3.1(k)) in periods with high levels of distributed PV operating, and that this is likely to deteriorate further in the coming years. This means that at times the power system will be operating without the intended safety nets, placing customers at risk in future.

AEMO advises that NSPs should immediately seek to identify and implement measures to restore net UFLS load (or equivalent emergency under-frequency response) to as close as possible to the level of

[2] Underlying load means all the electricity used by consumers, which can be sourced from the grid but also, increasingly, from other sources including consumers' rooftop photovoltaic (PV) and battery storage.

[3] For this analysis, DPV generation has been estimated based on AEMO's distributed PV forecasting system, ASEFS2. https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/solar-and-wind-energy-forecasting/australian-solar-energy-forecasting-system

[4] The extreme frequency excursion tolerance limit for system normal in the NEM mainland is 47 – 52Hz. AEMC (1 January 2020) Frequency Operating Standard, https://www.aemc.gov.au/sites/default/files/2020-01/Frequency%20operating%20standard%20-%20effective%201%20January%202020%20-%20TYPO%20corrected%2019DEC2019.PDF

60% of underlying load at all times. Where this is not feasible, AEMO will collaborate with NSPs to develop an approach that identifies a level of emergency under-frequency response that is achievable, while delivering a significant reduction in power system security risks.

AEMO has provided the information in this report to NSPs and JSSCs to facilitate collaboration on next steps, and co-development of potential remediation approaches. AEMO is seeking NSP input and suggestions on potential approaches, and feedback on the benefits, feasibility and any other relevant factors for the following possible next steps:

- **Addressing DPV impacts**, such that sufficient net UFLS load is maintained as DPV levels grow over the coming years. AEMO is seeking advice on the technical and economic feasibility of the following possible remediation approaches, and any others suggested by NSPs:
  - Adding further customer load into the UFLS scheme.
  - Establishing processes to periodically assess the incidence and level of reverse flows occurring at various UFLS circuits. This could possibly include establishing a real-time SCADA feed for total net New South Wales UFLS load, so this can be monitored in real time.
  - Removing circuits from the UFLS scheme if they are heavily affected by DPV and often demonstrating reverse flows, and replacing them with loads at other locations that are less affected by DPV.
  - Implementing dynamic arming (disarming UFLS relays when circuits are in reverse flows) at UFLS circuits where reverse flows are occurring.
  - Investigating the feasibility of more granular load tripping at the individual customer site level, such that distributed generation remains connected while customer load disconnects (possibly utilising smart-meter capability).

AEMO also welcomes advice from NSPs on alternative remediation approaches.

As noted above, Phase 2 of AEMO's assessment of UFLS will involve frequency studies, to determine the effectiveness of the UFLS scheme in managing various types of non-credible contingencies. This will include more detailed review of the frequency settings. Phase 2 will inform the scale and urgency for remediating the issues identified in this Phase 1 preliminary analysis. Further recommendations may follow from this subsequent analysis.

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1. Introduction

Emergency Frequency Control Schemes

Emergency Frequency Control Schemes (EFCS) are activated in the event of a large disturbance that causes an extreme frequency change which is beyond the containment capability of frequency control ancillary services (FCAS). EFCS are designed as a 'last line of defence' to manage multiple contingency events, and involve the automatic disconnection of generation or load in an attempt to rapidly rebalance the system.

Under Frequency Load Shedding (UFLS) is one type of EFCS that involves the automatic disconnection of customer loads during a severe under-frequency event. Frequency relays are installed at load circuits, with varying trip settings, designed to progressively disconnect loads in a controlled manner to arrest the frequency decline. Once the frequency disturbance has been arrested and the imbalance corrected, and when sufficient generation is available, loads can be reconnected.

AEMO's responsibilities

Under the National Electricity Rules (NER), AEMO has a number of power system security responsibilities that involve the coordination and review of EFCS, and determination of EFCS settings, with the objective of ensuring sufficient reserves to arrest the impacts of multiple contingency events, affecting up to 60% of the total power system load. As with all power system security responsibilities, AEMO can only achieve them with the assistance, cooperation and action of registered participants, in particular power system asset owners, who have corresponding NER obligations.

The key NER clauses outlining AEMO's responsibilities with regards to UFLS are outlined in Table 1.

Table 1 A selection of relevant AEMO responsibilities relating to UFLS

NER clause	Requirement
4.3.1(k)	Assess the availability and adequacy, including the dynamic response, of contingency capacity reserves and reactive power reserves in accordance with the power system security standards and to ensure that appropriate levels of contingency capacity reserves and reactive power reserves are available: (1) to ensure the power system is, and is maintained, in a satisfactory operating state; and (2) to arrest the impacts of a range of significant multiple contingency events (affecting up to 60% of the total power system load) or protected events to allow a prompt restoration or recovery of power system security, taking into account under-frequency initiated load shedding capability provided under connection agreements, by emergency frequency control schemes or otherwise.
4.3.1(n)	Refer to Registered Participants, as AEMO deems appropriate, information of which AEMO becomes aware in relation to significant risks to the power system where actions to achieve a resolution of those risks are outside the responsibility or control of AEMO.
4.3.1(pa)	Coordinate the provision of emergency frequency control schemes by Network Service Providers and determine the settings and intended sequence of response by those schemes.
4.3.2(h)	Develop, update and maintain schedules for each participating jurisdiction specifying, for each emergency frequency control scheme affecting each region in that participating jurisdiction, settings for operation of the scheme including the matters specified in paragraphs (m) to (p) ([EFCS settings schedule]).
4.3.2(ha)	In developing and updating EFCS settings schedules, in relation to an under-frequency scheme, consult with affected Network Service Providers and the relevant Jurisdictional System Security Coordinators.
5.20A.1(c)(4)	For its power system frequency risk review, assess the performance of existing EFCSs and identify any need to modify.

The purpose of this document

To deliver the responsibilities noted above, AEMO undertakes a periodic assessment of the availability and adequacy of EFCS in the NEM, including UFLS. UFLS review is underway at present, aiming to assess the adequacy of the existing scheme. The review is phased as follows:

- **Phase 1 – Data analysis:** Gather the required data from Network Service Providers (NSPs), and examine this data to identify any preliminary insights, including possibly commencing investigation on any initial actions that may be warranted.
- **Phase 2 – Frequency studies:** Frequency studies examining the behaviour of the power system in response to non-credible contingencies that trigger the UFLS scheme. This aims to determine whether the existing UFLS scheme is adequate across the NEM.
- **Phase 3 – Possible further work (as required):** Other work may follow depending on findings in Phase 3. This may include UFLS scheme retuning (changes to frequency settings) for some or all regions.

This report presents the findings of the analysis in Phase 1 for New South Wales. The report is prepared to share these preliminary findings with Network Service Providers (NSPs) and Jurisdictional System Security Coordinators (JSSCs) to inform collaboration on possible next steps.

In the next phase of this review, AEMO will conduct further studies to explore how the UFLS performs in various under-frequency disturbances, to determine whether further changes may be warranted to optimise performance of the scheme. In parallel, AEMO is seeking advice from NSPs on technical and economic feasibility of various remediation options. Through this process, AEMO will consult and collaborate with NSPs and JSSCs in the development of any recommendations.

Distributed PV impacts on UFLS

The impact of distributed PV (DPV) on the UFLS is a particular focus of this review. AEMO's analysis of UFLS efficacy in South Australia has found that the amount of net load available for response in the South Australian UFLS scheme is approaching zero in some periods, which reduces the ability of the scheme to arrest an under-frequency disturbance[5]. Furthermore, the operation of UFLS relays on circuits that are operating in reverse flows can act to exacerbate an under-frequency disturbance, rather than helping to correct it. Based on these initial findings in South Australia, AEMO is now exploring the impacts of DPV in other regions to determine where and when remediation may be required.

Load definitions

The following definitions have been applied throughout this report:

Table 2 Summary of definitions applied in this report

Term	Definition	How it has been calculated in this report
Distributed PV generation	Distributed PV includes rooftop systems and other smaller non-scheduled PV capacity, connected to the distribution network, and typically with a capacity <5MW. It excludes scheduled and semi-scheduled generation.	Total DPV generation in the region in each half hour interval has been estimated based on AEMO's distributed PV forecasting system, ASEFS2[6].

[5] AEMO (July 2020) 2020 Power System Frequency Risk Review – Stage 1, Appendix A1, https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2020/psfrr/stage-1/psfrr-stage-1-after-consultation.pdf?la=en

[6] https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/solar-and-wind-energy-forecasting/australian-solar-energy-forecasting-system

Term	Definition	How it has been calculated in this report
Operational demand	Operational demand in a region is demand that is met by local scheduled generating units, semi-scheduled generating units, and non-scheduled intermittent generating units of aggregate capacity ≥ 30 MW, and by generation imports to the region. It excludes the demand met by non-scheduled non-intermittent generating units, non-scheduled intermittent generating units of aggregate capacity <30 MW, exempt generation (e.g. rooftop solar, gas tri-generation, very small wind farms, etc), and demand of local scheduled loads.	The total operational demand in the region was drawn from AEMO's databases. The relevant PI tag is calculated by summing the generation at all the scheduled, semi-scheduled and non-scheduled ≥30MW generator terminals in the region, and the flows across inter-regional interconnectors.
Underlying load	Underlying load means all the electricity used by consumers, which can be sourced from the grid but also, increasingly, from other sources including consumers' rooftop photovoltaic (PV) and battery storage.	Total underlying load in the region in each half-hour interval was estimated as: Underlying load = Operational demand + Distributed PV generation
Net UFLS load	Net load in the UFLS refers to the aggregate total load measured on UFLS circuits at the location of UFLS relays, which is typically net of distributed generation operating on those circuits.	The measured load (net of distributed PV) on each UFLS circuit was provided by NSPs. These were summed to calculate the total net UFLS load in each half hour.

NSP and JSSC Responsibilities

The NER include a range of obligations and standards to be met by NSPs and other registered participants, and supporting actions by JSSCs, to support the achievement of the power system security responsibilities relating to UFLS. For reference, the key participant and JSSC responsibilities supporting UFLS adequacy are set out in the following tables - NSPs in Table 3, JSSCs in Table 4, and Market Customers in Table 5.

Table 3 Key NSP responsibilities relating to UFLS

NER clause	NSP responsibility
4.3.4(a)	Use reasonable endeavours to exercise its rights and obligations in relation to its networks so as to co-operate with and assist AEMO in the proper discharge of the AEMO power system security responsibilities.
4.3.4(b)	Use reasonable endeavours to ensure that interruptible loads are provided as specified in clause 4.3.5 and clause S5.1.10 of schedule 5.1 (including without limitation, through the inclusion of appropriate provisions in connection agreements).
4.3.4(b1)	In accordance with clause S5.1.10.1a of schedule 5.1, cooperate with AEMO in relation to, design, procure, commission, maintain, monitor, test, modify and report to AEMO in respect of, each emergency frequency control scheme which is applicable in respect of the Network Service Provider's transmission or distribution system.
S5.1.10.1(a)	In consultation with AEMO, ensure that sufficient load is under the control of under-frequency relays or other facilities where required to minimise or reduce the risk that in the event of the sudden, unplanned simultaneous occurrence of multiple contingency events, the power system frequency moves outside the extreme frequency excursion tolerance limits.
S5.1.10.1a(a)	Cooperate with AEMO in the conduct of power system frequency risk reviews and provide to AEMO all information and assistance reasonably requested by AEMO in connection with power system frequency risk reviews; and provide to AEMO all information and assistance reasonably requested by AEMO for the development and review of EFCS settings schedules.
S5.1.10.2	(for Distribution Network Service Providers): (a) provide, install, operate and maintain facilities for load shedding in respect of any connection point at which the maximum load exceeds 10MW in accordance with clause 4.3.5; (c) apply frequency settings to relays or other facilities as determined by AEMO in consultation with the Network Service Provider;

NER clause	NSP responsibility
S5.1.8	In planning a network, consider non-credible contingency events such as busbar faults which result in tripping of several circuits, uncleared faults, double circuit faults and multiple contingencies which could potentially endanger the stability of the power system. In those cases where the consequences to any network or to any Registered Participant of such events are likely to be severe disruption a Network Service Provider and/or a Registered Participant must in consultation with AEMO, install, maintain and upgrade emergency controls within the Network Service Provider's or Registered Participant's system or in both, as necessary, to minimise disruption to any transmission or distribution network and to significantly reduce the probability of cascading failure.

Table 4 Key JSSC responsibilities relating to UFLS

NER clause	JSSC responsibility
4.3.2(f)	Provide AEMO with (1) a schedule of sensitive loads in its jurisdiction, specifying: (i) the priority, in terms of security of supply, that each load specified in the schedule has over the other loads specified in the schedule; and (ii) the loads (if any) for which the approval of the Jurisdictional System Security Coordinator must be obtained by AEMO under clause 4.3.2(l); and (2) a schedule setting out the order in which loads in the participating jurisdiction, other than sensitive loads, may be shed by AEMO for the purposes of undertaking any load shedding under rule 4.8.

Table 5 Key Market Customer responsibilities relating to UFLS

NER clause	Market Customer responsibility
4.3.5	(a) For Market Customers having expected peak demands at connection points in excess of 10 MW, provide automatic interruptible load of the type described in clause S5.1.10 of schedule 5.1. The level of this automatic interruptible load must be a minimum of 60% of their expected demand, or such other minimum interruptible load level as may be periodically determined by the Reliability Panel, to be progressively automatically disconnected following the occurrence of a power system under-frequency condition described in the power system security standards. (b) Provide their interruptible load in manageable blocks spread over a number of steps within under-frequency bands from 49.0 Hz down to 47.0 Hz as nominated by AEMO.
S5.3.10	Network Users who are Market Customers and who have expected peak demands in excess of 10MW must provide automatic interruptible load in accordance with clause 4.3.5 of the Rules. Load shedding procedures may be applied by AEMO, or EFCS settings schedules may be determined, in accordance with the provisions of clause 4.3.2 of the Rules for the shedding of all loads including sensitive loads.

2. Approach

AEMO has worked with the Network Service Providers in New South Wales (Ausgrid, Endeavour Energy, Essential Energy, Evoenergy and Transgrid) during 2020 and 2021 to construct the necessary datasets for this analysis, as outlined in the sections below.

Half-hourly load data

In New South Wales, the UFLS relays are located at variety of voltage levels ranging from the 66 kV transmission level down to 11 kV distribution level. AEMO requested the half hourly load data from the relevant NSPs for financial years 2018-19 and 2019-20. The data provided by NSPs was either provided at the feeder level, or aggregated up to the relevant UFLS band. All NSPs also provided a setting schedule of time delay and frequency settings for the UFLS relays. Data provided at the feeder level was aggregated by AEMO to the relevant UFLS band.

The feeder level load measurements are net values inclusive of embedded generation; i.e. any embedded generation operating behind the measurement point will be reflected in the measured values provided to AEMO, and was not metered or netted off separately.

This dataset captures daily and seasonal net load variations at each location.

Ausgrid advised that the half hourly load data was sourced from historical SCADA data at each UFLS control point. The load data was based on magnitude of RMS current and was non-directional. Active power was estimated based on assumed voltage and power factor values. Similarly, Evoenergy provided historical RMS current values for each UFLS feeder which were converted to MW using the assumed voltage and power factor values provided by Evoenergy. Endeavour Energy indicated that the data supplied is a combination of historical directional MW measurements and converted RMS current for each UFLS feeder.

Transgrid provided directional MW data sourced from Transmission Use Of System (TUOS) reports. Where the TUOS metering point was higher than the UFLS relay level, load was distributed proportionally based on historical season averages with embedded generation accounted for. Essential Energy provided the load data in MW aggregated to the UFLS band only.

Large industrial customers

There are a number of large industrial customers included in the New South Wales UFLS scheme. The half hourly load for a small number of these loads was sourced from AEMO's SCADA systems (where the necessary load data was not provided by NSPs).

Installed capacity of DPV

The installed capacity of DPV on each UFLS band was estimated using the supplied NSP installed capacity data, and compared with that estimated based on the Clean Energy Regulator dataset on installed capacity of DPV by postcode in NSW (including all distributed PV < 30MW). A significant difference was found between the aggregate NSP provided installed capacity and that based on the CER dataset. To overcome this, the distribution of installed capacity across feeders was calculated using the supplied NSP data and scaled up to the total installed capacity from the CER dataset (since the CER dataset was considered likely to be more complete). Where NSP installed DPV capacity data was unavailable, the installed capacity was assumed to be proportional to the load on those feeders.

For this assessment, the half-hourly generation of DPV associated with each UFLS band was estimated for the historical 2018-19 to 2019-20 period based on the estimated generation of DPV across New South Wales in the relevant time period (based on AEMO's DPV forecasting system, ASEFS2), scaled according to the proportion of regional DPV installed on each UFLS band.

Future projections

This assessment includes some simple forward projections of UFLS load from 2020-21 to 2022-23, assuming continued growth in DPV installations (actuals data for the 2020-21 year was not available at the time of completing this analysis). To calculate these forward projections, future DPV installation growth rates were taken from the Net Zero scenario in AEMO's 2021 Electricity Statement of Opportunities (ESOO). This scenario was selected due to alignment with recently observed DPV installation rates, and was therefore determined to be most relevant for this near-term assessment. The installed capacity of DPV on each sub-transmission loop was scaled up in each year, based on the regional growth rate.

The underlying load for the 2019-20 in each half hour was estimated as:

Underlying load 2020 = Net load 2020 + PV generation 2020

Where underlying load refers to all the electricity used by consumers, which can be sourced from the grid but also, increasingly, from other sources including consumers' rooftop photovoltaic (PV) and battery storage. Net load refers to the underlying load net of distributed PV generation.

The half-hourly underlying load in future years was also scaled in line with the 2021 ESOO projections for the Net Zero scenario, via a growth factor applied to the 2019-20 underlying load. DPV generation was assumed to have the same half-hourly capacity factor as the reference year, with DPV generation scaled up based on the larger installed capacity. The net load at each UFLS circuit was then calculated as:

*Net load 2021 = (Underlying load 2020 * Growth Factor 2021) - PV generation 2021*

This provides an approximate indication of how UFLS load may evolve over the coming years, as DPV levels continue to grow.

3. Findings

3.1 Net load in UFLS

Figure 1 shows a duration curve of the total net (measured) load in the New South Wales UFLS scheme in financial years 2018-19 and 2019-20. Indicative future projections for 2020-21, 2021-22 and 2022-23 are also shown (actuals data was not available for the 2020-21 year at the time of completing this analysis). In historical years, total New South Wales UFLS load has reached a maximum of 8,816 MW and a minimum of 3,377 MW, and most of the time is within the range 4,000 – 7,000 MW.

Figure 1 UFLS load duration curves in historical and projected future years

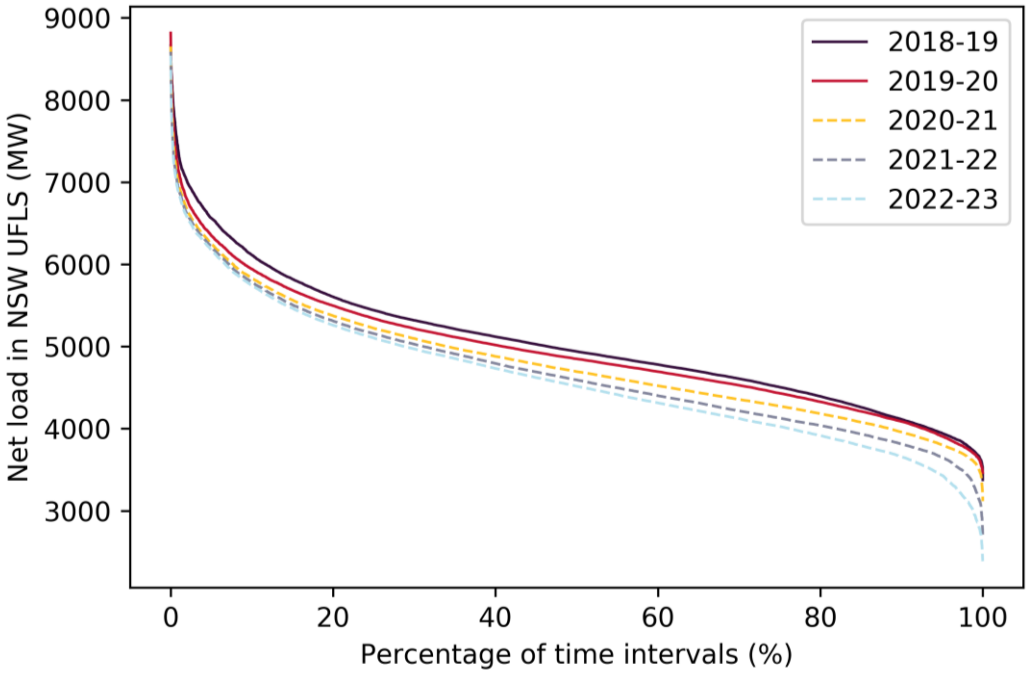


Figure 2 shows the minimum net UFLS load measured in the New South Wales UFLS scheme over the past several years in daytime and night time periods. Observations include:

- To date, minimum net UFLS load has occurred at night in New South Wales. The historical minimum net UFLS load recorded in New South Wales was 3,377 MW in 2018-19 (occurring at 3am, 7 April in 2019) and 3,463 MW in 2019-20 (occurring at 4:30am, 12 April in 2020).
- Due to continuing growth in distributed PV, the daytime minimum UFLS load has been declining. The historical daytime minimum net UFLS load in New South Wales was recorded at 3,665 MW in 2018-19 (occurring at 2pm, 31 March 2019) and 3,493 MW in 2019-20 (occurring at 10:30am, 12 April 2020).

Future projections anticipate a shift in New South Wales from night time minimums to daytime minimums for the first time. The projected minimum net UFLS load is predicted to occur in the middle of the day from 2021 and reach a minimum of 3,117 MW by mid-2021, 2,711 MW by mid-2022 and 2,387 by mid-2023 based on expected distributed PV growth and underlying load in the 2021 ESOO Net Zero scenario. Night time minimums are expected to remain reasonably constant over the same time period.

Figure 2 Minimum net UFLS load in historical and future years

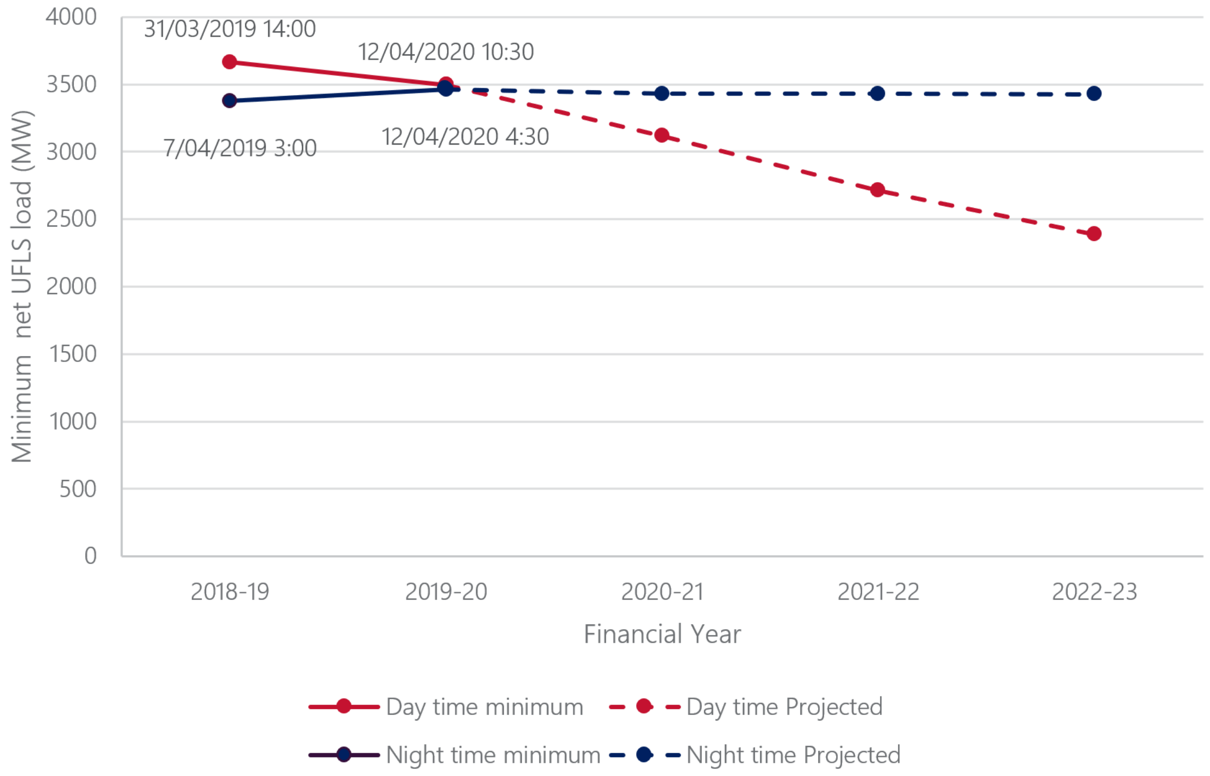
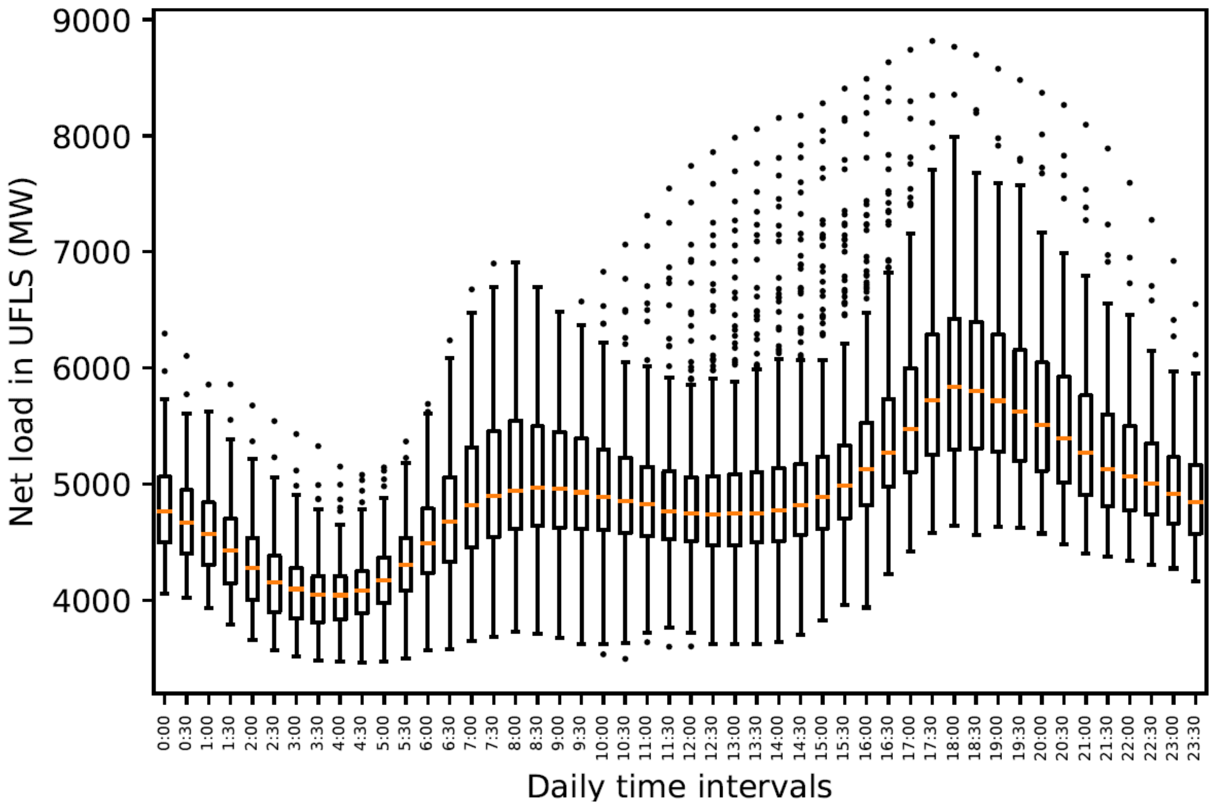


Figure 3 shows the distribution of net UFLS load by time of day, for the 2019-20 historical year. The orange bars indicate the median load level measured at each time of day. The lowest median net UFLS load occurs during night time periods (2.30am-5am). The outer bars indicate the maximum and minimum load levels (excluding outliers) measured at each time of day. The absolute minimum net UFLS load levels were also measured during the early morning (3.30am-5am) in 2019-20, although similarly low load periods were observed in the middle of the day (10am – 2pm).

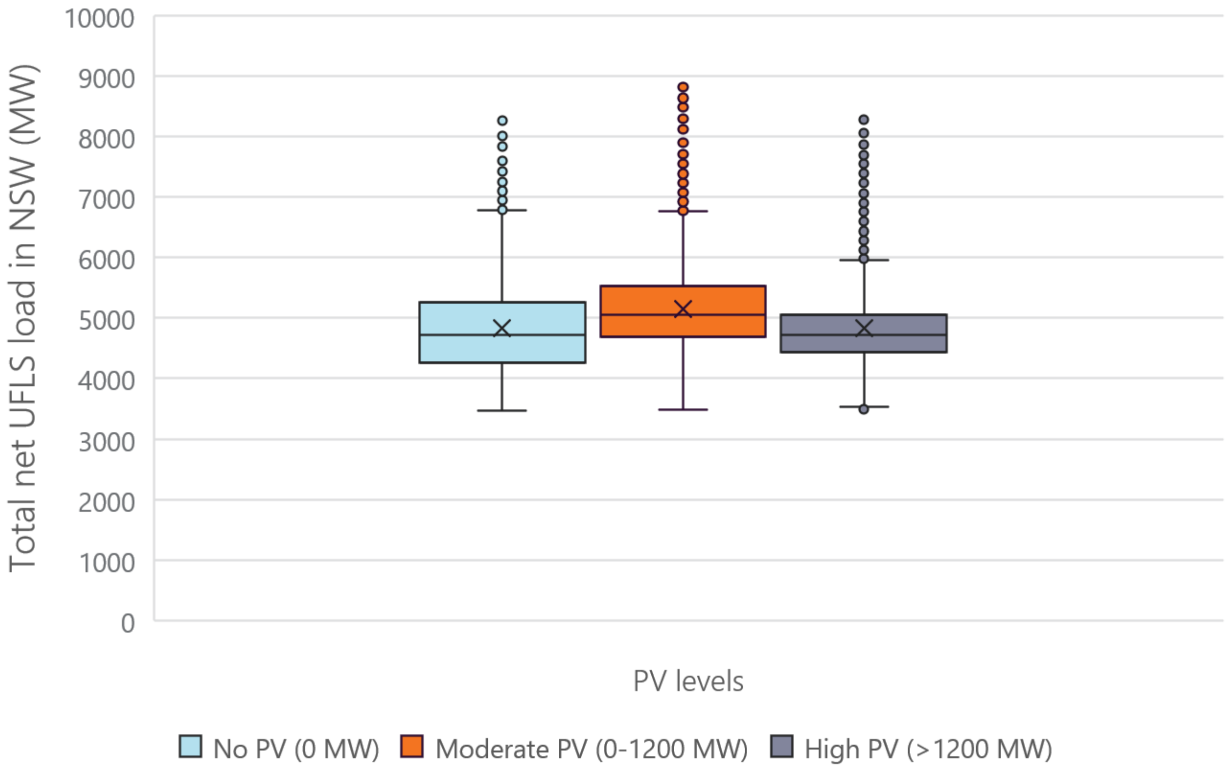
Figure 3 Distribution of net UFLS load in 2019-20



Orange bar: median. Top bar: max load, excluding outliers. Bottom bar, min load, excluding outliers.
Upper Quartile box edge: 75% data is lower than this level. Lower Quartile box edge, 25% data is lower than this level.

Figure 4 shows a box and whisker plot of the total net load in the New South Wales UFLS, divided into periods with no DPV operating, periods with moderate DPV operating (total NSW DPV generation in the range 0 MW to 1,200 MW), and periods with high levels of DPV operating (total NSW DPV generation exceeding 1,200 MW). Periods with high levels of DPV operating tend to show lower net UFLS load levels, although there is a wide range recorded in all types of periods.

Figure 4 Total net UFLS load in 2019-20 under three DPV scenarios



3.2 Net load in UFLS as a percentage of underlying load

The NER indicate that the amount of load in the UFLS should be adequate to arrest the impacts of a range of significant multiple contingency events, affecting up to 60% of the 'total power system load' (NER clause 4.3.1(k)).

Calculating 60% of total power system load

When these requirements were devised, this was a relatively straightforward equation, as it could be assumed that load on the power system at any time would largely equate to actual electricity demand by end use facilities. Therefore, a static UFLS scheme incorporating 60% of small customer loads, or 60% of expected maximum load at large sites, could generally ensure a corresponding quantity of net load could be disconnected to respond effectively to a large under-frequency event.

In a market with large quantities of DPV, which was not contemplated by the UFLS provisions in the NER, the operational demand (defined as total underlying customer load, net of DPV) in some periods will differ very significantly from the total underlying demand. The delta will vary by different amounts every day and in certain periods of the day. In some periods, operational demand will soon reach zero and become negative in South Australia, and in time this may also occur in other NEM regions. Determining UFLS requirements as a proportion of a potential zero or negative operational demand cannot provide a meaningful measure of power system needs.

For this analysis, AEMO has used total underlying load (calculated as operational demand + DPV generation) as a measure of the actual amount of customer load in the power system at a particular time. This provides an absolute measure of the actual customer load, regardless of whether it is supplied by scheduled generating units, or distributed generation. This report provides a comparison of the net load in the UFLS (being the amount of load available to provide an effective UFLS response to arrest a frequency decline), as a percentage of total underlying customer load. This can then be compared with the 60% value indicated in the NER to provide an approximate measure of the adequacy of emergency under-frequency response.

Defining the adequate amount of emergency under frequency response

60% of total underlying load in the region is used in this report as an indicative measure of the amount of total emergency under-frequency response that is adequate.

Emergency under frequency response could be delivered by traditional UFLS, or by equivalent responses such as fast frequency response (FFR) from batteries or curtailed solar farms (for example). Over time, as larger quantities of distributed batteries are installed, they will deliver an increasing amount of under-frequency droop response in line with requirements in AS/NZS4777.2:2020 (mandatory from 18 December 2021). To the extent that the dispatch levels and state of charge of these distributed batteries can be predicted and relied on, this will reduce the amount of emergency under-frequency response required from other sources.

The 60% target provides an indication of the operational envelope where AEMO has reasonable confidence that the response will be adequate to arrest the impacts of a range of significant multiple contingency events (affecting up to 60% of the total power system load). Given the low estimate of load relief in the NEM[7], it is anticipated that arresting a multiple contingency event affecting up to 60% of the power system will require a comparable capacity (MW) of emergency under-frequency response (delivered by UFLS, FFR, or other sources). In Phase 2 of the UFLS review, AEMO will be conducting frequency studies investigating the performance of the UFLS in the context of the evolving power system, modelling various selected non-credible contingency events. This will provide further insight on the adequacy of the UFLS response in various periods, and the appropriateness of the 60% of underlying load target.

It may be possible that a smaller quantity of emergency under-frequency response is adequate to sufficiently reduce risk in some periods. For example, in periods with high levels of distributed PV operating, there may be fewer centralised generators operating, and therefore less likelihood of a large multiple generator contingency event. However, it is noted that UFLS is intended as a general safety net that caters for any multiple contingency event, which by nature cannot be specified precisely. Distributed PV itself can also contribute to contingency events, with some disturbances showing up to 40% of the distributed PV in a region disconnecting in response to voltage disturbances, phase angle jumps, maloperation of frequency protection and other phenomena[8]. There are a very large number of possible multiple contingency event sequences that could occur, many of which have never been observed before given the rapid transition of the power system, so it is difficult to determine a manageable set of specific contingency events to analyse. It is also extremely difficult to accurately model the behaviour of the power system and the operation of UFLS schemes under these circumstances, given the intermingling of distributed PV and UFLS loads at the distribution level, which is not typically represented in AEMO's power system models. It is a significant process (and may not be ultimately possible) to confirm with high confidence that there are definitely no non-credible events that could occur beyond a certain contingency size in certain periods, and therefore to confirm that a smaller quantity of emergency under-frequency response is adequate.

Regardless of the precise target, this report indicates that UFLS levels are trending towards very low levels that are clearly far from adequate. Given the short timeframes involved, AEMO recommends that NSPs pursue remediation options immediately, targeting the 60% of underlying load level where possible. This is the level at which AEMO has reasonable confidence the response is adequate. Where it is identified that achieving the 60% target is not economically or technically feasible, AEMO proposes to work with NSPs to investigate whether a smaller amount of response (less than 60% of underlying load) could be sufficient in some periods. This investigation can be targeted towards the specific options available, and focused on demonstrating adequacy in the specific periods where shortfalls may remain.

Assessment of adequacy of response

Bringing together the above factors, AEMO has applied the following measure to assess the adequacy of the emergency under-frequency response:

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[7] AEMO, Load Relief, https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/ancillary-services/load-relief

[8] AEMO (May 2021) Behaviour of distributed resources during power system disturbances, https://aemo.com.au/-/media/files/initiatives/der/2021/capstone-report.pdf?la=en&hash=BF184AC51804652E268B3117EC12327A

$$\frac{Net\ UFLS\ load\ in\ the\ region + FFR}{Total\ underlying\ load\ in\ the\ region} \geq 60\%$$

Where:

- Net UFLS load in the region provides the total net load available for shedding on UFLS (net of distributed PV generation), and therefore gives an indication of the amount of response from the UFLS scheme that will contribute to arresting a frequency decline.
- FFR is the capacity of response (MW) delivered by Fast Frequency Response from batteries, curtailed solar farms, or other sources. For simplicity in this report, the level of FFR that can be guaranteed has been assumed to be zero, but this will change over time as levels of distributed batteries grow, or if arrangements are implemented to procure this response from certain customers.
- Total underlying load in the region is the total customer load (regardless of whether it is supplied by centralised or distributed generation), and therefore provides a measure of the total size of the power system that is independent of the quantity of distributed PV operating.

AEMO has applied this measure to give an approximate indication of the adequacy of emergency under-frequency response, and provide a measure of how it is changing over time. Values that are slightly below this 60% measure are unlikely to present a significant risk, whereas values far below the 60% level represent a significant deterioration in emergency under-frequency response capability, far below levels anticipated in the NER, which needs to be addressed as a priority.

3.2.1 Analysis for New South Wales

Figure 5 shows the total net UFLS load as a percentage of the total underlying load in New South Wales, for the 2019-20 historical year. In periods with no DPV generating, this percentage remains above 60% most of the time, with only a few outliers below the 60% level. However, in periods with high levels of DPV operating, this percentage falls below 52% more than half the time, and in some periods is as low as 44%.

This reduction in load available during these periods suggests that DPV is likely starting to impact the effectiveness of UFLS in New South Wales.

Figure 5 Total net UFLS load over total underlying load in 2019-20 (Actuals)

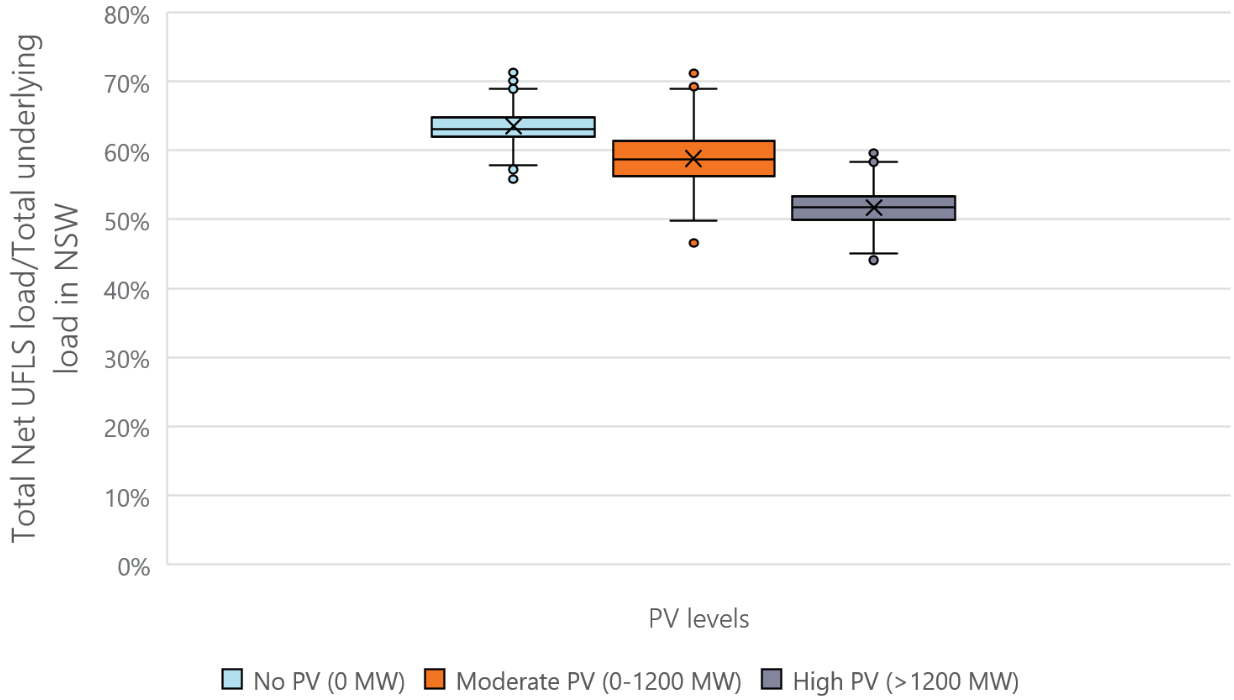


Figure 6 shows the projection of the total net UFLS load as a percentage of total underlying load, projecting forward to 2022-23. By 2022-23, it is projected that around half of all high DPV periods will have net UFLS load less than 42% of total underlying load in New South Wales. It is projected that net UFLS load will be less than the 60% threshold in almost three quarters of moderate DPV periods in 2022-23. In the lowest period, net UFLS load in New South Wales is projected to fall to 29% of total underlying load in New South Wales.

Figure 6 Total net UFLS load over total underlying load in 2022-23 (Projected)

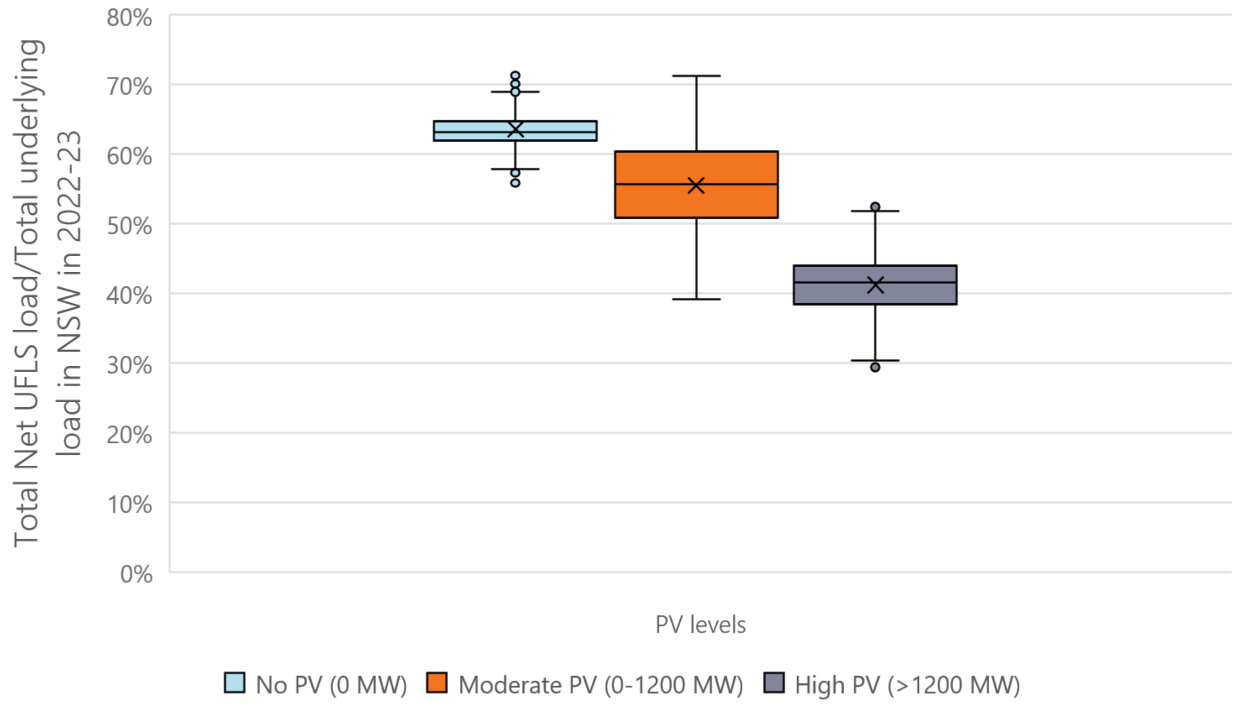


Table 6 provides a summary of historical and forward projection data, showing the minimum net UFLS load as a percentage of the total underlying load in New South Wales. This minimum percentage has declined from 46% in 2018-19 to 44% in 2019-20, and is projected to decline further to 29% by 2022-23.

Table 6 Net UFLS load summary

	Historical		Projections – Constant annual DPV growth		
	2018-19	**2019-20**	**2020-21**	**2021-22**	**2022-23**
Total DPV installed in NSW (MW)	2345	3163	3980	4797	5614
Minimum operational load in NSW (MW)	5613	5541	4952	4317	3811
Minimum net UFLS load in NSW (MW)	3377	3463	3117	2711	2387
Minimum net UFLS load (Minimum % of total underlying load)	46%	44%	40%	34%	29%

3.2.2 Analysis by individual Network Service Provider

There are a number of network service providers (NSPs) in New South Wales and the Australian Capital Territory: TransGrid, AusGrid, Endeavour Energy, Essential Energy and EvoEnergy.

This analysis has been conducted for the New South Wales and Australian Capital Territory (ACT) region as a whole, aggregating the net UFLS load available across all NSPs in this region. This is a technically sound approach to assessing UFLS adequacy, since emergency under-frequency response is required in aggregate across a region to manage severe non-credible contingencies. If a sub-region can separate from the rest of the grid, then it may be necessary to maintain sufficient emergency under-frequency response in that sub-region. This is not typically the case for the grid in New South Wales and the ACT.

Some NSPs may be serving a large proportion of industrial customers, and will therefore be less affected by growth in distributed PV. Other NSPs may be serving a large proportion of residential customers, and will therefore be more severely affected by growth in distributed PV. This means that some NSPs may have lower cost remediation options available than other NSPs. It is likely to minimize overall costs and therefore be in the interests of customers to aim for a combined target of adequate emergency under-frequency response across the whole region, rather than requiring each NSP to meet a 60% target individually.

Furthermore, given the rapid trend towards reducing net UFLS load across the entire NEM, it is likely that all NSPs will need to implement all technically and economically feasible actions available. This means that the individual percentages met by each NSP may be relatively less important – the more important task is to identify and implement all feasible options to slow the decline, and restore this capability across the region as far as possible.

However, on request from the NSPs, AEMO explored a breakdown of the dataset by NSP. This was only possible for Ausgrid, who provided data of sufficient quality for this assessment to be conducted. For the datasets provided by TransGrid, Endeavour Energy, Essential Energy and Evoenergy, the datasets were not sufficiently complete for this analysis to be conducted accurately. AEMO can work with these NSPs to calculate these percentages if desired.

Ausgrid

The analysis was able to be completed for Ausgrid with the historical percentages presented in Figure 7 for 2019-20. Total net UFLS load in Ausgrid's network remains above 60% of the total underlying load served by Ausgrid for periods with no DPV generating, and in the majority of periods with moderate levels of DPV generating (0 – 1,200 MW). During periods of high DPV generation (>1,200 MW), the percentage drops below 53% in in the majority of periods, and reached a minimum of 47%.

Figure 7 Ausgrid Total net UFLS load over total underlying load in 2019-20 (Actuals)

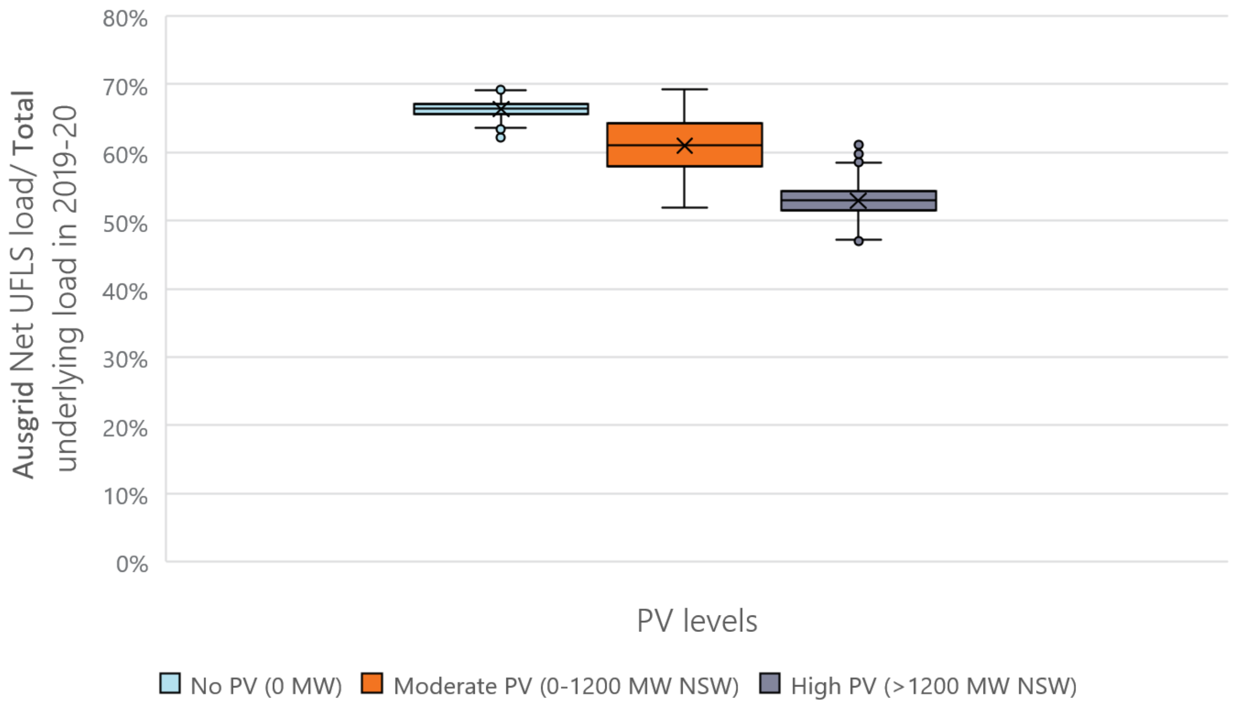
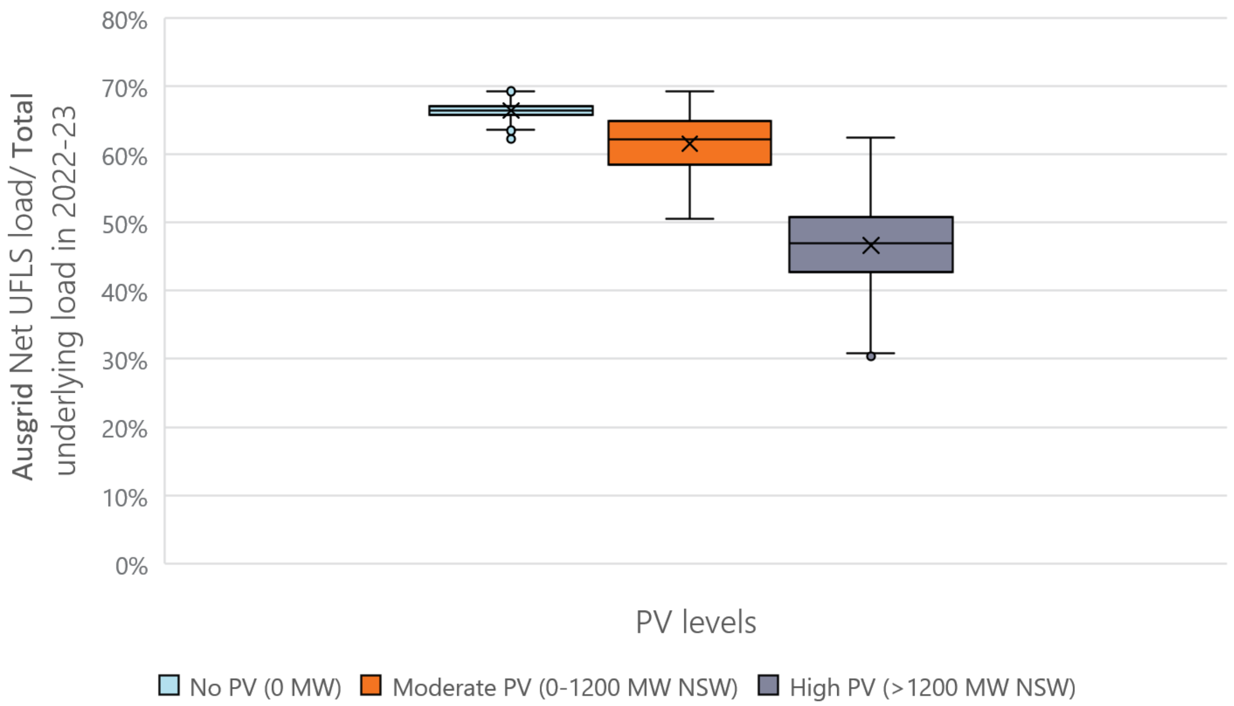


Figure 8 shows Ausgrid's projected total net UFLS load as a percentage of total underlying load served by Ausgrid in 2022-23. The projection indicates that during high DPV periods, UFLS net load will be less than 47% of total underlying load during most periods, falling as low as 30% in the lowest cases.

Figure 8 Ausgrid Total net UFLS load over total underlying load in 2022-23 (Projected)



AEMO can work with TransGrid, Endeavour Energy, Essential Energy and Evoenergy to conduct analysis of this type if more complete datasets are provided by those NSPs.

3.3 Load distribution on frequency stages

Figure 9 shows the cumulative net load in New South Wales UFLS, spread across the various frequency trip settings. The frequency (Hz) for each UFLS stage are shown along the horizontal axis. As frequency falls, progressively more load will trip to arrest the frequency decline. For simplification, frequency settings with a time delay ≤ 1 second have been aggregated as the New South Wales UFLS scheme consists of over 120 unique frequency and time delay combinations. On the right of the chart, several UFLS stages with longer time delays are shown. These stages assist with frequency recovery if frequency remains low following an event for an extended interval.

Figure 9 shows the cumulative UFLS load profile for a number of time periods:

- The minimum, average, and maximum net UFLS load measured in daytime periods (orange)
- The minimum, average, and maximum net UFLS load measured in night time periods (blue)

For all time periods, the cumulative net load profile is relatively consistent across the frequency stages.

Figure 9 Cumulative net load in UFLS (2019-20)

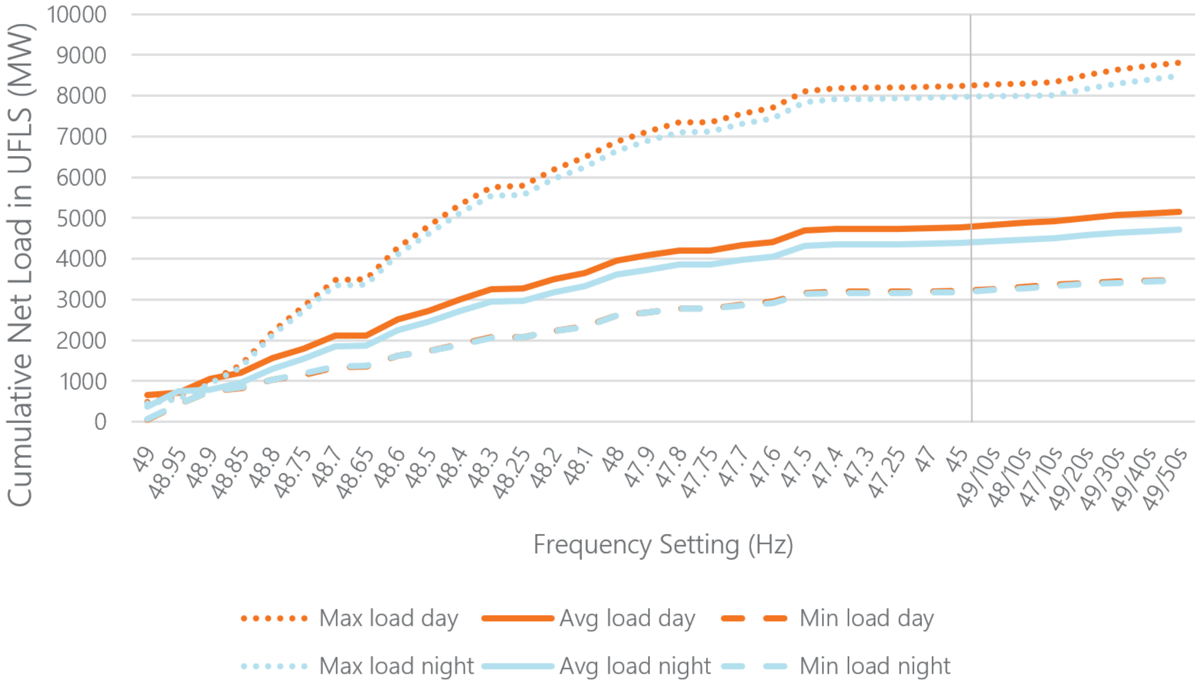


Figure 10 shows the cumulative net load as a percentage of the total underlying load in New South Wales UFLS across the frequency trip settings. The time periods are consistent with those used in Figure 9. The percentage profiles remain reasonably consistent throughout the frequency range, except for the period of minimum daytime UFLS load. The cumulative percentage falls just short of 50% with all frequency bands accounted for in this period. This period also experiences the highest level of distributed PV generation, in excess of 1,650 MW, more than double the amount of distributed PV generation in the average daytime period (812 MW).

Figure 10 Cumulative net load in UFLS / total underlying load in NSW (2019-20)

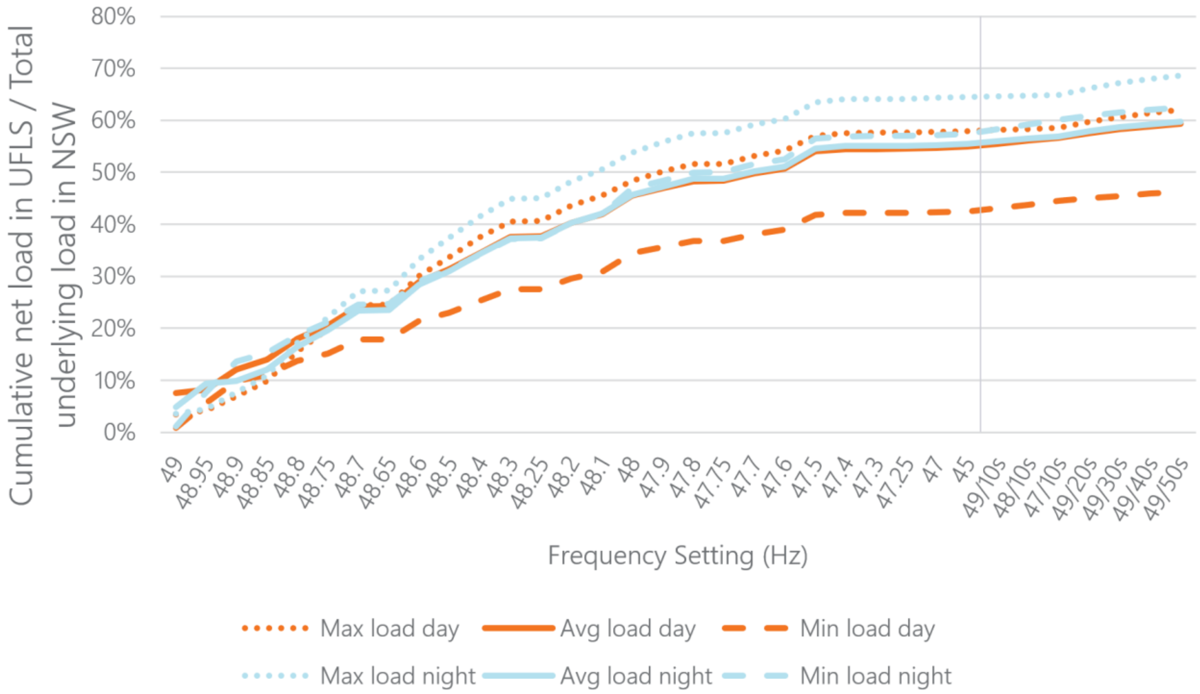


Figure 11 shows the cumulative net UFLS load profile for the minimum daytime UFLS load periods in 2018-19 and 2019-20 and projected forward to 2022-23. The profiles remain consistent down to 48.9 Hz as the early frequency bands above that level are dominated by a number of industrial loads. As the frequency reduces, the shape of the profile remains reasonably consistent across years with a reduction in cumulative MW each financial year.

Figure 11 Cumulative net load in UFLS for minimum daytime load time intervals

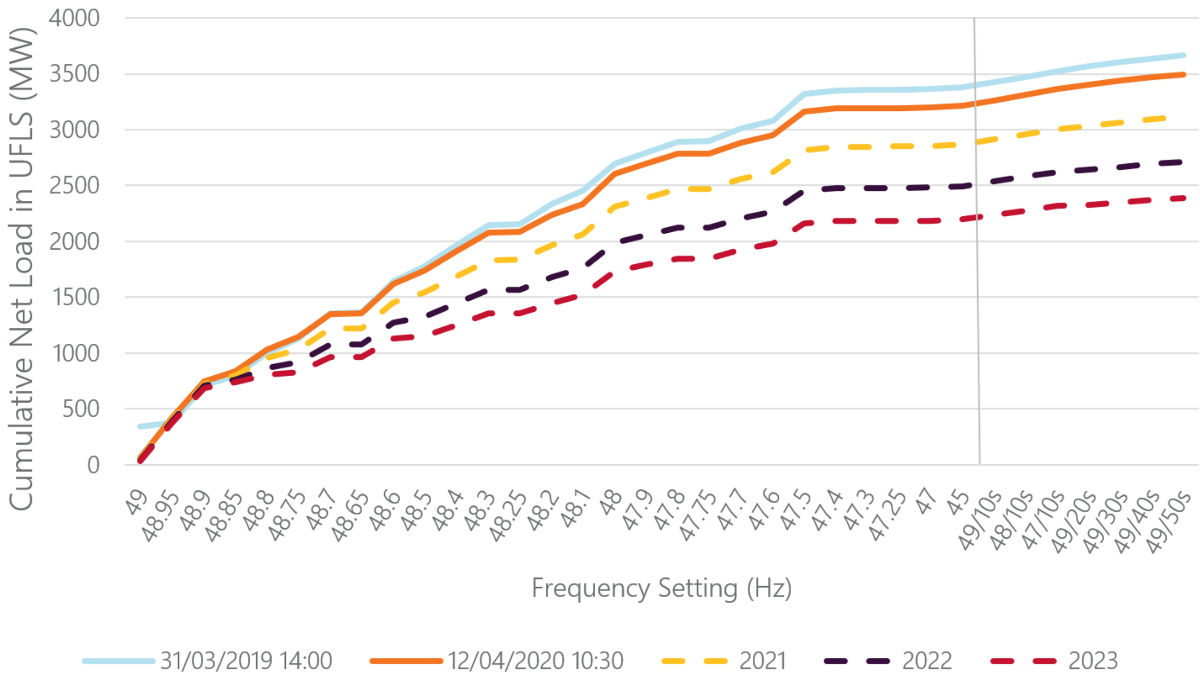
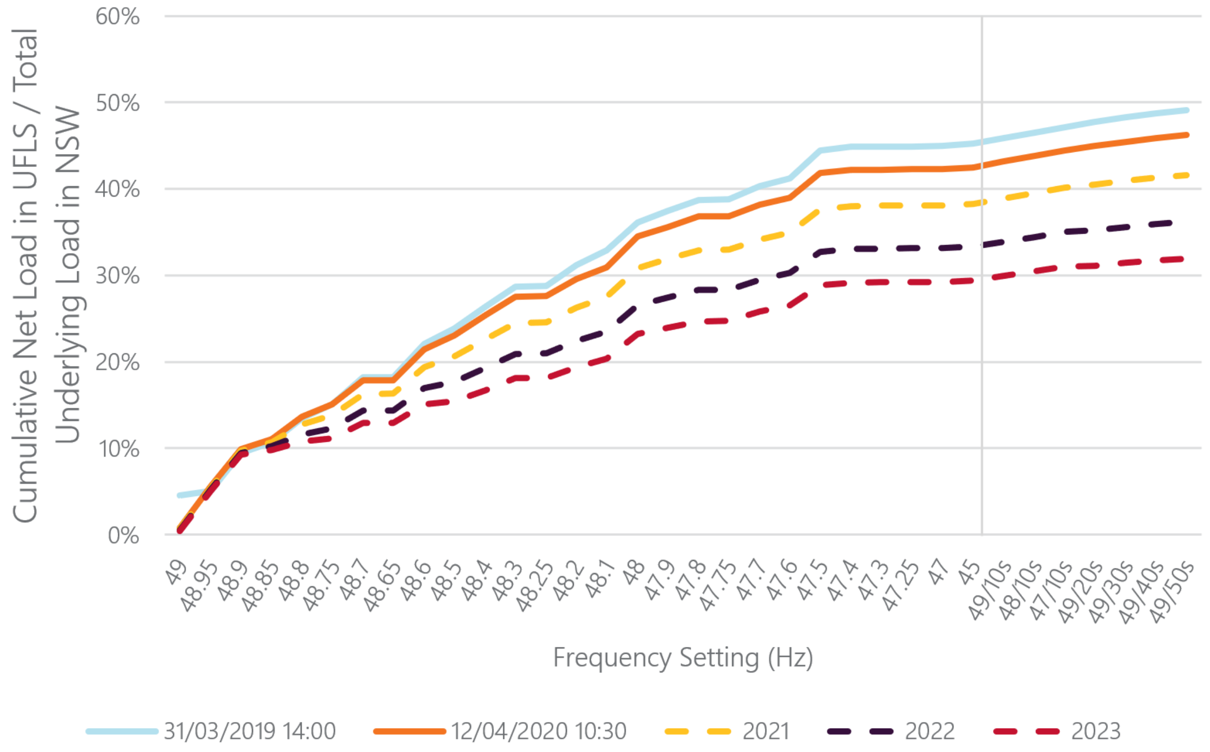


Figure 12 shows the cumulative net UFLS load as a percentage of total underlying load profile for the same historical and projected minimum daytime UFLS load periods in Figure 11.

Figure 12 Cumulative net load in UFLS / total underlying load for minimum daytime load time intervals



A more detailed assessment of the UFLS frequency settings will be conducted in Phase 2 of the analysis. This represents only a preliminary assessment.

3.4 Distributed PV in UFLS

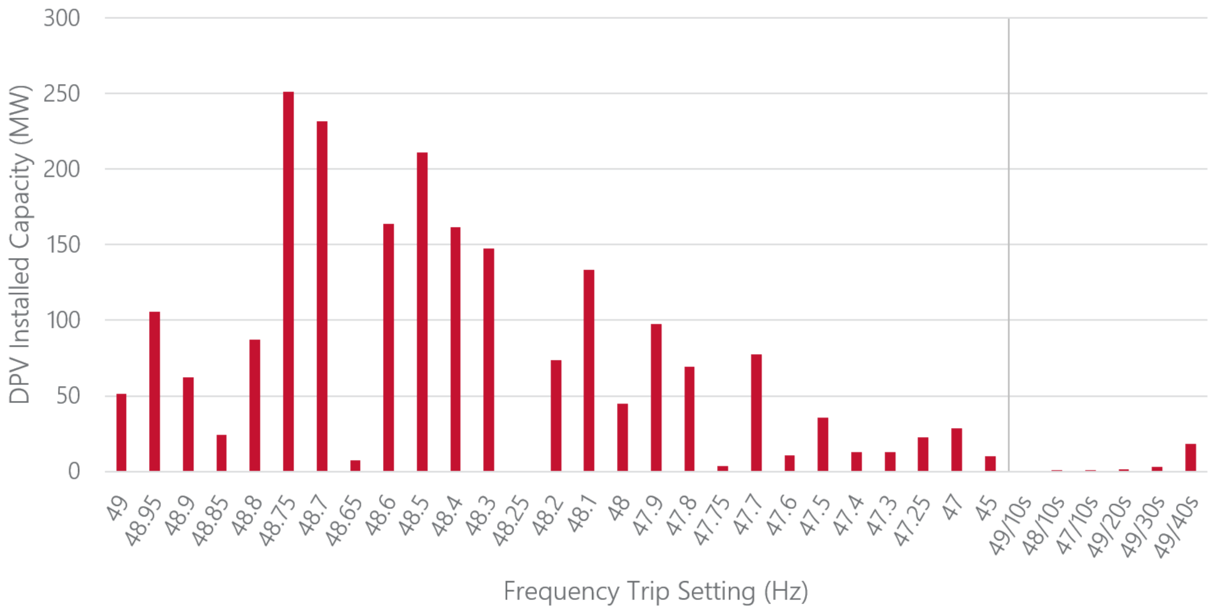
As of mid-2020, it is estimated that there was a total of 3,163 MW of DPV installed in New South Wales. Of this, based on the data provided to AEMO by NSPs, it is estimated that approximately 2,182 MW was installed on a circuit included in the UFLS. This indicates that around 69% of the DPV installed in New South Wales is connected behind a UFLS relay.

This can be compared with the proportion of total underlying load in New South Wales that is included in the UFLS. The ratio of total underlying load in the UFLS compared with the total underlying load in New South Wales[9] varies somewhat period to period, but is typically between 65% and 70%. This indicates that the amount of DPV installed behind UFLS relays (69%) is approximately proportionate to the amount of underlying load in UFLS.

Figure 13 shows the total quantity of DPV installed capacity across each of the UFLS stages (indicated by the frequency at which the associated UFLS relay will trip, with the delayed trip bands indicated at the far right with their respective delay times of 10s, 20s, 30s and 40s). The earlier stages (above 48 Hz) have the largest quantities of DPV installed.

[9] Calculated as: Total Underlying Load on UFLS in NSW / Total Underlying Load in NSW

Figure 13 Installed capacity of DPV in New South Wales as at 30 June 2020



3.5 Reverse flows

The dataset was analysed to determine if reverse flows could be observed at any UFLS circuits. When UFLS circuits are in reverse flows, the triggering of UFLS relays will result in a net trip of generation, rather than load, and will act to exacerbate an under-frequency disturbance, rather than helping to correct it. Furthermore, customers will be disconnected, but no benefit will be delivered in arresting the frequency decline.

Analysis of reverse flows could not be completed for all New South Wales NSPs as the provided data lacked the granularity required or comprised of approximations using season averages which may hide a reverse flow condition. Some small reverse flows were identified on the remaining NSP data submissions but due to their relatively small size and low percentage of time periods it was difficult to ascertain whether they were formed by an anomaly in the data or actually represented a reverse flow condition.

It is requested that NSPs investigate the incidence of reverse flow conditions occurring on UFLS circuits in their networks, as the owners and experts of the data available to them. Where reverse flows are occurring, dynamic arming of UFLS relays should be considered (such that the relay will automatically disarm when the circuit is in reverse flows).

3.6 Over-frequency response

This review focuses on emergency under-frequency response. AEMO will also undertake an assessment of emergency over-frequency response. Preliminary studies indicate that periods with high levels of distributed PV generating demonstrate a significant over-frequency response that assists in arresting over-frequency disturbances, related to PV disconnection behaviour and the over-frequency droop response required from distributed inverter connected resources under AS/NZS4777.2:2015.

AEMO's investigation is continuing in this area, particularly related to the adequacy of the over-frequency response in periods without significant levels of distributed PV operating, and assessing frequency recovery dynamics following a non-credible disturbance. This ongoing analysis may highlight the need for further management actions.

3.7 Market evolution

The power system is rapidly evolving, and some of the changes occurring may have implications for the effectiveness of emergency frequency control schemes. Some relevant changes may include:

- **Fast Frequency Response** – Large-scale batteries and other inverter connected generators (such as curtailed solar farms) can delivery Fast Frequency Response (FFR) – a rapid injection of active power in response to a fall in frequency, delivered in sub-second timeframes. AEMO's preliminary analysis indicates that delivers an effective emergency under-frequency response that can reduce the amount of UFLS load required. Batteries need to be at a suitable dispatch level with adequate headroom, and a suitable state of charge to deliver a response. Solar farms typically need to be pre-curtailed to deliver an under-frequency response. This response therefore cannot be guaranteed from market participants, unless suitable commercial arrangements are put in place.
- **Primary Frequency Response** – all scheduled and semi-scheduled generators dispatched above 0MW in the NEM are now required to respond automatically to changes in power system frequency[10]. Scheduled loads (including batteries that are charging) or batteries dispatched at 0 MW are not required to respond. This response assists with arresting a frequency decline in the event of a non-credible disturbance, reducing the amount of UFLS response required. Implementation of this rule change is underway at present.
- **Distributed batteries** – New installed distributed batteries will soon be required to deliver an under-frequency droop response (requirements in AS/NZS4777.2:2020, mandatory for new installations from 18 December 2021). To the extent that the dispatch levels and state of charge of these distributed batteries can be predicted and relied on, this will reduce the amount of emergency under-frequency response required from other sources.
- **Virtual Power Plants** – Virtual power plants, composed of aggregated distributed assets, are increasingly participating in the market and seeking to offer new services including frequency control. The focus to date has been on delivery of Frequency Control Ancillary Services (FCAS), which are designed to manage credible contingency events. The market is designed to be indifferent to whether these services are delivered by distributed assets or centralised market participants, so to the extent that the same services are delivered by new types of providers this is unlikely to affect requirements for emergency under-frequency response.
- **Wholesale Demand Response** – A wholesale demand response (WDR) mechanism is being implemented to allow consumers to sell demand response in the wholesale market, either directly or through aggregators[11]. Under the final rule, a new category of registered participant, a demand response service provider (DRSP), will be able to bid demand response directly into the wholesale market as a substitute for generation. A DRSP can also engage directly with a customer without the involvement of that customer's retailer. This is intended to facilitate a move to a two-sided market, characterised by the active participation of the supply and demand side in dispatch and price setting. To the extent that this is successful, it may increase demand levels in low load periods where prices are low. This may somewhat increase the amount of net load available on UFLS circuits in low load periods, although the amount of response is difficult to quantify. This analysis applies the demand projections in the AEMO 2021 ESOO.
- **Electric Vehicles and other changes to load profile** – Load composition is changing. The emergence of new types of flexible loads, such as electric transport, could change the size and shape of the load profile, which could affect the amount of net load available on UFLS circuits. The size and shape of this effect is difficult to predict precisely. This analysis applies the demand projections in the AEMO 2021 ESOO, which aims to account for these factors as far as possible.

These elements have not been explicitly analysed in this Phase 1 report, which aims to provide only a simple analysis of availability of UFLS load. They can be considered in the next phase.

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[10] AEMC (26 March 2020) Mandatory Primary Frequency Response, https://www.aemc.gov.au/rule-changes/mandatory-primary-frequency-response

[11] AEMC (11 June 2020) Wholesale demand response mechanism, https://www.aemc.gov.au/rule-changes/wholesale-demand-response-mechanism

4. Next Steps

AEMO has provided the information in this report to NSPs to facilitate collaboration on next steps in accordance with respective NER responsibilities, and co-development of potential remediation approaches. AEMO is seeking advice from NSPs on the range of possible remediation approaches, including developing an understanding of technical and economic feasibility, effectiveness, and other potential barriers or relevant factors.

This analysis indicates that, in periods with high levels of distributed PV operating, the amount of load under the control of under-frequency relays is now below the levels contemplated in the NER (clause 4.3.1(k)) as adequate to arrest the impacts of a range of significant multiple contingency events. This is likely to deteriorate further in the coming years. This means that at times the power system will be operating without the intended safety nets, placing customers at risk in future.

Accordingly, AEMO advises that NSPs should immediately seek to identify and implement measures to restore net UFLS load (or equivalent emergency under-frequency response) to as close as possible to the level of 60% of underlying load at all times, under NER clause 5.1.10.1. If this is not feasible, AEMO will collaborate with NSPs to develop an approach that identifies a level of emergency under-frequency response that is achievable, while delivering a significant reduction in power system security risks.

4.1 Addressing DPV impacts

As discussed in Section 3.2, there are now periods where the total net UFLS load in New South Wales is below the indicative thresholds defined in the NER, and this is projected to continue to decline as DPV levels continue to increase. Without ruling out other possibilities, remediation options may include some combination of the following:

Table 7 Possible options for consideration

Option	Details	Considerations
Add further customer load into the UFLS scheme	Identify customers that are not presently included in the UFLS scheme. Add UFLS relays.	Sensitive customers need to be considered. This is a short-term stop gap measure only.
Establish UFLS monitoring	Establish processes to periodically assess the incidence and level of reverse flows occurring at various UFLS circuits. It may be beneficial to establish a real-time SCADA feed of total net UFLS load in New South Wales. This could facilitate monitoring of UFLS load in real time by both AEMO and the NSPs, and could facilitate active management strategies in periods where UFLS load is low. For example, a real-time SCADA feed of total UFLS load has been established in South Australia, and is now used as the basis for a constraint that limits flows on the Heywood Interconnector when total UFLS load is low.	To establish a SCADA feed, it will be necessary to sum real-time measurements from all UFLS circuits, at the level where UFLS relays are located.
Remove affected UFLS circuits and replace with other loads	Remove UFLS circuits from the UFLS scheme if they are heavily affected by DPV and often demonstrating reverse flows, and replace them with loads at other locations that are less affected by DPV.	This is a short-term stop gap measure only.

Option	Details	Considerations
Dynamic arming	Implement dynamic arming (disarming UFLS relays when circuits are in reverse flows) at UFLS circuits where reverse flows are occurring. As the first step, NSPs may need to conduct an assessment of the incidence of reverse flows in their networks. This could not be delivered as part of this analysis, because the NSP dataset was not provided at sufficient granularity.	This may require replacement of UFLS relays, if they do not have this capability at present
Site-specific load shedding	Explore more granular approaches to load shedding that allow separation of customer loads and DPV at the individual site level. Some smart meter technology and other types of relays suitable for installation at individual customer sites may be suitable, but trials and careful scheme design will be required.	Careful consideration will be required around impacts on distribution voltages from selectively shedding customer load on distribution feeders while distributed PV remains operating. If voltages exceed protection thresholds for distributed PV it may trip, which would undermine the operation of the scheme.
Fast Frequency Response (FFR)	Explore alternatives to under-frequency load shedding, such as fast frequency response (sub-second power injection from inverter connected resources, such as batteries or curtailed solar farms). AEMO's studies suggest that FFR is an effective alternative to under-frequency load shedding. The NER allow NSPs to consider "other facilities" (S5.1.10.1(a)).	Careful design of the response will be required, accounting for the distribution network if the response is procured from distribution level assets.

Longer term options may have long lead times for implementation, and therefore need to be considered early.

NSPs may find benefits from a holistic approach; for example, considering the impacts of distributed PV on distribution voltage management, and exploring the interaction between UFLS and under voltage load shedding (UVLS) schemes as part of the same work program.

AEMO requests that NSPs explore the available options for managing growing DPV levels and the impact on UFLS load, and provide advice to AEMO on options, their technical and economic feasibility, and any other relevant barriers or factors.

4.2 Further work

AEMO will be undertaking further analysis as part of the next Phase of the UFLS review (Phase 2). This will involve frequency studies that explore the impacts on UFLS effectiveness. This review may reveal the need for further changes, possibly including changes to frequency settings and other management measures.

Glossary

This document uses many terms that have meanings defined in the National Electricity Rules (NER). The NER meanings are adopted unless otherwise specified.

Term	Definition
DER	Distributed Energy Resource
DNSP	Distribution Network Service Provider
DPV	Distributed photovoltaics
EFCS	Emergency Frequency Control Scheme
FCAS	Frequency Control Ancillary Services
JSSC	Jurisdictional System Security Coordinator
NER	National Electricity Rules
NSP	Network Service Provider
TNSP	Transmission Network Service Provider
UFLS	Under Frequency Load Shedding